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Evolution of tectonic structures within the salt diapirs: a numerical study

Marta Adamuszek & Marcin Dąbrowski

Computational Geology Laboratory, Polish Geological Institute - National Research Institute, Lower Silesia Branch, Jaworowa 19, 53-122 Wrocław, Poland, e-mail: marta.adamuszek@pgi.gov.pl

The salt diapirs are often highly heterogeneous and their internal architecture can be very complex. This is a result of an intensive deformation that acts on the lithologically layered evaporate series during the diapir growth. Correct interpretation of the internal structure of a salt diapir is of economic interest, e.g. for planning exploration and operation in a mine and for environmental and safety reason. Internal geometry is analysed based on data obtained from boreholes, underground mine galleries and geophysical studies. Both borehole data and underground mine observations provide only a spatially limited image of the internal diapir structure. Consequently, the detailed structural analysis of the diapir is a challenging task. The employed tools do not allow for an unambiguous interpretation, thus, complementary tools must be involved. Understanding of the evolution of the internal salt architecture can help building a correct interpretation.

We numerically investigate the initiation and evolution of tectonic structures within the salt diapirs comprising mechanically stratified evaporate series. We analyse the role of range of parameters such as mechanical properties of the layered evaporate series and the initial spatial arrangement of different rock types. In the study, we focus on the relationship between the structures such as folds and boudinage structures that develop on a small-scale (corresponding to the outcrop scale in the salt mine galleries) and a large-scale (corresponding to the whole diapir scale). Additionally, the influence of the internal structure development on the evolution of the overall diapir shape is examined.

In the numerical model, we use non-linear viscous rheology for the evaporate series and the overburden. We solve an incompressible Stokes equation in the presence of the gravity using the finite element method solver MILAMIN (Dabrowski *et al.*, 2008). The diapir evolution is simulated in two dimensions. The development of complex structures is analysed using the resolved interface method, since this is a suitable method to trace the evolving rock interfaces in high resolution and, thus, to accurately describe the evolution of the internal diapir structures.

References

DABROWSKI, M., KROTKIEWSKI, M. & SCHMID, D. W., 2008. MILAMIN: MATLAB-based finite element method solver for large problems. *Geochemistry Geophysics Geosystems*, 9: Q04030

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SHRIMP U-Pb zircon geochronology of the Jawornik granitoids (West Sudetes, Poland)

Dawid Białek

University of Wrocław, Institute of Geological Sciences, pl. M. Borna 9, 50-204 Wrocław, Poland,
e-mail: dawid.bialek@ing.uni.wroc.pl

Orlica–Śnieżnik Dome (OSD), one of the biggest geological unit of the Western Sudetes, constitutes southesternmost extent of the Saxo-Thuringian Zone. This unit is composed of belts of high-grade orthogneisses, surrounded by amphibolite facies metasedimentary and metavolcanic rocks, including numerous tectonic bodies of high pressure and rarer ultra high-pressure mafic and acidic rocks. The mechanism of the geodynamic evolution of the Orlica–Śnieżnik Complex is still debatable (Chopin *et al.*, 2012; Mazur *et al.* 2012 and references therein). The northern part of the ODS is delineated by a supracrustal belt commonly referred to as Złoty Stok–Skrzynka Shear Zone (ZSSsz), which is considered as a product of intense deformation that occurred during the Variscan orogeny. The ZSSsz is comprised of medium-grade metasediments, gneisses, acid and basic metavolcanic rocks, with a polyphase deformation history. The best preserved structure is a subvertical NE–SW striking metamorphic foliation, resulting from the E–W-directed lateral shortening, described as S2 by Murtezi (2006) and Chopin et al (2012). Rocks of the ZSSsz have been intruded by a string of elongate plutons defining the Jawornik granitoids. These sheeted-bodies are interpreted as dykes and sills injected parallel to the shear zone and dykes evolving into sills are observed locally. Small dykes up to 0.4 m in width are asymetrically folded together with the host rocks. Jawornik granitoids are characterized by macroscopically poor-defined, heterogeneously distributed lithological variations. Fine-grained, biotite-bearing granodiorites (Bt type) is the dominant rock type, but hornblende-bearing granodiorites (Hbl+Bt type), tonalities and monzonitic granites (Bt+Msc type) are common (Burchart, 1958). A part of the Jawornickie granitoids are considered to be syn-tectonic with D2, and part post-D2 on the basis of the field structural observations in the country rocks (Cwojdziński, 1977) and AMS study (Białek & Werner, 2002).

Two granite samples were dated by the 40Ar/39Ar step heating method (Białek & Werner, 2004). From Hbl+Bt sample hornblende yielded plateau age of 351.1± 3.7 Ma and coexisting biotite 349.6±3.8 Ma. Muscovite from Bt+ Msc type showed a plateau age of 344.6±3.8 Ma, whereas biotite yielded a concordant plateau age of 343.1±3.8 Ma (Białek and Werner, 2004). Chopin *et al.* (2012) using the same method dated two metapelites samples collected at 300 m and at few meters from the contact with Jawornik granites. Muscovite, defining syn-shear foliation yielded plateau ages of 347.9 ±8.6 Ma and 335.2 ± 12.6 Ma respectively (Chopin *et al.*, 2012) which overlap within error with cooling ages from neighboring granites.

Two types of Jawornickie granitoids – Hbl+Bt type and Bt-Msc type, were selected for U-Pb SHRIMP dating of zircons. The data from Hbl+Bt was collected under separate conditions for the cores and rims. The data from the cores show a spread of ages from ~350 Ma to ~650 Ma, with the majority of the data clustered towards the younger ages. Within this range of ages there are two more significant groups at ~350 Ma (Concordia age 351 ± 1.3 Ma) and ~450 Ma (Concordia age 455 ± 5.2 Ma). Within the spread of data from the rim analyses there are a few ages that are common, as well as a distinct group at the oldest end of the spectrum. The Concordia age for this oldest rim group is 361.5 ± 2.6 Ma. Two slightly younger groups are seen, though with only a few analyses, with Concordia ages of 336.3 ± 1.7 Ma and 304.7 ± 2.2 Ma.

Zircons from Bt+Msc variety are significantly lower in uranium concentration, typically lower than 100 ppm and often as low as 10 ppm. The zircons show a large spread of ages from ~250 Ma to 2800 Ma. No ages produce a particularly significant cluster, with only a small group of 3 zircons at ~340 Ma. The Concordia age for this group is 336.3 ±2.4 Ma, although with only 3 points this is not a statistically reliable value. The 336 Ma age is very similar to the age seen in rims of Hbl+Bt variety.

This data confirm previous observations of different ages and different position relative to tectonic structures of various types of Jawornik granitoids. They also prove that magma for different varieties was derived from different source rocks.

References

BURCHART, J., 1958. O granitoidach jawornickich Sudetów Wschodnich. Arch. Miner., 22: 237–348

CWOJDZIŃSKI, S., 1977. Stosunek granitoidów jawornickich do deformacji matamorfiku lądecko-śnieżnickiego. *Kwartalnik Geologiczny*, 21: 451–464.

BIAŁEK, D. & WERNER, T., 2002. The Jawornickie granitoids: magnetic fabric and relationship with the Złoty Stok–Skrzynka shear zone. *Mineralogical Society of Poland – Special Papers*, 20: 68–70.

BIAŁEK, D. & WERNER, T., 2004. Geochemistry and Geochronology of the Javornik Granodiorite and its Geodynamic Significance in the Eastern Variscan Belt. *Geolines*, 17: 22–23.

CHOPIN, F., SCHULMANN, K., SKRZYPEK, E., DUJARDIN, J. R., LEHMANN, J., MARTELAT, J. E., LEXA, O., CORSINI, M., EDEL, J. B., ŠTÍPSKA, P. & PITRA, P., 2012. Crustal influx, indentation, ductile thinning and gravity redistribution in a continental wedge: building a Moldanubian mantled gneiss dome with under- thrust Saxothuringian material (European Variscan belt). *Tectonics*, 31, TC 1030, doi:10.1029/2011TC002951.

MAZUR, S., SZCZEPAŃSKI, J., TURNIAK, K. & MCNAUGHTON, N., 2012. Location of the Rheic suture in the eastern Bohemian Massif: Evidence from detrital zircon data, *Terra Nova*, 24 (3): 199–206.

MURTEZI, M., 2006. The acid metavolcanic rocks of the Orlica–ŚnieżnikDome (Sudetes): Their origin and tectono-metamorphic evolution, *Geologia Sudetica*, 38: 1–38.

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Processed aeromagnetic maps of Bou Chber area (Central Morocco) and their geological significance

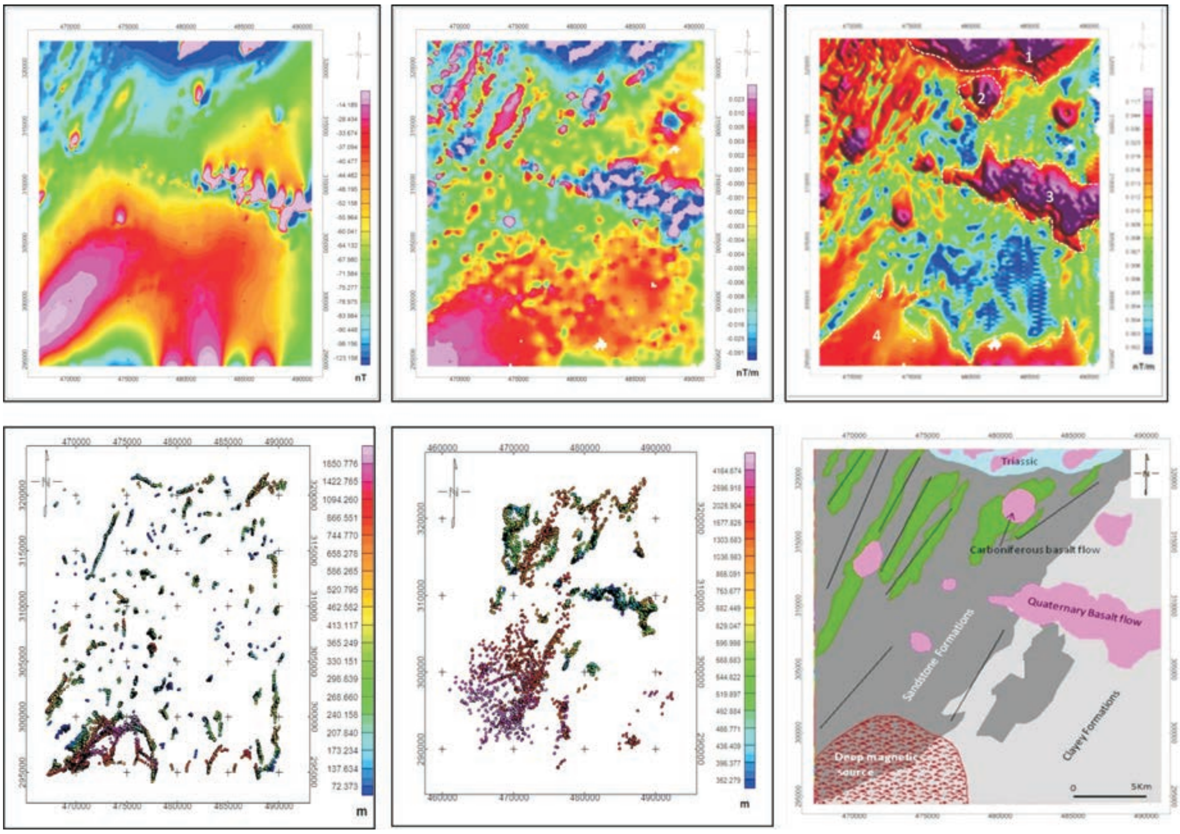
Nawal Bouya & Hmidou El Ouardi

CartoTec Group Research, University Moulay Ismail, Faculty of Sciences, Dept of Geology, PB. 11201 Zitoune, Meknes, Morocco, e-mail: nawal_bouya@hotmail.fr; hmioduelouardi@yahoo.fr

Aeromagnetic data have been used recently in Morocco for geological mapping after its use for a long time in the mining prospecting (Bouya *et al.*, 2013 a, b; Bouya, 2014) and throughout the world since some decades (Galdeano, 1980; Blakely, 1995; Grauch *et al.*, 2001; Aspler *et al.*, 2003; Randrianasolo, 2009; Aryamanesh *et al.*, 2009). Based onto magnetic susceptibility, it allows to highlight different petrographic types at map scales (Gleize, 1992; Bouchez, 1997). However, it's always difficult to assign a magnetic anomaly to a specific geological facies (Henkel, 1991; Clark, 1997; Naba, 2007; Randrianasolo, 2009).

This study concerns the geological interpertation of aeromagntic data of Bou Chber region from Central Morocco. Processed magnetic maps obtained from different standard methods known in aeromagntism, were compared to field geological structures. We propose then a geological sketch of the Bou Chber non-mapped area and we interpret magnetic anomalies detected in this region.

Studied area corresponds to a segment of the famous Fourhal-Telt syncline trending NE–SW. Stratigraphic series correspond to alternate clays and sandstones attributed to the Visean–Namurian stage, which are overlapped by Devonian–Visean allochthonous limestones. These series are folded as a NE–SW direction like the rest of Central Moroccan Meseta. It's known that magnetic anomalies could be induced by crystalline rocks or metamorphic basement, or can be generated by linear tectonic contacts (Grauch *et al.*, 2006). The first obtained processed map is the residual magnetic anomaly map. The reduction-to-pole technique applied to the latter permits to obtain the RTP map which will become the base for applications of various filters. So the RTP map allows to find different geological contours as well as major geological structures that characterize this region. Obtained maps permit to distinguish four areas that show strong magnetic anomalies, the north end of the map coincides with the edge of the plateau of Agourai, a strong anomaly oriented E–W in the east-central part of the map aligning along the Oued Ifrane and finally two strong anomalies in the southern part of the map. The application of the Euler deconvolution to the magnetic data of Bou Chber area permits to detect many contacts, two semicircular contacts occurring in the southern part of the map, others oriented



NE–SW in the NW part and finally linear N–S contacts observed in the eastern part of the map. Euler map of structural index (SI = 3) confirms these structures and highlights a semicircular structure in the southern part of the map that may be caused by deep magnetic source.

The first strong E–W anomaly detected in the northern part, corresponds to the Triassic outcrops bordering the Mesozoic plateau of Agourai. The second strong circular anomaly detected, few km south, corresponds to basaltic Carboniferous flows (Driouch *et al.*, 2010). The strong magnetic signature of these outcrops justifies their mineralogical composition and geochemical characteristics of basic and/or ultrabasic rocks (Thomas *et al.*, 2002). The third E–W strong anomaly detected in the central part, coincides with a Quaternary basalt flow. It is characteristic of basaltic Plio-Quaternary volcanism that marked the magmatic province of the Middle Atlas and Central Morocco. Finally, the fourth strong anomaly was highlighted in the southern part of the map. This anomaly may be caused by a deep magnetic source. From the intensity of the magnetic signal, we can assume that this deep source correspond to basic magmatic rocks analogous to basic flows exposed in the northern region of Bou Chber. The estimated depth of this magnetic source from Euler deconvolution and the analysis of the magnetic signal is about 2100 m.

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References

ARYAMANESH, M., 2009.Aeromagnetic data interpretation to locate buried faults in Yazd Provinec-Iran. *World Appl. Sci. Jl.*, 6 (10): 1429–1432.

ASPLER, L. B., M. Pilkington & Miles W. F., 2003: Interpretations of Precambrian basement based on recent aeromagnetic data, Mckenzie Valley, Northwest Territories. *Geological survey of Canada, Current research-C2.*

BLAKELY, R. J., 1995. Potential Theory in Gravity and Magnetic Applications. *Cambridge University Press.*

BOUCHEZ, J. L., 1997. Granite is never isotropic: an introduction to AMS studies of granitic rocks.in J.L. Bouchez, D.H. W. Hutton & W.E. Stephens (eds.), Granite: from segregation of melt to emplacement fabrics, Kluwer Academic Publishers, Dordrecht: 95–112.

BOUYA, N., 2014. Utilisation des données géophysiques aéroportées magnétiques et spectrométriques dans la cartogra- phie géologique de la partie NE du massif central marocain et des causses moyen-atlasiques. Thèse Doctorat, Univ. Moulay Ismail, Fac. Sciences, 190 p.

BOUYA, N., EL OUARDI, H., HABIBOU, E. H., MERCIER, E. & ANSAN V., 2013A. Aeromagnetic data used for mapping the Agourai plateau structures (Tabular Middle Atlas, Morocco). *Afr. Geoscience Rev.*, 20 (1–2): 13–20.

BOUYA, N., EL OUARDI, H., HABIBOU, E. H., MERCIER, E. & ANSAN, V., 2013b. Geological interpretation of the aeromagnetic survey in the Agourai area (Central Morocco). *Central European Geology*, 56(4).

CLARK, D. A., 1997. Magnetic petrophysics and magnetic petrology: aids to geological interpretation of magnetic surveys. *Journal of Australian Geology and Geophysics*, 17(2): 83–103.

DRIOUCH, Y., BÉZIAT, D., GRÉGOIRE, M. LAGUENINI, F., BEN ABBOU, M., NTARMOUCHANT, A., RODDAZ, M., DAHIRE, M., BENNOUNA, A., BELKASMI, M., BRUSSET, S. & DEBAT., P., 2010. Clinopyroxene trace element compositions of cumulate mafic rocks and basalts from the Hercynian Moroccan Central Meseta: Petrogenetic implications. *Jl. Afr. Earth Sci.*, 56: 97–106.

GALDEANO, A., 1980. La cartographie aéromagnétique du Sud-Ouest de l'Europe et de la région Afar: réalisation, méthodes de traitement, applications géodynamiques. Thèse ès-Sciences physiques, Université Paris VII, France.

GLEIZES, G., 1992. Structure des granites Hercyniens des Pyrénées de Mont-Louis-Andorre à la Maladeta. Thèse 259 p, Univ. Toulouse III, France.

GRAUCH, V. J. S., SAWYER, D. A, MINOR S. A., HUDSON M. R. & THOMPSON R. A., 2006. Gravity and Aeromagnetic Studies of the Santo Domingo Basin Area, New Mexico. Chapter D of The Cerrillos Uplift, the La Bajada Constriction, and Hydrogeologic Framework of the Santo Domingo Basin, Rio Grande Rift, New Mexico. Edited by Scott A. Minor. U.S. Geological Survey, Denver: 63–86.

GRAUCH, V. J. S., HUDSON M.R. & MINOR S. A., 2001. Aeromagnetic expression of faults that offset basin fill, Albuquerque basin, New Mexico. *Geophysics*, 66: 707–720.

HENKEL, H., 1991. Petrophysical properties (density and magnetization) of rocks from the northern part of the Baltic shield. *Tectonophysics*, 192: 1–19.

NABA, S., 2007. Propriétés magnétiques et caractčres structuraux des granites du Burkina Faso oriental (Craton Ouest Africain, 2,2 – 2,0 Ga) : implications géodynamiques. Thčse Doctorat, 166 p, Univ. Toulouse, France.

RANDRIANASOLO, E. B., 2009. Nouvelles méthodes de cartographie sur le socle protérozoïque du sud de Madagascar. Nature et géométrie de la croute continentale d'un domaine orogénique en convergence, implications économiques. Thèse de Doctorat, 307 p, Univ. Joseph Fourier, Grenoble, France.

THOMAS, E., MOUGIN, B., DEBÉGLIA, N. & PERRIN J., 2002. Apport des levés géophysiques aéroportés, à la recherche et la prospection des ressources en eau: Application à la región du Léon (Finistère), Etude réalisée dans le cadre des opérations de service public du BRGM 2002 PIR-222.

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Studies of AMS fabrics in Ordovician sedimentary rocks, Barrandian, Czech Republic

Jan Černý [1, 2] & Rostislav Melichar[1]

[1] *Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlarska 2, 611 37 Brno, Czech Republic,*
e-mail: 176111@mail.muni.cz, 56@mail.muni.cz
[2] *Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 269, 165 00 Praha-Lysolaje, Czech Republic,*
e-mail:jcerny@gli.cas.cz

The study was focused on Ordovician sedimentary rocks and their anisotropy of magnetic susceptibility (AMS). The area under study is situated in the Prague Synform, Bohemian Massif, Czech Republic. Sedimentation in the basin began by Ordovician transgression and continued with siliciclastic rocks to Lower Silurian. The Upper Silurian is typical by carbonatic rocks as well as Devonian. The Silurian and Devonian sedimentary rocks are intensely folded and thrusted (Melichar, 2003), while the Ordovician-rock deformation is not visible. The aim of the study was to find out whether the Ordovician rocks are actually un-deformed or was affected by strain by using AMS.

Over 1500 samples were taken from 56 sites throughout dozen Ordovician formations. Temperature dependence of magnetic susceptibility was measured on the samples as well as AMS, which was compared to structural analysis of individual localities. In some specific cases, x-ray analysis or microscopic studies were used.

Results and interpretations: Analysis of temperature dependence of magnetic susceptibility showed that all Ordovician formations are controlled by paramagnetic minerals (Černý, 2010).

1) In majority sites normal sedimentary (e.g., Fig. 1c) or strain fabrics (e.g., Fig. 1b) were recognized. Very important for further interpretations seem to be fabrics from the neighbor of Skřípel village where two different tectonic fabrics were found (Černý & Melichar, 2012), or from the neighbor of Dobřichovice. There were also found inverse and intermediate fabrics in the area.

2) Inverse fabrics found in 4 sites were caused by fibrous ankerite (e.g., Fig. 1a). Fibers were grown perpendicularly to the bedding plane in the fibrous microveins and cone-in-cone textures. The maximum susceptibility direction is parallel to crystallographic axis *c* of ankerite in the samples.

3) Intermediate fabrics or their relics were exclusively linked to all localities in two basal Ordovician formations (e.g., Fig. 1d). In this case, we cannot speculate about simple combination of normal and inverse fabrics, but about autoregulatory diagenetic processes.

References

ČERNY, J., 2010. Magnetic anisotropy of the Ordovician sedimets from the Prague Synform [in Czech]. MS, master thesis. Masaryk University. Brno. Czech Republic.

ČERNÝ, J. & MELICHAR, R., 2012. AMS Fabric differences in relation to ramp within Ordovician rocks, Barrandian, Czech Republic. 10th Meeting of the Central European Tectonic Studies Group (CETeG) 2–5 May 2012. Zemplínska Šírava – Medvedia hora, Slovakia. *Mineralia Slovaca*, 44: 76. Bratislava. Slovakia.

MELICHAR, R., 2003. Matters of thrust tectonic in the Prague Synform [in Czech]. MS, habilitation thesis. Masaryk University. Brno. Czech Republic.

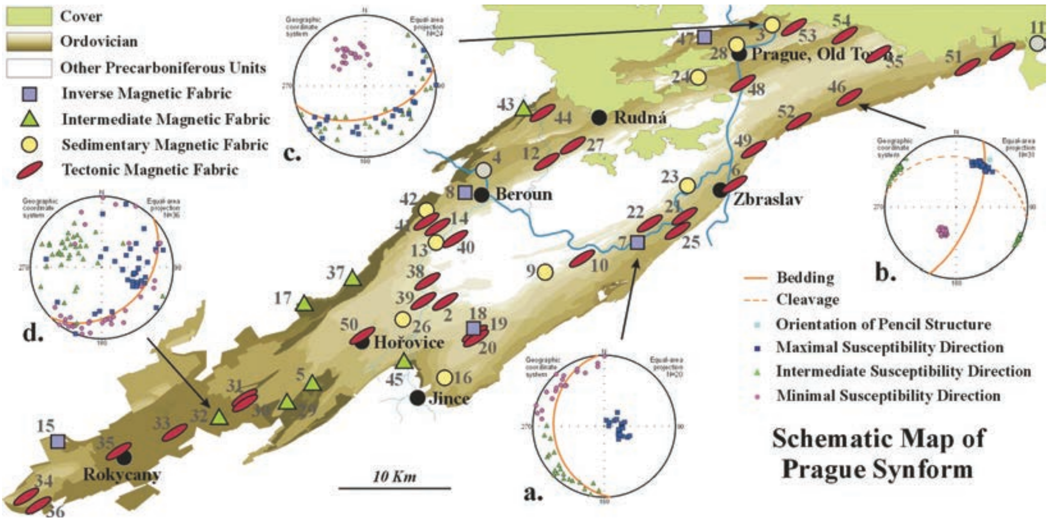

Fig. 1. Localization of different found types of AMS fabrics in Prague Synform. Diagrams show examples of results for each kind of found fabric; a) Inverse magnetic fabric; b) Tectonic magnetic fabric; c) Sedimentary magnetic fabric; d) Intermediate magnetic fabric.

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The origin and role of a calcite-filled microcrack generation in a metamorphic crystalline complex: The characterization of a fossilised seismic permeability system

Gergely Dabi[1], Bernadett Bajnóczi[2], Félix Schubert[1] & Tivadar M. Tóth[1]

[1] *Department of Mineralogy, Geochemistry and Petrology, University of Szeged, 2 Egyetem street, 6722 Szeged, Hungary, e-mail: dabi@geo.u-szeged.hu; schubert@geo.u-szeged.hu; mtoth@geo.u-szeged.hu*
[2] *Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, 45 Budaörsi street, 1112 Budapest, Hungary, e-mail: bajnoczi@geochem.hu*

The Mecsekalja Zone (SE Mecsek Mountains, SW Hungary) metamorphic rocks are cross cut by a generation of a pervasive calcite filled microcrack system. Cathodoluminescence images reveal that the microcracks develop due to the fragmentation of the rock forming feldspar crystals (Fig. 1A), and the microcrack density is proportional to the feldspar content of the host rock (cf. Fig. 1). Stable isotope data from the microcrack calcite display a linear trend with oxygen isotope compositions between 14.6‰ and 30.3‰ and carbon isotope compositions between –9.7‰ and 1.7‰, and indicate that the parent fluid is related to the Early Cretaceous dyke magmas (Fig. 2A). The trend itself provides two interpretations. According to the first, the linear trend is a result of isotope exchange between the parent fluid, and the oldest and most widespread occurring calcite vein generation ($Cal_{EB}1$, Fig. 2A). The isotope exchange model applied to the data (Rye & Bradbury, 1988) is sensitive to the CO_2 concentration of the fluid, and predicts a fluid with higher molal CO_2 ratios ($X_{CO2} = 0.35$) during the isotope exchange process than the maximum CO_2 concentration of the fluids entrapped in the primary inclusions (X_{CO2} is lower than 0.015, as implied by microthermometry, Fig. 2A). The relevance of the isotope exchange model in the formation of the isotope trend supposes the segregation and loss of massive amount of CO_2 before the fluids entrapment in the microcrack calcite. The formation of the trend can also be a result of mixing of the volcanic fluid with seawater intruded into the microcrack system of the crystalline rocks. Since both scenarios are well documented attendants of seismic activity (Weise *et al.*, 2001; Lin *et al.*, 2003), the microcrack generation is interpreted as the seismic damage zone of the Ófalu Fault (the north-western boundary of the Mecsekalja Zone) during its active period in the Early Cretaceous. The microporosity system is considered to be the fossilised analogue of the pervasive crack systems detected around recently active faults (Hiramatsu *et al.*, 2005; Li *et al.*, 2006), which calls the attention on the relevance of short lived co-seismic pervasive crack damage in the redistribution of crustal fluids subsequent to earthquakes.

The rock-type dependent microcrack density calls the attention on the existence of a compartmentalized seismic damage zone around seismic faults in metamorphic complexes of heterogeneous lithology, like the Mecsekalja Zone. This suggests that the damage zone in a metamorphic complex is basically different from those described in more homogeneous lithologies, and the decrease of microcrack density is not monotonous towards the protolith.

Homogenisation temperatures of the fluids entrapped in the microcrack calcite reveal the existence of rock-type dependent fluid–rock subsystems, in conjunction with the formation of different crack densities in different rock-types. The more narrow range of fluid densities suggests hydrostatic fluid pressure in the feldspathic rocks, while the wide range of densities in the less feldspathic chlorite gneiss indi-

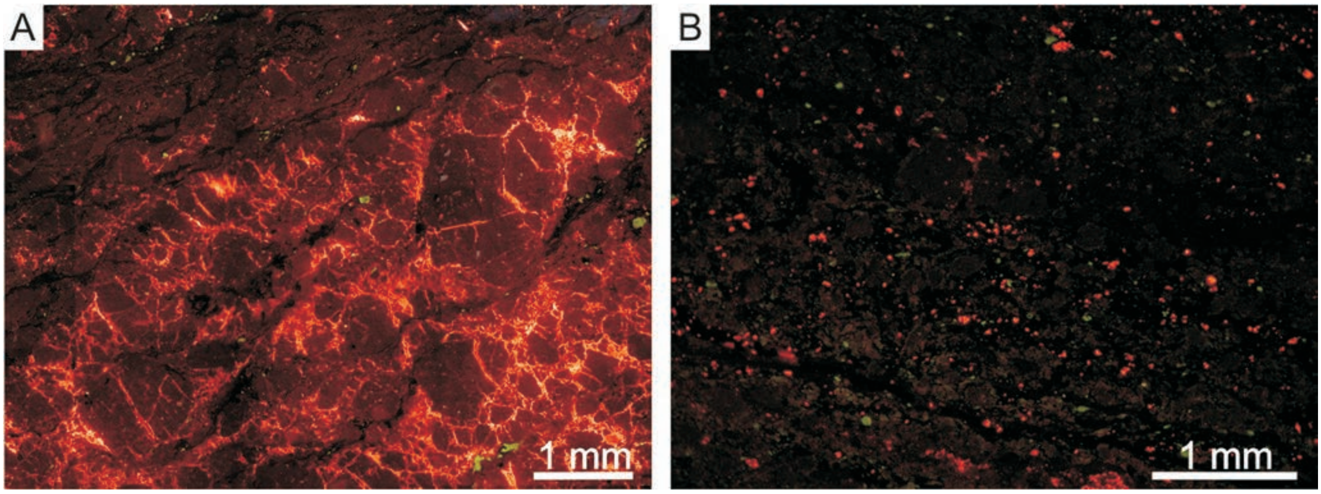

Fig. 1. A. Cathodoluminescent image of a pervasive microcrack system in a feldspathic rock type. B. The microcrack calcite is present as small disseminated patches in a micaceous rock type.

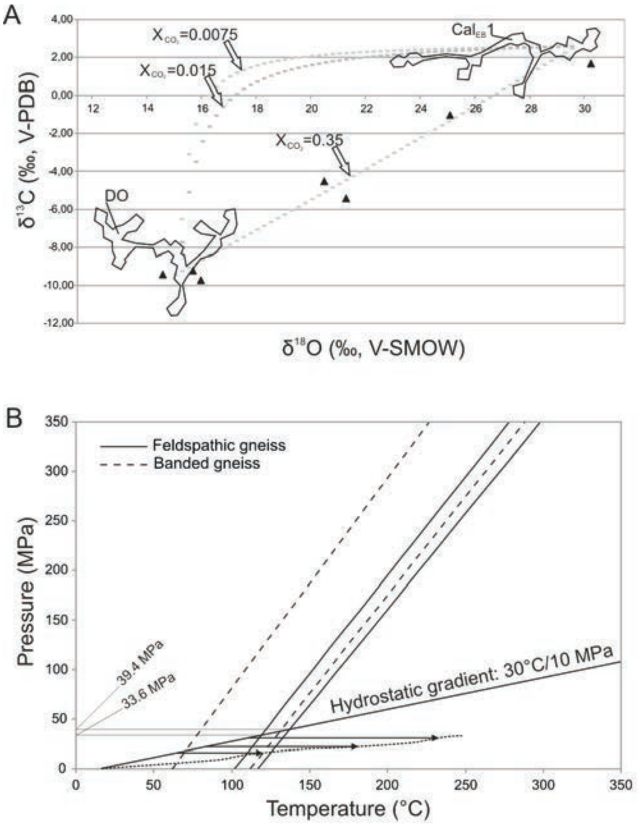

Fig. 2. **A.** Stable isotope compositions of the microcrack calcite. The dashed lines are the results of the isotope exchange model, and represent the conformation of the calcites' stable isotope compositions due to isotope exchange with the vein calcite generation of most widespread occurrence (Cal1) at the study area. DO – stable isotope compositions of the East Mecsek dyke ocelli. **B.** Isochores constructed from the *T* data measured in the primary inclusions of the feldspathic gneiss microcrack calcite. The dashed line figures a possible conformation of the fluid temperatures with depth due to locally different magmatic upheat (symbolized by horizontal arrows with different lengths). The conformation of the fluid temperature is unknown, the intersection of the curve with the solid isochores marks the real depth of formation.

cates deformation related fluid pressure increase in an undrained fluid–rock subsystem or the decrease of the parent fluid's temperature due to lower water–rock ratio. The parent fluid's salinities indicate the connection between the microcrack fluids and interpillow sulphate chimneys in the western continuation of the Mecsekalja Zone to the west and suggest that they were part of the same hydraulic system (Jáger *et al.*, 2012). Isochores constructed based on the homogenisation temperature data measured in the feldspathic rock types and corrected with an average (30 °C/km) hydrostatic gradient suggest maximum hydrostatic pressures between 33.6 and 39.4 MPa (Fig. 2B). These values are consistent with burial depth between 2.9 and 3.5 km, assuming a seawater column of 400–500 m above the rock column. However the magmatic heat carried by the volcanic fluids and the volcanic upheat of the metamorphic host rock possibly perturbed the fluids temperature from that marked out by the hydrostatic gradient (Fig. 2B), i.e. the real formation depth is possibly lower than that is deduced from the application of the hydrostatic gradient.

References

HIRAMATSU, Y., HONMA, H., SAIGA, A., FURUMOTO, M. & OOIDA, T., 2005. Seismological evidence on characteristic time of crack healing in the shallow crust. *Geophys. Res. Lett.*, 32 (9): 4.

JÁGER, V., MOLNÁR, F., BUCHS, D. & KODĚRA, P., 2012. The connection between iron ore formations and "mud-shrimp" colonizations around sunken wood debris and hydrothermal sediments in a Lower Cretaceous continental rift basin, Mecsek Mts. Hungary. *Earth Sci. Rev.*, 114: 250–278.

LI, Y.-G, CHEN, P., COCHRAN, E.S., VIDALE, J.E. & BURDETTE, T., 2006. Seismic evidence of rock damage and healing on the San Andreas Fault associated with the 2004 M 6.0 Parkfield earthquake. *Bull. Seismol. Soc. Am.*, 96: 349–363.

LIN, A., TANAKA, N., UDA, S. & SATISH-KUMAR, M., 2003. Repeated coseismic infiltration of meteoric and seawater into deep fault zones: a case study of the Nojima fault zone, Japan. *Chem. Geol.*, 202: 139–153.

RYE, D.M. & BRADBURY, H.J., 1988. Fluid flow in the crust: an example froma Pyrenean thrust ramp. *Am. J. Sci.*, 288: 197–235.

WEISE, S.M., BRÄUER, K., KÄMPF, H., STRAUCH & G., KOCH, U., 2001. Transport ofmantle volatiles through the crust traced by seismically released fluids: a natural experiment in the earthquake swarm area Vogtland/NW Bohemia, central Europe. *Tectonophysics*, 336: 137–150.

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Finite element modeling of fault-propagation folding above a rigid basement: A case study of the Nysa Kłodzka Graben (Sudetes, SW Poland)

Marcin Dąbrowski [1,2] & Janusz Badura [1]

[1] *Polish Geological Institute - National Research Institute, Lower Silesia Branch, Jaworowa 19, 53-122 Wrocław, Poland*
[2] *Physics of Geological Processes, University of Oslo, Norway*

Monoclinic folds have been described in the Late Cretaceous sediments of the Nysa Kłodzka Graben since Closs (1922) and they have been interpreted to have developed above fault blocks. The strata cropping out along the graben flanks are traditionally considered to correspond to the lowermost sedimentary units of the graben. The results of electoresistance surveys in the area demonstrate the presence of multiple small fault blocks in the basement. Here, we investigate whether forced folding due to faulting in the basement might have brought the thin layers (10–40 m) of the Cenomanian or Lower Turonian, which are at a depth of 300–600 m in the center of the graben, to their current position.

We present a finite element study of fold development in sedimentary cover above a fault in rigid basement. The layers constituting the sedimentary cover are treated as non-Newtonian fluids in creeping flow (Stokes flow) regime with gravity. MILAMIN (Dabrowski *et al.*, 2008), a Matlab implementation of the finite element method, is used to compute the deformation field above the basement. We use unstructured triangular computational meshes to accurately represent the evolving structures, with an interface-fitting mesh refined above the fault. The lithostratigraphic column is based on a data compilation from the literature. We investigate the influence of fault kinematics (extensional, contractional & in sequence), fault dip, rheological behavior of the sedimentary cover and erosion on the structural development of monoclinic folds above the rigid basement. The results of our modeling are compared to structural features extracted from a self-developed 3D Nysa Kłodzka Graben model, which is predominantly built on data obtained during electroresistance surveys.

References

CLOSS, H., 1922, Der Gebirsbau Schlesiens und die Stellungs-einer Bodenschätze. *Gebrüder Borntraeger*, 8: 1–107. Berlin

DABROWSKI, M., KROTKIEWSKI, M. & SCHMID, D. W., 2008, MILAMIN: MATLAB-based finite element method solver for large problems, *Geochem. Geophys. Geosyst.*, 9: Q04030

Geologia Sudetica, 2014, 42: 11.

Magnetic anisotropy and tectonics of the Upper Proterozoic rocks of Barrandian

Konstantin Dudinskiy & Rostislav Melichar

Department of Geological Sciences, Masaryk University, Kotlárská 2, 61137 Brno, Czech Republic, e-mail: 418712@mail.muni.cz

This work represents the first results of AMS research in Kralupy–Zbraslav and Štěchovice formations. These formations are located in Barrandian from central Bohemia region among Prague, Rožmitál pod Třemšínem and Nový Knín. It is a 15–20 km wide and about 60 km long stripe of slates, siltstones, graywackes, and conglomerates. The belt is oriented in SW–NE direction and main bedding surfaces as well as cleavage planes strike approximately in the same way.

Oriented samples were taken by manual drilling machine from outcrops or in laboratory from oriented stones. Cores, 25 mm in diameter and 20–25 mm length, were measured in AGICO laboratories, on MFK1 device.

The first sets of samples were studied in five localities, where anisotropy of magnetic susceptibility (AMS) was measured. Orientation of principal directions of AMS is shown in azimuthal plots (see Fig. 1). These pilot results indicate that AMS is not uniform in the area under study, and therefore strain influence was different in different domains. AMS shows expected SW–NE direction of magnetic lineation (K1) on localities S-4 and K-2, which well corresponds to trend of pencil structures found on these localities. Similar fabric (less intensive) seems to be on S-11 site. Another pattern of AMS was found at S-15 site, where perpendicular orientation was recognized (K1 in NW–SE direction). And the last studied locality, S-12 shows very diffuse fabric, which may originated in sedimentary process.

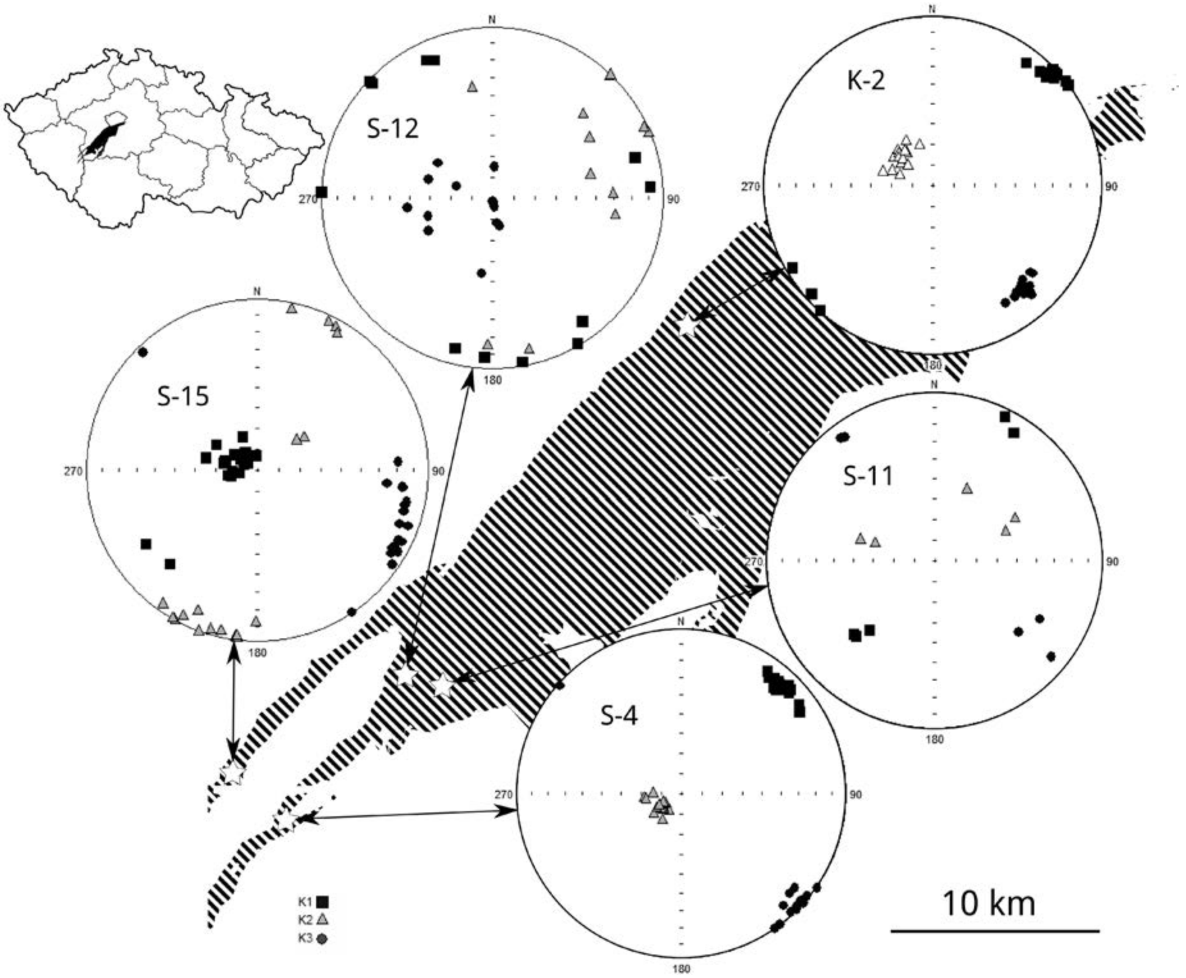

Fig. 1. Measured magnetic fabrics (Lambert proektion, geographic coordinate system) on region scheme, K1 – directions of maximum magnetic susceptibility (magnetic lineation), K3 – directions of minimum magnetic susceptibility (magnetic foliation), K2 – directions of middle susceptibility.

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Petrological and geophysical evidence for a one-time detachment fault in the metamorphic basement of the Pannonian basin, S Hungary

Ágnes Fiser-Nagy & Tivadar M. Tóth

University of Szeged, Departament of Mineralogy, Geochemistry and Petrology, Hungary, e-mail: agnes.nagy@geo.u-szeged.hu; mtoth@geo.u-szeged.hu

The Pannonian Basin has a crystalline basement with a rather complicated metamorphic and structural development. During the Neogene basin subsidence, deep sub-basins evolved surrounded by basement highs. The industrial interest about the numerous fractured hydrocarbon reservoirs of these basement highs allows the investigation of them. As there is no surface outcrop in the region, the metamorphic rock bodies can only be examined using the several bore cores and well-logs, which penetrated the uplifted regions.

One of these basement reservoirs is the Kömpöc – Csólyos-E (Köm – Csó-E) fractured hydrocarbon field (Fig. 1), situated in the Körös Complex, south from the Szank and northeast from Zsana regions. According to the well documentation, the rock columns in the wells are tectonically disturbed, the rocks are strongly, but in varying degrees deformed. The classification of the lithologies is complicated by the intense deformation and the superposition of different stages of the tectonical events.

The main mass of the metamorphic block of Köm – Csó-E (Fig. 1.) consists of polymetamorphic (S1 and S2 textures) sillimanite biotite gneiss (Fig. 2e), probably with intrusive igneous origin (myrmekitic feldspars, idiomorphic zircon grains). The orthogneiss body locally encloses unweathered and in varying degrees altered amphibolite xenoliths (Fig. 2f). The orthogneiss block underwent more consecutive deformation events. The different deformational phases overprinted each other in wide varieties, but the most general sequence is the following: mylonite (Fig. 2a, b)   pseudotachylite (Fig. 2c)   cataclasite (Fig. 2c, d)   fault breccia (Fig. 2d)   fractures and veins (Fig. 2). These fault rocks with different physical circumstances appear close to each other within a narrow field. Such a superposition structure of fault related rocks usually appears along detachment faults (Lister & Davis, 1989), where during the uplift of a shear zone the ductile deformation changes to brittle. Mylonite forms in higher temperatures, while as soon as it reaches the brittle zone cataclasite starts to develop. The identified rock types were extended along each well with using the well documentation and the well-logs. According to these result, the metamorphic block of the field consists of two main blocks; a northern gneiss – mylonite block and a southern gneiss – cataclasite block.

The Köm – Csó-E field has two neighbouring reservoirs with similar petrographic features; Kiskunhalas-NE (Kiha-NE) field and Jánoshalma (Jh) High (Fig. 1).

The incompatible rock column of the Kiha-NE field (Fig. 1) consists of four main rock units. In the lowermost structural position, an orthogneiss with amphibolite xenoliths is common. On the basis of the petrological character-

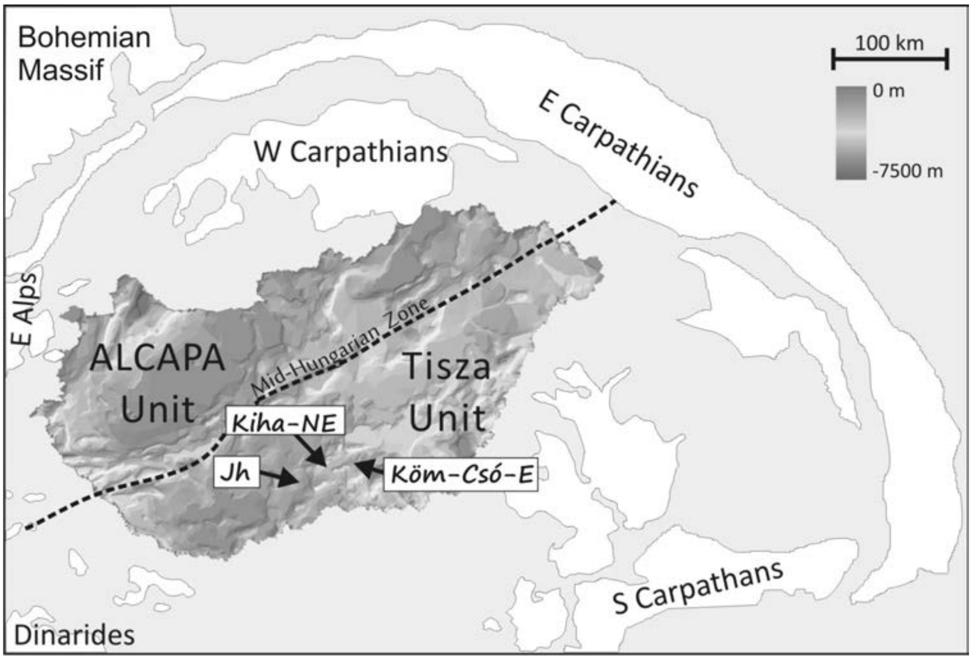

Fig. 1. Location of the Jánoshalma High (Jh), the Kiskunhalas-NE field (Kiha-NE) and the Kömpöc – Csólyos-E field (Köm-Csó-E) in the Pannonian Basin (after Haas *et al.*, 2010).

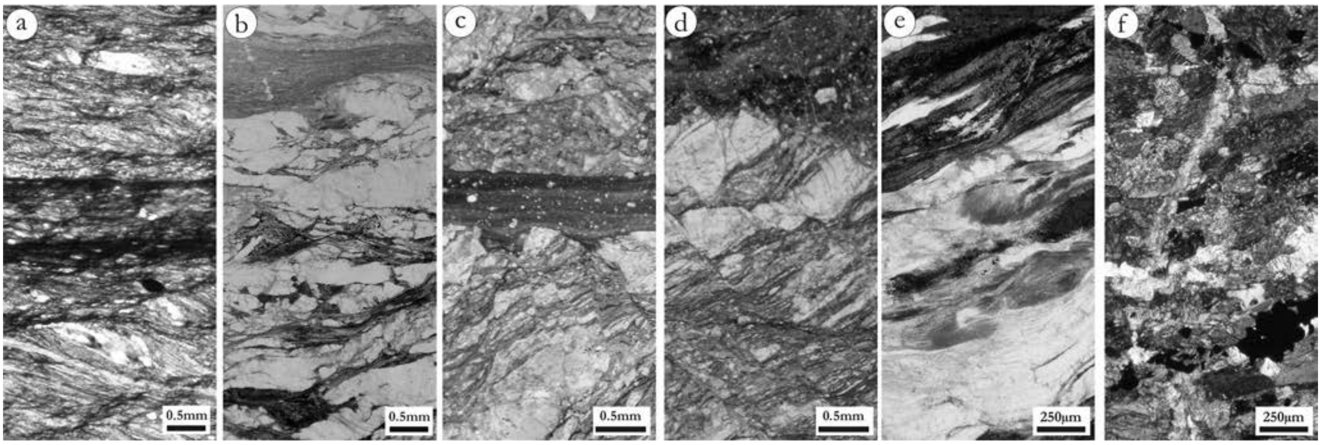

Fig. 2. The characteristic rock types of Kömpöc - Csólyos-E. **a)** mylonite (2N); **b)** protomylonite with ultramylonite band (on the top of the image) (1N); **c)** pseudotachylite in catalcalsic geiss (1N); **d)** fault breccia (upper part of the image) and cataclasic gneiss (lower part of the image) (1N); **e)** sillimanite biotite gneiss (1N); **f)** unweathered amphibolite (2N).

istics it is similar to the orthogneiss body of the neighbouring Jh High ($T < 580$°C, Zachar & Tóth, 2004). The next lithology unit upwards is the mylonitized orthogneiss, which clearly differs from the next graphitic gneiss mylonite type in its mineral assemblage. The extensional fabric elements (C/S fabric, apatite bookshelf, boudinaged clasts and deformed quartz grains) are common in both mylonite types. In accordance with the quartz suture thermometer (Kruhl & Nega, 1996), the temperature of the deformation event of these two mylonite types is estimated as T_{def}~455°C and the metamorphic temperature of the graphitic gneiss mylonite is T ~410 ± 45°C using a carbonaceous material thermometer by Raman microspectroscopy (eg.: Beyssac *et al.*, 2002). The uppermost member of the ideal rock column, a graphitic carbonate phyllite, occurs only in a limited area of the site. Its carbonaceous material thermometer results suggest a T ~370 ± 15°C. According to these results there is approximately 200°C difference in characteristic metamorphic temperatures between the bottom (orthogneiss) and top (graphitic carbonate phyllite) (Nagy & M.Tóth, 2012). With using of open-hole well-logs, lithology boundaries were estimated and the results were represented along geological sections. The gneiss/mylonite boundaries appear as a low angle (<5°) plane with northern dip (13–18°); interpreted as a one-time detachment fault linked to a formation of a core complex (Fiser-Nagy & Tóth, 2014).

The Jh High (Fig 1.) consists mainly of a uniform orthogneiss block with presence of xenoliths and xenocrysts of incompatible compositions and metamorphic evolutions. The xenoliths are of different sizes from tiny crystals up to possibly huge mafic lenses. Late granitoid veins intruded the gneiss body after the two-phase metamorphism. There are several samples with evidence of post-peak ductile deformation (dynamic recrystalisation of quartz, kink bands, mica fishes and very fine grained mica bands). The dynamic recrystallization of the quartz grains in the granitoid veins suggests that this low grade mylonitisation took place before the granitoid intrusion (Zachar, M. Tóth 2004).

In all three studied situation the metamorphic basement mainly consists of orthogneiss; in the cases of Jh and Kiha-NE the orthogneiss is probably identical, in Köm – Csó-E it has slightly different mineralogical composition. The evidence of a one-time detachment fault in Kiha-NE and Köm – Csó-E suggests some relationship between these neighbouring basement highs, too. There in Kiha-NE both the footwall and the hanging wall are exposed, while in the Köm – Csó-E area the wells penetrated the complicated fault rocks and the orthogneiss basis. Jh gneiss also underwent in an intense ductile deformation and so probably represents the footwall of the same structure.

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References:

BEYSSAC, O., GOFFÉ, B., CHOPIN, C. & ROUZAUD, N., 2002. Raman spectra of carbonaceous material in metasediments: a new geothermometer. *J Metamorph Geol*, 20: 859–871.

FISER-NAGY, Á., VARGA-TÓTH, I., M. & TÓTH, T. 2014. Lithology identification using open-hole well-log data in the metamorphic Kiskunhalas-NE hydrocarbon reservoir, South Hungary. *Acta Geod Geophys*. In Press.

HAAS, J., BUDAI, T., CSONTOS, L., FODOR, L. & KONRÁD, GY., 2010. Pre-Cenozoic geological map of Hungary, 1:500 000. Geological Institute of Hungary

KRUHL, J. H. & NEGA, M., 1996. The fractal shape of sutured quartz grain boundaries: application as a geothermometer. *Geol Rundsch*, 85: 38–43.

LISTER, G. S. & DAVIS, G. A., 1989. The origin of metamorphic core complexes and detachment faults formed during Tertiary continental extension in the northern Colorado River region, USA. *J. Struct. Geol*., 11/1-2: 65–94.

NAGY, Á, M. & TÓTH, T. 2012. Petrology and tectonic evolution of the Kiskunhalas-NE fractured CH-reservoir. S-Hung Cent Eur Geol, 55/1: 1–22.

ZACHAR J, M. & TÓTH, T. 2004. Pertology of the metamorphic basement of the Tisza Block at the Jánoshalma High, S Hungary. *Acta Geol Hung*, 47/4: 349–371.

Geologia Sudetica, 2014, 42: 14–15.

Late Miocene depositional units and syn-sedimentary deformation in the western Pannonian basin, Hungary

László I. Fodor[1], Orsolya Sztanó[2], Imre Magyar[3], Balázs Törő[4], András Uhrin[5], Attila Várkonyi[6], Gábor Csillag[7], Szilvia Kövér[1], Zoltán Lantos[7], András Németh[3], Márton Palotai[2] & Lilla Tőkés[2]

[1] *MTA-ELTE Geological, Geophysical and Space Science Research Group, Hungarian Academy of Sciences at Eötvös University, Budapest 1117 Pázmány P. sétány 1/C, Hungary, e-mail: lasz.fodor@yahoo.com*
[2] *Department of General and Applied Geology, Eötvös University, Budapest 1117 Pázmány P. sétány 1/C, Hungary*
[3] *MOL Plc., 1117 Budapest, Október 23. út 18, Hungary*
[4] *Department of Geological Sciences, University of Saskatchewen, Saskatoon, Canada*
[5] *Eriksfjord, Stavanger, Norway*
[6] *O & G Developement Ltd., 1024 Budapest, Lövoház utca 39, Hungary*
[7] *Geological and Geophysical Institute of Hungary, Budapest, Stefánia 14, Hungary*

The Pannonian Basin system is due to late Early to Mid-Miocene lithospheric extension and related crustal faulting between 19 and 11.6 Ma (Tari, 1996). The faults bounded more or less isolated sub-basins with few hundred meters of terrestrial to marine sediments while the intermittent basin highs were marked by a reduced sedimentation or erosion.

At the beginning of the Late Miocene, the sedimentation has been changed and the brackish Lake Pannon developed. Between 11.6 and 9.7 Ma the former basin highs were progressively inundated and the surface and volume of the lake increased (Magyar *et al.*, 1999; 2013). Since 9.7 Ma onwards clastic input via extensive fluvial networks progressively filled the lake, large scale normal regression took place.

Late Miocene deposition pattern, facies relationship and coeval structural geometry and kinematics, as well as their influence on sedimentation was studied by the help of surface structural, sedimentological and paleontological observations, by 2D and 3D seismic reflection data sets. Our research extended into the Transdanubian Range (TR), the largest high in the Miocene, and sub-basins west, south and south-east from the paleo-high.

The transgressive phase resulted in in a spatially variable facies pattern (Sztanó *et al.*, 2013). Deep lacustrine marls of large thickness accumulated in the deep sub-basins (Endrod Fm) and condensed marls in the less than 100 m deep waters covering the flanks of the basement highs. This latter lithofacies (Szák Fm) is characteristic along the western margin of the TR during 9.5–9 Ma. The clastic input reached the western Pannonian basin from the NW and N. As rivers entered the lake, deltas of ca. 20–50 m thick coarsening upwards successions were formed. These shelf deltas prograded towards the several hundred meter high basin-margin slopes, and also towards flooded basement highs where slopes were missing (Sztanó *et al.*, 2013). Deltas were prograding across both type of areas, but above deep basins deltaic successions has a large thickness, while on highs they compose reduced sequences.

Systematic mapping of shelf-to-basin clinoforms clearly indicate the influence of basement highs which deflected slope progradation into a direction sub-parallel to highs (Uhrin *et al.*, 2009; Uhrin, 2011; Töro *et al.* 2012; Várkonyi 2012). These basement highs were partly inherited from the syn-rift deformation, however, seismic sections clearly demonstrate active syn-sedimentary faulting during the transgressive phase and partly during slope progradation, ca. between 11.6 and 8.5 Ma. Fault-controlled abrasional gravels and fault breccias are found along the margins of TR, were most likely coeval with the flooding of highs and might have occurred between 9.5 and 8.8 Ma. Surface measurements suggest an E–W to ESE–WNW extensional (transtensional) stress field in agreement with seismic fault mapping (Balla & Dudko, 1996; Fodor *et al.*, 1999).

Southeast from the Lake Balaton, several faults of the wide Mid-Hungarian shear zones were reactivated. Namely, the Balaton fault zone was a sinistral transpressional structure (Várkonyi, 2012). The transtensional Ozora trough could be active between 8.6 and 8 Ma (Töro *et al.*, 2012). Along strike continuation of the Tóalmás Zone the sinistral pull-apart Adony basin developed, and the basin-margin fault continued north-eastward (Tóalmás Fault) (Palotai, 2013). On the other hand, south from the TR, thickness of basinal marls decreased above E–W trending transpressional ridges (Kilimán and Belezna Highs, Skorday, 2010) which were active between ca. 12 and 9 Ma. After the cessation of deformation during slope progradation between 9 and 8 Ma, a new phase of folding started and reactivated the E–W trending anticlines from ca. 8–7.5 Ma. Although this could be considered as the first step in neotectonic reactivation (Horváth,

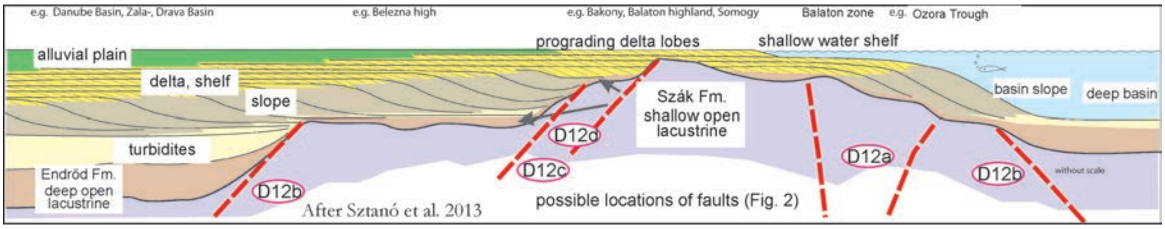

Fig. 1. Simple model for facies relationships, depositional environments of late Miocene (Pannonian) sediments in the NW half of the Pannonian Basin, after Sztanó *et al.* (2013). Note possible locations of syn-sedimentary faults.

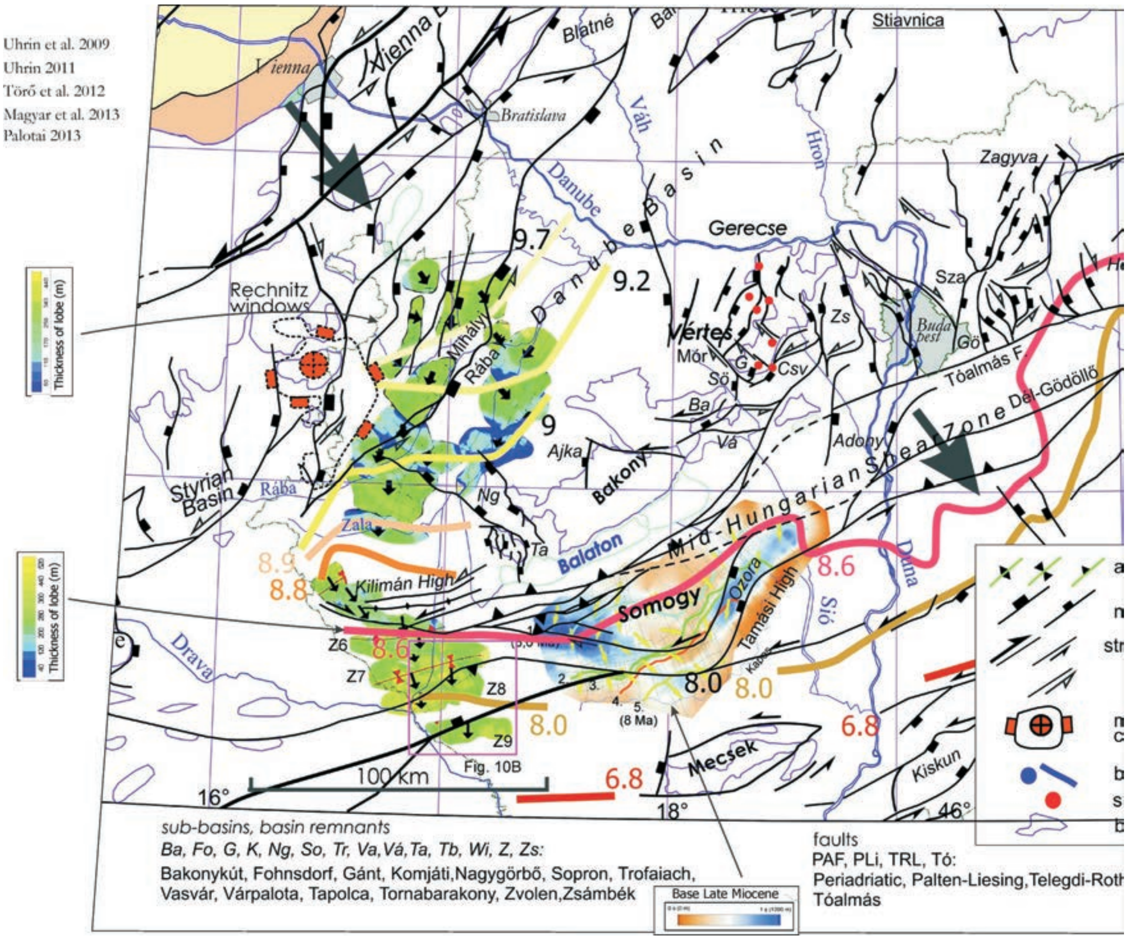

Fig. 2. Map of Late Miocene structures superimposed on large shelf-margin slope units (Uhrin *et al.*, 2009; Uhrin, 2011; Töro *et al.*, 2012). Large and small arrows indicate slope progradation. Ages of shelf edge after Magyar *et al.* (2013).

1995), regional subsidence counterbalanced anticlinal growth and deltas overstepped folds.

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References

BALLA, Z. & DUDKO, A., 1996. Fractures in Pannonian layers. *Földtani Közlöny*,126, 209–262.

FODOR, L., CSONTOS, L., BADA, G., GYÖRFI, I. & BENKOVICS, L., 1999. Tertiary tectonic evolution of the Pannonian basin system and neighbouring orogens: a new synthesis of paleostress data. In: Durand, B., Jolivet, L., Horváth, F., Séranne, M. (eds): The Mediterranean Basins: Tertiary extension within the Alpine Orogen. *Geological Society, London, Special Publications*, 156: 295–334.

HORVÁTH, F., 1995. Phases of compression during the evolution of the Pannonian Basin and its bearing on hydrocarbon exploration. *Marine and Petroleum Geology*, 12: 837–844.

MAGYAR, I., GEARY, D. H., SÜTO-SZENTAI, M., LANTOS, M. & MÜLLER, P., 1999. Integrated biostratigraphic, magnetostratigraphic and chronostratigraphic correlations of the Late Miocene lake Pannon deposits. *Acta Geol. Hung*, 42: 5–31.

MAGYAR, I., RADIVOJEVIĆ, D., SZTANÓ, O., SYNAK, R., UJSZÁSZI, K. & PÓCSIK, M., 2013. Progradation of the paleo-Danube shelf margin across the Pannonian Basin during the Late Miocene and Early Pliocene. *Global and Planetary Change*.

PALOTAI, M., 2013. Oligocene-Miocene Tectonic Evolution of the central part of the Mid-Hungarian Shear Zone. PhD thesis, Eötvös Universtiy, Department of Physical and Applied Geology, Budapest, Hungary, 147 p.

SKORDAY, E. 2010. Az Ortaháza-Kilimáni-gerinc és északi előterének szerkezete. MSc work, Eötvös University, 88 p.

SZTANÓ O., MAGYAR I., SZÓNOKY M., LANTOS M., MÜLLER P., LENKEY L., KATONA L. & CSILLAG G., 2013. Tihany Formation in the surroundings of Lake Balaton: type locality, depositional setting and stratigraphy. 2012. *Földtani Közlöny*, 143: 73–98.

TARI, G., 1996. Extreme crustal extension in the Rába river exten- sional coridor (Austria/Hungary). *Mitt. Gesell. Geol. Berg- baustud. Österreich*, 41: 1–18.

TÖRO B., SZTANÓ O. & FODOR L., 2012. Inherited and syndepositional structural control on the evolution of the slope of Lake Pannon, Northern Somogy, Hungary. *Földtani Közlöny*, 142/4: 339–356.

UHRIN A., 2011: Vízszintváltozási ciklusok és kialakulásuk okai a késő-miocén Pannon-tó egyes részmedencéiben. PhD dissertation, Eötvös University, Dept. of General and Applied Geology, 127 p.

UHRIN A., MAGYAR I. & SZTANÓ O., 2009. Control of the Late Neogene (Pannonian s.l.) sedimentation by basement deformation in the Zala Basin. *Földtani Közlöny*, 139: 273–282.

VÁRKONYI A., 2012. Észak-Somogy késő-kainozoos deformációjának és üledékképzodésének vizsgálata szeizmikus adatok alapján. MSc work, Eötvös University, Dept. of Regional Geology, 108 p.

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On the crustal-scale triangle zone in the Holy Cross Mountains (northeastern foreland of the European Variscides)

Łukasz Gągała[1, 2]

[1] *Georex Assistance Technique, 145 rue Michel Carré, 95100 Argenteuil, e-mail: lgagala@georex.com;*
[2] *Institute of Geological Sciences, Polish Academy of Sciences, ul. Twarda 51/55, 00-818 Warszawa*

The Holy Cross Mountains (HCM) comprise a solitary Paleozoic massif that emerges from beneath a Permian–Mesozoic cover ~100 km beyond the southwestern edge of the East European Craton (EEC). Their importance as the best exposed part of the Trans-European Suture Zone has been long appreciated. The HCM experienced tectonic inversion in the Late Cambrian (Sandomirian phase: a time-equivalent of the late Timanian orogeny), Late Silurian–Early Devonian (Caledonian), Late Carboniferous (Variscan), and the Late Cretaceous–Paleocene (Laramide). Most of the present regional structural fabric was inherited after Variscan shortening. The Variscan structures overprint, yet not entirely conceal the pre-existing Caledonian and Sandomirian geometries.

The Paleozoic of the HCM consists of two tectonostratigraphic units – the Kielce and Łysogóry Zones. These are separated by the Łysogóry Thrust (Holy Cross Fault) (Fig. 1). The two zones differ in terms of stratigraphy and structural expression of the main deformation phases. The Kielce Zone is made up of Early Cambrian–Early Carboniferous sediments resting on top of unidentified substratum. The post-Cambrian strata attain ~1–2 km in thickness; the underlying Early-Mid Cambrian strata are thick (~1–2 km?), yet their base is not exposed. The sedimentary succession of the Kielce Zone contains two unconformities that correspond to the Sandomirian and Caledonian deformation phases. The sediments have been deformed into a series of ESE-trending folds. The Łysogóry Zone consists of Mid Cambrian–Late Devonian sediments that reach ~7 km in thickness. These are stratigraphically continuous, with the exception of a locally developed Caledonian-related unconformity between the Upper Silurian and the Lower Devonian. The most prominent structural feature of the Łysogóry Zone is a large NNE-dipping homocline directly adjacent to the Łysogóry Thrust.

New structural descriptions and kinematic interpreta-

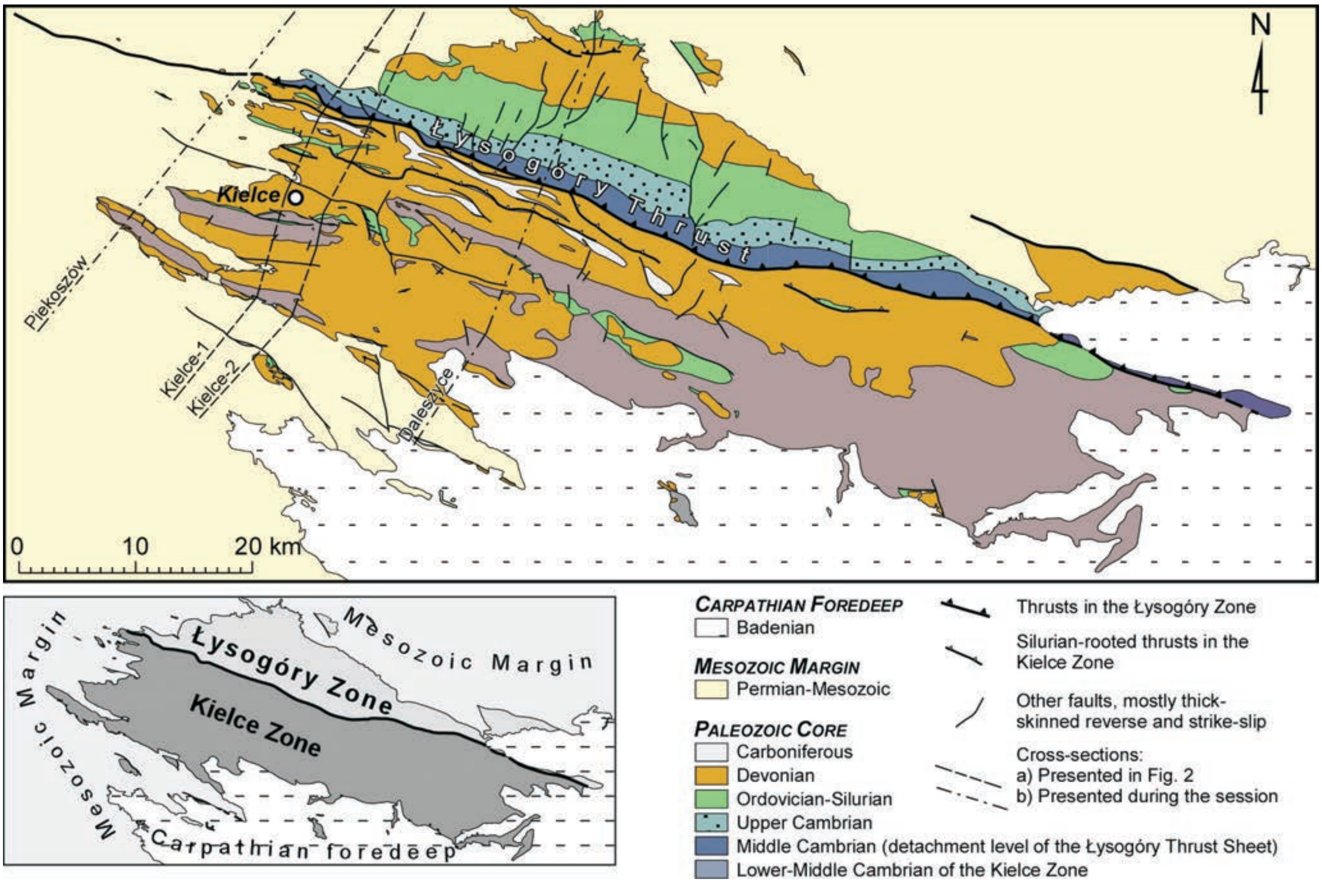

Fig. 1. Simplified geological map of the Holy Cross Mountains.

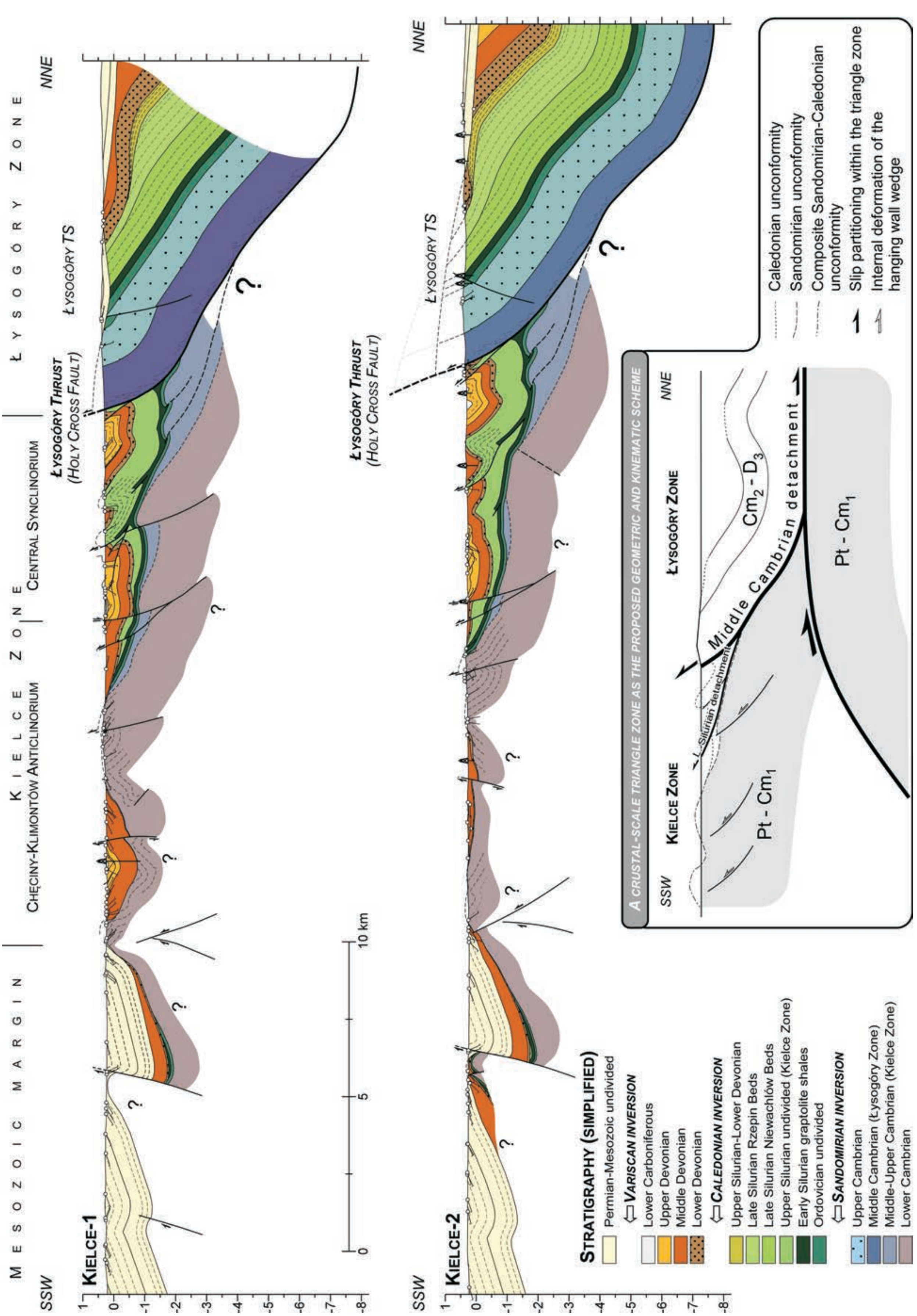

Fig. 2. Structural cross-sections through the western part of the Holy Cross Mountains and the concept of the triangle zone as the best-fit explanation of Variscan structural geometries and kinematics.

tions of the HCM are presented, with a particular emphasis on the geometric and kinematic links between the Kielce and Łysogóry Zones. Regional structures have been investigated by cross-section balancing techniques. Four cross-sections were constructed, two of which are included in this abstract (Figs 1 and 2). This work focuses on the well-exposed and well-mapped western and central parts of the HCM (Fig. 1).

The Kielce and Łysogóry Zones form a geometrically and kinematically coherent contractional belt. This belt consists of two distinct structural entities: 1) a south-vergent thin-skinned system comprising the Łysogóry Zone and the northern part of the Kielce Zone, and 2) a thick-skinned system that has experienced less shortening and which incorporates the central and southern parts of the Kielce Zone. The thin-skinned system has been thrust to the south along a detachment that follows Mid Cambrian shales beneath the Łysogóry Zone and climbs up to Early Silurian graptolite shales in the northern part of the Kielce Zone. The foreland reach of the thin-skinned system is controlled by the subsurface extent of the Early Silurian graptolite shales. The structural anatomy of the HCM therefore does not fit with its division into the Kielce and Łysogóry Zones based on stratigraphic criteria.

The southern anticlinorial part of the Kielce Zone involves a series of Cambrian-cored anticlines. The anticlines have inconsistent wavelengths, amplitudes, shape ratios and show irregular transverse profiles. The Cambrian-cored anticlines therefore do not permit discrimination between end-member kinematic mechanisms (i.e. detachment folding or fault-propagation folding). Folding must have resulted from localized involvement of the Early Cambrian strata without a common detachment plane. Selective activation of basement-rooted faults, sealed by the Lower Cambrian is the proposed mechanism (Fig. 2).

The northern part of the Kielce Zone forms a tightly folded synclinorium. Here, a series of short-wavelength, south-vergent, and fault-related Silurian-cored anticlines have a common detachment in the Early Silurian graptolite shales. In the western part of the HCM, these Silurian-cored anticlines form a small imbricate fan. This fan is linked to the Łysogóry Thrust through the basal detachment and thus forms the leading edge of the Łysogóry thin-skinned system (Fig. 2).

The hinterland limit of the Silurian-cored imbricate fan is formed by the Łysogóry Thrust. The thrust dips 35–45° NNE, steepening to 70–85° NNE in the west as a result of piggy-back rotation. The Łysogóry Thrust is a thin-skinned structure rooted in the Mid Cambrian shales of the Łysogóry Zone. It has transported detached sediments of the Łysogóry Zone onto the Kielce Zone. The Łysogóry Thrust Sheet (ŁTS) forms the hanging wall of the Łysogóry Thrust. The ŁTS has a homoclinal geometry, with the oldest sediments adjacent to the basal thrust and successively younger strata cropping out towards the hinterland. The western part of the ŁTS hosts a Caledonian-related progressive unconformity (Fig. 2). The unconformity results in a thickness reduction of the Late Silurian–Early Devonian stratigraphic units and indicates that the ŁTS was active during the Caledonian inversion. The existence of Latest Silurian–Early Devonian growth strata in the subsurface is predicted (Fig. 2). To the north, the ŁTS descends into the deep Bodzentyn Syncline (partly included in Fig. 2). Thickness extrapolation from the core of the syncline constrains the position of the flat-ramp transition of the Łysogóry Thrust at depth.

The structure of the HCM indicates a dominant role of plain-strain shortening during Variscan inversion. The Łysogóry Thrust accommodates ~3–4 km of Variscan shortening and the frontal, Silurian-floored imbricate fan accommodates ~1.5–1.7 km. Tectonic transport was from the structural depression in the north (Łysogóry Zone) to the structural high in the south (Kielce Zone). Such a configuration is diagnostic of passive-roof backthrusting. The structure of the HCM is therefore interpreted as a crustal-scale triangle zone that was created by the indentation of the leading edge of the Kielce Zone into the Mid Cambrian detachment of the Łysogóry Zone (Fig. 2, inset scheme). This solution complies with the present (?Variscan) structural geometries but also offers a key to understanding the kinematics of the Caledonian and Sandomirian phases of inversion. In both cases, repetitive thrusting of the Kielce Zone over the Łysogóry Zone can explain the accelerated subsidence in the Late Cambrian and Late Silurian as well as the regional deformation pattern fitting to the triangle-zone scenario. A comprehensive justification of these statements will be provided separately.

An important consequence of the presented model is the idea of a permanent kinematic coupling of the Kielce and Łysogóry Zones in the Paleozoic. The Łysogóry Thrust (Holy Cross Fault) is a superficial, thin-skinned structure that does not continue below the Middle Cambrian. The structural boundary between these two Zones is the inferred NNE-vergent basement ramp carrying the Kielce Zone on top of the Łysogóry Zone. This ramp may sole down to the brittle/ductile transition or may have deeper foundations.

Geologia Sudetica, 2014, 42: 19–20.

Alongstrike changing structure of the Carpathian thrust front east of Tarnów (SE Poland) as intersection phenomenon related to thrust-floor palaeotopography

Andrzej Głuszyński[1,2] & Paweł Aleksandrowski[1,2]

[1] *Polish Geological Institute – National Research Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland,*
e-mail: andrzej.gluszynski@pgi.gov.pl
[2] *Institute of Geological Sciences, Wroclaw University, ul. Cybulskiego 32, 50-205 Wroclaw, Poland,*
e-mail: pawel.aleksandrowski@pgi.gov.pl

Structural geometry of the Carpathian orogenic front between Tarnów and Pilzno was investigated, using borehole and 2D and 3D seismic data. The study revealed the Carpathian orogenic front is a complex fold-thrust zone with structural geometry that is apparently changing along-strike. At places the frontal thrust of the Carpathians is blind and accompanied by well developed wedge tectonics phenomena (Fig. 1A). Elsewhere it is emergent at the surface and shows an apparently simple structure (Fig. 1B). The base of the fold-thrust zone rests on a substratum with highly variable palaeotopography (Fig. 2), which, during the thrusting, was apparently covered with salt-bearing evaporite of areally limited extent. The thrusting took place in Badenian to Sarmatian stages of the Miocene epoch.

The wedge tectonics phenomena include backthrusts and a prominent crocodile structure. The tectonic wedge is formed by stacked thrust-slices of the Cretaceous-to-Oligocene flysch of the Skole nappe. This wedge has forced a basal Miocene evaporitic layer (including salt) to split into two horizons (1) the lower one, which acted as a tectonic lubricant along the floor thrust of the forward-moving flysch wedge, and (2) the upper one, along which the Miocene sediments of the Carpathian foredeep were underthrusted by the flysch wedge (Fig. 1A). This resulting crocodile structure has the flysch wedge in its core, a passive roof of Miocene sediments at the top and tilted Miocene strata at its front, defining a frontal homocline. A minor triangle zone, cored with deformed evaporites, has formed due to backthrust branching at the rear of the frontal monocline. The thrust deformation's intensity quickly declines towards the foreland. Frontal fault-bend anticlines in the Miocene strata trace the northern limit of the deformation related to the Carpathian orogen. The anticlines affect both pre- and syntectonic strata; they are buried by posttectonic sediments. Locally, above the frontal backthrust, fault-bend frontal anticlines are developed over oblique and frontal ramps. They are accompanied by a SW-plunging syncline related to an oblique ramp in the west.

At other places, the Carpathian flysch and its basal thrust, emerge at the surface. We infer the flysch must have once also formed a wedge there, but currently the most part of it has been removed by erosion that followed its elevation above the present-day topographic surface on the frontal thrust (Fig. 1B).

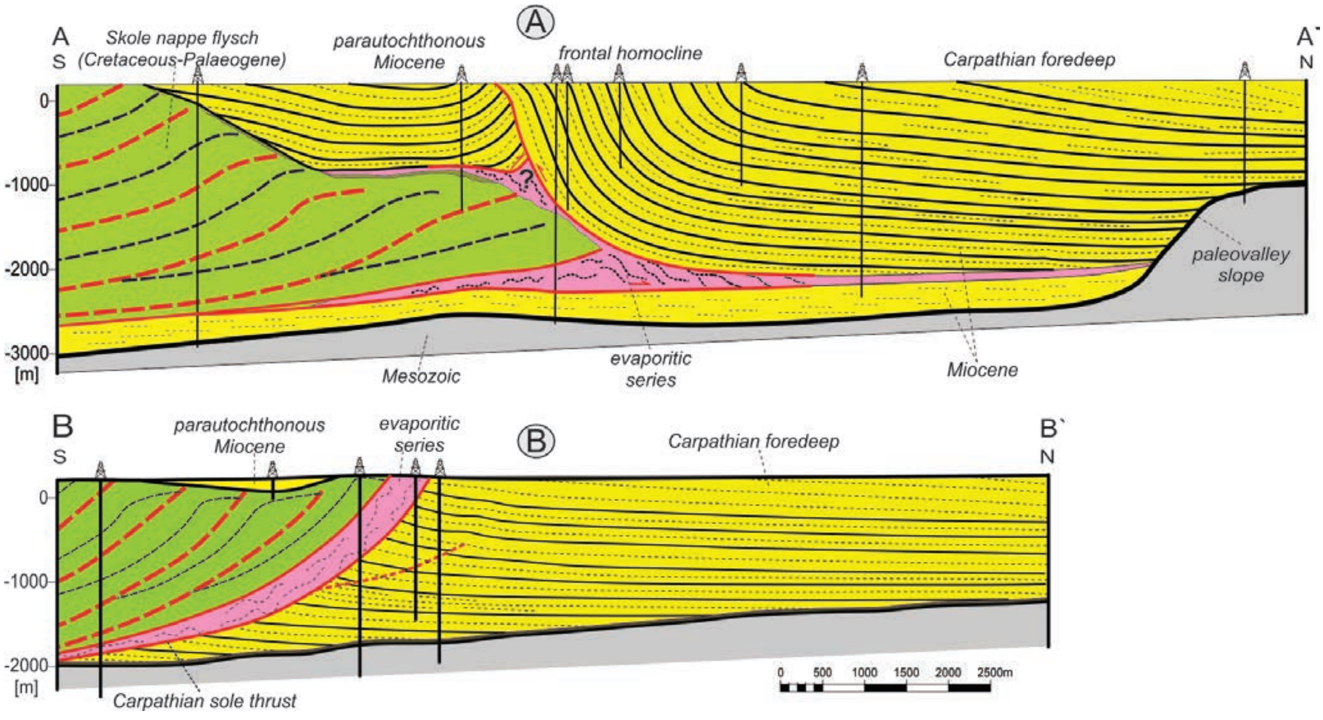

Fig. 1. Two examples of cross-sections across the Carpathian front east of Tarnów.

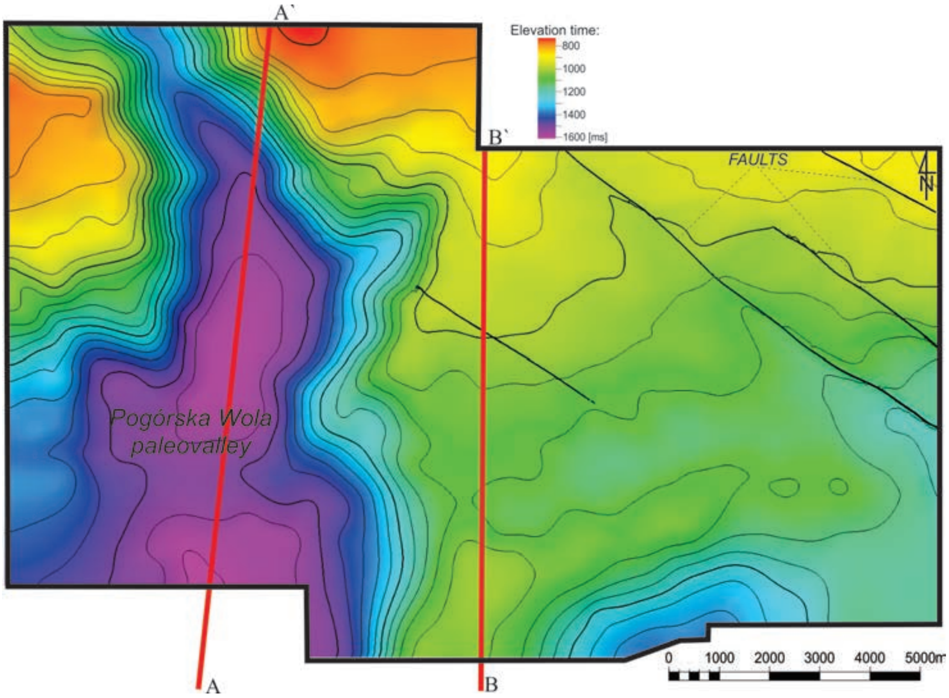

Fig. 2. Map of foredeep base surface in time domain based on 3D seismics showing location of cross sections.

The Skole flysch units overlie a relatively thin zone of deformed Miocene evaporitic series that covers autochthonous clastic Miocene sediments of the inner parts of the Carpathian foredeep. The sediments are southerly dipping at a shallow angle below the Outer Carpathian nappe structure. The Miocene, in its turn, rests on top of erosionally dissected Mesozoic sedimentary cover of the Malopolska terrane, being part of the Trans-European Suture Zone of the Palaeozoic West European platform.

Our study indicates that the lateral variations in the structural geometry at the thrust front of the Carpathian orogen are due to different levels of erosional truncation that were controlled mainly by a predeformational palaeotopography of the base of the Carpathian foredeep. At the same time, the wedge tectonics phenomena owe their formation to the limited lateral extent of the evaporitic layer and its facies changes.

At erosionally lowered locations of the foredeep's base, represented by the 800 m-deep palaeovalley of Pogórska Wola (Fig. 2), the Carpathian thrust front is a fully preserved, subsurface structure, concealed below the Miocene molasse of the foredeep. On the other hand, in areas where the pre-thrusting erosion was not so efficient (outside the palaeovalley, in the Pilzno segment), the Carpathian orogenic front is emergent at the surface. We infer that the originally existent flysch tectonic wedge, splitting the evaporite at its front, was thrusted to upper levels and then eroded at such locations.

The results of this study are illustrated by a set of cross-sections and a 3D model constructed using the Petrel Software (^{TM}Schlumerger).

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Pseudotachylites of the Złoty Stok-Skrzynka tectonic zone, Śnieżnik metamorphic, Sudetes

Roman Gotowała, Aneta Piotrowska & Piotr Wojtulek

Institute of Geological Sciences, University of Wrocław, pl. M. Borna 9, 50-204 Wrocław, Poland,
e-mail: roman.gotowala@ing.uni.wroc.pl, aneta.piotrowska@ing.uni.wroc.pl, piotr.wojtulek@ing.uni.wroc.pl

While mapping the central and northern parts of the Złoty Stok – Skrzynka tectonic zone, on both Polish and Czech sides, the authors encountered the dikes of dark, ultramylonitic rocks. The features of their occurrence, which are: dominant petrographic attributes visible macroscopically, obvious mylonitization, also vicinity of quartzites occurrences and granitoid intrusion and finally, the location at fault zones allowed the authors to classify tentatively (field) these rocks as pseudotachylites group.

The discussion on the origin and nature of pseudotachylites dates back to the beginning XXth century and refers to glassy massive rocks occurring in the form of dikes which are located in different regions of the world, most often in the vicinity of intrusive massifs and large fault zones, especially overthrusts (e.g. Northwest Highlands, Cheviot Hills, Glen Coe – Scotland, Outer Hebrides Thrust Faults, Himalayan Thrust Fault, Parys Region of South Africa) (Higgins, 1971). One of the first descriptions of these rocks gave Shand (1916) claiming that pseudotachylites came from the rocks containing them, through melting due to influence of thermal shock or alternatively by gas-fluxing. An important factor in this type of heat-generating process of creating of pseudotachylites can be the thermal effect of friction in a fault zone (local "hot spot" – Bowden *et al.*, 1947). The confirmation of this hypothesis could be the smooth transition zones in small areas where is visible a clear gradation from the thin glassy rock through mylonite, ultramylonite, to the non-deformed rock. This last feature was visible in the rock described from the Złoty Stok – Skrzynka tectonic zone.

A detailed interpretation of the genesis of pseudotachylites, based on the full complement such as: field, petrographic, X-ray and chemical studies, described from their occurrences in Canada and South Africa, gave Philpotts (1964). Author concluded that "pseudotachylites are the result of fusion of rocks either by frictional heat or very hot gases probably developed in a fault zone during period of rapid displacement". According to this author melted material is forced into fractures where is begin to cool (Higgins, 1971). Pseudotachylite is classified to the fault rock group, which forms mainly in upper part of the crust (Fossen, 2012).

The composition of the pseudotachylites correspond closely to the rocks in which they occurs. Fragments of them are included in fine-grained groundmass as porphyroblasts. The significant role in their formation is assumed to the presence of rocks rich in quartz, which may be due to its mechanical properties (Philpotts, 1964). The main pro-

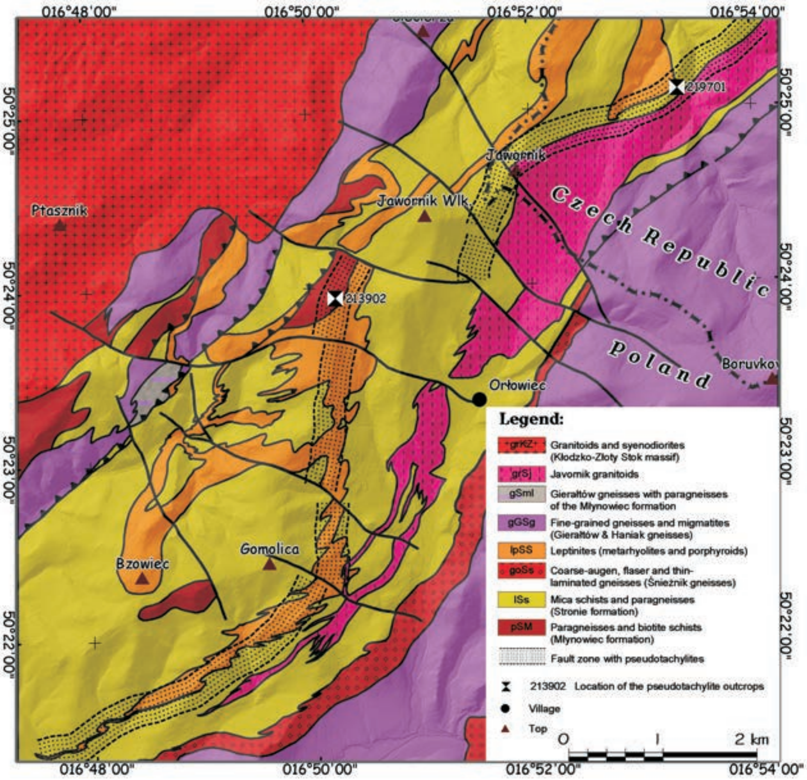

Fig. 1. Location of investigated samples on the geological map of the Złoty Stok – Skrzynka tectonic zone.

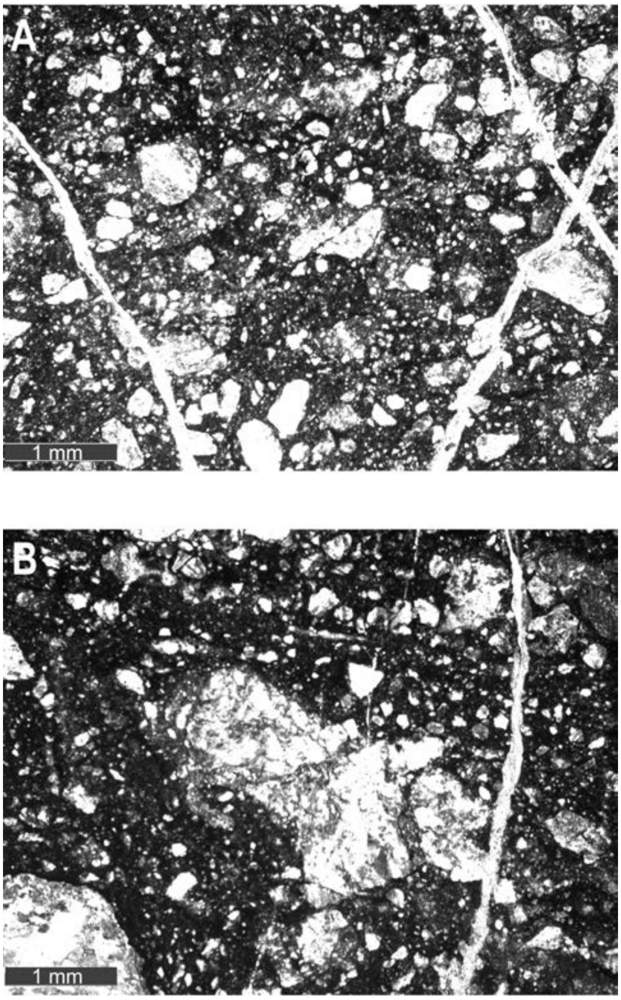

Fig. 2. Ultramylonite from the Złoty Stok – Skrzynka tectonic zone, photomicrographs, transmitted light, one polar; **A** – rounded quartz porphyroblasts occurring on the opaque, fine-grained to aphanitic groundmass. Part of blasts are uniform, whereas the majority are cataclazed and dismembered. The veins are composed of quartz; **B** – amebodal, cataclazed porphyroblast surrounded by fine-grained to aphanitic groundmass that mimic the blast boundary. The edges are rounded.

cesses having influence on these rocks formation include: frictional fusion, shock processes and "cataclasis at high strain rate during seismic slip events" (Wieland, 2006).

Rock classified by us as pseudotachylite, occurs both in outcrops as simple dikes and frequently was encountered as single blocks. For the initial petrographic determinations we collected samples from two outcrops, one of which is located on the Czech side on the NE slopes of the Muflon hill (Fig.1, 219701) and the second is located on the E slopes of a hill 745.11 m a.s.l., westwards from the Jaworowa pass (Fig.1, 213902). Both positions are located among different rocks. In the vicinity of the first outcrop there is a tectonic contact of Jawornickie granitoids and leptynites with narrow zone highly mylonitized shists, graphite shists, light quartzites and amphibolites (Stronie Formation). The vicinity of the other outcrop is dominated by schists and biotite paragneisses (Młynowiec Formation) and bright strongly tectonized quartzites (Stronie Formation). However, both dikes are located in very similar structural position. They are cutting rocks on intensively dislocated inverted limbs of large antiforms. This dislocations are clearly defined as reverse faults. The strike of these faults has a direction NE–SW and the blocks of the described rock was observed along this zone. In both described outcrops pseudotachylites occur in the form of dikes. The gradation from the glassy rock in the centre and laminated mylonite towards borders of the dike is visible in the 219701 locality. In the 213902 there is an intrafoliational penetration of the pseudotachylites into the precinct of surrounding gneisses. The contact of the pseudotachylite dikes with adjacent rocks ranges from sharp cut-off veins to graduall disappearance of its features, and, a clear color change from brown and navy blue to lighter steel and blue. In both outcrops strike of pseudotachylite dikes is close to the main foliation (which is corresponds to layers boundaries), but they have clearly steeper dips (more about the 20–30ş) which emphasizes of the dike nature of these occurrences.

The rock in the outcrop 219701 can be macroscopically described as a dark, quartzitic ultramylonite with the transition to mylonite which has a characteristic alternation of dark and bright lamella from 2 to 10 milimeters. The dark color of the rock may be caused by magnetite crystals occurring within the quartzitic groundmass (feature observed in the microscope view).

The sample from 213902 in macroscopic scale represents dark to brown and blue color mylonite, without visible orientation of components. In the dark groundmass occur scattered and rounded grains of quartz. The rock consist of black, nearly opaque and aphanitic groundmass and quartz porphyroblasts of various sizes (100 μm – 4 mm). The porphyroblasts are often dismembered and cataclazed, uniform grains occur rarely. Locally their edges are rounded and they have ameboidal shape. Both dark groundmass and porphyroblasts are cut by veins filled by quartz (Fig.2).

The rock of the both samples were probably affected by friction processes originated from an intense shearing in the fault zones. The influence of thermal factor, considered as a possible one formation of pseudotachylites, is less visible, but based on preliminary petrographic analysis should be not excluded. Both the thermal effect of intrusive bodies in the vicinity of described rocks and the possibility of generating thermal effects in tectonic processes should be considered in the next examinations. Both outcrop positions are in fact located in the NE–SW trending regional range fault zone with an imbricate structures (Fig.1).

References

BOWDEN, F. P., STONE, M. A. & TUDOR G. K., 1947. Hot spots on rubbing surfaces and the detonation of explosives by friction. *Roy. Soc. London. Proc*., 188: 329.

FOSSEN, H., 2012. Structural Geology. Cambridge University Press, New York.

HIGGINS, M. W., 1971. Cataclastic rocks. Geological Survey Professional Paper, 687. Washington.

PHILPOTTS, A. R., 1964. Origin of pseudotachylites. *American Journal of Science*, 262 (8): 1008–1035.

WIELAND, F. 2006. Structural analysis of impact-related deformation in the collar rocks of the Vredefort Dome, South Africa. Unpublished PhD dissertation. School of Geosciences, University of the Witwatersrand, Johannesburg.

Geologia Sudetica, 2014, 42: 23–24.

Synsedimentary distensive heritage and thrusting structuration: geometric modeling of the Jebel Fert El Bir (South Rifian Ridges, Northern Morocco)

El Hassania Habibou[1], Hmidou El Ouardi[1], Mohamed Habibi[1] & Eric Mercier[2]

[1] *CartoTec group, Moulay Ismail University, Faculty of Sciences, Department of Geology, PB 11201 Zitoune, Meknes, Morocco;*
e-mail: hassania-habibou@hotmail.com; hmidouelouardi@yahoo.fr; habibim58@gmail.com
[2] *University of Nantes, UMR-6112 of CNRS, Planetology and Geodynamic Laboratory, Nantes, France;*
e-mail: eric.mercier@univ-nantes.fr

Introduction: The South Rifian Ridges (SRR) are located at the frontal part of the Rif Cordillera. They comprise elongated hills, formed mainly by Jurassic rocks. The SRR are grouped into two great ensembles separated by the Volubilis depression (Fig.1). They are formed by a sedimentary sequence starting with Triassic rocks, a thick Jurassic sequence, and locally, a marly Cretaceous series in the Eastern Ridges. Unconformable Lower and Middle Miocene marls as well as sandstones of Middle-Upper Miocene cover the Mesozoic series. The SRR correspond generally to anticlinal hinges of SW and S vergence located in the mountain front and associated with thrusts of the Prerif nappe sheets. They are complex folds, with a kilometric length and periclinal ends. Recent structural studies (Haddaoui, 2000; Sani *et al.*, 2007; Habibou *et al.*, 2012) interpreted these structures as ramp propagation folds born on the main thrusts in this region probably started to develop since the Early Miocene. The most active deformation phase affecting Pliocene rocks consisted of N–S to NE–SW oriented compression.

In this work, we want to understand the influence of early extensional structures which are formed in the foreland basin on the evolution of fault propagation folds of SRR, we modeled the structure of Fert El Bir anticline by Ramp software (EM) (Mercier, 1995) which turns out especially useful for this end. This program takes into account extensional synsedimentary tectonics.

Structure of Fert El Bir: This Jebel is located in the Eastern arc, north of the Zerhoune ridge (Fig. 2A), which extends between Moulay Idriss town and Douar El Kifane (Fig. 2A). It corresponds to an asymmetric faulted anticline. The northern flank formed by the Middle Lias is pending moderately, but the southern flank is sub-vertical and formed by the Domerian limestones to miocene. The Fert El Bir anticline is bordered southward by the reverse fault of Moulay Idriss and seems to overlap Jebel Zerhoune (Fig. 2B). In his works, Haddaoui (2000) considered that this reverse fault before tectonic inversion had played as a normal fault during Jurassic and it is responsible of the creation of the ramp during the development of the fault fold. While Faugčres (1978) insists on the replay of old normal faults into reverse faults well as Triassic salt diapirism, which generate a faulted asymmetric anticline

Direct modelling: The geometric evolution of Jebel Fert El Bir is interpreted onto different stages (Fig. 3):

Stage 1: During Domerian-Bajocian, the southern part of Fert El Bir correspond to a shoal area characterized by reduced and condensed sedimentation. This area, separates two subsiding zones: the northern part of Fert El Bir and the current location of Jebel Zerhoune.

Stage 2: At the beginning of the Miocene compression, existing normal fault had localized raising of the decollement level and induced the genesis of the ramp. The propagation of this ramp is accompanied by the creation of a fault propagation fold within the meaning Jamison (1987) and of passive transport of the upper part of the initial normal fault and the corner of the Triassic salts.

Stage 3: It is characterized by a modification of deformation style. This passes from brittle/plastic field to a brittle

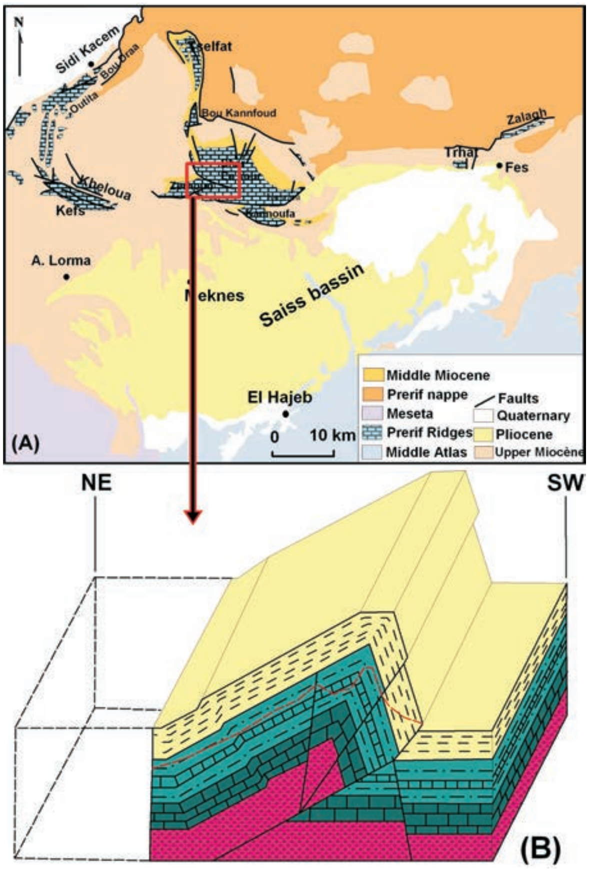

Fig. 1. A. Geological setting of South Rifian Ridges, Northern Morocco and structural scheme of the South Rifian Ridges and location of studied fold. **B.** Geometrical model of the studied structure.

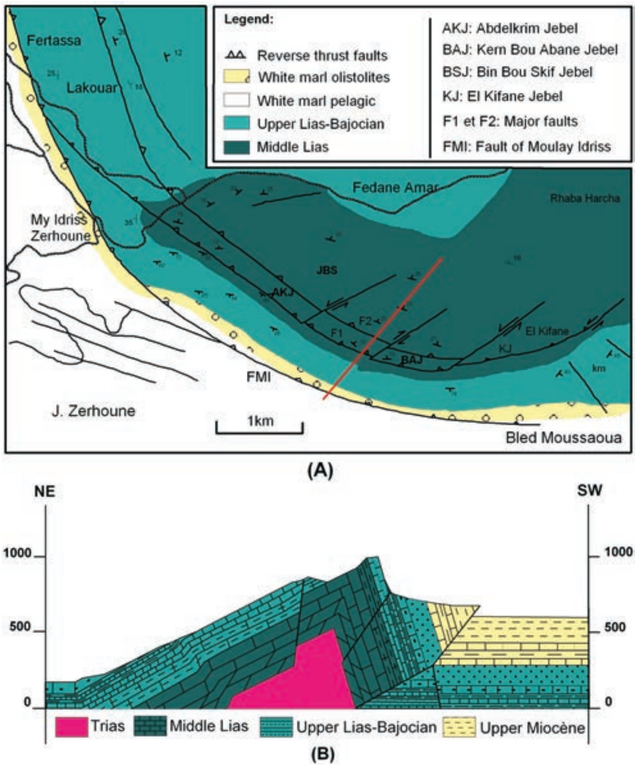

Fig. 2. A. Structural map of J. Fert El Bir (Haddaoui, 2000; modified). B. Geological section of J. Fert El Bir.

context. The ramp after crossing the Jurassic, came lock on the competent level Aaleno-Bajocian. The deformation is transferred along a brittle fracture which affects the blocked structure. In this case, the fracture is limited to the inside of the forelimb, because it comes to a sector where the rocks are strongly deformed and work hardened.

Discussion and Conclusion: The synsedimentary extensional faults seem to be transported during shortening phases and have only guided the location of the ramp. Previous works in the area have considered that these structures were iverted during Miocene compressional stages. It is likely that normal faults have only determined the place where overlaps were developed. If the ramp corresponded to an old extensional fault, listric or not, this would not be a fault-propagation fold that would develop, because it is characterized by the fact that it grows, by accommodating, the same time as propagates the newly formed fracture which serves as a ramp (Suppe & Medwedeff, 1990). Conversely, if the ramp is pre-existing, we will get an anticline of type “Fault-bend fold” (Suppe, 1983).

The model proposed here implies that the structure of J. Fert El Bir which is perpendicular to the constraint, accords perfectly with the model of fold propagation frontal ramp. The sub-horizontal upstream flank shows sub-horizontal normal faults affecting Jurassic series.

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References

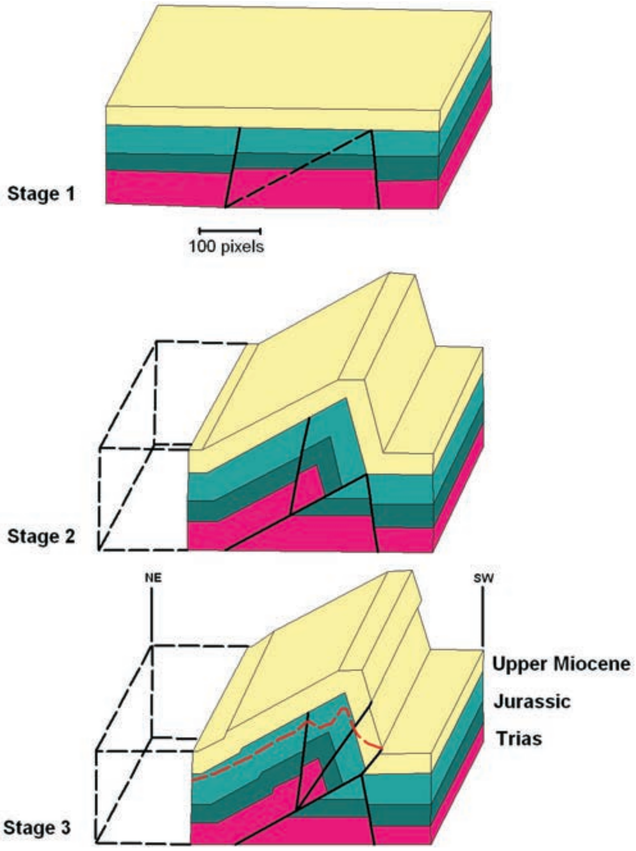

Fig. 3. Geometric Evolution of the structure of fault propagation fold of Fert El Bir.

FAUGÈRES, J. C., 1978. Les Rides sud rifaines; évolution sédimentaire et structurale d’un bassin atlantico-mésogène de la marge africaine. Thèse Doctorat D’Etat, Université de Bordeaux I.

HABIBOU, E. BOUYA N., EL OUARDI, H. & MERCIER, E., 2012. Ramp folds and fracturing in the Southern Rifian Ridges between autochthonous Atlasic domain and alloch- thonous formations of the Rif cordillera (Northern Morocco), *Mineralia Slovaca*, 44: 65–70.

HADDAOUI, Z., 2000. Influence de la géometrie d’un bassin Jurassique sur la propagation des chevauchements neogènes: Geodynamique meso-Cenozoïque des rides sud-rifaines (Maroc). Modelisation geometrique et numerique, [unpublished Ph. D. thesis] Université Mohammed V, Rabat.

HYGHE, P. & MUGNIER, J.L., 1992. Short-cut geometry during structural inversions: competition between faulting and reactivation. *Bull. Soc. Géol. France*, 163/6: 691–700.

JAMISON, W. R., 1987. Geometric analysis of fold development in overthrust terranes. *Journal of Structural Geology*, 9(2): 207–219.

MERCIER, E., 1995. Les plis de propagations de rampes: cinématique, modélisation et importance dans la tectogenèse. Habilitation à diriger les recherches, Univ. Cergy-Pontoise.

SANI, F., DEL VENTISETTE, C. MONTANARI, D. BENDKIK, A. & CHENAKEBET, M., 2006. Structural evolution of the Rides Prerifaines (Morocco): structural and seismic interpretation and analogue modelling experiments. *International Journal of Earth Sciences*, 96: 685–706.

SUPPE, J., 1983. Geometry and kinematics of fault-bend-folding. *American Journal of Science*, 283, 684–721.

SUPPE, J. & MEDWEDEFF, D. A., 1990. Geometry and kinematics of fault-propagation folding. *Eclogae Geologicae Helvetiae*, 83: 409–454.

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The Cambrian magmatic activity in the Zamtyn Nuruu range, Mongolian Altai

Pavel Hanžl[1], David Buriánek[1], Axel Gerdes[2], Kristýna Hrdličková[1], Vojtěch Janoušek[1] & Karel Schulmann[1]

[1] *Czech Geological Survey, Klárov 3, 118 21 Prague 1, Czech Republic, e-mail: pavel.hanzl@geology.cz;*
[2] *Institut für Geowissenschaften, J. W. Goethe Universität, Altenhöferallee 1, 60438 Frankfurt am Main; Germany*

The Zamtyn Nuruu crustal block situated in the easternmost tip of the Mongolian Altai is exposed between the Paleozoic volcanosedimentary prism of the Gobi-Altai Domain in the S and the Neoproterozoic–Cambrian accretionary wedge with ophiolite remnants (the Lake Zone) in the N. The Zamtyn Nuruu block of the pre-Cambrian age is composed of variegated metasedimentary rocks in the upper part while the lower part is formed by orthogneisses, migmatites and amphibolites accompanied by syn-tectonic gabbro and diorite intrusions. The mineral assemblage of amphibolites corresponds to P–T conditions of about 680 ± 60 °C and 8.6 ± 1 kbar. The partial melting of migmatized members may possibly have been caused by decompression during the fast exhumation. These rocks are covered by terrestrial siliciclastic sediments and, together with them, intruded by post-tectonic Late Cambrian granites (Hrdličková *et al.*, 2010).

The usually foliated mafic intrusive rocks form bodies elongated parallel to foliation in adjacent amphibolites. They are medium- to coarse grained, varying from pyroxene-amphibole to biotite-amphibole gabbro (rarely with cumulate fabrics) and diorite.

The mafic igneous rocks are basic to intermediate (SiO_2 = 46.7–55.5 wt. %), metaluminous, calc–alkaline with low K_2O/Na_2O of 0.1–0.2. The chondrite-normalized REE patterns are rather flat (La_N/Yb_N = 3.5–6.7) with positive Eu anomalies (Eu/Eu* = 1.0–1.3). Composition of the surrounding amphibolites is similar (SiO_2 = 46.8–53.8 wt. %, K_2O/Na_2O = 0.1–0.7). The REE patterns show varied, but usually low degree of fractionation (La_N/Yb_N = 0.7–4.7).

The LA ICP-MS zircon age of 542 ± 4 Ma from gabbro dates time of zircon crystallization and zircon age of 517 ± 5 Ma from diorite is interpreted as timing its emplacement. Hf isotope compositions are close to that of depleted mantle (ε_{Hf} = 8.2–10.2). Trace-element signatures (enrichment in Ba, Th, U, K, Pb and Sr accompanied by Rb, Nb, P and Zr depletion if compared with NMORB) as well as isotopic data ($^{87}Sr/^{86}Sr_{550}$ = 0.7047–0.7056 and l_{Nd} = 2.1–2.7) point to primitive source of mafic rocks and only limited role for crustal contamination.

Our data, together with those of Hrdličková *et al.* (2010), provide an evidence of Cambrian (c. 540 and 510 Ma) magmatic activity evolving from syn-tectonic mafic magmatic arc to post-tectonic relatively mature granites in the SE tip of the Lake Zone. Similar rocks can be traced more to the west (Dijkstra *et al.*, 2006) and form a large magmatic arc in the Mongolian Altai part of the Central Asian Orogenic Belt (Janoušek *et al.*, 2014).

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References:

DIJKSTRA, A. H., BROUWER, F. M., CUNNINGHAM, W. D., BUCHAN, C., BADARCH, G. & MASON, P. R. D. 2006. Late Neoproterozoic proto-arc ocean crust in the Dariv Range, Western Mongolia: a supra-subduction zone end-member ophiolite. *J. Geol. Soc*. 163: 363–373.

HRDLIČKOVÁ, K., GERDES, A., GILÍKOVÁ, H., BAT-ULZII, D. & HANŽL, P. 2010. Burd Gol granite massif as a product of the Late Cambrian post-orogenic magmatism in the SE part of the Lake Zone, Gobi Altay, SW Mongolia. *J. Geosci.*, 55: 369–386.

JANOUŠEK, V., JIANG, Y., SCHULMANN, K., BURIÁNEK, D., HANŽL, P., LEXA, O., GANCHULUUN, T. & BAT-TUSHIG, A. 2014. The age, nature and likely genesis of the Cambrian Khantaishir arc, Lake Zone, Mongolia. *Geoph. Res., Abstr*. 16, EGU2014-6108.

Geologia Sudetica, 2014, 42: 26.

The equivalent of the Polička augen gneisses inside the Moldanubicum north of Žďár nad Sázavou

Pavel Hanžl, David Buriánek & Kristýna Hrdličková

Czech Geological Survey, Leitnerova 22, 658 69 Brno, Czech Republic, e-mail: pavel.hanzl@geology.cz

Biotite to amphibole-biotite augen gneisses (known also as “pearl gneiss”) with oval feldspar eyes usually up to few mm in size are characteristic rocks of the Polička Unit. Although, the “pearl gneiss” bears distinctive metamorphic fabrics with penetrative foliation and banding suggesting a metasedimentary protolith, most of the “pearl gneisses” of the Polička Unit are of the magmatic origin (Buriánek *et al.*, 2009).

The Polička Unit is situated in the NE part of the Bohemian Massif and belongs to the Bohemicum in the classical concept of Mísař *et al.* (1983). The Polička Unit is outcropped in the NW–SE oriented belt approximately between villages of Proseč and Bystré in the tectonic footwall of the Svratka Unit and it is covered by the Cretaceous sediments from the NE. The augen gneisses form a continuous sheet along the contact with the Svratka Unit. This sheet is swollen in elongation to the NW toward the contact with the Paleozoic sediments of the Hlinsko Unit. Bodies of porphyritic metagranodiorites (Miřetín pluton) are exposed here inside the augen gneisses. Belt of the augen gneisses with porphyritic metagranodiorites trace a shape of the Svratka anticline towards the SW and near to Vortová village rotates towards the SE in the narrow belt following internal structure of the Svratka Unit in footwall and terminates inside the Moldanubicum as an isolated relict near Stržanov (4.5 km N of Žďár nad Sázavou).

The augen gneiss from Stržanov locality is a dark grey fine to medium grained rock with oval augens of plagioclase (andesine), rare K-feldspar and poikiloblastic amphibole. Matrix is composed of quartz, plagioclase (An_{39-46}), biotite (X_{Fe} = 0.62–0.64; Al^{IV} = 2.39–2.47 apfu). Magnesiohornblende (X_{Fe} = 0.34–0.46) is replaced by actinolite (X_{Fe} = 0.50–0.52).

Augen gneiss from the Stržanov can be classified as metadiorite and geochemically fits well with metagranitoids and augen gneisses of the Polička Unit. They are represented by diorite (tonalite) – granodiorite – granite row with SiO_2 in range 57.3–70.3 wt. %. Rocks are calc-alkaline of high-K series with K_2O/Na_2O = 0.8–1.6, mafic members are metaluminous while acid are peraluminous. The chondrite-normalized REE patterns show medium degree of fractionation and pronounced negative Eu anomaly (La_N/Yb_N = 6.7–14.7, Eu/Eu* = 0.4–0.9). Trace-element signatures show enrichment in Rb, Ba, Th, U, K and Pb accompanied by Sr, Nb and Ti depletion if compared with NMORB and together with plotting in geotectonic discriminations diagrams indicate origin on active continental margin. The position of the metadiorite of the Polička Unit inside the Moldanubicum is still obscure. Nevertheless, exposures of metagranodiorites rimming contact of the Svratka and Polička Units in the NE and forming the NW–SE oriented belt inside the Svratka Unit in the SW do not fit well with the interpretation as syntectonic intrusion of these rocks between the Hlinsko and Svratka Units (Pitra *et al.* 1994). Granodiorites intruded (327 ± 6 Ma Schulmann *et al.* 2005; 346 ± 5 Ma Vondrovic *et al.* 2011) into the metasedimentary complex of the Polička Unit and were affected by subsequent deformation related with the thrusting of the Polička Unit over the Svratka Unit (Buriánek *et al.* 2009). Relict of the Polička metadiorite in the Moldanubicum lies on the NW–SE oriented shear zone corresponding with shorter limb of the drag fold of the Svratka anticline developed along the contact of the Moldanubicum and Svratka Unit.

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Refrences

BURIÁNEK, D., HRDLIČKOVÁ, K. & HANŽL, P., 2009. Geological position and origin of augen gneisses from the Polička Unit, eastern Bohemian Massif. *J. Geosci.*, 54(2): 201–219.

MÍSAŘ, Z., DUDEK, A., HAVLENA, V. & WEISS, J., 1983. Geologie ČSSR I. Český masív. 333 pp. SPN, Praha.

PITRA, P., BURG, J., P., SCHULMANN, K., & LEDRU, P., 1994. Late orogenic extension in the Bohemian Massif: petrostructural evidence in the Hlinsko region. *Geod. Acta (Paris)*, 7(1): 15–30.

SCHULMANN, K., KRÖNER, A., HEGNER, E., WENDT, I., KONOPÁSEK, J., LEXA, O., & ŠTIPSKÁ, P., 2005. Chronological constraints on the pre-orogenic history, burial and exhumation of deep-seated rocks along the eastern margin of the Variscan Orogen, Bohemian Massif, Czech Republic. *Am. J. Sci.*, 305(5): 407–448.

VONDROVIC, L., VERNER, K., BURIÁNEK, D., HALODOVÁ, P., KACHLÍK, V. & MÍKOVÁ, J., 2011. Emplacement, structural and P-T evolution of the 346 Ma Miřetín Pluton (eastern Tepla-Barrandian Zone, Bohemian Massif): implications for regional transpressional tectonics. *J. Geosci.*, 56(4): 343–357.

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Water-fluxed melting of the continental crust: example from Zanskar, NW Himalaya

Pavlína Hasalová[1] & Roberto Weinberg[2]

[1] *Centre for Lithospheric Research, Czech Geological Survey, Klárov 3, 118 21, Prague 1, Czech Republic,*
e-mail: pavlina.hasalova@geology.cz
[2] *School of Geosciences, Monash University, Clayton, 3800, VIC, Australia, e-mail: roberto.weinberg@monash.edu*

Water-fluxed melting, also known as fluid- or water-present melting, is a fundamental process in the differentiation of continents. Its importance has been underestimated in the past 20 years during which research efforts focused on dehydration melting reactions involving hydrate phases, in the absence of a separate aqueous phase. Three key issues are raised to argue against the importance of water-fluxed melting: (i) There is only small volume of water stored in the lower or middle crust, and what little exists is migrates through narrow high permeability paths of limited impact in surrounding rocks. (ii) Water-saturated melts produced by water influx are inhibited from rising because decompression leads to solidification, therefore this process does not give rise to large upper crustal batholiths. (iii) Difficulties in fluxing rocks at conditions above the water-saturated melting. Fluids will pond at the water-saturated solidus isotherm and promote melting. The volume decrease accompanying water-saturated melting causes a pressure drop attracting more fluids into the area in a positive feedback and trapping the melts. The perception that water-fluxed melting is unimportant goes against the rock record which, supported by experiments, suggest that this is a common crustal process and that the issues raised do not impede water-fluxed melting from impacting on crustal evolution. In this contribution, we will argue against these three issues, using migmatites in NW Zanskar, Himalaya as an example.

Water-fluxing can occur at any point of the metamorphic evolution of a terrane. At upper amphibolite facies it will typically cause congruent melting and form minimum melts. At higher temperatures it may be associated with incongruent melting and the dehydration melting of micas, and be associated with the production of hornblende or anhydrous peritectic minerals. A number of incongruent melting reactions have been proposed to account for the paragenesis encountered where fluid fluxed suprasolidus terranes have been inferred. These melts are undersaturated in water and are therefore capable of rising to form plutons. The influx of even relatively small volumes of fluids early in the prograde path can significantly affect the volumes of melt produced during subsequent dehydration reactions. Crustal conditions corresponding to the water-saturated solidus represent a trap for fluids where water is consumed in melting reactions and the negative ΔV of the reaction causes a pressure drop that attracts more fluids and holds the melt in the anatectic region. Nevertheless there are numerous examples where water has by-passed this trap and reached the core of hot terranes. The water-saturated solidus trap may be overcome in two ways. One is the direct influx of fluids into hot terranes by means of efficient fluid channels such as fractures and shear zones, intrusion of large bodies of water-rich magmas or fluids with low water activity, such as brines. In this case, water-fluxing generates water-undersaturated melts that are upwardly mobile and may have anhy-

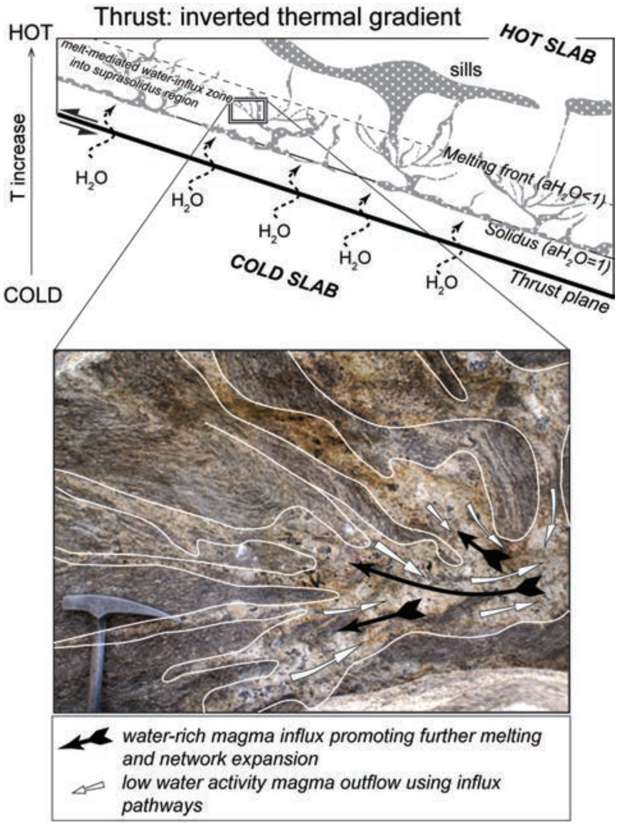

Fig. 1. Water influx into a thrust with inverted geothermal gradient. Melting starts when water reaches conditions equivalent to the water-saturated solidus (aHO=1). Melt rises up-temperature and becomes the water-transport agent, triggering melting in order to dilute its high water content, as dictated by the liquidus curves. Migration establishes an upward expanding magma network. Notice that the water-saturated curve is slightly steeper than the isotherms, assumed to be parallel to the thrust plane. Inset photograph: Melt influx pathways may become outflux pathways depending on fluctuations in melt pressure in the system and changes in large scale pressure gradients. A network could already exist if the rock was undergoing dehydration melting, and this could be re-used and expanded by influx of water-rich magmas. Example from Tml-bearing leucosomes in the Higher Himalayan Crystallines of Zanskar, NW India.

drous peritectic phases typically associated with dehydration melting reactions. The other is up-temperature migration of water-saturated melts either in regions of inverted geothermal gradient (Fig. 1) or by lateral or downward migration, in which case their migration is unrestricted by decompression crystallization. Up-temperature migration triggers water transfer from the melt to the dry surroundings promoting the generation of water-fluxed undersaturated ($aH_2O < 1$) melts, with water contents defined by the liquidus curves. This is a process of water-fluxed melting mediated by water-rich anatectic melts. Thus, only water-saturated melts that remain in or close to the source and eventually crystallize, record high water activity. All other melts that are extracted from the source and interact with other rocks are likely to lose this signature. Water-fluxed melting typically conjures the thought of water-saturated melts when in fact this is a particular case of the more general process of a system that is ultimately rock-dominated, where aqueous fluids, either as a separate phase or dissolved in melts, are ultimately consumed to generate low water-activity melts.

Other limiting factor for water-fluxing hot terranes is their expected low porosity and permeability. The combination of deformation, magmatism and metamorphism gives rise to conditions where aqueous fluids are released and to transient pressure gradients and permeable paths that drive fluid migration. Water-fluxed melting is naturally controlled by these pathways and pathway heterogeneities and variable water fluxes lead to heterogeneous melt production from place to place, even at a metre, as well as multiple melting events during a single tectono-thermal event, leading to a spread in zircon and monazite ages. Fluid influx sets up a water activity gradient in the hot surroundings, with water activity decreasing away from the influx point. This means that fluid flux raises locally and temporarily the water activity in its surrounding and thus drives melting around the regions of fluid ingress.

Thus, active tectonics and magmatism play a key role in promoting water-fluxed melting. Tectonic activity in particular is responsible for the burial of hydrous rocks, as deep fluid sources, and for maintaining pressure gradients that drive fluid and melt migration, as well as maintaining high permeability channels, and geothermal gradients that favor water-fluxing and melt migration (Fig. 1). Water-fluxed melting may impact in the continued development of an orogeny. For example in the Zanskar Himalayas water-fluxed melting may have weakened the core of the orogeny triggering the onset of a period of extension leading to a relaxation of the taper angle. Furthermore, water-fluxed melting consumes the energy buffering peak metamorphic temperatures.

In summary, we suggest that melting due to the fluxing of aqueous fluids is a widespread process that can take place in diverse tectonic environments. Active tectono-magmatic processes create conditions that trigger the release of aqueous fluids and deformation-driven, transient high permeability channels, capable of fluxing voluminous high-temperature regions of the crust where it triggers melting.

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Relative reactivation and kinematic potential analysis of some faults in the NE part of the Bohemian Massif

Josef Havíř

Institute of Physics of the Earth, Masaryk University, Tvrdého 12, 602 00 Brno, Czech Republic, e-mail: Josef.Havir@ipe.muni.cz

The "optimality" of fault plane orientation in respect to reactivation of this fault in a given stress tensor can be very simply quantified using reactivation potential parameter, which is based on calculation of distance between stress state point of analyzed fault plane and Coulomb failure criterion line in the Mohr graph. In principle, three possible definition of this distance exists, all three definition were used (Mildren *et al.* (2002), parameter DP_f – distance parallel to normal stress axis; Švancara *et al.* (2008), parameter D_{st} – distance parallel to shear stress axis; Vavryčuk *et al.* (2013), parameter I – distance perpendicular to failure criterion line). Despite the fact, those reactivation potential parameters based on different discussed definitions differ each from other, their relative values are same. The relative reactivation potential parameter D_r (Havíř 2012) is defined as relative value of reactivation potential, which varies from 0 (the most optimal orientation of fault plane) to 1 (the worst orientation of fault plane for reactivation). The relative reactivation potential analysis can be combined with calculation of kinematic potential parameters defined as rake of block movement for given fault geometry and given reduced stress tensor.

The usage of relative reactivation and kinematic potential analysis is shown on example of the NE part of the Bohemian massif. Possible reduced stress tensors representing recent stress field orientation were set according to breakout and focal mechanism data (Peška, 1992; Špaček *et al.*, 2006). In the case of extensional stress field with steep maximum compression axis, the values of relative reactivation parameter D_r calculated for NW–SE to NNW–SSE fault systems (for instance Sudetic Marginal Fault, Bělá Fault, Bušín Fault etc.) are smaller in comparison to W–E faults (for instance Marginal Jeseníky Fault). But in the case of stress field with subhorizontal both maximum and minimum stress axes, the values of relative reactivation potential of W–E systems and NW–SE to NNW–SSE systems can be similar. The NW–SE to NNW–SSE fault systems show tendency to significant normal dip-slip component of movement in most part of analyzed sets of reduced stress tensors.

This study illustrate robustness of the discussed simple method, which can produce interesting results taking into account the uncertainty in some model parameters: principal stresses orientation, shape ratio of reduced stress tensor, coefficient of friction and/or dip of fault plane.

References

HAVÍŘ, J., 2012. Relative reactivation potential analysis – a simple robust tool for seismotectonic studies in regions of low seismic activity (examples from the Bohemian massif, Czech Republic). *GA ESC 2012, book of abstracts. August 19-24, Moscow*, 352–353.

MILDREN, S. D., HILLIS, R. R. & KALDI, J. 2002. Calibrating predictions of fault seal reactivation in the Timor Sea. *APPEA Journal*, 42: 187–202.

PEŠKA, P., 1992. Stress indications in the Bohemian Massif: reinterpretation of borehole televiewer data. *Studia geoph. et geod.*, 36: 307–324.

ŠPAČEK, P., SÝKOROVÁ, Z., PAZDÍRKOVÁ, J., ŠVANCARA, J. & HAVÍŘ, J., 2006. Present-day seismicity of the southeastern Elbe Fault System (NE Bohemian Massif). *Studia geoph. et geod.*, 50 (2): 233–258.

ŠVANCARA, J., HAVÍŘ, J. & CONRAD W., 2008. Derived gravity field of the seismogenic upper crust of SE Germany and West Bohemia and its comparison with seismicity. *Studia geoph. et geod.*, 52 (4): 567–588.

VAVRYČUK, V., BOUCHAALA, F. & FISCHER, T., 2013. High-resolution fault image from accurate locations and focal mechanisms of the 2008 swarm earthquakes in West Bohemia, Czech Republic. *Tectonophysics*, 590: 189–195.

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Early Carboniferous doming in Gobi–Altai tectonic belt, Mongolia: recorded by syn-tectonic sedimentation in intra-mountain basin

Danping Hu[1], Yingde Jiang[2,3], Ondrej Lexa[2,3], Karel Schumann[1,3] & Pavla Štípská[3]

[1] *Université de Strasbourg, France*
[2] *Institute of Petrology and Structural Geology, Charles University in Prague, Czech Republic*
[3] *Czech Geological Survey, Klárov 3, 11821 Prague 1, Czech Republic;*

The Gobi–Altai tectonic belt in central Mongolia located between the main Mongolian Lineament and the Trans-Altai Fault, and this region reveals a complex and a polyphase structural evolution which remains not well understood. The striking feature of the region is marked by the development of thermal dome structures cored by the granitic plutons. Recent studies have revealed these granitic plutons are mainly of Late Devonian–Early Carboniferous formation ages (Kröner *et al.*, 2010), implying the domes were likely formed during this time period. The Carboniferous basin may therefore record the pivotal information on the evolution of these domes.

In the present study, we mainly focus on the lithological, structural as well as detrital zircon in geochronological aspects of the Carboniferous sediments seated between the Tseel and Tosgt domes in the central of Gobi–Altai tectonic belt. The studied area is featured by two granitic-migmatitic domes associated with a large belt of low-grade Paleozoic sediments and volcanic rocks. The Carboniferous sediments seated on the top of the sedimentary sequence is mainly composed of terrigenous clasts which now finding as sandstone, siltstone, mudstone and conglomerate. The structural evolution of the region involves: (1) a early flat green schist-facies fabric locally preserved in basement rocks (Tugrig Fm); (2) a sub-vertical fabric developed in the Tugrig Fm and also Devonian sequence under E–W oriented compression associated by syn-tectonic emplacement of magmatic complexes which from thermal domes in the region; (3) a subsequent event affected the whole sequence, including Carboniferous sequence under N–S compression regime during Permian. Our primary Zircon U-Pb and Hf isotopic data resemble those of the neighboring preexisted sedimentary sequences and granitic rocks. Taken together, these results permit us to interpret that the detritus of the carboniferous rocks most likely represent the erosion product of the preexisted rocks nearby in an intra-mount basin setting, which directly linked to the formation of granitic domes in the region. The simultaneous sedimentation, erosion, and tectonic uplift of the domes is portrayed by the progressive compressional tectonic regime of the Gobi–Altai in Devonian–Carboniferous (Lehmann *et al.*, 2010).

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References

LEHMANN, J., SCHULMANN, K., LEXA, O., CORSINI, M., KRÖNER, A., ŠTÍPSKA, P., TOMUPHUU, D., & OTGONBATOR. D, 2010. Structural constraints on the evolution of the Central Asian Orogenic Belt in SW Mongolia, *American Journal of Science*, 310: 575–628.

KRÖNER, A., LEHMANN, J., SCHULMANN, K., DEMOUX, A., LEXA, O., TOMURHUU, D., ŠTÍPSKA, P., LIU, D. & WINGATE, M. T. D, 2010. Lithostratigraphic and Geochronological Constraints on the evolution of the Central Asian Orogenic Belt in SW Mongolia: Early Paleozoic Rifting followed by Late Paleozoic Accretion, *American Journal of Science*, vol. 310: 523–574.

Geologia Sudetica, 2014, 42: 31–32.

Vestiges of Cadomian back-arc environments in the Nové Město belt and the western part of the Orlica–Śnieżnik Dome

Sławomir Ilnicki[1], Jacek Szczepański[2] & Christian Pin[3]

[1] *Institute of Geochemistry, Mineralogy and Petrology, Faculty of Geology, University of Warsaw, Al. Żwirki i Wigury 93, 02-089 Warszawa, Poland, e-mail: slawomir.ilnicki@uw.edu.pl*

[2] *Institute of Geological Sciences, Faculty of Earth Science and Environmental Management, University of Wroclaw, Pl. M. Borna 9, 50-205 Wrocław, Poland, e-mail: js@ing.uni.wroc.pl*

[3] *Département de Géologie, CNRS and Université Blaise Pascal, 5 rue Kessler, 63038 Clermont-Ferrand, France, e-mail: C.Pin@opgc.univ-bpclermont.fr*

Metabasites in the Nové Město Unit (NMU) and the Orlica–Śnieżnik Dome (OSD) are both parts of metamorphosed volcano-sedimentary successions in the central part of the Sudetes. Metabasalts in the western part of the OSD form small exposures (lava flows and sills) embedded within metasedimentary rocks of the Stronie and Młynowiec Formations. Metabasalts of the NMU form: (1) ca. 30 km long and 2–3 km wide belt composed mainly of amphibolites extending along western border of the core part of the OSD as well as (2) greenstones interfingered within phyllites of the NMU. The age of the NMU metabasalts is only traditionally regarded as Neoproterozoic.

Metabasalts of the western part of the OSD, which were emplaced coevally with the accumulation of the protolith of the Stronie Formation, show diverse geochemical features. Immobile trace element and Nd isotope features allow distinction of dominant, E-MORB-like to mildly enriched N-MORB-like tholeiites (Zr/Nb 9-27, $\varepsilon\mathrm{Nd}_{530}$ +0.2 to +6.7), and scarce but genetically important OIB-like alkaline (Zr/Nb 5, $\varepsilon\mathrm{Nd}_{530}$ +2.2) or strongly depleted tholeiitic rocks (Zr/Nb 67, $\varepsilon\mathrm{Nd}_{530}$ +7.9; Fig. 1). All magmas were extracted at shallow levels from different mantle sources. The OIB affinity is interpreted to reflect an EM-type asthenopheric source whilst groups of tholeiitic rocks indicate involvement of depleted MORB-type mantle (DMM). Several geochemical signatures, the decoupling between Nd isotope and trace element characteristics, and melting models indicate variable enrichment of the DMM-like source here ascribed to asthenosphere-derived OIB-like melts and a contribution from a supra-subduction zone (Fig. 1b).

The NMU metabasites also show geochemical characteristics of tholeiitic basalts varying from N-MORB-like (Zr/Nb 58, $\varepsilon\mathrm{Nd}_{530}$ +6.2), to dominant, variably enriched intermediate between N-MORBs and E-MORBs (Zr/Nb 12–32, $\varepsilon\mathrm{Nd}_{530}$ +2.6 to +5.9), to enriched basalts intermediate between E-MORBs and OIBs (Zr/Nb 12–14, $\varepsilon\mathrm{Nd}_{530}$ +2.7 and

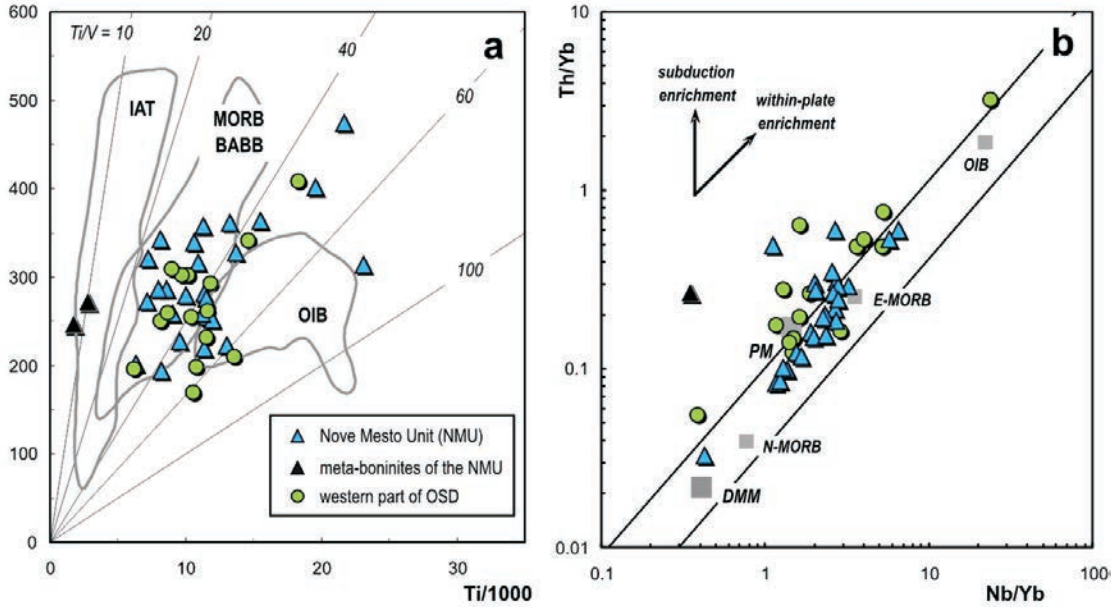

Fig. 1. Geochemical features of metabasites from the Nové Město Unit (NMU) and the western part of the Orlica–Śnieżnik Dome (OSD). a. The V-Ti diagram of Shervais (1982). b. Th/Yb vs. Nb/Yb diagram of Pearce & Peate (1995). Heavy diagonal lines of constant Th/Nb indicate the array of basalts from non-subduction settings. Vectors show the subduction and within-plate enrichment. Black triangles denote the position of meta-boninites from the NMU. Abbreviations: DMM – depleted MORB mantle, E-MORB – enriched MORB, IAT – island arc tholeiites, N-MORB – normal MORB, OIB – ocean island basalts, PM – primitive mantle. The OIB, PM, E-MORB and N-MORB values are from Sun & McDonough (1989), DMM values from Workman & Hart (2005).

Fig. 1). Similarly, the parental magmas to the protoliths of the NMB meta-tholeiites were generated in spinel stability field from depleted, fertile and non-residual asthenospheric mantle (DMM). The presence of enriched meta-tholeiites with mildly radiogenic Nd isotope composition on time-integrated basis (εNd_{530} +2.6 do +4.1) is probably related to metasomatic event (OIB-like melts formed in garnet stability field) in the depleted source shortly prior to the magma generation. The mantle source of the NMU meta-tholeiites was also heterogeneously and randomly metasomatised by subduction-related component introduced into the mantle wedge predominantly as melts generated at the expense of sediments embedded in the subducted lithospheric slab. Although the degree of subduction input seems smaller than in case of the OSD metabasites, the influence of subduction zone in the NMU meta-tholeiites is firmly endorsed by the presence of the recently reported rare high-Ca metaboninites (Mg# 71–74, TiO_2 0.29–0.46 wt.%, CaO/Al_2O_3 0.8–1.1, Zr/Nb 77, εNd_{530} +2.9; Ilnicki, 2013). Geochemical features of meta-boninites are akin to high-Ca boninites recognised in back-arc basins of North Tonga and of the Dachadaban area (the North Quilan oceanic-type suture zone, China). In particular, they are similar to meta-boninites found in the Neoproterozoic basement in the SE part of the Teplá–Barrandian (the Kralupy–Zbraslav and the Štechovice Groups; Ilnicki, 2013 and references therein).

The occurrence of boninites in the NMU relates this area to the Teplá–Barrandian zone, as only there in the Bohemian Massif boninite dykes were also found. Moreover, the generation of the boninite magma could have been related to ridge subduction and slab break-off under conditions of vanishing activity of the back-arc zone. In the regional context, the association of boninites and the back-arc basin basalts (BABB) in the NMU is interpreted as a part of the back-arc system of the Cadomian volcanic arc preserved in the SE part of the Teplá–Barrandian. Likewise, contrasting BAB- and within-plate-like affinities of the OSD metabasites, and petrogenetic constraints from the contemporaneous ca. 530 Ma Stronie formation rift basin (Szczepański, 2010; Mazur *et al.*, 2012; 2013), connect the appearance of the OSD mafic volcanics with the cessation of the suprasubduction zone activity (Ilnicki *et al.*, 2013). Thus it is plausible that the generation of protoliths to the metabasites of the NMU and the western part of the OSD records the analogical processes taking place in Neoproterozoic in various places of the Cadomian–Avalonian belt developed along the active Gondwanan margin (e.g. Nance *et al.*, 2010 and references therein).

References

ILNICKI, S., 2013. Metabazyty pasma Nového Města. *Archivum Mineralogiae Monograph*, 5: 1–204. Wydawnictwa Uniwersytetu Warszawskiego, Warszawa.

ILNICKI, S., SZCZEPAŃSKI, J. & PIN, C., 2013. From back-arc to rifted margin: Geochemical and Nd isotopic records in Neoproterozoic?–Cambrian metabasites of the Bystrzyckie and Orlickie Mountains (Sudetes, SW Poland). *Gondwana Research*, 23: 1104–1121.

MAZUR, S., SZCZEPAŃSKI, J., TURNIAK, K. & MCNAUGHTON, N. J., 2012. Location of the Rheic suture in the eastern Bohemian Massif: evidence from detrital zircon data. *Terra Nova*, 24: 199–206.

MAZUR, S., TURNIAK, K., SZCZEPAŃSKI, J. & MCNAUGHTON, N. J., 2013. Vestiges of Saxothuringian crust in the Central Sudetes, Bohemian Massif: Zircon evidence of a recycled subducted slab provenance. *Gondwana Research*, in press: 10.1016/j.gr.2013.11.005.

NANCE, R. D., GUTIÉRREZ-ALONSO, G., KEPPIE, J. D., LINNEMANN, U., MURPHY, J. B., QUESADA, C., STRACHAN, R. A. & WOODCOCK N. H., 2010. Evolution of the Rheic Ocean. *Gondwana Research*, 17: 194–222.

PEARCE, J. A. & PEATE, D. W., 1995. Tectonic implications of the composition of volcanic arc magmas. *Earth and Planetary Science Annual Review*, 23: 251–285.

SHERVAIS, J. W., 1982. Ti-V plots and petrogenesis of modern and ophiolitic lavas. *Earth and Planetary Science Letters*, 59: 101–118.

SUN, S. S. & MCDONOUGH, W., F., 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle compositon and processes. In: Saunders AD, Norry MJ (eds): Magmatism in ocean basins. *Geological Society of London Special Publication*, 42: 313–345.

SZCZEPAŃSKI, J., 2010. Provenance and tectonometamorphic evolution of the supracrustal series from the Bystrzyckie Mountains crystalline Massif. Wrocławska Drukarnia Naukowa PAN, Wrocław, 166 pp.

WORKMAN R. K. & HART S. R., 2005. Major and trace element composition of the depleted MORB mantle (DMM). *Earth and Planetary Science Letters*, 231: 53–72.

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Late Cambrian protolith age of the Młynowiec–Stronie Group and the Devono-Carboniferous polyphase metamorphic evolution of the Orlica–Śnieżnik Dome (NE Bohemian Massif)

Mirosław Jastrzębski[1], Bartosz Budzyń[2,3] & Wojciech Stawikowski[4]

[1] *Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Wrocław, Podwale 75, 50-449 Wrocław, Poland; e-mail: mjast@interia.pl*
[2] *Institute of Geological Sciences, Polish Academy of Sciences, Kraków Research Centre, Senacka 1, 31-002 Kraków, Poland*
[3] *Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, 30-063 Kraków, Poland*
[4] *Institute of Geology, Adam Mickiewicz University, Maków Polnych 16, 61-606 Poznań, Poland*

The Orlica–Śnieżnik Dome (OSD) is located in the NE part of the Bohemian Massif and mainly consists of Cambrian orthogneisses and the metavolcano-sedimentary rocks. The latter have disputable protolith ages and are subdivided into the Stronie Formation which was metamorphosed under amphibolite-facies conditions and the Młynowiec Formation which experienced local migmatization (Fig. 1; Don *et al.*, 2003). Our new studies provide new data on (i) protolith age of the metasedimentary formations, (ii) their position in the structure of the OSD as well as (iii) timing of the tectonic and metamorphic events that occurred in the OSD.

The studies were conducted along the transects crossing the sequence built by paragneisses of the Młynowiec Formation, light quartzites and mica schists of the Stronie Formation in the eastern part of the OSD (Fig. 1). We observed neither evidence of large-scale tectonic transport nor any structural unconformity between the two formations. The boundaries between these rocks are all gradational and mainly characterized by gradual changes in quartz and phyllosilicates content, presumably reflecting the sedimentary and chemical differences in their protoliths.

The U-Pb SHRIMP dating of zircons from the light quartzite sample with higher muscovite and lower Kfs content (Qtz – 84%, Ms – 15%, Kfs – 1%, Opq – 1%) indicates that this rock mainly contains rounded detrital grains of Lower Cambrian, Neoproterozoic and Palaeoproterozoic ages. In this rock, however, 10% of zircon population belongs to euhedral ~500 Ma old zircons that could be interpreted as a part of the syndepositional volcanogenic material deposited together with well sorted quartz sands. In a K-feldspar rich quartzite collected from the same outcrop (Qtz – 75%, Kfs – 19%, Ms – 4%), 10% of the zircon population is represented by ovoid Neoproterozoic grains, while 90% of the zircon population belongs to ~500 Ma euhedral zircons with well preserved pyramid terminations. The mineral composition, zircon morphology and a narrow age spectrum obtained for this rock question the long-distance sedimentary transport of these zircons and suggest tuffitic/volcanic protolith of this rock. Our data thus suggest that the protolith of rocks forming the boundary between the Młynowiec and Stronie formations comprised pelitic, quartzose and, occasionally, metatuffitic and metavolcanic rocks deposited during Late Cambrian.

The structural studies indicate that the penetrative foliation in the Młynowiec–Stronie Group is parallel to the penetrative foliation in the orthogneisses, and is concordant to the locally observed contacts between the orthogneisses and metasediments. Both these lithological contacts and penetrative foliation locally dip at different angles: shallow, moderate to high, and display different dip azimuths: E, NE, N, NW and W in different domains of the eastern part of the OSD (Fig. 1). In all studied rocks of the Młynowiec–Stronie Group, this penetrative foliation is axial planar to the tight, N–S trending folds F2. This foliation, labeled S2, contains relics of the earlier metamorphic foliation S1, preserved also as inclusion trails in Grt and Pl porphyroblasts. Our pseudosection thermobarometry applied for rocks of the Młynowiec Formation, when compared with P-T record of the other metasediments in eastern part of the OSD (e.g. Štipská *et al.*, 2012), suggests that rocks of the Stronie Formation, non-migmatized rocks of the Młynowiec Formation and migmatized part of the Młynowiec represent respectively shallower to deeper metamorphic levels. Subsequently, top-to-the-N(NE) tectonic movements reactivated former fabrics, produced further uplift and cooled the rocks to greenschist facies conditions (D3 stage). The S2 foliation and Barrovian metamorphic zones were finally folded and generally inclined toward W(NW) (D4 stage). In consequence, the metamorphic structure of the OSD was disturbed so that the migmatic rocks outcrop in cores of the large-scale antiforms, mostly in the SE part of the OSD.

This study aims also to provide new monazite data to verify a hypothesis of Cambro-Ordovician contact metamorphism or regional metamorphism of the Młynowiec–Stronie Group and to constrain the age of the Variscan metamorphic events in the OSD. Paragneisses of the Młynowiec Formation, light quartzites and mica schists of the Stronie Formation and the adjacent orthogneisses were selected for electron microprobe Th-U-total Pb dating of monazite. Samples were collected at different distances from the contact between the orthogneisses and metasediments. Monazite from a medium-grained orthogneiss yielded dates ranging from 546 to 322 Ma, while three age domains of ca. 480 Ma, ca. 420 Ma and ca. 370 Ma have been obtained for a fine-grained orthogneiss. Two age domains of 370–360 Ma and 340–335 Ma were obtained from monazite in two porphyroblastic paragneisses, out of which the older ages are recorded by inclusions of monazite in staurolite, plagioclase, and also by matrix monazite. Ca. 337 Ma age yielded monazite in leucosome of the migmatized Młynowiec para-

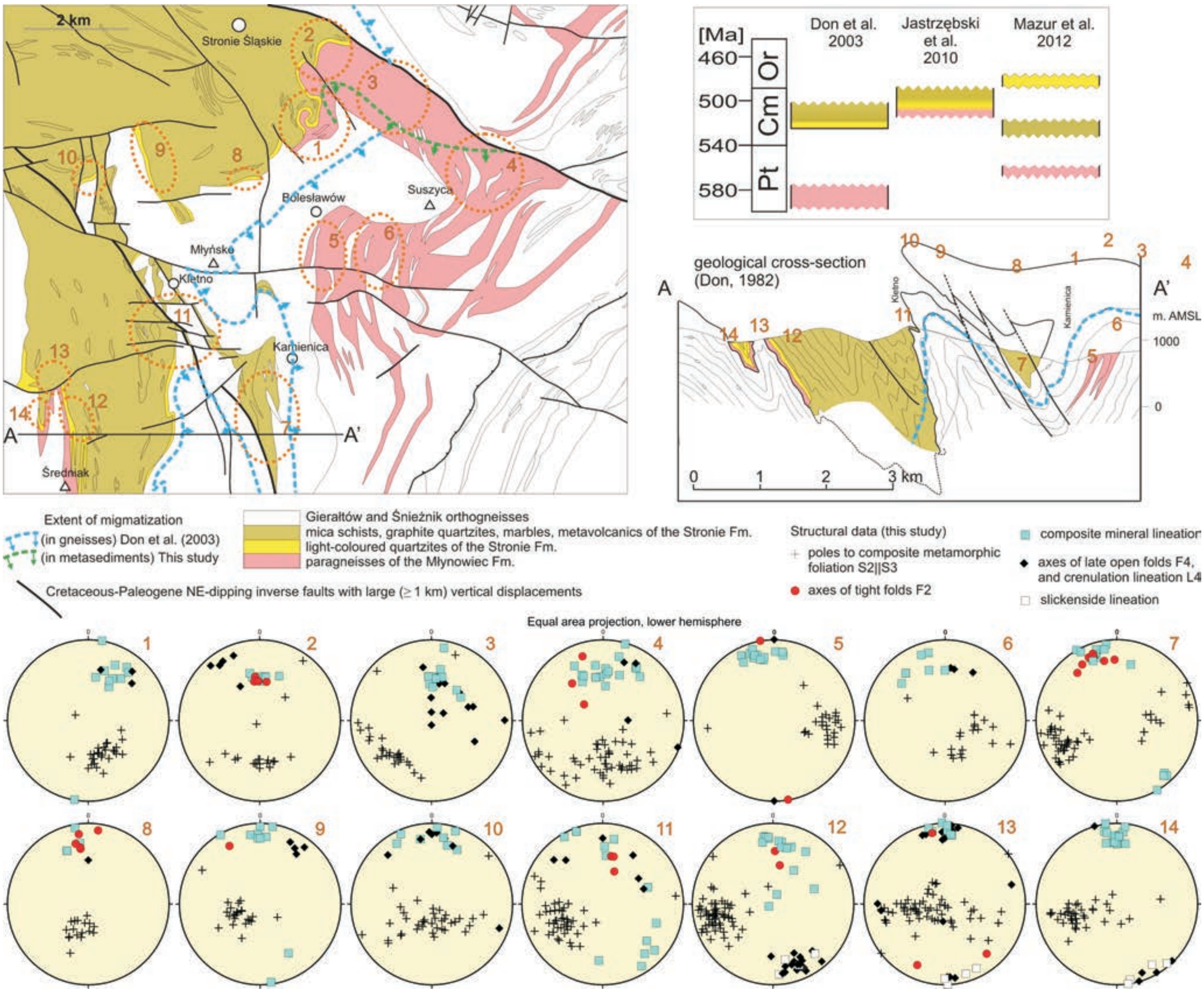

Fig. 1. New structural data from the Młynowiec–Stronie Group drawn on the base map of Don *et al.* (2003) and geological cross-section of Don (1982).

gneiss, while ca. 330 Ma age and a several dates of ca. 355 Ma were obtained for matrix monazite in melanosome. Monazite in K-feldspar bearing light quartzites shows record of older ages of 525–460 Ma, and younger ages of ca. 360 Ma and 340 Ma. Only younger age domains of ca. 365 Ma and 340–330 Ma are defined by monazite from two K-feldspar free light quartzites, and one K-feldspar bearing light quartzite. Similar two age domains of 370–360 Ma and 340–330 Ma yields monazite from six mica schists, with a faint record of ca. 406 Ma in one of these samples.

The geochronological results suggest polyphase Devono-Carboniferous metamorphic evolution that included at least two tectonometamorphic episodes. Microstructural context of the studied grains indicates that the record of 370–360 Ma ages likely defines a progressive metamorphism (D1-D2), whereas pervasive record of 340–330 Ma ages could reflect either peak metamorphic conditions (D2) or superimposed penetrative shearing connected with exhumation (D3). Monazite data show no clear evidence for pre-Variscan metamorphism of the Młynowiec–Stronie Group. Cambrian to Ordovician monazites developed only in K-feldspar rich rocks, i.e. the orthogneisses and K-feldspar light quartzites, which indicates growth of the Early Palaeozoic monazites during formation of their, respectively, magmatic and partially volcanic protoliths.

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References

DON, J., 1982. Tektonika łupków strefy Siennej oraz korelacja rozwoju gnejsów z etapami deformacji metamorfiku Śnieżnika. *Geologia Sudetica*, 17: 103–124.

DON, J., SKÁCEL, J. & GOTOWAŁA, R., 2003. The boundary zone of the East and West Sudetes on the 1:50 000 scale geological map of the Velké Vrbno, Staré Město and Śnieżnik Metamorphic Units. *Geologia Sudetica*, 35: 25–59.

ŠTÍPSKÁ, P., CHOPIN, F., SKRZYPEK, E., SCHULMANN, K., PITRA, P., LEXA, O., MARTELAT, J.E., BOLLINGER, C. & ŽÁČKOVÁ, E., 2012. The juxtaposition of eclogite and mid-crustal rocks in the Orlica–Śnieżnik Dome, Bohemian Massif. *Journal of Metamorphic Geology*, 30: 213–234.

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Deformation and metamorphic record within the subduction-exhumation channel as recorded in the Krkonoše–Jizera Mountains, Bohemian Massif

Petr Jeřábek[1], Jiří Konopásek[2,3] & Eliška Žáčková[2]

[1] *Institute of Petrology and Structural Geology, Faculty of Science, Charles University in Prague, Albertov 6, 12843 Prague 2, Czech Republic*
[2] *Czech Geological Survey, Klárov 3, 11821 Prague 1, Czech Republic*
[3] *Centre for Geobiology and Department of Earth Science, University of Bergen, Allegaten 41, N-5007 Bergen, Norway*

The Krkonoše–Jizera Mountains in the Bohemian Massif cover an important tectonic boundary with the the Saxothuringian lower plate in the West and the Teplá-Barrandian upper plate in the east. The subduction and exhumation processes brought together three distinct lithological complexes of the Saxothuringian lower plate: a) the metabasalts with the affinity to oceanic crust; b) metasediments of the former continental passive margin and c) metagranitoids representing the pre-Variscan Saxothuringian continental crust. Detailed structural analysis carried out in the vast region of the Czech part of the Krkonoše–Jizera Mountains revealed that the relatively simple geometry of the Variscan nappe stack related to underthrusting of the Saxothuringian plate has been modified by a large scale isoclinal/sheath fold during the later exhumation process. Thus while in the eastern part of the studied area the east-dipping nappe stack preserves its original geometry characterized by structurally higher metabasalts, intermediate metapelites and lower orthogneiss, towards the east this sequence becomes overturned. The observed geometry corresponds to a large scale isoclinal fold with three main limbs extending from Žacléř to Železný Brod that is locally accompanied by a small scale isoclinal folds throughout the entire studied region. Both the small-and large-scale isoclinal folds are geometrically concordant and characterized by generally east-dipping axial planes and E–W trending axes, which are subparallel to the stretching lineation. In the eastern part of the studied area the isoclinal folds locally show sheath fold geometries indicating strong simple shear component.

The axial planar cleavage S2 represents the dominant fabric of the studied area and it is characterized by the greenschist facies grade with PT conditions of 350–450°C and 0.3–0.7 GPa. In metapelites this metamorphism is accompanied by widespread blastesis of albite. The earlier S1 fabric is associated with chlorite-muscovite-garnet assemblage with estimated PT conditions of 470–550°C and 1.0–1.4 GPa. The locally observed older relic assemblages of garnet-chloritoid-paragonite in micaschist and chloritoid-paragonite in phyllite indicate the peak metamorphic PT conditions of ~470°C and 1.9 GPa and 400–500°C and 1.4–1.8 GPa, respectively. Although this relic assemblage is difficult to associate with observed structures, it probably corresponds to the early stages of S1 development.

The dynamically recrystallized quartz aggregates sampled along the arc of the studied fold indicate systematic spatial variation in shear sense obtained from Crystal Preferred Orientation (CPO). Thus while the CPOs in the fold hinge zone show top-to-the west shear sense, in the fold limbs the shear sense is opposite. The opposite shear senses indicating both thrust and detachment kinematics can be best explained by the S2 overprint of S1 folded fabrics in the limbs of the large scale isoclinal fold while the S1 remains preserved in the mechanically more stable hinge zone. The difference between the kinematics of S1 and S2 fabrics thus documents an important switch between the S1 related nappe stacking process and S2 related folding and exhumation of the stack.

The geometry of the large scale isoclinal fold has been subsequently modified by N–S compression resulting in the development of small- to large-scale folds with steep E–W trending axial planes. The very last folding event characterized by E–W shortening is associated with local development of small-scale folds and kink bands.

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The Clay and Závist faults – one large strike-slip fault in the east part of Barrandian (Bohemian Massif)

Martin Knížek & Rostislav Melichar

Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic,
e-mail: kniza@sci.muni.cz, melda@sci.muni.cz

The Clay Fault is a significant tectonic structure of the southeastern part of the Barrandian. It has NE–SW direction with length of over 30 km and separates the Cambrian sediments on the southeast from the Upper Proterozoic on the northwest. Fault has been traced into depth equal 1.5 km thanks to long-time mining in well-known Březové Hory district. Orientation of the Clay Fault surface gradually changes from subvertical on the NE (Havlíček, 1973) to the steeply (70°) dipping to the northwest on the SW (e.g., Bambas, 1990). The northeastern end of the fault disappears in the Proterozoic rocks near Dobříš town, as any fault is hardly noticeable in such rocks. But the southwestern ending of Clay Fault is evident and marked by so-called Rožmitál Block of Lower Paleozoic sediments (Havlíček *in* Chlupáč *et al.*, 1998), which is rimed by narrow granodiorite intrusion of Blatná type. This structure could be interpreted as a fallen block originated by pull-apart mechanism, which leads to acceptance of sinistral strike-slip movement along the main fault surface.

Both walls of Clay Fault are cut by steep basaltic dikes striking in N–S direction. Old miners tracked these dikes due to mineralization of hydrothermal veins coupled with them. They counted that the veins as well as the dikes are usually cut and terminated by the Clay Fault. Havlíček (1981) and Mašek (1986) interpreting geological map admitted, that basaltic dikes pass through the structure of the Clay Fault, which dated tectonic movement along the fault to Cambrian. Our new research rejected the possibility of continuation of the dikes through the fault (Šešulka *et al.*, 2011) and the age of movement should be post-Silurian.

The second fault under study, i.e. Závist Fault, was defined by Kettner (1911). He described it as a fault separated from the Clay Fault, because he found its opposite dip direction. The Závist Fault is noticeable between Dobříš and Mníšek pod Brdy, where it divides the Cambrian and Ordovician sediments on the NW and the Proterozoic flysh rocks on the SE. It continues about 30 km to the Prague-Kamýk, where it branches into two thrust splays called the Úvaly faults (Havlíček, 1950). Kinematics of Závist Fault can be derived from stratigraphic relations and/or paleostress analysis. According to the stratigraphy, Kettner (1911) considered this fault to be an overthrust. Results of paleostress analysis of footwall quartzites from Černolice indicate subvertical σ_2 and subhorizontal σ_1 axis oriented in N–S direction, which – base on Anderson's theory (Anderson, 1972) – points out sinistral strike-slip regime on the Závist fault.

The Clay and Závist faults are connected one another not only by the same direction but also by continuous change of their dip. The Clay Fault gradually changes its steep dipping to NW on the SW to subvertical orientation on the NE. Here, near Dobříš town, Závist Fault continuously varies analogously from subvertical position (on SW) to medium dipping to the SSE on the NE. It is obvious, that both faults are forming one single structure, whose surface is screwed into form of propeller. Construction of stratigra-

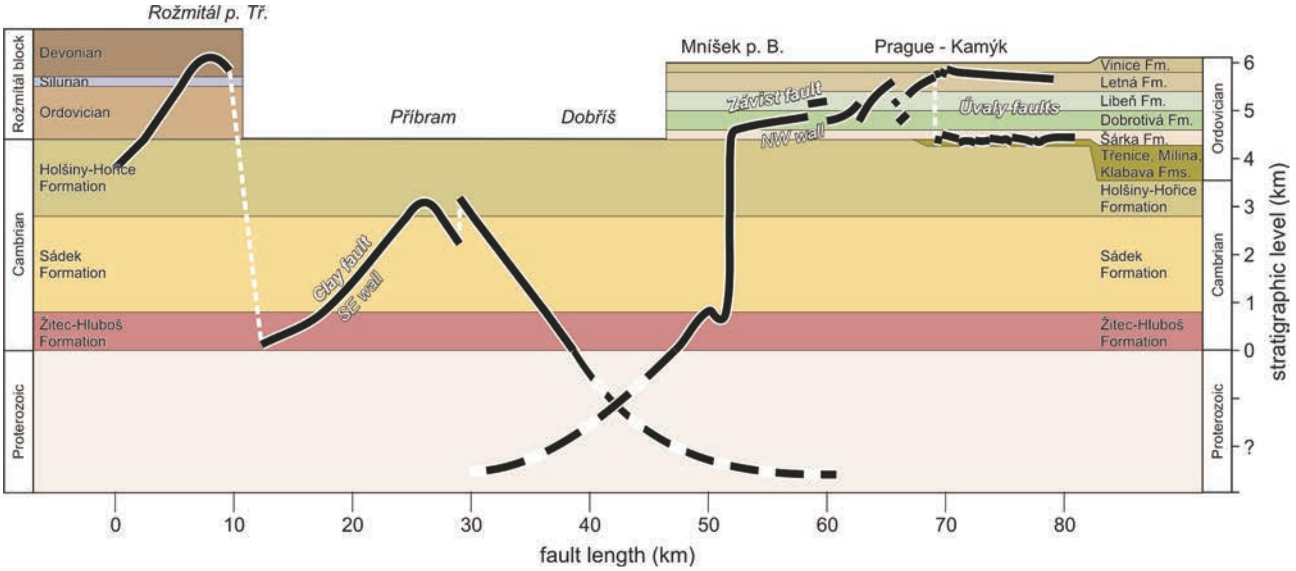

Fig. 1. Stratigraphy fault-cut diagram for Clay Fault (SE wall) and Závist Fault (NW wall).

phy fault-cut (SFD) diagram was used to testify, whether faults movements are compatible (Fig. 1). Cross-cutting fault-cut lines indicate partially rotational nature of movement along the unified fault surface. The axis of rotation is projected to place near Dobříš town, where both walls of the fault take place in the Proterozoic sediments. Shared activity of both faults corresponds to sinistral strike-slip movement with a slight rotation producing different components relating to distance from rotational axis. As the main phase of tectonic movement is partly synchronous with granodiorite intrusion, we assume the Tournaisian and Visean age of tectonic activity along the fault.

References

ANDERSON, E. M., 1972. The dynamics of faulting and dyke formation with applications to Britain. *Hafner Publishing Company. New York.*

BAMBAS, J., 1990. Březohorský rudní revír. *Komitét sympozia Hornická Příbram ve vědě a technice. Příbram.* [in Czech]

CHLUPÁČ, I., HAVLÍČEK, V., KŘÍž, J., KUKAL, Z. & ŠTORCH, P., 1998: Paleozoic of the Barrandian (Cambrian to Devonian). *Czech geological survey. Prague.*

HAVLÍČEK, V., 1950. Geologie úvalského staršího paleozoika. *Sborník Státního geologického ústavu Československé republiky, oddíl geologický*, 17: 141–182. [in Czech]

HAVLÍČEK, V., 1973. Horizontální posuny na Příbramsku. *Věstník ÚÚG*, 48: 225–228. [in Czech]

HAVLÍČEK, V., 1981. Development of a linear sedimentary depression exemplified by the Prague Basin (Ordovician–Middle Devonian; Barrandian area – central Bohemia). *Journal of Geological Sciences, Geology*, 35: 7–43.

KETTNER, R., 1911. Vrstevní zlom mezi Závistí a Modřanskou roklí. *Sborník České společnosti zeměvědné*, 17: 256–258. [in Czech]

MAŠEK, J. 1986. Geological map of ČSSR 1:25000. 12–433 Rosovice. *ÚÚG. Praha.*

ŠEŠULKA, V., KNÍŽEK, M. & MELICHAR, R., 2011. Geophysical research of Clay fault in the vicinity of village Pičín (Barrandian, Bohemian Massif). *Travaux géophysiques*, 40: 80– 81.

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The orthogneisses – lost rocks in the Žiar Mts. (Western Carpathians)

Milan Kohút

Dionýz Štúr State Institute of Geology, Mlynská dolina 1, 817 04 Bratislava, Slovakia, e-mail: milan.kohut@geology.sk

The orthogneisses form an important component of the Central Western Carpathians (CWC) in the autochthonous position as part of a crystalline basement (Tatricum and Veporicum) as well as form basis of Krížna nappe (Fatricum) in an allochthonous setting. Generally, there are present various structural types e.g. coarse grained “augen” orthogneisses and medium grained (stromatitic) – “banded gneisses” representing mylonites in which the outlines of the original K-feldspar parent megacrysts are still clearly visible as polycrystalline elongate aggregates of new daughter grains. These rocks are known in nearly all Tatric core mountains (e.g. the Považský Inovec Mts., the Tríbeč Mts., the Malá Fatra Mts., the Veľká Fatra Mts., the Západné Tatry Mts., the Nízke Tatry Mts., the Branisko Mts.), and the Starohorské Vrchy Mts., frequently occurred in the Veporic part of the Slovenské Rudohorie Mts., as well as sporadically were described in the crystalline islands within the Central Slovakia Volcanic Field (e.g. Vyhne). Review of their historical and petrographical aspects was given by Kohút (2004). It was Hermann Vetters (1909) who first identified and mapped these rocks within the Western Carpathians in the Žiar Mts (ŽM). However, during construction of General geological map of Czechoslovakia in a scale of 1 : 200000 (‘60s of XXth century) these rocks were mapped as migmatized gneisses and/or common granites – therefore were omitted from map of mentioned area – ŽM. Recently, these sheared granitic rocks were reaffirmed in the frame of detailed geological mapping of the Žiar mountains (Kohút *et al.*, 2013) in the area where were identified by Vetters (l.c.) hundred years ago.

These old felsic granitic rocks sheared and dynamically metamorphosed to “banded” and “augen” orthogneisses form only southern part of studied ŽM between Malá Čausa and Sklené villages. They are pale- to dark-grey colour, medium- to coarse-grained rocks with planar – foliated and “augen” S-C fabric, locally with typical up to 8 cm large K-feldspar phenocrysts, having mylonitic, blastomylonitic and lepidogranoblastic texture. Basic mineral composition is quartz, plagioclase, K-feldspar, biotite, muscovite, ±sillimanite, accessory minerals: zircon, monazite, apatite ±garnet. The precursors of these rocks were mostly biotite and muscovite-biotite monzogranites to granodiorites. Geochemically they are typical medium- to high-potassium magmatic rocks ($K_2O \geq Na_2O$) of the calk-alkaline series, with peraluminous character (ASI = 1.16 ~ 1.24) what is common feature of all porphyritic granitic rocks within CWC. Studied ŽM orthogneisses exhibit distribution within granite and shifting to granodiorite field in the O’Connor’s An-Ab-Or normative diagram. These rocks display general felsic character with B < 150, and clear dominance of biotite over muscovite within field III (Debon & Le Fort’s A vs. B diagram) of common crustal derived granitic rocks. Their primary granitic source could be recycled mixture of greywackes and arkoses. Possible melting of sedimentary crustal source in the pre-collisional stadium is inferred on the basis of R1-R2 diagram. Generally, we suppose that these ŽM orthogneisses represent former pre-collisional crustal VAG granites. The crustal S-type character of these rocks well indicates classical diagrams of Chappell & White (1974). Although it is rather ambiguous in the Na_2O vs. K_2O diagram (partial affiliation to I-type), the situation is clear from CaO vs. FeO_{total} diagram, as higher contents of iron are not saturated by elevated values of calcium (what is common for the presence of hornblendes in the I-type rocks), whereas lower calcium values suggest only for the presence of biotites and/or reflect peraluminous S-type character of common CWC orthogneisses. The uniform low to moderate REE´s show typical fractionated pattern with distinct negative Eu anomaly, and partly elevated HREE contents are apparently controlled by presence of monazite and apatite. The moderate initial Sr values (I_{Sr} = 0.707 ~ 0.718) suggest for slight influence by lower crustal source, whereas recalculated initial Nd values ($\varepsilon_{Nd(i)}$ = –6.1 ~ –8.3) indicate dominance of crustal source what confirmed values of the Neodymium crustal index (NCI = 0.88 ~ 0.97). The apparent neodymium crustal residence ages suggest that magmatic precursor of these ŽM orthogneisses were generated from the Meso-Proterozoic crustal source $T_{(DM2st)}$ = 1460 ~ 1630 Ma what is in accordance to similar rocks described in CWC (Kohút & Nabelek, 2008) and/or the Variscan/Caledonian granitic rocks of the Central Europe (Liew & Hofmann, 1988). The hybrid multi-recycled origin of ŽM orthogneisses is well documented by Hf zircon isotopic signature because the Proterozoic zircon restitic cores (2670 ~ 730 Ma) have mantle derived initial Hf values ($\varepsilon_{Hf(i)}$ = +13.0 ~ +5.4), indeed the Cambrian to Ordovician protomagmatic zircons (540 – 475 Ma) have typical crustal ($\varepsilon_{Hf(i)}$ = –4.8 ~ –7.0) characteristic, whereas the Carboniferous metamorphic/anatectic overprinted zircon rims (360 – 330 Ma) display mixture character ($\varepsilon_{Hf(i)}$ = +3.8 ~ –0.4) influenced by lower crust. The Hf $_{(DM2st)}$ zircons crustal residence model ages vary for the ŽM orthogneisses in age interval 970 ~ 2400 Ma, indeed these Hf model ages are partly older then WR two stages $Nd_{(DM)}$ model ages. The U-Th-Pb zircon dating by means of SHRIMP was carried out with an aim to solve their protomagamtic and metamorphic/anatectic ages. Detailed CL and BSE zircon study revealed typical multistage origin with presence rather complicated internal textures, frequent inherited cores, oscillatory zoned and/or newly grown domains at rims for majority of zircons. Protomagmatic age of original S-type granitic precursor was identified from spot dating of magmatic zoned crystals giving ages between 505 and 470 Ma with concordia age close 485 Ma, whereas anatectic overgrown zircon rimes yielded ages around 350 and/or 330 Ma. Noteworthy, that monazites from strongly sheared orthogneiss gave EMP – CHIME dating age 365 Ma indicating probably maxima of dynamic, metamorphic deformation processes.

However, our recent study proved that ŽM orthogneisses are related to the Mesozoic sequences of the Fatricum (Krížna nappe) alike in the Starohorské Vrchy Mts., having thrust fault boundary with neighbouring Tatric basement.

References

CHAPPELL, B. W., & WHITE, A. J. R., 1974. Two contrasting granite types. *Pacific Geology*, 8: 173–174.

KOHÚT, M., 2004. The orthogneisses of the Western Carpathians: An overview. *Mineralia Slovaca*, 36 (3/4): 141–155. (In Slovak with English summary)

KOHÚT, M. (ED.), HAVRILA, M., FILO, I., MAGLAY, J., ŠIMON, L., NAGY, A. & BARÁTH, I., 2013. Explanation to geological map 1 : 25 000, sheets: 36–131 Ráztočno, 36–133 Handlová (part) and 35–242 Prievidza (part) [Žiar Mts.– South part]. Project 19-10 Region Žiar. Manuscript archive ŠGÚDŠ – Geofond Bratislava, 219 pp + 10 Attachments. (In Slovak)

KOHÚT, M. & NABELEK, P. I., 2008. Geochemical and isotopic (Sr, Nd and O) constraints on sources for Variscan granites in the Western Carpathians – implications for crustal structure and tectonics. *Journal of Geosciences*, 53: 307–322.

LIEW, T. C. & HOFMANN, A. W., 1988. Precambrian crustal components, plutonic associations, plate environment of the Hercynian fold belt of Central Europe: indications from a Nd and Sr isotopic study. *Contrib. Miner. Petrol.*, 98: 129–138.

VETTERS, H., 1909. Beiträge zur Geologie des Zjargebirges und des angrenzenden Teiles der Mala Magura in Oberungarn. Besonders Abgedruckt aus dem LXXXV. Bande der Denkschriften der mathematisch – naturwissenschaftlichen Klasse der Kaiserlichen Akademie der Wissenschaften. Wien, 1-60, mit 2 Karten, 6 Tafeln und 4 Textfiguren.

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AMS of Cambrian volcanic rocks in Barrandian

Kristina Kolářová[1], Jan Černý[1, 2] & Rostislav Melichar[1]

[1] *Department of Geological Sciences, Masaryk University Brno, Kotlářská 267/2, 611 37 Brno, 269536@mail.muni.cz, 176111@mail.muni.cz*
[2] *Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 269, 165 00 Praha-Lysolae, Czech Republic*

Křivoklát–Rokycany volcanic complex represents main body of Cambrian volcanic rocks in Barrandian area. Just only part of the complex remains due to it´s limitation by a tectonic fault with the NE–SE direction in the south. Main body is compound of younger rhyolite zone and older andesite-dacite one. Feeding structure fulfilled by the Sýkořice Porphyr is situated in the NE. It consists of diamagnetic minerals while real value of magnetic susceptibility in the complex reaches values in order of magnitudes at least 10^{-5} SI (paramagnetic). AMS makes possible to distinguish 3 types of volcanic rocks in the older part. Two groups have a dominant compound of ferromagnetic particles with different sizes of magnetic susceptibility. Paramagnetic minerals control magnetic fabrics of the third group. Different magnetic fabrics have most probably relation to the changes of viscosity and mineral composition of the rock. The highest degree of anisotrophy with oblate character was found close to the contact of andesites and dacites. Several feeding centers are situated in the rhyolite part, particularly near tectonic fault boundary of NE part of the complex. The sense of flow to NW might be derived from the position of feeding centers. The direction of prolate bubbles was successfully measured at one locality and it can be referred as magmatic flow direction. Those directions are parallel to magnetic lineation (K1) and perpendicular to the direction of minimum magnetic susceptibility (K3). Therefore it´s likely that the maximal susceptibility direction (K1) obtained by AMS can represent magma flow direction in the other localities as well. So we can expect that the orientation of the flow based on the results of AMS is oriented in NW–SE direction in the andesitic part.

References

KOLÁŘOVÁ, K., 2013. Stavba a anizotropie magnetické susceptibility vulkanitů křivoklátsko-rokycanského pásma. MS, diploma thesis. Faculty of Science, Masaryk University. Brno

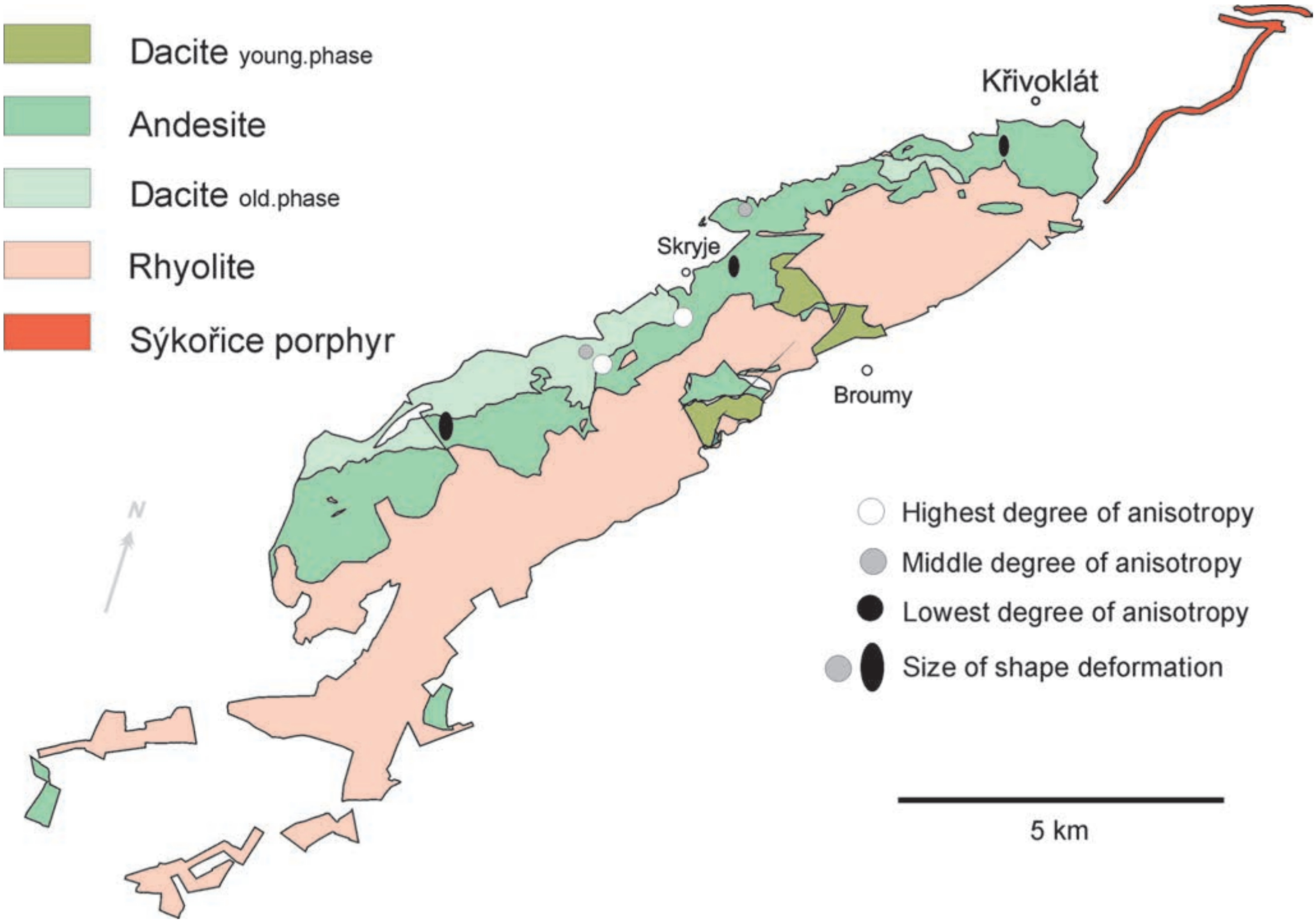

Fig. 1. Schematic map of Křivoklát-Rokycany volcanic complex and its degree of anisotropy and shape parameter.

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Post-rift deformations in the surroundings of Rechnitz tectonic window, Eastern Alps

Gábor Kovács

Department of Geophysics and Space Sciences, Eötvös Loránd University, 1/C Pázmány P. str, H-1117 Budapest, Hungary
Department of Geology, University of West Hungary, 4. Károlyi Gáspár square, H-9700 Szombathely, Hungary,
e-mail: skovacsgabor@caesar.elte.hu

The study area is a transition zone between the still uplifting Eastern Alps and the subsiding Danube Basin, bordered by Rába/Raab on SE and S, Lapincs/Lafnitz on W, Bernstein and Rechnitz–Koszeg Mountains on N and Répce/Rabnitz on E. Several investigations focused on the Southern, Southeastern flank of Rechnitz tectonic window in order to get information about young tectonism of the study area. The aim of this paper is to summarize and interpret the results of these tectonic investigations complemented with the reconsidered interpretation of seismic sections and results of geomorphometrical methods (Kovács *et al.* see in this volume). The pre-Cenozoic basement of the research area consists of different Alpine nappes, which are separated by detachment fault, that where active during the syn-rift extension of the area (from 19 Ma; Fodor *et al.*, 2011) and the exhumation of the Rechnitz tectonic window (Tari *et al.*, 1992).

During the Late Miocene sedimentation (from ~11.6 Ma, the basin was filled by different types of sedimentary units, while it evolved from deep lake through delta slope, to delta (Magyar *et al.*, 1999). The geometry of these structures is more or less explored, that makes it usable in the recon-

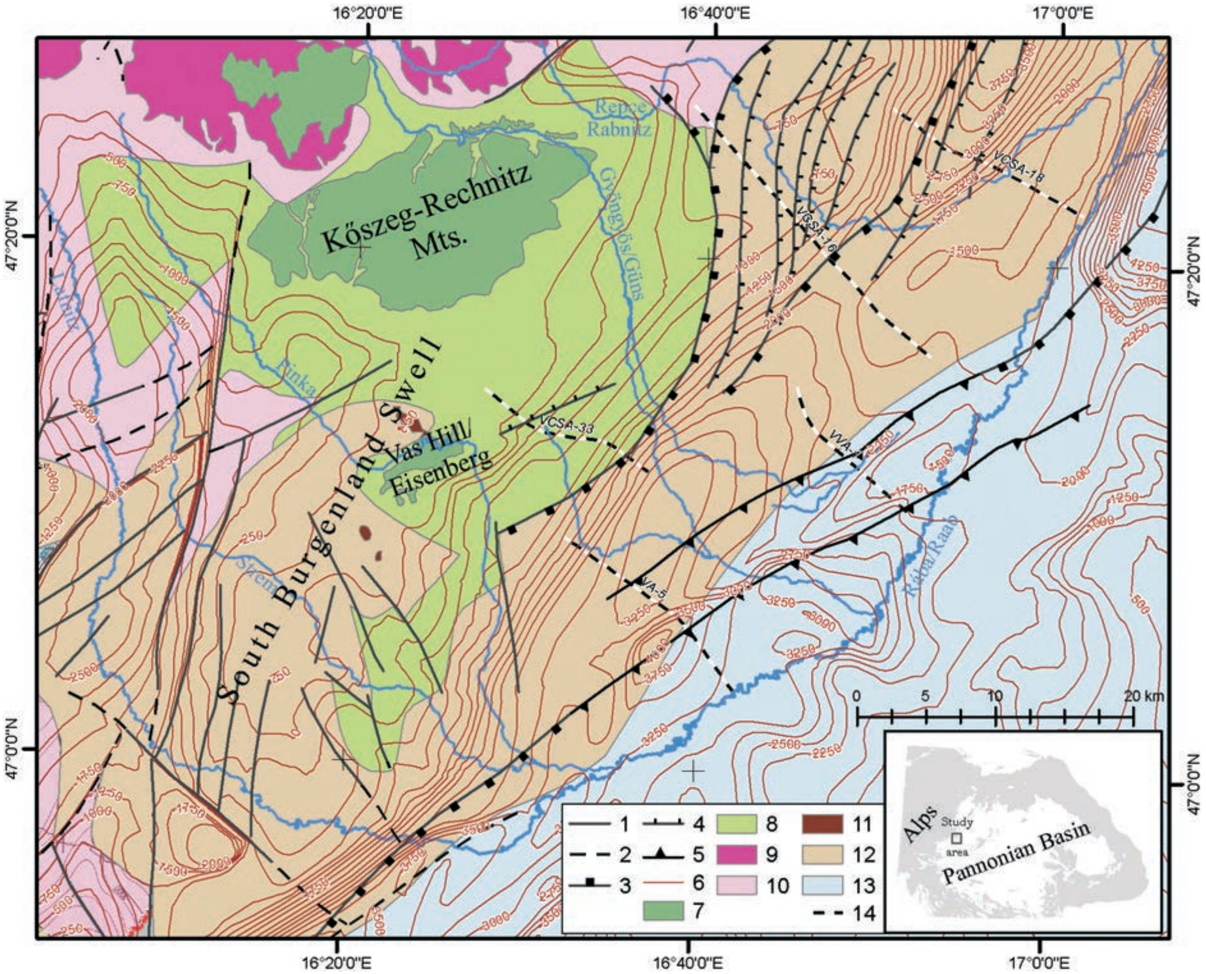

Fig. 1. Pre-Tertiary basement geology of the study area (based on Flügel, 1988; Tari & Horváth, 2010; Fodor *et al.*, 2011). 1 – unspecified, proven structural line; 2 – unspecified, ambiguous structural line; 3 – detachment fault; 4 – normal fault; 5 – thrust fault; 6 – contour of basement depth; 7, 8 – outcropped, buried Penninic nappe; 9, 10 – outcropped, buried Lower Austroalpine nappes; 11, 12 – outcropped, buried Upper Austroalpine nappes; 13 – younger nappes; 14 – referred seismic sections.

struction of post-sediment deformation. In the latest period (from ~8.7 Ma) the area was a marsh zone producing horizontal clayey layers with thin lignite horizons. This alternating se- diment style provides the opportunity to correlate layer horizons between borehole data and to follow these horizons by geophysical methods. Later small-scale deformations cau- sed only minor changes in layer geometry. Since surface erosion was more effective than these tectonic deformations, the effects of these deformations are hardly observable in the present morphology. Variegated geomorphometrical methods (presented in a different paper of this volume; Kovács & Telbisz, 2013) were used to detect the superficial expression of these deformations.

A general conclusion drawn from this and previous studies is that the large-scale morphology of the surface reflects the basin-ridge system of the pre-Cenozoic basement. Above South Burgenland Swell (Sachsenhofer *et al.*, 1997) the terrain is more uplifted (~50–100 m), while the base level is the same for the whole area. It explains why the western area is much more eroded. This unit is bordered by young ~N–S faults radial to uplifting tectonic window of Koszeg–Rechnitz Mountains possibly of post-rift activity (Nebert, 1979; Kosi *et al.*, 2003). Topographic swath analyses applied for the surface and for Pleistocene gravel terraces distinctly, revealed the post-sediment tilting of different blocks (Telbisz *et al.*, 2013; Kovács & Telbisz, 2013) of South Burgenland Swell. Nebert (1979) claimed the tectonic origin of Pinka and Strem valleys. Tectonic origin of other morphological lines radial to Koszeg–Rechnitz Mountains are suggested by some local measurements (Repce scarp: Szabó & Kovács, 2014; Lower Gyöngyös scarp: unpublished field report) but further investigations are needed.

Using geomorpometrical methods it is also demonstrated that uplift has been an active process above the subsurface ridge of Penninic rocks. Surface is relatively uplifted above the buried east-northeastern ridge of Eisenberg/ Vas Hill and Koszeg–Rechnitz Mountains, and further on above the southern foreland of the latter. On the totally plain southeastern area possible surface deformations could be detected using geomorphometrical tools. River style investigation (see Kovács *et al.* in the same volume) revealed strikingly regular shape in the southwestern area. Seismic sections perpendicular to the revealed features also demonstrate folded geometry in the underlying Late Miocene sediments. Deformation along the northeastern sections smoothly follows the basement morphology. Synclinal forms can be the result of the post-sediment activity of the detachment fault. Basement morphology is not reflected directly in the surface morphology in the southern part, however thrust faults of the basement and connected anticlinal folds of the burying Late Miocene sediments can be observed in the seismic profiles.

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References

BERECZKI, L., GÄRTNER, D., KEMÉNY, M., PÉNTEK, A., KOVÁCS, G., TIMÁR, G., MOLNÁR, G. & SZÉKELY, B., 2013. Where do the Alps’ foothill end? The depths of the Pre-Cenozoic basement in the foreground of Vas-hegy – Alpokalja, Western Hungary. *Geographia Na- pocensis*, 7: 33–42

FLÜGEL, H. W., 1988: Steirisches Becken – Südburgenlandische Schwelle. Geologische Bundesanstalt.

FODOR, L., UHRIN, A., PALOTÁS, K., SELMECZI, I., TÓTHNÉ MAKK, Á., RIZNAR, I., TRAJANOVA, M., RIFELJ, H., JELEN, B., BUDAI, T., KOROKNAI, B., MOZETIČ, S., NÁDOR, A. & LAPANJE, A., 2011. A Mura–Zala-medence vízföldtani elemzést szolgáló földtani-szerkezetföldtani modellje. Magyar Állami Földtani Intézet, 46 p. (in Hungarian with English abstract)

FÜLÖP, J., 1994. Magyarország geológiája. Paleozoikum II. Akadémiai Kiadó, Budapest, 444 p. (in Hungarian)

JASKÓ, S., 1964. A nyugat-vas megyei barnakoszénterület. *Földtani Kutatás*, 7: 24–48 (in Hungarian)

KOSI, W., SACHSENHOFER, R. F. & SCHREILECHNER, M., 2003. High resolution sequence stratigraphy of Upper Sarmatian and Lower Pannonian Units in the Styrian Basin, Austria. In: Piller, W. E. (Ed.) Stratigraphia Austriaca, Österr. Akad. Wiss., Schriftenr. Erdwiss. Komm. 16: 63–86.

KOVÁCS, G. & TELBISZ, T., 2013. Tektonikus és fluviális hatások a Koszegi-hegység és a Rába közti dombvidék kialakulásában (The role of tectonic and fluvial forces in the formation of the hilly area between Koszeg Mountains and Rába River). *Földtani Közlöny*, 143: 157–176 (in Hungarian with English abstract)

MAGYAR, I., GEARY, D. H. & MÜLLER, P., 1999. Paleogeographic evolution of the Late Miocene Lake Pannon in Central Europe. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 147: 151–167.

NEBERT, K. 1979. Die Lignitvorkommen Südostburgenlands. *Jahrbuch der Geologischen Bundesanstalt*, 122: 143–180.

PASCHER, G. A., 1999. Geologische Karte des Burgenlandes. *Geologischen Bundesanstalt 1:200 000*

SACHSENHOFER, R. F., LANKREIJER, A., CLOETINGH, S. & EBNER, F., 1997. Subsidence analysis and quantitative basin modelling in the Styrian Basin (Pannonian Basin System, Austria). *Tectonophysics*, 272: 175–196.

SZABÓ, V. & KOVÁCS, G., 2014. Geophysical and GIS study of gravel layer on Gyöngyös plain and Köszeghegyalja, W-Hungary. *Geophysical Research Abstracts*, 16: 385

TARI, G., HORVÁTH, F. & RUMPLER, J., 1992. Styles of extension in the Pannonian Basin. *Tectonophysics*, 208: 203–219.

TARI, G. & HORVÁTH, F., 2010. A Dunántúli-középhegység helyzete és eoalpi fejlodéstörténete a Keleti-Alpok takarós rendszerében: egy másfél évtizedes tektonikai modell idoszerusége. *Földtani Közlöny*, 140: 483–510.

TELBISZ, T., KOVÁCS, G., SZÉKELY, B. & SZABÓ, J., 2013. Topographic swath profile analysis: a generalization and sensitivity evaluation of a digital terrain analysis tool. *Zeitschrift für Geomorphologie*, 57: 485–513.

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New constrains to the Mesozoic structural evolution of the Inner Western Carpathians achieved by metamorphic, structural and geochronological data

Szilvia Kövér & László I. Fodor

MTA-ELTE Geological, Geophysical and Space Science Research Group, Hungarian Academy of Sciences at Eötvös University Budapest, 1/C Pázmány sétány, H-1117-Budapest, Hungary, e-mail: koversz@yahoo.com

A complex thin-skinned nappe pile of the Inner Western Carpathians was studied in the central part of the Rudabánya Hills, NE Hungary. A new structural model and evolution were suggested on the basis of structural, metamorphic petrological, geochronological and paleontological data.

The investigated nappes derive from the Neotethys Ocean and its attenuated continental margins and built up by Triassic and/or Jurassic sedimentary rocks. The flysch-type, fine to coarse-grained sedimentary sequence of the Telekesoldal nappe is marked by Bajocian-Callovian sedimentary age (~160–170 Ma) and low-grade metamorphism (1.5–2.5 kbar and 300–350°C). Stratigraphical, sedimentological and structural features are similar to that of the Meliata unit, so we consider the Telekesoldal sequence as part of the Meliata unit. The Torna nappe system built up by Triassic sedimentary cover rocks of an attenuated continental crust suffered low-grade overprint with 3–4.5 kbar and 300–350°C, corresponding to 10–15 km of burial. This tectonic burial resulted in $S_{0\text{-}1}$ foliation in both tectonic units. Because of their very similar early deformational history (D_1 foliation, D_2 folding, D_3 kink-type folding) and metamorphic degree, it is supposed that the tectonic contact of the Torna and Telekesoldal nappes is a **pre-metamorphic nappe contact**. Newly obtained K-Ar ages put a time constraint of **142–113 Ma** for D_1 phase.

The metamorphosed, deformed and exhumed Meliata and Torna rocks were emplaced onto non-metamorphic Triassic to Jurassic series (D_4 phase). Outcrop- and map-scale structures refer to NW–SE shortening and **southeast-vergent nappe emplacement**.

Later, the metamorphosed over non-metamorphosed tectonic couplet was thrust again onto the metamorphic Meliata nappe system along E–W striking thrusts (D_5 phase). Thrusting associated with reworking of the previous nappe contacts and map-scale F_5 folding. Fold vergency indicates **southward tectonic transport**.

Research on the basal cataclastic breccias of the overthrusting units permits to establish a relative chronology of D_4 and D_5 **thrust contacts** and the p-T data of the movements. Trapped fluids in syn-kinematic minerals indicated temperature up to **200–320°C** and pressure up to **3.6 kbar** during the D_4 nappe movements. Fluid inclusions from the D_5 contact resulted in significantly lower p-T values (200–260°C, 0.3–1.0 kbar), indicating thrusts in shallower crustal level. This is in agreement of the relative chronology of the D_4 and D_5 deformation phases.

Migrating high temperature fluids along the nappe contacts caused partial or total reset of the K-Ar isotope system, thus the measured **87–94 Ma** is suggested to be connected to nappe movements.

Geodynamic implication: the 150–160 Ma south-directed subduction of the West Carpathian margin (marked by the blueschist-facies Bôrka nappe slice) continued to 140 Ma. At that time, the uppermost, Mesozoic part of the previously thinned crust entered the subduction zone, indicated by the medium-pressure metamorphism of the Torna unit. Part of the Jurassic Meliata sediments submerged into the subduction zone, too. This is the time (D_1) when the Torna structural unit underplates the tectonically buried Meliata sedimentary melange. Meanwhile, part of the already HP metamorphosed oceanic and continental crustal fragments (Bôrka nappe) exhumed to the foot of the buried Meliata sedimentary melange. Ongoing compression pushed tectonic slices of the HP unit into the Meliata unit as a tectonic matrix. Low-grade prograde metamorphism of the Torna and Meliata tectonic units and retrograde metamorphism of the Bôrka HP nappe were coeval, indicated by K-Ar data (140–120 Ma).

Probably during that time period a considerable strike-slip deformation could rearrange the Triassic to Jurassic passive margin units. Namely, the Silica nappes and other non-metamorphosed units were emplaced south from the buried units by strike-slip displacement. This model, postulated already for the Eastern Alps, could explain the facies relationship of Triassic margin sequences.

The mid-Cretaceous Eoalpine phase resulted in thick- and thin-skinned nappe movements in the Western Carpathians: they have southeast- and south-vergency in the study area. These later D4 and D5 phases dominate the present tectonic geometry. Rearrangement of the metamorphosed and non-metamorphosed units and their duplication may be responsible for the former contradictory views on the structural setting.

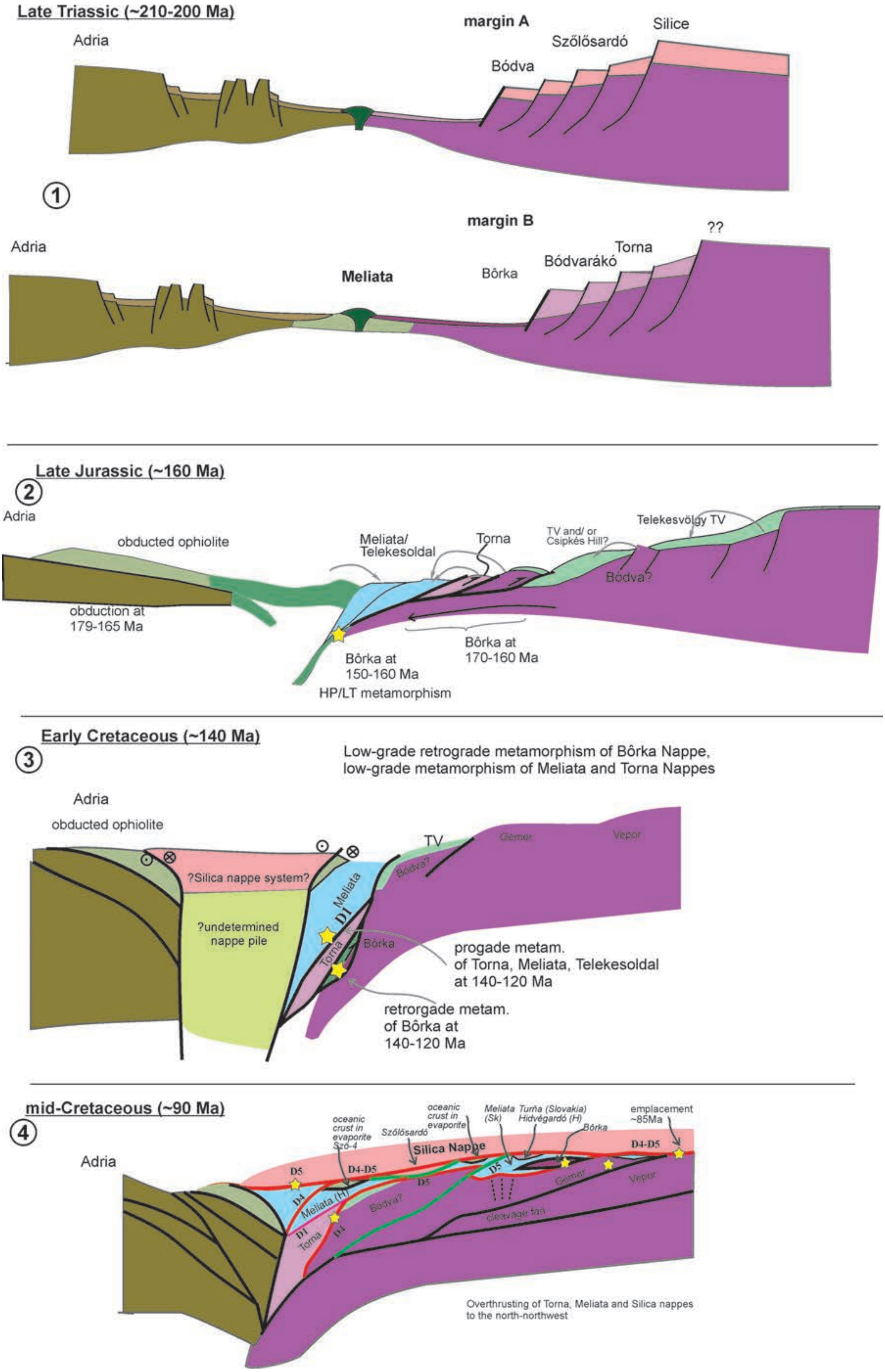

Fig. 1. Schematic structural evolution of the study area during the Mesozoic. Note that Triassic paleogeographic position of some tectonic units is only tentative.

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Crustal-scale buckling and associated crustal flow – lessons from analogue modeling

Ondřej Krýza[1], Ondrej Lexa[1,2], Karel Schulmann[2,3], Denis Gapais[4], Alexandra Guy[4] & John Cosgrove[5]

[1] *Institute of Petrology and Structural Geology, Charles University in Prague, Albertov 6, 128 43, Czech Republic*
[2] *Czech Geological Survey, Centre for Lithosphere Research, Klárov 3, 118 21 Prague 1, Czech Republic*
[3] *Université de Strasbourg, IPG-EOST, UMR 7516, 1 Rue Blessig, Strasbourg 67084, France*
[4] *Géosciences Rennes, UMR 6118 CNRS, Université de Rennes 1, 35042 Rennes cedex, France*
[5] *Department of Earth Sciences and Ingeneering, Imperial College, London, Prince Consort Road, UK*

Recent structural and geophysical observations from central Asia show that the crustal-scale buckling of Mongol-Okhotsk subduction zone was accompanied with heterogeneous thickening of adjacent crust and deformation of lithospheric mantle. In order to simulate processes related to this oroclinal bending and deformation of surrounding lithosphere we present a complex analogue model of buckling of vertically layered domain which is surrounded by horizontally anisotropic material.

In our experiments we used 43/26/4 cm (width/length/height) modelling box and one sided piston mechanism. Modeled domain is formed by several layers oriented along two principal directions. Central part is formed by two vertical and gently arcuated ductile layers oriented parallel to the shortening direction. This domain is surrounded by horizontal two-layer (brittle/ductile) segment located in the side of future fold amplification. Both domains are supported by higher viscosity material representing the upper mantle. This structure is embedded in ductile material of variable viscosity to suppress negative influence of lateral boundary conditions.

Materials and geometry of the model are scaled according to standard analogue modeling principles (Hubbert, 1937; Ramberg, 1981; Brun, 2002). Upper crustal layer is formed by Fontainebleau sand with specific and well-known material properties (Brun, 2002; Cagnard, 2006). Ductile lower crust and vertical „weak'' layer are represented by silicone putty of a relatively low viscosity, while upper mantle layer is represented by higher viscosity silicone (like a surrounding material in some experiments). For the most competent vertical layer (buckling controlling layer), we used high viscosity silicone combined with plastic and elastic sheets. It should be noted that all used silicone putties are Newtonian materials deformed at constant temperature.

Following evolutionary trends were commonly observed: 1) amplification of fold associated with indentation of central domain by propagating fold hinge. Because of pure-shear deformation geometry and vertical thickening of horizontal layers, the fold amplification is relatively small due to resistance of the central domain. 2) The indentation of central domain is compensated by lower crustal horizontal flow in opposite direction. 3) The deepest mantle material is filling the region in front of propagating fold hinge.

We suggest that our model may simulate the folding of Mongol-Okhostks subduction zone together with ribbon continent and deformation of adjacent oceanic crust during Asain Paleozoic orogeny. The model is set up to explain mechanical behavior of surrounding crust, its thickening, horizontal flow of deep crust and deformation of lithospheric mantle. The results are discussed in the frame of current tectonic models of Central Asian Orogenic Belt.

References

BRUN J. -P., 2002. Deformation of the continental lithosphere: Insights from brittle-ductile models. *Geological Society, London, Special Publications*, 200: 355–370.

CAGNARD F., BRUN J.-P. & GAPAIS D., 2006. Modes of thickening of analogue weak lithospheres. *Tectonophysics*: 421, 145–160.

HUBBERT, K., 1937. Theory of scale models as applied to the study of geological structures. *Geological Society of America Bulletin*, 48: 1459–1520.

RAMBERG, H., 1981. Gravity Deformation and the Earth Crust. *Academic Press*, London and New York.

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Structure and Phanerozoic evolution of the SW edge of the East European Craton in Poland – new insight from high-effort seismic reflection data (project PolandSPAN)

Piotr Krzywiec[1], Michał Malinowski[2], Stanisław Mazur[1], Vinton Buffenmyer[3] & Marek Lewandowski[1]

[1] *Institute of Geological Sciences, Polish Academy of Sciences, 51/55 Twarda str., 00-818, Warsaw, Poland, e-mail: piotr.krzywiec@twarda.pan.pl*

[2] *Institute of Geophysics, Polish Academy of Sciences, 64 Ks. Janusza str., 01-452 Warsaw, Poland, e-mail: michalm@igf.edu.pl*

[3] *ION Geophysical, 225 E 16th Ave. 1200, Denver, CO 80203, USA*

The SW edge of the East European Cratonic edge in Poland has recently been the focus of very intense exploration for unconventional hydrocarbons. As a result, approximately 2200 kms of regional high-effort seismic reflection data has been acquired using following acquisition parameters:

– ultra-long offsets (12 km)
– long record lengths (12 sec)
– tight station spacing (25 m)
– high fold (480)

The acquired data was processed through PSDM and was calibrated by public-domain deep research wells. Results of seismic data interpretation were supplemented by 2D gravity – magnetic modeling.

Cratonic edge in Poland is bordered by, and also partly superimposed on, the Teisseyre – Tornquist Zone which is separating the cratonic plate from the West European Platform (Fig. 1; Ziegler, 1992; Doornenbal & Stevenson, 2010). During the Precambrian/Cambrian, the cratonic edge underwent extension and rifting of the Rodinia supercontinent, while Cambrian–Ordovician subsidence was driven by a post-rift lithospheric thermal cooling (Poprawa *et al.*, 1999; Poprawa, 2006a). In the Silurian, the cratonic edge was under the strong influence of the Caledonian thrust belt, and was incorporated into its flexural foredeep basin (Poprawa *et al.*, 1999; Nawrocki & Poprawa, 2006; Poprawa, 2006b). The Silurian Caledonian foredeep basin encompassed vast areas stretching from the present-day Sweden across Estonia, Latvian, Lithuania, Russia (i.e. Kaliningrad District), Poland, Belarus, Ukraine and farther to the southeast (Poprawa *et al.*, 1999; Skompski *et al.*, 2008; Zdanaviciute & Lazauskiene, 2007).

Late Paleozoic (Bretonian and Variscan) and Mesozoic tectonic movements have resulted in compartmentalization of the Lower Paleozoic basin into the Baltic, Podlasie and Lublin sub-basins.

In the Baltic Basin, the large-scale seismic geometry of the thick (up to 6–7 km, post-erosional) Silurian succession reflects the progressive progradation of the Caledonian foredeep basin fill toward the east-southeast. The Precambrian basement and Cambrian–Silurian sedimentary cover is deformed by faults that might have been formed as a normal faults during the passive margin stage and then reactivated as reverse faults during the Bretonian (latest Devonian–early Carboniferous) tectonic phase and assiociated uplift of the Mazury–Belorussian High (Anteclise). Structural deformations documented within the Baltic Basin also include intense Late Triassic normal faulting, rooted in either the Silurian shales or Precambrian basement.

The Podlasie Basin is characterized by a system of deeply rooted reverse fault zones, active mostly during the Bretonian tectonic phase. Preserved Silurian succession is characterized by a progradational pattern suggesting sediment input from the northwest.

Within the northeastern part of the Lublin Basin and also partly within the Podlasie Basin intense Bretonian (latest Devonian–early Carboniferous), reverse/strike-slip faulting has been identified. These reverse faults, with large throws up to 3 km, are deeply rooted within the Precambrian basement and follow regional southwest-northeast tectonic grain known from this part of the East European Craton and delineated by the magnetic data (Fig. 1B).

The axial part of the Lublin Basin is characterized by Variscan (late Carboniferous, cf. Narkiewicz, 2007; Krzywiec, 2009) mostly thin-skinned, compressional deformations detached either at the base of Silurian or within the Mid Devonian. Major faulting along the southwestern edge of the Lublin Basin was interpreted as thin-skinned. It led to thrusting of the Radom–Kraśnik block over the Paleozoic infill of the Lublin Basin. The detachment zone is interpreted to be above top of the Precambrian basement at depth as great as 20 km.

Within the axial part of the Lublin Basin, previously unknown deeply rooted steep fault zone has been identified. This fault zone, characterized by the total throw in order of almost 3 km, together with another similar fault zone, the Grójec fault zone, characterized by similar displacement at the basement level, are located at the edges of the Malopolska Gravity High. Within this part of the basin also evidences for the Neoproterozoic rifting have been identified that might have taken place at the SW continuation of the Orsha–Volyn Aulacogen (Pacześna & Poprawa, 2005).

References

DOORNENBAL, J. C. & STEVENSON, A. G. (EDS)., 2010. Petroleum Geological Atlas of the Southern Permian Basin Area. EAGE Publications b.v. (Houten).

KRZYWIEC, P., 2009. Devonian–Cretaceous repeated subsidence and uplift along the Tornquist–Teisseyre Zone in SE Poland – insight from seismic data interpretation. *Tectono- physics*, 475(1): 142–159.

NARKIEWICZ, M., 2007. Development and inversion of Devonian and Carboniferous basins in the eastern part of the Va-

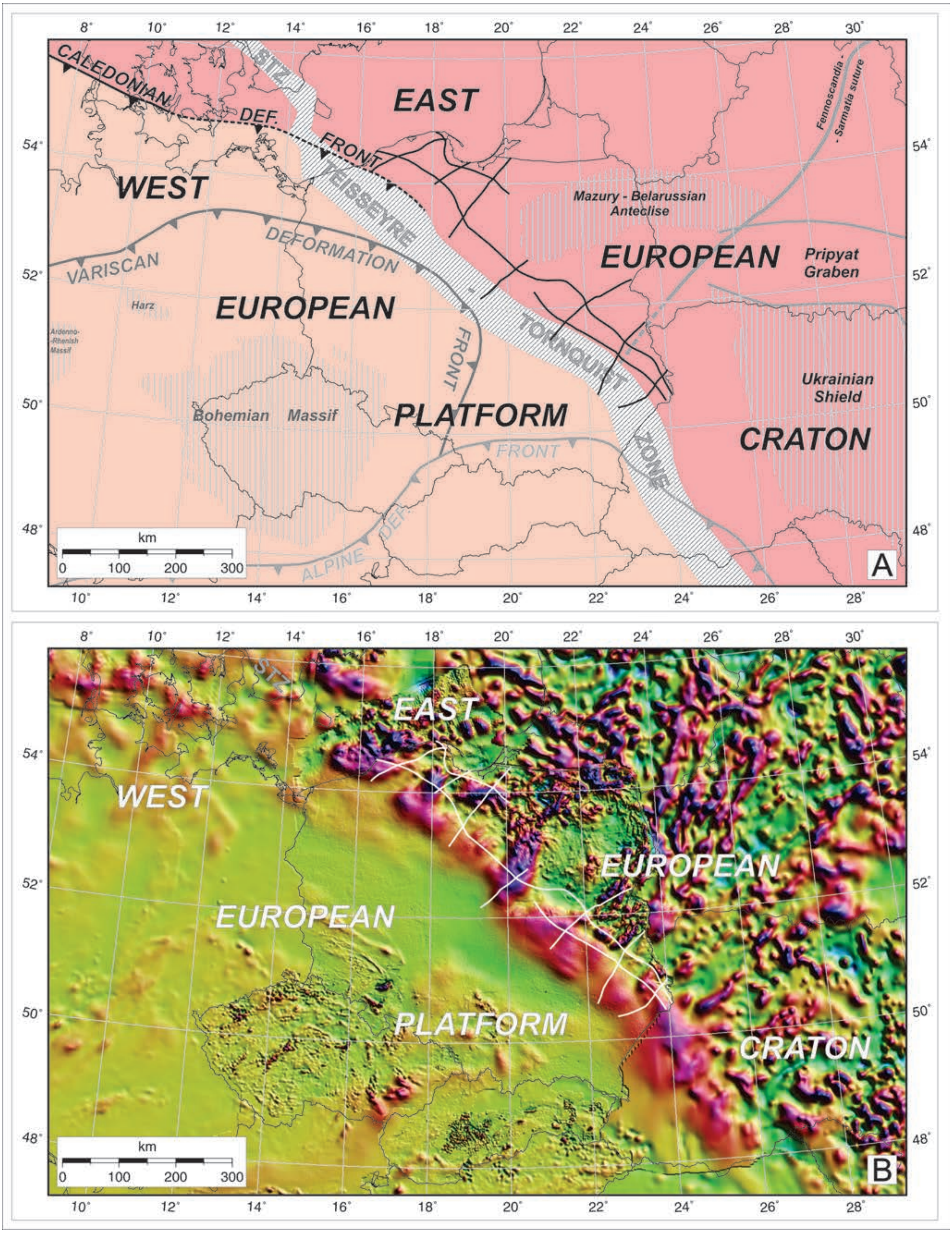

Fig. 1. Location of PolandSPAN survey (black lines on panel A, white lines on panel B) at the background of: A – map showing major crustal units of central Europe (after Pharaoh, 1999; Narkiewicz, 2007, simplified and supplemented), and B – magnetic map (magnetic data prepared by Dr Olga Rosowiecka, PGI-NRI, using data compiled by Dr Stanisław Wybraniec, PGI-NRI).

riscan foreland (Poland). *Geological Quarterly*, 51(3): 231–256.

NAWROCKI, J. & POPRAWA, P., 2006. Development of Trans-European Suture Zone in Poland: from Ediacaran rifting to Early Paleozoic accretion. *Geological Quarterly*, 50(1): 59–76.

PACZEŚNA, J. & POPRAWA, P., 2005. Relative role of tectonic and eustatic processes in development of the Neoproterozoic and Cambrian stratigraphic sequences of the Lublin–Podlasie basin. *Przegląd Geologiczny*, 53: 562–571 (in Polish with English summary).

PHARAOH, T., 1999. Palaeozoic terranes and their lithospheric boundaries within the Trans-European Suture Zone, a rewiev. *Tectonophysics*, 314: 17–41.

POPRAWA, P., 2006a. Neoproterozoic break-up of the supercontinent Rodinia / Pannotia recorded by development of sedimentary basins at the western slope of Baltica. *Prace Państwowego Instytutu Geologicznego*, CLXXXVI: 165–188 (in Polish with extended English summary).

POPRAWA, P., 2006b. Development of the Caledonian collision zone along the western margin of Baltica and its relation to the foreland basin. *Prace Państwowego Instytutu Geologicz- nego*, CLXXXVI: 189–214 (in Polish with extended English summary).

POPRAWA, P., ŠLIAUPA, S., STEPHENSON, R. & LAZAUSKIENE, J., 1999. Late Vendian – early Palaeozoic tectonic evolution of the Baltic Basin: regional tectonic implications from subsidence analysis. *Tectonophysics*, 314: 219–239.

SKOMPSKI, S., ŁUCZYŃSKI, P., DRYGANT, D. & KOZŁOWSKI, W., 2008. High-energy sedimentary events in lagoonal successions of the Upper Silurian of Podolia, Ukraine. *Facies*, 54: 277–296.

ZDANAVICIUTE, O. & LAZAUSKIENE, J., 2007. The petroleum potential of the Silurian succession in Lithuania. *Journal of Petroleum Geology*, 30(4): 325–337.

ZIEGLER, P. A., 1990. Geological Atlas of Western and Central Europe, 2nd edition. Shell Internationale Petroleum Maatschappij B.V. and Geological Society Publishing House, Bath, 239 pp.

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The use of OpendTect in seismic interpretation

Jacek Kubalski

Adam Mickiewicz University, Wieniawskiego 1, 61-712 Poznań, e-mail: jacekpiotrkubalski@gmail.com

Seismic reflection techniques are used to map the subsurface distribution of stratigraphy and structures, thus they are the key to delineate potential hydrocarbon reservoirs.

OpendTect is a complete seismic interpretation software package in an open source environment. It enables the user to process, visualize and interpret multi-volume seismic data using attributes and modern visualization techniques such as RGB-Blending and Volume Rendering.

OpendTect has a broad attribute engine, with a large variety of purposes. It supports various horizon-tracking algorithms, a well-tie module that enables the interpreter to correlate well information (logs) to the seismic on-the-fly TD (or DT) conversion and batch processing of volumes and horizons.

OpendTect uses commercial and non-commercial plug-ins like:

– Dip-steering that allows the user to create a (dip-) SteeringCube which contains local dip and azimuth information of seismic events at every sample location,

– HorizonCube. A HorizonCube consists of a dense set of correlated 3D stratigraphic surfaces. Each horizon represents a (relative) geologic time line,

– Well Correlation Panel (WCP). A plugin that is used for picking well markers and correlating markers guided by seismic evidence,

– The Neural Network plug-in supports Supervised and Unsupervised Neural Networks. The main application of Unsupervised NN is clustering of attributes and/or waveforms for seismic facies analysis. The Supervised approach is used for more advanced seismic facies analysis, to create object “probability” cubes such as TheChimneyCube® and TheFaultCube® and is used for inversion to rock properties,

– The SSIS plug-in (Sequence Stratigraphic Interpretation System) supports full sequence stratigraphic analysis, including automated wheeler transforms, systems tracts interpretation and annotations.

In this paper I will try to introduce those tools and show a typical tutorial on how to process and visualize seismic data and well logs.

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Two-wavelength folding in the Lublin Basin (Central Poland) indicates a depth- and lithology-dependent role of the layer-parallel-shortening

Mateusz Kufrasa[1], Łukasz Gągała[1, 2] & Piotr Krzywiec[1]

[1] *Institute of Geological Sciences, Polish Academy of Sciences, ul. Twarda 51/55, 00-818, Warsaw, Poland, e-mail: mateusz.kufrasa@twarda.pan.pl, piotr.krzywiec@twarda.pan.pl*

[2] *Georex Assistance Technique, 145 rue Michel Carré, 95100 Argenteuil, France, e-mail: lgagala@georex.com*

The Lublin Basin is located above the southwestern edge of the East European Craton (paleocontinent Baltica). Sedimentary infill contains Neoproterozoic–Carboniferous strata unconformably covered by the Permian–Mesozoic sediments. In this abstract only the Devonian–Carboniferous part is dealt with. The Early Devonian comprises ≤2.1 km thick clastic sediments. They are covered by ≤1.6 km thick Mid-Late Devonian carbonates, evaporites, marls, shales with subsidiary siliciclasitcs. The Carboniferous contains claystones, mudstones and siltstones grading into sandstones interbedded with coal seams. Its top is everywhere erosional.

The Lublin Basin was inverted in the late Westphalian–Stephanian. As shown by recently acquired deep seismic reflection data, this Variscan inversion was mostly thin-skinned (Krzywiec *et al.*, 2013). It took place in front of the Radom–Kraśnik Block displaced towards NE above the Precambrian basement. Multiple detachment levels produced complex fold pattern in Devonian and Carboniferous strata. Deformed pre-Permian sedimentary cover of the Lublin Basin was unconformably covered with a Permian–Mesozoic succession of the Mid-Polish Trough (MPT). Late Cretaceous–Paleogene inversion of the MPT led to minor reactivation of some of the deeper structures of the Lublin Basin.

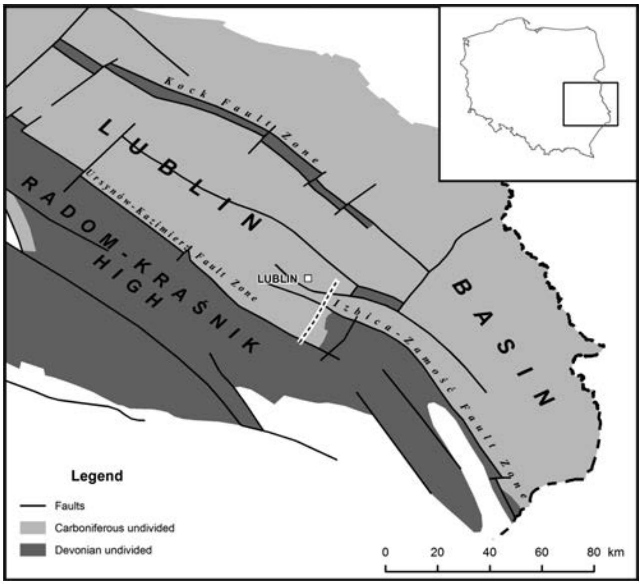

Fig. 1. Schematic geological map of the Lublin basin. Extent of Devonian and Carboniferous strata, as well as main fault zones and line of seismic transect is marked (based on Pożaryski & Dembowski, 1983).

Recently acquired seismic data in the central part of the Lublin Basin (Fig. 1) provided high-resolution image of the intra-Mid–Upper Devonian and intra-Carboniferous small-scale folds and thrusts, superimposed on the km-scale folds that involve the full sedimentary sequence (Fig. 2). The aim of this contribution is to describe the geometry and mechanics of this peculiar structural pattern.

The superposition of short- and long-wavelength folds and thrusts occurs in the southwestern part of the Lublin Basin, in between the Radom–Kraśnik Block and the Wilczopole Anticline (Fig. 2). To the north of the Wilczopole Anticline, the short-wavelength structures disappear. The main structural fabric is formed by km-scale folds. These show concentric geometries in the sub-Mid Devonian levels.

The short-wavelength folds and thrusts occur in the upper part of the folded section. The deepest ones appear below the Mid Devonian seismic marker, but bulk of the structures of this type is concentrated in the Late Devonian interval. The most prominent are low-angle thrusts displacing the Mid Devonian marker. They flatten down ~300–400 m below the top-Mid Devonian. These thrusts show constant northeastern vergence and cut-off angles of ~10–30° regardless the dip of bedding. Displacements vary from ~50 to ~1100 m, with the average of ~200 m. These low-angle thrusts transfer the shortening into the overlying Late Devonian strata. The slip transmission has been accommodated by forward-propagating thrusts (6–8, 24–26 km of the cross-section in Fig. 2), minor duplexing (20–21 km) or fish-tail backthrusting (23–24 km). This shortening is dissipated in the Upper Devonian by numerous, diminutive anticlines, low-angle thrusts and fish-tail wedges. The density of these minor structures is higher in the vicinity of the slope of the Radom–Kraśnik Block than in the more distal parts of the Lublin Basin. The preferred northeastern vergence is also clearer near the Radom–Kraśnik Block. Although the minor folds and thrusts are dispersed within the entire Late Devonian section utilizing numerous internal detachment levels, they seem to concentrate preferably in the interval located ~800 m above the Mid-Devonian seismic marker. It is possible that this horizon corresponds to the evaporite-bearing Ciecierzyn Member.

The concentration of small-scale contractional structures in the higher part of the profile indicates a difference in shortening between the Early Devonian and the Mid-Devonian–Carboniferous sections. In order to quantify this difference a line-length restoration of the selected marker horizons was done. This simple exercise has shown that the

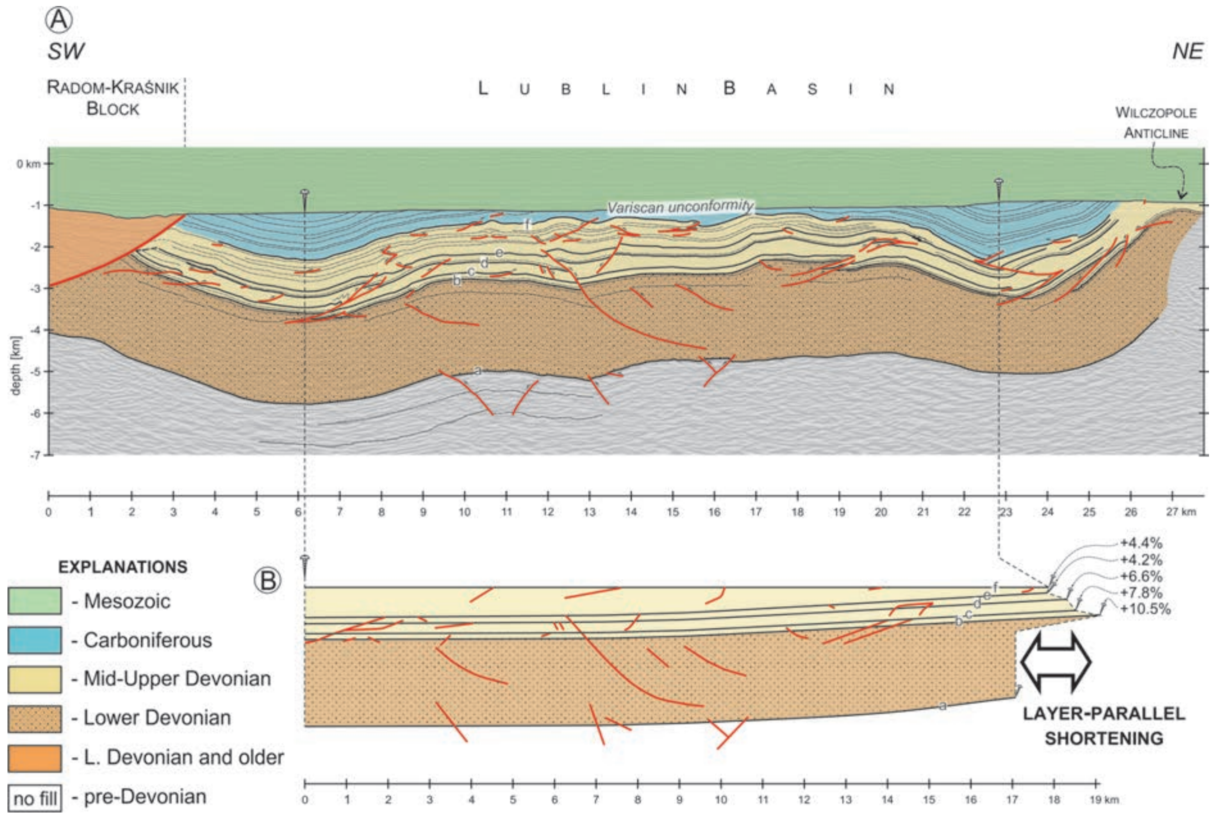

Fig. 2. A. Underlined seismic pattern which shows small-scale thrusting and folding in the Mid-Devonian–Carboniferous strata; B. Line-length restoration of selected marker horizons which reveals more geometrically restorable shortening in the Mid-Devonian–Carboniferous part than in the Early Devonian interval.

Mid-Devonian–Carboniferous strata absorbed 4–10% of shortening more than the top-pre-Devonian marker (Fig. 2).

The constant cut-off angles of minor thrusts prove their initiation in horizontal strata. The short-wavelength structures affecting the Mid-Devonian–Carboniferous levels are therefore inferred to initiate during early phases of shortening. The absence of similar structures in the underlying Early Devonian sediments suggests that at these deeper levels the incipient shortening must have been accommodated by a different mechanism. Here, the same amount of horizontal contraction was possibly absorbed by the layer-parallel shortening (LPS) instead of small-scale folding and thrusting. The ~4–10% difference in the amount of geometrically restorable shortening between the shallow and deep horizons (Fig. 2B) quantifies the LPS-surplus at depth. The vertically variable susceptibility of the sediments to the LPS is conceptually explained in accordance to the results of sandbox modeling published by Koyi *et al.* (2003). They conclude that the LPS is a depth-dependent shortening mechanism more efficient under a thick overburden than near the surface. It is a proposed interpretation of the general pattern observed in our seismic line. However, it fails to explain a sharp structural boundary between the finely folded Late Devonian–Carboniferous part of the section and coplanar Early Devonian part. This contrast coincides with the lithologic boundary between the dominantly clastic Early Devonian and carbonate-shaly-evaporitic Mid and Late Devonian. According to Koyi *et al.* (2003) the amount of LPS is dependent on the strength of the detachment. Weak detachment facilitates a quick cessation of the LPS and initiation of folding, while a strong detachment favors more LPS before the folding/thrusting commences. Accordingly, it is proposed that during a progressive shortening of the Lublin Basin the numerous weak horizons dispersed through the Late Devonian section promoted an early transition from the LPS to short-wavelength folding, while the LPS continued to operate in the underlying, lithologically uniform Early Devonian strata. Ultimately the entire section was involved into regional, km-scale folds.

Acknowledgments: MOVE® software used for cross-section construction was kindly provided by Midland Valley.

References

KOYI, H. A., SANS, M., TEIXELL, A., COTTON, J. & ZEYEN, H., 2003. The Significance of Penetrative Strain in the Restoration of Shortened Layers – Insights from Sand Models and the Spanish Pyrenees. *AAPG Memoire*, 82: 1–16.

KRZYWIEC, P., LIS, P., BUFFENMYER, V., MALINOWSKI, M. & LEWANDOWSKI, M. 2013. Regional Geologic Characterization of the Polish Lower Paleozoic Unconventional Play Using an Integrated Seismic and Well Data Approach (extended abstract). *SPE AAPG SEG Unconventional Research Technology Conference*, 12-14.08, Denver.

POŻARYSKI, W. & DEMBOWSKI, Z. (Eds.) 1983. Mapa geologiczna Polski i krajów ościennych bez utworów kenozoicznych, mezozoicznych i permskich 1:1 000 000. Państwowy Instytut Geologiczny, Warszawa.

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Structure orientation analysis of Nové spojení Tunnel (Vítkov hill, Barrandian, Czech Republic)

Klára Lakotová[1], Martin Knížek[1] & Milan Kössler[2]

[1] *Department of Geological Sciences, Faculty of Science, Masaryk University Brno, Kotlářská 2, 611 37 Brno, Czech Republic, e-mail: 379980@mail.muni.cz, kniza@sci.muni.cz*
[2] *ARCADIS CZ a.s., Geologická 988/4, 152 00 Praha 5, Czech Republic*

Depending on pattern of discontinuity geometry, geological properties of any specific rock unit of discontinuous rock mass can vary significantly. The determination of statistically homogenous domains defined by distinct geometry pattern of discontinuities is essential for detailed engineering research of discontinuous rock mass. Discontinuities include structures such as bedding planes, foliations, joints, and faults (Miller, 1983).

Discontinuity data of the Southern railway tunnel of Nové spojení were analysed in order to characterize structure orientation of Vítkov hill. Vítkov hill forms a significant elevation located on the right riverbank of Vltava between Žižkov and Karlín in Prague. Tunnels of Nové spojení encounter Ordovician Šárka and Dobrotivá Formations (Prague Synform, Barrandian). Deformation of sedimentary rock is significantly affected by Prague Fault.

Over 3000 major bedding planes and joint set traces were selected as representative data for statistical analysis of discontinuity strike. The tunnel was divided into total of 25 sections, 50 m each. However Western tunnel terminal section turned out to be less than 20 m and Eastern ending section 51 m. Twenty-five individual data sets were created from strike measurements of each section. In order to determine data sets' properties, strike measurements were divided into 12 intervals, 30° each. Strike frequency and cumulative relative frequency was calculated. All of twenty-five data sets shown non-Gaussian distribution. Five of twenty-five data set didn't met Chi-Square Test conditions for expected intervals counts. On the basis of data sets properties and analysis purpose, Kolmogorov–Smirnov Test was selected as alternative to more common Chi-Square Test (Kulatilake *et al.*, 1996). Kolmogorov–Smirnov Test is a non-parametric test for one dimensional probability distribution. Test permits the comparison of two data sets without making assumptions about their distributions (Borradaile, 2003). Assuming discontinuities have similar strike distributions for statistical homogeneity of domains, adjacent sections were compared. In addition to Komogorov–Smirnov Test, every result for two adjacent sections was verified by visual comparison of corresponding pair of contoured diagrams. As a result of statistic analysis of discontinuity strike, Southern tunnel of Nové spojení was divided into five domains. In every domain, strike directions form three to four dominant discontinuity clusters. These dominant clusters correspond with assumption that statistically homogenous domain have similar strike distribution (see Fig. 1).

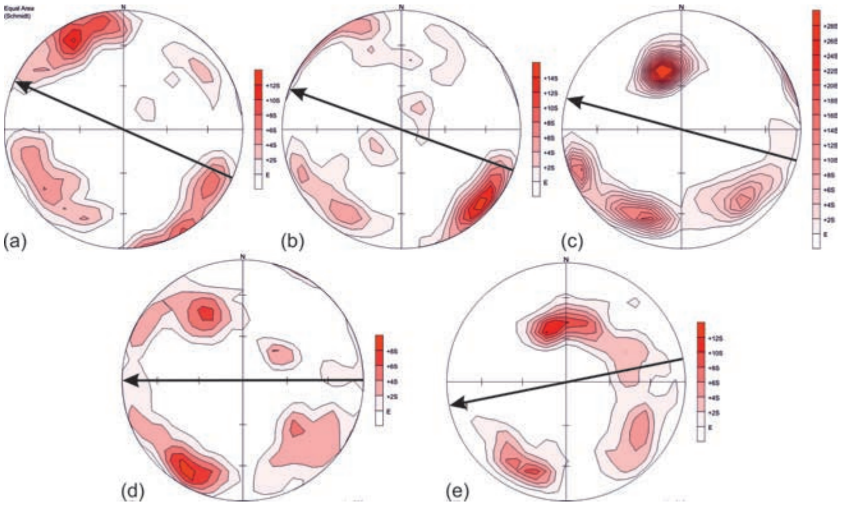

Fig. 1. Five contoured diagrams represent different statistically homogenous domains. The domains were selected from 1251 m long discontinuous rock mass of Southern tunnel of Nové spojení. Five domains are a result of statistical analysis of strike measurement with use of Kolmogorov–Smirnov Test. From Western tunnel portal to Eastern (a) 35.6–350 meters of tunnel, (b) 350–500 m, (c) 500–950 m, (d) 950–1150 m, (e) 1150–1251 m. Arrow indicates direction of tunnelling.

References

BORRADAILE, G., 2003. Statistic of earth science data: their distribution in space, time and oriation. Springer-Verlag Berlin Heidelberg.

KULATILAKE, P. H. S. W., CHEN, J., TENG, J., SHUFANG, X. & PAN, G., 1996. Discontinuity Geometry Characterization in a Tunnel Close to the Proposed Permanent Shiplock Area of the Gorges Dam Site in China. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 33 (2): 255–277.

MILLER S. M., 1983. A Statistical Method Evaluate Homogeneity of Structural Population. *Mathematical Geology*, 15 (2): 317–328.

Geologia Sudetica, 2014, 42: 53.

Timing of rifting and drifting in the central part of Atlantic Ocean

Lucia Ledvényiová

Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská Dolina G, 842 15, Bratislava, Slovakia, e-mail: ledvenyiova@fns.uniba.sk

Fragmentation and rifting of the Atlantic Ocean began in Upper Triassic (approximately 230–200 Ma; Schettino & Turco, 2009), with drifting following in Lower Jurassic (200–185 Ma). The whole process started in the central area, which ranges from the north of South America to Nova Scotia on the border of USA and Canada. The first oceanic crust formed in the area of Baltimore Canyon Trough.

The extensional forces and rifting reactivated pre-existing Paleozoic faults, and propagated along them (Nemčok *et al.*, 2005). The main controlling faults of the rift system strike in NE–SW to ENE–WSW direction. Based on the controlling kinematics, the Central Atlantic is divided into three segments – northern, central, and southern. The northern and southern segments moved orthogonally along NE–SW faults, while the central segment moved along sinistral transtensional faults. Kinematics of the central segment resulted in formation of numerous pull-apart basins, for example near Morocco (Nemčok *et al.*, 2005).

According to stratigraphic data, rifting began in the southern segment (Carnian to Rhaetian–Hettangian) and progressed northward, with the same age range for central segment, and Carnian–Norian to Rhaetian–Pliensbachian in the northern segment (Cornet & Olsen, 1985; Nemčok *et al.*, 2005; Hafid *et al.*, 2008). Similarly to the timing of rifting, onset of drifting occurred with slightly different timing in the three segments as well. It began in Rhaetian–Hettangian or Hettangian–Pliensbachian in the southern segment, followed by the central segment in Hettangian–Toarcian, and the northern segment in Pliensbachian (Olsen *et al.*, 2002; Schlische *et al.*, 2003; Nemčok *et al.*, 2005; Schettino & Turco, 2009).

References

CORNET B., & OLSEN, P. E., 1985. Summary of the Biostratigraphy of the Newark Supergroup of Eastern North America with Comments on Early Mesozoic Provinciality, *in* Weber, R., ed., Simposio Sobre Floras del Triasico Tardio, su Fitogeografia y Paleoecologia. Memoria, III Congreso Latino-americano de Paleontologia, Mexico: 67–81.

HAFID M., TARI, G., BOUHADIOUI, D., EL MOUSSAID, I., ECHARFAOUI, H., ADT SALEM, A., NAHIM, M. & DAKKI, M., 2008. Atlantic Basins, *in* Michard, A., O. Saddiqi and A. Chalouan, eds., Continental Evolution: The Geology of Morocco: structure, stratigraphy, and tectonics of the Africa-Atlantic-Mediterranean Triple Junction. Springer-Verlag Berlin Heidelberg, Germany: 303–329.

NEMČOK, M., STUART, C., SEGALL, M. P., ALLEN, R. B., CHRISTENSEN, C., HERMESTON, S. A. & DAVISON, I., 2005, Structural Development of Southern Morocco: Interaction of Tectonics and Deposition. *GCCSEPM 25th Annual Bob F. Perkins Research Conference, Texas, USA*: 151–202.

OLSEN, P. E., KENT, D. V., ET-TOUHAMI, M., FOWELL, S. J. & WHITE, B., 2002. Cyclicity, Time Scale and Correlation of the Triassic and Early Jurassic Rift Strata of the Argana Basin, Morocco; http://www.ldeo.columbia.edu/~polsen/ nbcp/olsen.gmpt3.html

SCHETTINO, A., & TURCO, E. 2009. Breakup of Pangaea and Plate Kinematics of the Central Atlantic and Atlas Regions. *Geophys.*, 178: 1078–1097.

SCHLISCHE R. W., WITHJACK, M. O. & OLSEN, P. E., 2003. Relative Timing of CAMP, Rifting, Continental Breakup, and Basin Inversion: Tectonic Significance, in Hames, W. E., G. C. McHone, P. R. Renne, C. Ruppel, eds., The Central Atlantic Magmatic Province: Insights from Fragments of Pangea, *Geophysical Monograph*: 33–59.

Geologia Sudetica, 2014, 42: 54.

Switches in deformation mechanisms from the perspective of numerical simulations

Petra Maierová[1], Ondrej Lexa[2], Jan Franěk[1], Petr Jeřábek[2] & Karel Schulmann[1]

[1] *Center for Lithospheric Research, Czech Geological Survey, Prague, Czech Republic*

[2] *IPSG, Faculty of Science, Charles University, Prague, Czech Republic e-mail: petra.maierova@geology.cz*

Coupled thermal-mechanical numerical simulations provide useful insights into the parameters controlling crustal deformation and describe the origin and geometries of various geological structures. However, the validity of such numerical simulations is limited by a large number of weakly constrained parameters. Namely the description of material behavior – rheology – is not fully determined and yet it largely affects the results of simulations.

Laboratory experiments and microstructural studies of natural rocks have identified distinct mechanisms of rock ductile deformation such as dislocation and diffusion creep, grain boundary sliding, solution-precipitation etc. The selection of dominant deformation mechanism in individual mineral phases depends on many parameters, mainly temperature, differential stress, strain rate and grain size, which often change during progressive deformation. In the laboratory deformation experiments, the important factors such as stress, strain and temperature can be determined with a relatively good accuracy. This, however, is not the case of naturally deforming samples where the actual cause of change in deformation mechanisms is often unclear.

In the southern Moldanubian domain (Bohemian Massif, central European Variscides) several large granulite massifs outcrop as a part of a lower-crustal belt embedded in mid-crustal migmatites. These massifs were interpreted to result from collision-related forced diapiric ascent of lower-crustal material towards the middle crust and subsequent lateral spreading. Three types of microstructure were distinguished in the predominating felsic granulites. The oldest relict microstructure with large grains (>1000 μm) of feldspar deformed probably by dislocation creep at peak HT eclogite facies conditions. Subsequently at HP granulite-facies conditions, chemically-induced recrystallization led to development of a fine-grained microstructure (~50 μm grain size) indicating diffusion creep, probably combined with grain-boundary sliding. This was associated with flow within the lower crust and/or the growth of the diapirs. The third and youngest microstructure shows ~100 μm grain size and deformation by dislocation creep under amphibolites-facies conditions. It is related to final stacking and spreading of the Moldanubian domain.

In order to interpret and simulate this sequence of deformation styles, we use (i) deformation mechanism maps, (ii) simple and (iii) complex numerical simulations. The former numerical setup represents a block of material subjected to simple shear. Rate of shearing and temperature are imposed, similarly to laboratory experiments. The latter numerical setup represents a part of an orogenic root with growing diapirs such as those in the Moldanubian domain. It contains several materials with predefined properties, while stress, strain and temperature evolve in a more natural manner in this case. We test how evolution of the system depends on the experimentally determined flow laws, which approximate deformation mechanisms observed in natural samples. Besides that we consider number of other factors: change of the mean grain size due to stress, thermal annealing of grains, change of mineral composition and grain size due to evolving pressure-temperature conditions, melting/solidification, and influence of fluids.

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Tectonic contact of the Brno Massive and Devonian sediments in the north part of the Moravian Karst

Tomáš Marhanský & Rostislav Melichar

Faculty of Science, Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic, e-mail: to222mi@gmail.com

Over the years, various authors have shown various perspectives on interpretation of the contact between Brno Massive and Moravian Karst. The Brno Massive is a Cadomian plutonic rock body, which has undergone variscan metamorphosis and Moravian Karst as a Devonian sedimentary complex. They do not allways have a normal stratigraphic contact as they were affected by tectonic processes. The Brno Massive is formed mainly by more or less deformed granitic rocks. Moravian Karst sequence starts with devonian basal clastics, occasionally continues with Petrovice Shale. The upper devonian sequence of Moravian Karst is formed by limestones.

Zapletal (1922; Fig. 1A) interpreted the occurence of Devonian rocks in the crystalline body by a system of longitudal and transverse subvertical faults. In Kettner´s model (1935; Fig. 1B), the Devonian rocks form stripes with N–S direction. Kettner implied that the faults are suborizontal but he did not mark them in his map. He also showed in his cross sections that Brno Massive is thrusted to the eastern direction over the sequences of Moravian Karst. Dvořák and Slezák (1960) in their work implied, that the Moravian Karst was moved up towards to the W over the Brno Massive. They also imply that during the thrusting process closed to open folds were formed (Fig. 1C).

Our latest research confirmed Kettner´s idea and shows us that the overall structure is mainly subhorizontal (Fig. 1D). Brittle-ductile mylonitic shear zones found in the area imply that thrusting has taken place under green-schist facies condition. The thrust planes are gently dipping to the west and intersect the surface forming long curved lines in app. N–S direction (Fig. 1D.)

References

DVOŘÁK, J. & SLEZÁK, L., 1960. Mapování Moravského krasu – mapa odkrytá, M-33-94-C-d (Blansko). MS. Česká geologická služba. Praha.

KETTNER, R. & AUGUSTA J., 1935. Geologická mapa okolí Sloupu na Moravě. 1:50 000. *Časopis Vlastivědné Společ- nosti muzejní v Olomouci, Olomouc*, 48.

ZAPLETAL, K., 1922. Geotektonická stavba Moravského krasu. *Časopis Moravského zemského Musea, Brno,* 20: 220–256.

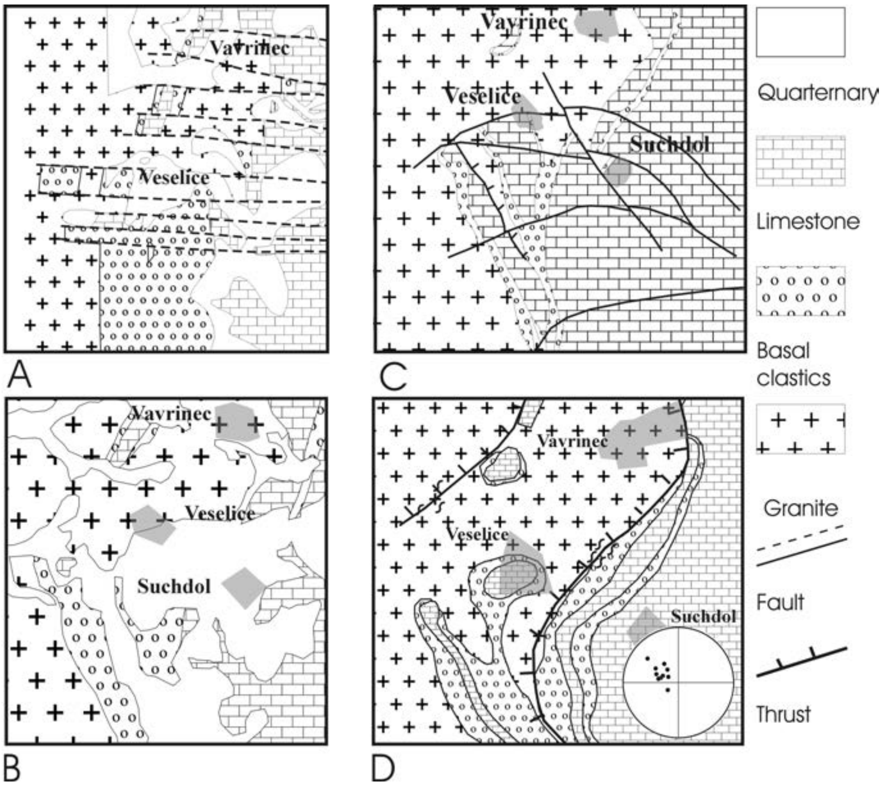

Fig. 1. Four maps showing the individual interpretations of the contact between the Brno Massive and Moravian Karst: 1A. Zapletal (1922), simplified; 1B. Kettner & Augusta (1935), simplified; 1C. Dvořák & Slezák (1960), simplified; 1D. Map showing the current perspective and plot diagram with poles representing the bedding orientations.

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Saxothuringian provenance of suspected terranes in the Central Sudetes, Bohemian Massif: zircon evidence of a recycled subducted slab

Stanislaw Mazur[1, 2], Jacek Szczepański[1], Krzysztof Turniak[1] & Neal J. McNaughton[3]

[1] *Institute of Geological Sciences, University of Wrocław, 50-204 Wrocław, Pl. Borna 9, Poland, stanislaw.mazur@ing.uni.wroc.pl*
[2] *GETECH, Kitson House, Elmete Hall, Elmete Lane, Leeds LS8 2HJ, UK*
[3] *John de Laeter Centre for Mass Spectrometry, Curtin University, GPO Box U1987 Perth, Western Australia 6845*

Six detrital zircon concentrates from the metasediments and metavolcanics of the Central Sudetes, Bohemian Massif, have been dated using SHRIMP II (Fig. 1; Mazur *et. al.*, 2012, 2013). Four metasedimentary samples yielded Precambrian age spectra similar to those that are characteristic of the Cadomian terranes: (1) Archean and Paleoproterozoic zircons scattered between 3380 and 1860 Ma, and (2) abundant Neoproterozoic zircons dated at 800–560 Ma. Two of the analysed samples also contain Early Cambrian and Early-Late Cambrian zircons. The estimated maximum sedimentation ages for the Młynowiec (ML 20) and Wyszki (W1) paragneisses are 563±6 Ma and 566±4 Ma, respectively. Younger maximum sedimentation ages were obtained for the Stronie schist (R2; 532±6 Ma) and for the Goszów quartzite (Q1; 490±9 Ma). Consequently, the metasediments of the the Orlica–Śnieżnik dome are interpreted as three distinct metasedimentary successions. They represent a Neoproterozoic back-arc basin, Early Cambrian incipient rift basin, and a Lower Ordovician post-rift succession, respectively.

Two metavolcanic and volcanic samples were analysed along with the metasediments. The Kłodzko Fortress pyroclastic metarhyodacite (TKT03) gave an igneous emplacement age of 536±2 Ma equal within error with the maximum sedimentation age of the Stronie schist. The magmatic precursor to the subvolcanic Gniewoszów metarhyolite (G1) was dated at 501±3 Ma, the age that closely correlates with the emplacement of the Orlica–Śnieżnik gneisses.

The Wyszki/Młynowiec monotonous metagreywackes (Fig. 2) collectively bear a resemblance to the Rothstein Formation cropping out in the Torgau–Doberlug Syncline of the Saxo-Thuringian zone. Zircon data suggest deposition of the Rothstein Formation at c. 565–570 Ma (Buschmann *et al.*, 2001) i.e., at the same time as the maximum depositional age for the Wyszki/Młynowiec sequence. The geochemical signature of the Wyszki metagreywacke succession is characteristic of sediments laid down in an arc-related setting (Szczepański, 2010), similar to the Rothstein Formation that is assumed to have originated in a back-arc setting (Linnemann *et al.*, 2007).

The ages of syn-depositional volcanism in the Kłodzko Fortress unit (536 ±2 Ma) and sedimentation of the Stronie sequence (532±6 Ma) overlap within error and suggest a common or similar source for those volcano-sedimentary units (Fig. 2). Their geochemical affinity to subduction-related volcanic rocks (Kryza *et al.*, 2003; Szczepański, 2010) can be explained by recycling of Cadomian orogenic crust using the analogy to the lower Cambrian Zwethau Formation of the Saxo-Thuringian zone (Linnemann and Romer, 2002). The latter is considered a shallow marine deposit that accumulated in an incipient rift basin, succeeding cessation of the Cadomian orogeny (Linnemann *et al.*, 2007). A similar interpretation is applied to the Klodzko Fortress unit and the Stronie sequence, taking into account their lithological inventory and maximum deposition age similar to that of the Zwethau Formation (534 Ma; Elicki, 1997).

The emplacement mode of felsic metavolcanics into the upper part of the Stronie sequence has thus far remained unclear since their contacts are tectonised, and primary features obliterated by pervasive deformation. However, because of the similarity of age to the igneous precursor to the Orlica–Śnieżnik orthogneisses, the Gniewoszów metarhyolite probably represents a subvolcanic intrusion into the lower Cambrian Stronie sequence (Fig. 2) as also suggested by field evidence (e.g., Don *et al.*, 2003). This conclusion can tentatively be extrapolated to the other occurrences of felsic metavolcanic rocks since their geochemical signature is fairly uniform and fits to that of the orthogneisses (Murtezi, 2006).

The latest Cambrian (490±9 Ma) maximum sedimentation age of the Goszów quartzite and the high maturity of its protolith suggest correlation with the Lower Ordovician sandstone deposits (“Armorican Quartzite”; Fig. 2) that are widespread in the Cadomian part of Central and Western Europe (e.g., Linnemann *et al.*, 2007). The Lower Ordovician overstep sequences can be classified as post-rift sediments or deposits of a rift-drift transition (e.g. Linnemann *et al.*, 2007).

The dated samples come from two adjacent suspect terranes – the Orlica–Śnieżnik dome and the Kłodzko massif in the Central Sudetes that are characterised by contrasting timing of metamorphism and exhumation. Despite this difference, the results obtained show a similar provenance of the studied units and their common affinity to the Saxo-Thuringian terrane. Since the Central Sudetes are separated from Saxo-Thuringia by a collisional suture, the pre-Variscan rocks must represent the deformed and metamorphosed, allochthonous equivalents to Saxo-Thuringian lithologies. They were probably subducted together with the Saxo-Thuringian passive margin during a Variscan collision and then exhumed within an accretionary wedge in front of Brunia/East Avalonia.

References

BUSCHMANN, B., NASDALA, L., JONAS, P., LINNEMANN, U. & GEHMLICH, M., 2001. SHRIMP U–Pb dating of tuff-derived and detrital zircons from Cadomian marginal basin fragments (Neoproterozoic) in the northeastern Saxothurin-

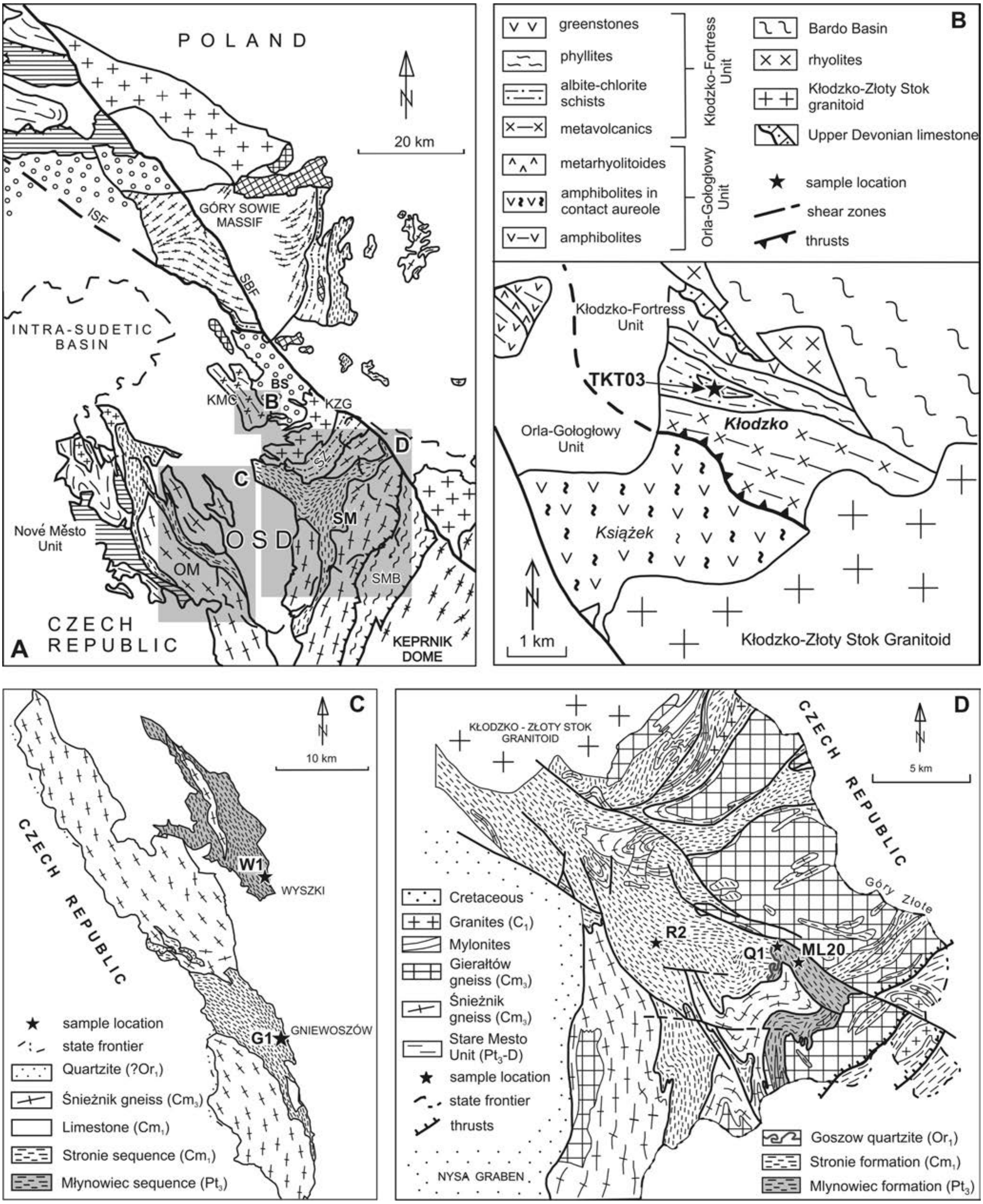

Fig. 1. Location of the analysed samples within (A) Central Sudetes, (B) Kłodzko massif, (C) Orlica massif, and (D) Śnieżnik Massif. BS – Bardo Structure; ISF – Intra-Sudetic Fault; KMC – Kłodzko Metamorphic Complex; KZG – Kłodzko-Złoty Stok Granitoid; OM – Orlica Massif; OSD – Orlica–Śnieżnik Dome; SBF – Sudetic Boundary Fault; SMB – Staré Mesto Belt; SZ – Skrzynka Shear Zone; SM – Śnieżnik Massif.

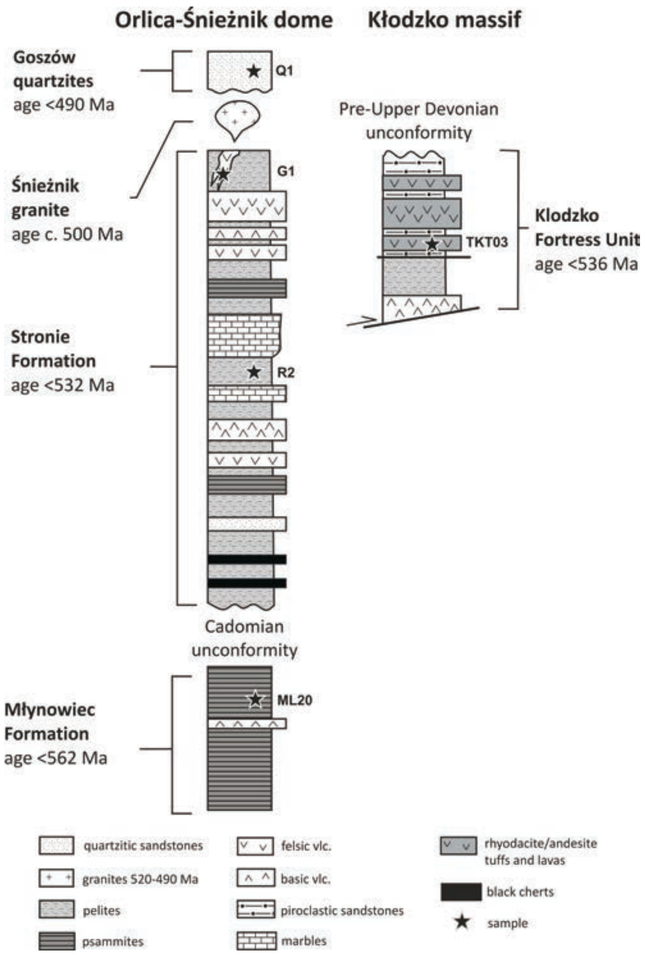

Fig. 2. Simplified lithostratigraphy of the Orlica–Śnieżnik Dome and the Kłodzko Fortress unit of the Klodzko massif (potential equivalent to the Stronie Formation).

gian Zone (Germany). *Neues Jahrbuch Geologie Paläontologie, Monatshefte*: 321–342.

DON, J., SKÁCEL, J. & GOTOWAŁA, R., 2003. The boundary zone of the East and West Sudetes on the 1:50 000 scale geological map of the Velké Vrbno, Staré Mesto and Śnieżnik Metamorphic Units. *Geologia Sudetica*, 35: 25–59.

ELICKI, O., 1997. Biostratigraphic data of the German Cambrian – present state of knowledge. *Freiberger Forschungshefte*, 466: 155–165.

KRYZA, R., MAZUR, S. & PIN, C., 2003. Subduction- and non-subduction-related igneous rocks in the Central-European Variscides: geochemical and Nd isotope evidence for a composite origin of the Kłodzko Metamorphic Complex, Polish Sudetes. *Geodinamica Acta*, 16: 39–57.

LINNEMANN, U. & ROMER, R. L., 2002. The Cadomian orogeny in Saxo-Thuringia, Germany: Geochemical and Nd-Sr-Pb isotopic characterization of marginal basins with constraints to geotectonic setting and provenance. *Tectonophysics*, 352: 33–64.

LINNEMANN, U., GERDES, A., DROST, K.& BUSCHMANN, B., 2007. Cadomian orogenic processes – The ultimate cause for the opening of the Rheic Ocean: Constraints by Laser Ablation-ICP-MS U–Pb zircon dating and analysis of the geo- tectonic setting (Saxo-Thuringian zone, Bohemian massif, Germany). In: Linnemann, U., Kraft, P., Nance, R.D., Zulauf, G., (Eds.), The Geology of Peri-Gondwana: The Avalonian–Cadomian Belt, Adjoining Cratons and the Rheic Ocean, *Geological Society of America, Special Papers*, 423: 61–96.

MAZUR, S., SZCZEPAŃSKI, J., TURNIAK, K. & MCNAUGHTON, N. J., 2012. Location of the Rheic suture in the eastern Bohemian Massif: evidence from detrital zircon data. *Terra Nova*, 24: 199–206.

MAZUR, S., TURNIAK, K., SZCZEPAŃSKI, J. & MCNAUGHTON, N. J., 2013. Vestiges of Saxothuringian crust in the Central Sudetes, Bohemian Massif: Zircon evidence of a recycled subducted slab provenance. *Gondwana Research*, in press: http://dx.doi.org/10.1016/j.gr.2013.11.005.

MURTEZI, M., 2006. The acid metavolcanic rocks of the Orlica–Śnieżnik Dome: their origin and tectonometamorphic evolution. *Geologia Sudetica*, 38: 1–38.

SZCZEPAŃSKI, J., 2010. Provenance and tectonometamorphic evolution of the supracrustal series from the Bystrzyckie Mts. Crystalline Massif. Wrocławska Drukarnia Naukowa PAN, Wrocław, 166 pp.

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Magnetic parameters and its application in determination of Petrofabric of northern Alvand pluton, western Iran

Masoud Mirzaei[1], Prokop Závada[2, 3], Mohammad Mohajjel[1], Habib Alimohammadian[4] & Fatemeh Alizadeh[5]

[1] *Department of Geology,, faculty of basic sciences, Tarbiat Modares university, Tehran, Iran, e-mail: masoud.mirzaei@modaes.ac.ir*
[2] *Geophysical Institute, Academy of Sciences of the Czech Republic, Boční II/1401, 141 31 Prague 4, Czech Republic*
[3] *Institute of Petrology and Structural Geology, Charles University, Prague, Czech Republic*
[4] *Environmental magnetism and paleomagnetism laboratory, geological survey of Iran, Tehran, Iran*
[5] *Tectonic group, faculty of sciences, Shahrood university, Shahrood, Iran*

The Northern Alvand granite pluton is located at northern part of the Sanandaj–Sirjan zone (SSZ) and west of Hamadan city in western Iran. During the Mesozoic, the oceanic crust of the Neotethys was subducted beneath the Eurasian plate, then magmatic-metamorphic belt, namely, SSZ with 1500 km length along strike and 150–200 km in width was formed (e.g. Alavi, 1994; Mohajjel *et al.*, 2003). The 200 km^2 large Alvand pluton intruded the Triassic–Jurassic phyllites known as Hamadan schist. The pluton is dominated by porphyritic granite with the following mineral composition: orthoclase, plagioclase, microcline, quartz, and biotite, with accessory muscovite, tourmaline, apatite, zircon, and ±chlorite.

Since slightly deformed granites show no mesoscopic magmatic fabrics in field, for the first time, we employed AMS (Anisotropy of Magnetic Susceptibility) method to investigate magnetic fabric of this intrusive body. The magnetic measurements of 260 oriented samples revealed that the magnetic susceptibility ranges between 60 µSI and 478 µSI, with 197 µSI in average, thus northern Alvand pluton can be classified as paramagnetic granites, although the thermomagnetic measurements show a distinguishable drop on the magnetic Curie temperature, so we prefer name it a weakly magnetic granite. T parameter varies from –0.67 to 0.97 that is in oblate form especially in eastern part of the pluton and the mean value of it is about 0.12 and tends to be more oblate with increasing Pj which indicates the planar magnetic fabric of this intrusive body. The main magnetic fabric carrier is biotite, inferred from thermomagnetic curves and oriented thin-section observations. Petrofabric analysis confirmed the correlation of K_1 and lineation inferred from biotite and some elongated ferruginous opaque minerals, also these observations indicates high-temperature solid-state deformation like GBM (Grain Boundary Migration) especially at the margin of the pluton and the low-temperature ones like SGR (Sub Grain Rotation) in other parts.

Foliation pattern shows an N–S to NE–SW trends. Our preliminary interpretation for mode of emplacement is that the tension gashes made by dextral shearing and magma pressure opened them and produced space for its emplacement, because of that foliation pattern encompasses the country rocks in many part of the pluton, but also further analysis is essential for comprehensive interpretation.

References

ALAVI, M., 1994. Tectonics of the Zagros Orogenic belt of Iran: new data and interpretations. *Tectonophysics*, 229: 211–238.

MOHAJJEL, M., FERGUSSON, C. L. & SAHANDI, M. R., 2003. Cretaceous–Tertiary convergence and continental collision, Sanandaj–Sirjan zone, western Iran. *Journal of Asian earth sciences*, 21: 397–412.

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Depositional and hydrocarbon habitats of the Guyana passive margin – preliminary results

Matej Molčan

Masaryk University Brno, Kotlářska 2, 602 00 Brno, Czech Republic, e-mail: 404343@mail.muni.cz

The Guyana passive margin encompasses the Guyana–Suriname sedimentary basin located between Venezuela to the North and Suriname to the South, along the northern South American continental margin. The Guyana–Suriname basin is an extensional basin further composed of a number of smaller pull-apart sub-basins formed by transtension resulting from two main events, the opening of the Central and Equatorial Atlantic segments. The margin was formed by the progressive counterclockwise rotation of Africa relative to South America initiated by rifting during the late Jurassic to early Cretaceous. The opening was initiated in the South Atlantic and progressed northward. South and Central Atlantic segments were finally connected during the Barremian to Aptian by the separation of the Demerara Plateau and Guinea Rise. The available dataset consists of at least ~20 industry wells and around 10 more pseudo wells constructed to increase well control and to fill in data gaps. The offshore area has been extensively imaged using seismic surveys, with both 2D multi-channel seismics and tight 3D grids, which yield generally very good resolution. The depositional and hydrocarbon habitats of the said area involve burial and thermal modelling of selected wells from the dataset. Potential candidates are simulated in PetroMod 1D in order to constrain the subsidence history that the basin has undergone throughout time. Preliminary results show an increased sediment influx in the W and NW part of the basin. This can be attributed to the siliclastic input from the Orinoco River located NW of the basin forming a delta offshore Venezuela. Basin geometry varies spatially mainly depending on the phase of rifting and the type of prevailing tectonic settings such as normal faulting produced by the break-up between North America and Africa, and strike-slip faulting resulting from the opening of the Equatorial segment. This can be seen from the subsidence histories of each of the generalised clusters of wells scattered across the area. Preliminary subsidence analysis shows that from the late Triassic until Jurassic the basin has undergone rapid subsidence as a result of rifting, however the following thermal subsidence had a more pronounced effect.

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Post-metamorphic structural evolution of a Variscan basement high in the Pannonian Basin, SE Hungary

László Molnár, Tivadar M. Tóth & Félix Schubert

Department of Mineralogy, Geochemistry and Petrology, University of Szeged, Hungary, e-mail: molnar.laszlo@geo.u-szeged.hu

The Pannonian Basin consists of Neogene deep subbasins that are separated by metamorphic basement highs, which in many cases act as fractured hydrocarbon reservoirs. One of the best known basement high is the Szeghalom Dome (SzD) (Fig. 1.), composed of Variscan metamorphic rocks (mainly gnesses and amphibolites) with diverse pressure-temperature-time histories. These metamorphic blocks were juxtaposed by post-Variscan structural movements which were coupled with the formation of wide brittle fault zones and significant porosity enhancement. However, the interpretation of these hydrodynamically important fault zones can be problematic as they are often below the limit of seismic resolution. The aim of this study is to reconstruct the structural evolution of the SzD and determine the role of the fault zones in the local fluid flow regimes.

The borecores and well-log data of seven wells were investigated from the central part of SzD (Fig 1.). The well-log data were calibrated on the depth intervals of wells that overlapped with the core samples. The discriminant functions were defined to separate the lithologic groups based on their well-log properties: first, to define the difference between the undeformed wall rock and the tectonized depth intervals, then to reveal the internal structure of the fault zones.

The undeformed host rock and the tectonized samples were separated using the following discriminant function:

D(1-2)=1.1 * natural gamma – 0.5 * log resistivity – 0.9 * density

The fault rock types were then defined by the application of these functions:

D3= 0.7 * neutron porosity – 0.5 * log resistivity

D4= 0.6 * density – 0.9 * natural gamma

The intensely fractured host rock and the coarse fault breccias of the analyzed borecores presumably form the damage zone of the fault zones. In contrast, the intervals of cataclasite and fault gouge are up to one meter wide and are considered as the fault cores. These fault cores imply to the presence of major fault zones and mark the locations of largest displacements.

Based on the correlation of the available well-log data,

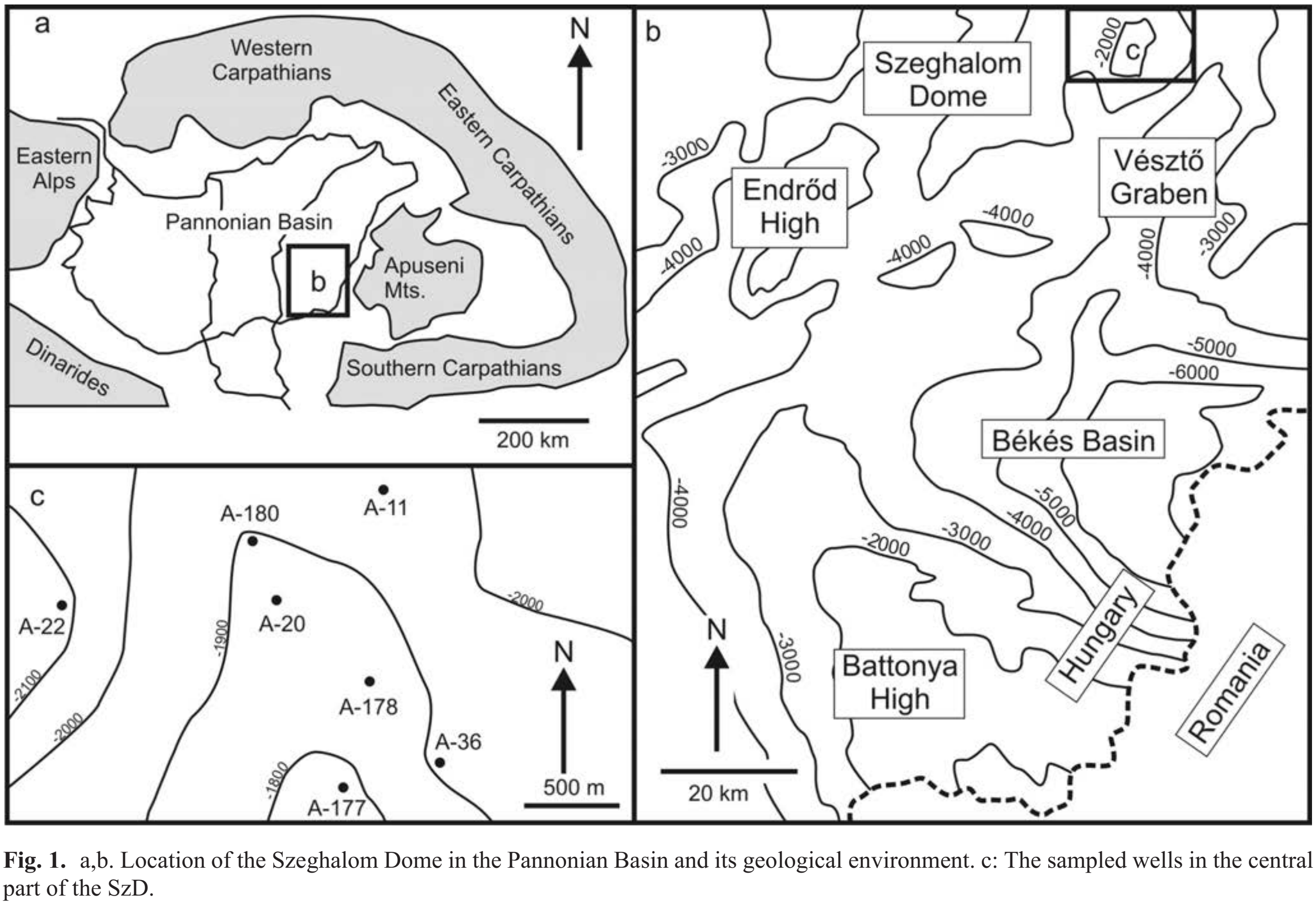

Fig. 1. a,b. Location of the Szeghalom Dome in the Pannonian Basin and its geological environment. c: The sampled wells in the central part of the SzD.

SzD can be interpreted as series of low-angle thrust surfaces. The numerous occurrence of the deformed horizons define dominantly low angle (8°–13°) fault planes with typically south-southeastern dip and indicate their relatively similar origin. According to the analogies from the crystalline basement, formation of these low angle (≈5–15°) sequences throughout the basement of the Pannonian Basin are related to Eoalpine (late Cretaceous) compressional activity with formation of northwest-vergent thrust faults (Tari *et al.* 1999) (Fig. 2). The spatial arrangement of the thrust surfaces indicate some post-Cretaceous tectonic activity with high angle normal faulting: approximately 150 meters of vertical displacement combined with tilting of the hanging wall block. Extensional tectonic activity has been widely reported in the SzD and can be related to the formation of horst-graben structures during the syn-rift stage of the opening of the Pannonian Basin during the middle Miocene (Tari *et al.*, 1999) (Fig. 2).

The reconstructed fluid evolution was based on earlier analyses of petroleum inclusions from the fracture-fillings of the amphibolites or the damage zones of faults (Schubert *et al.*, 2007) and unpublished industrial (well test) data. The fact that most the analyzed fluid inclusions are from the amphibolites and totally absent in the gneisses, indicate that the

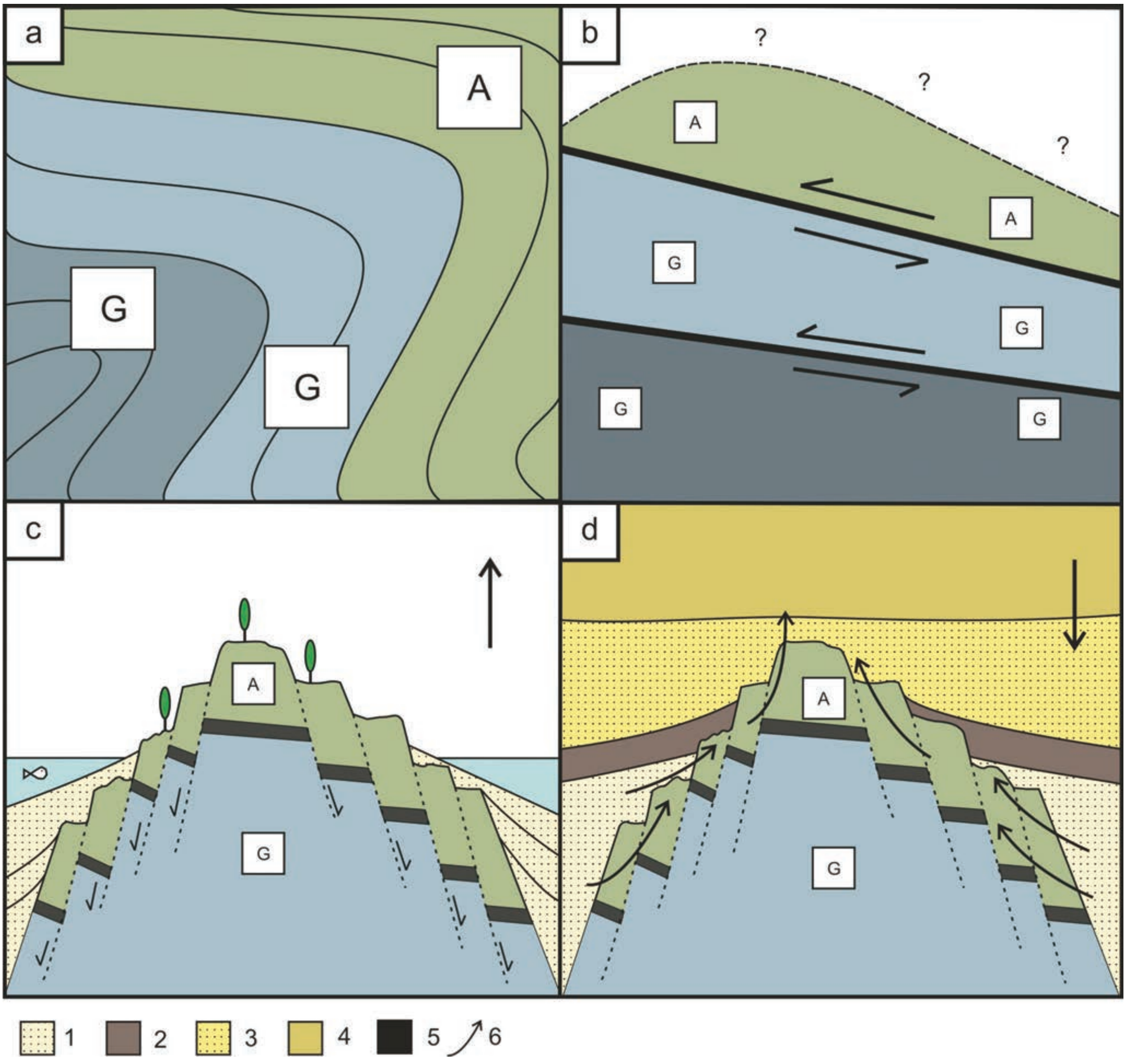

Fig. 2. Schematic model of the geodynamic and fluid evolution of the SzD. 1: Coastal conglomerate 2: Basal clay marl (Endrod Formation) 3: Turbidite-rich sediments (Szolnok Formation) 4: Delta front sediments (Algyo Formation) 5: Main fault zones, 6: Regional fluid flow system. "A" marks the amphibolite-rich zones, while "G" the gneiss-dominant parts. a: Variscan metamorphism. b: Eoalpine compressional tectonics, which juxtaposed the diverse metamorphic blocks in unknown depth. c: Middle Miocene (Badenian) exhumation of the SzD with the formation of a series of high-angle normal faults and the deposition of Pannonian clastic sediments. d: Recent hydraulic system with significant overpressure under the local aquitard.

main storage capacity is related to the former lithology, strengthing the results on the fracture network geometry of SzD (M Tóth, 2008). The amphibolite-rich lithologies are dominant in the structurally topmost metamorphic block of the basement. In this model, the damage zones of faults with their limited width and spatial distribution served as migration pathways towards these sporadic bodies. The quite permeable behavior of the fault zones is unlined by the rather productive well-tests.

The diverse fluid inclusion data (by the geochemical features and the degree of maturation of the analyzed hydrocarbon) indicating that even though the fractured masses are often aligned along the same, wide brittle fault zones, their samples represent separated hydrodynamic regimes, at least during the cementation of the fractures. This compartmentalization can be explained most likely by the combined effects of the intense multistage Neogene tectonic activity (Juhász *et al.* 2002) and the strong permeability anisotropy of the fault zones (Evans *et al.*, 1997).

There is strong dissimilarity between the paleo and recent petroleum system of SzD regarding the possible source rocks: the earliest date of paleo-fluid migration recorded by the fluid inclusions was the Cretaceous (according to their biomarkers, Schubert *et al.*, 2007), while the data of Schubert *et al.* (2007) indicate that the migration ended before the Badenian exhumation of the SzD. In contrast, the currently produced hydrocarbon originated from upper Miocene shales in the adjacent sub-basins south from SzD (the Békés Basin or the Vészto Graben). In the light of the industrial data, SzD has a very strong hydraulic connection with the overlying sediments as the metamorphic basement can drain the adjacent overpressured basins under regional aquitard (Endrod Formation) and behaves as a migration pathway towards the overlying clastic sediments (Szolnok and Algyo Formation) (Fig. 2.). The results of Juhász *et al.* (2002) on the hydraulic connection between the basement and the overlying sediment from the middle Miocene period support this hypothesis.

References

EVANS, J. P., FORSTER, C. B. & GODDARD, J. V., 1997, Permeability of fault-related rocks and implications for fault- zone hydraulic structure. *Journal of Structural Geology*, 19: 1393–1404.

JUHÁSZ, A., M. TÓTH, T., RAMSEYER, K. & MATTER, A., 2002. Connected fluid evolution in fractured crystalline basement and overlying sediments, Pannonian Basin, SE Hungary. *Chemical Geology*, 182: 91–120.

M. TÓTH, T., 2008. Repedezett, metamorf fluidumtárolók az Alföld aljzatában. D.Sc. Thesis (In Hungarian), 399 p.

SCHUBERT, F., DIAMOND, L. W. & M. TÓTH, T., 2007. Fluid-inclusion evidence of petroleum migration through a buried metamorphic dome in the Pannonian Basin, Hungary. *Chemical Geology*, 244: 357–381.

TARI, G., DÖVÉNYI, P., DUNKL, I., HORVÁTH, F., LENKEY, L., STEFANESCU, M., SZAFIÁN, P. & TÓTH, T., 1999. Lithospheric structure of the Pannonian basin derived from seismic, gravity and geothermal data. In: Durand B, Jolivet L, Horváth F, Séranne M (eds.): The Mediterranean Basins: Tertiary Extension within the Alpine Orogen. *Geological Society, London, Special Publications*, 156: 215–250.

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High-Ti muscovite as a prograde relict in HP granulites with metamorphic Devonian zircon ages (Běstvina granulite body)

Radmila Nahodilová[1], Pavla Štípská[2, 3], Roger Powell[4], Jan Košler[5] & Martin Racek[1, 6]

[1] *Czech Geological Survey, 11821 Praha 1, Czech Republic*
[2] *Center for Lithospheric Research, Czech Geological Survey, 11821 Praha 1, Czech Republic*
[3] *Ecole et Observatoire des Sciences de la Terre, Institut de Physique du Globe, CNRS UMR 7516, Université de Strasbourg, 1 rue Blessig, F-67084 Strasbourg Cedex, France*
[4] *School of Earth Sciences, University of Melbourne, Victoria 3010, Australia*
[5] *Department of Earth Science, University of Bergen, P.O. Box 7803, NO-5020 Bergen, Norway*
[6] *Institute of Petrology and Structural Geology, Charles University, 12843 Praha 2, Czech Republic*

High-pressure kyanite-K-feldspar granulites in the Běstvina granulite body, which belongs to the Variscan orogenic root in the Bohemian Massif, preserve muscovite, rutile and kyanite inclusions in garnet. High-Ti muscovite (Ti = 0.09–0.20 p.f.u., Si = 0.21–3.24 p.f.u.) included in garnet is associated with quartz and is in crystallographic continuity with biotite, interpreted in terms of exsolution from an original less-dioctahedral higher-Ti muscovite. The assemblage garnet-kyanite-antiperthite-perthite-quartz-rutile and the mineral compositions indicate a peak of metamorphism at about 900°C and 17–21 kbar, based on *P-T* pseudosection modelling, ternary-feldspar and Zr-in-rutile thermometry. The matrix assemblage garnet-kyanite-plagioclase-K-feldspar-quartz-rutile-ilmenite and garnet rim compositions at contact with feldspars and quartz indicate the end of overall equilibration in the presence of melt at 12–14 kbar and 820–840°C. Embayments of biotite and plagioclase locally replacing garnet, and connected with modification of garnet composition, may indicate sites of last isolated melt or diffusion of H_2O from that melt down to 10 kbar and 800°C. Zircon with uniform cathodoluminescence (CL) pattern is present as rims around cores with faint oscillatory zoning, or as entire rounded grains. These zircons gave a cluster of ages at 359 ± 4 Ma, interpreted as the age of metamorphism. Zircon ages from the cores with common faint oscillatory zoning range from 500 to 398 Ma, and are interpreted as magmatic grains variably reset during metamorphism. Two older ages obtained on cores of 620 ± 18 Ma probably represent an inherited zircon component. Molar isopleths of zircon along the *P-T* path in pseudosections suggest that crystallization of metamorphic zircon occurred during decompression and cooling from 17–21 kbar and 900°C to 12–14 kbar and 820–840°C. The inferred *P-T* path and the age of metamorphism make a suggestion of a geodynamic model that considers the granulites to be a part of a subducted plate that failed to continue to subduct and was spread below the upper plate.

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Alpine nappe transport of the high-pressure exhumed blocks from the Meliatic oceanic realm collision zone over Gemericum (Inner Western Carpathians)

Zoltán Németh & Martin Radvanec

State Geological Institute of Dionýz Štúr, Mlynská dolina 1, SK-817 04 Bratislava, Slovakia, e-mail: zoltan.nemeth@geology.sk

Two outliers of the Alpine Meliatic Bôrka nappe, transported during AD_{1a} deformation phase from the Meliatic oceanic realm collision zone, located south of Gemericum, into the North-Gemeric zone, are known and well defined in localities of Dobšiná and Jaklovce (Eastern Slovakia). Both outliers demonstrate their complicated internal tectonic and lithological setting, differing from that in their footwall, and encompass also several mélange blocks. As indicated at the end of this contribution, their transport path differed, and some criteria, which should be taken into consideration at reconstruction attempts, are mentioned.

In the case of *Dobšiná*, the *allochthonous position* and *north-vergent transport* of the Bôrka nappe outlier were revealed by mesoscopic structures in walls of former serpentinite quarry, as well as in exploration adit. Three petrologically defined exhumed blocks of dimensions 3–15 meters inside the serpentinite matrix – glaucophanites (blocks 1 and 2) and garnet-clinopyroxenite/rodingite (3), transported by the nappe, mutually differ in their exhumation kinematics in the serpentinite matrix in their home area (i.e. the pre-nappe transport = pre-AD_{1a} structures).

Exhumed block 1 – glaucophanite represents an oval body. An exhumation kinematics consisted of rotation movement of "exhumation balls". This is demonstrated by the stretching lineations around the perimeter of the exhumed body, indicating in recent position the exhumation to E–ESE, as well as by the absence of any systematic planar structures inside the body, passing outside to serpentinite mylonite matrix. Moreover, the lenticular exhumed block 1 occurs in the mélange of similar spherical fragments in serpentinite matrix. Based on structural relations, we interpret this glaucophanite block as entering the ultramafic body in the deeper level of the exhumation channel, than it was in the case of exhumed block of glaucophanite 2, and the block of garnet-clinopyroxenite/rodingite 3. Inside the ultramafics, the block 1 passed longer exhumation path, characteristic with rotation kinematics of an spherical object. This exhumation of the glaucophanite block 1 from relatively deeper levels of exhumation channel can be indicated also by its more southern location in the serpentinite body in comparison with blocks 2 and 3. The suggested vertical geometry of the Meliatic exhumation channel south of Gemericum, took into consideration the situation in frontal part of the Bôrka nappe in the Dobšiná area. During exhumation of blocks 2 and 3 the block 1 was located relatively deeper in the exhumation zone. This geometry corresponds with finding that glaucophanites are relatively abundantly present in exhumed Bôrka nappe mélange close to suture zone (e.g. in the Šugov valley or the Nižná Slaná Depression). Moreover, we cannot forget the spatial reduction of the nappe outlier in north-south direction being caused by imbrication in the phases AD_{1a} and AD_{1b}, so the length of serpentinite body in an uncompressed state could differ from the recent 800 m, as well as the mutual distance of exhumed blocks 3 and 2, vs. block 1 could several times overreach recent ca 200 metres.

Exhumed block of glaucophanite 2 has, similarly as block 1 "frozen" east-trending exhumation transport inside the serpentinite body. Its position in frontal parts of the nappe caused its later segmenting by the thrust plane of AD_{1b} imbrication. The planar structures of AD_{1a} and AD_{1b} phases differ in ductility with evolution of a-tectonites (line-

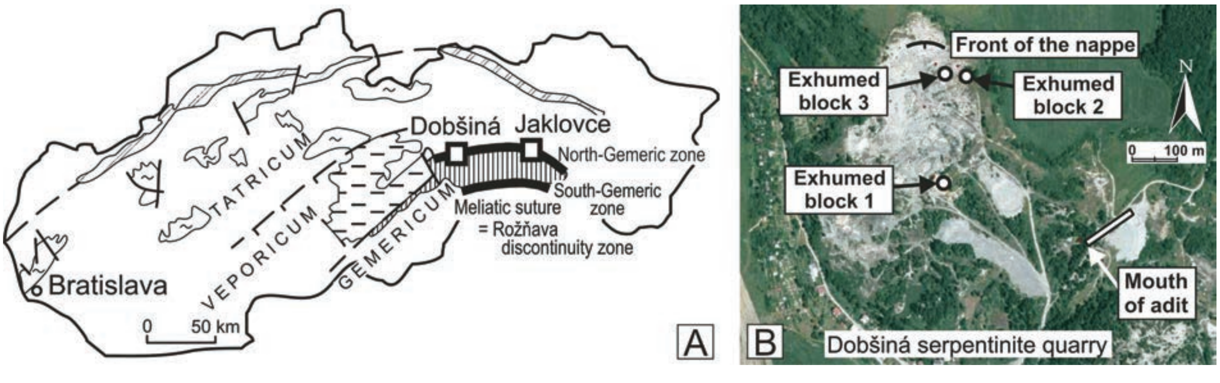

Fig. 1 Position of Gemericum in the Alpine tectonic setting of Western Carpathians. The South-Gemeric zone with the Meliatic suture (designated also as the Rožňava discontinuity zone) was the home area of the Meliatic Bôrka nappe, whose outliers at Dobšiná and Jaklovce are present in the North-Gemeric zone (A). Three exhumed blocks of the high-pressure metamorphic rocks in the Dobšiná serpentinite quarry. These blocks were transported by the Bôrka nappe from the South-Gemeric zone over Gemericum to the Dobšiná area (B).

ations) in the first case, and brittle-ductile shears in the second case.

Exhumed garnet-clinopyroxenite/rodingite block 3 indicates, as the only one, the west-vergent exhumation kinematics with exhumation planar structures dipping to E to ENE. The base of block 3 is represented by an ultramylonite zone.

In the *Jaklovce* area the Meliatic Bôrka nappe outlier has even more complicated tectonic setting, being caused by its more complex lithology (serpentinite, gabbro, retrograde eclogite, radiolarites, calcitic marbles, black shales; cf. Németh *et al.*, 2012, Fig. 1 ibid), as well as its position inside AD_3 NE–SW and NW–SE trending shear zones. The allochthonous position of outlier marbles over autochthonous carbonates was demonstrated by paleopiezometry (l.c.), as well as by unconformity in bedding of allochthonous part (gen. 330/55°), contrasting with prevailing general NW–SE regional trend of bedding and discontinuities of $AD_{1\text{-}3}$ phases.

The transport kinematics of the Bôrka nappe from the area of recent Meliatic suture zone south of Gemericum (the Rožňava discontinuity zone, cf. Pawliszyn, 1978, in Grecula, 1982) over Gemericum into the North-Gemeric zone has to take into consideration following facts: (1) Transpression kinematics, which applied during exhumation and collision transport in the area of Meliatic suture zone (pre-AD_{1a}), was demonstrated by meso- and micro-structures and pebble deformation analysis (cf. e.g. Németh *et al.*, 1997, Figs 1 and 2 ibid.). (2) The visualization of the transport path of the post-Jurassic and pre-Upper Cretaceous transport of the Bôrka nappe from the South-Gemeric zone to North-Gemeric zone was made complicated by the space reduction during $AD_{1a\text{-}c}$ phases, but mainly by the strike slips in AD_3 phase, causing arc-bending of the Gemericum, as well as sigmoidal bend in the western part of Gemericum. It affected the position and relative transport path of the nappe body into the Dobšiná area. Due to AD_3 shearing, applying model of asymmetric indentor trending NNE, the Bôrka nappe transport into the Jaklovce area seems to be straightforward (indicated also by kinematic indicators), but the relative transport path to Dobšiná area was modified by sinistral shearing in the Transgemeric shear zone and further parallel strike slip zones at the western margin of the indentor.

References

GRECULA, P., 1982. Gemericum – segment of the Paleotetyan riftogenous basin. *Alfa, Bratislava*: 1–263.

NÉMETH, Z., 2002. Variscan suture zone in Gemericum: Contribution to reconstruction of geodynamic evolution and metallogenetic events of Inner Western Carpathians. *Slovak Geol. Mag.*, 8 (3-4), 247–257.

NÉMETH, Z., GAZDAČKO, Ľ., NÁVESŇÁK, D. & KOBULSKÝ, J., 1997. Polyphase tectonic evolution of Gemericum (the Inner Western Carpathians) outlined by review of structural and deformational data. In: Grecula, P., Hovorka, D. & Putiš, M. (eds.): Geological evolution of Western Carpathians. *Monograph, Geocomplex, Bratislava*, 215–224.

NÉMETH, Z., RADVANEC, M., KOBULSKÝ, J., GAZDAČKO, Ľ., PUTIŠ, M. & ZÁKRŠMIDOVÁ, B., 2012. Allochthonous position of the Meliaticum in the North-Gemeric zone (Inner Western Carpathians) as demonstrated by paleopiezometric data. *Miner. Slov.*, 44 (1): 57–64.

NÉMETH, Z. & RADVANEC, M., 2013. The clarification of the geological setting and tectogenesis in the area Delava-Babiná-Ostrá, Dobšiná and Jaklovce (Spiš-Gemer Ore Mts., Western Carpathians). *Final report. Manuscript, Geofond archive, Bratislava*, 1–171.

PAWLISZYN, J., 1978. Magnetotelluric method. In: Report on geophysical measurements, Poproč area. *Manuscript, Geofond archive, Bratislava*, 1–189.

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Mg- and Fe-metasomatism from Gemer-Vepor Contact Zone

Nikol Novotná[1,2], Pavel Pitra[2], Petr Jeřábek[1]

[1] *Institute of Petrology and Structural Geology, Charles University, Albertov 6, 128 43 Praha 2, Czech Republic*
[2] *Géosciences Rennes, Université Rennes 1, 35042 Rennes, France*

The Gemer-Vepor Contact Zone (GVCZ) is the boundary zone between the Gemer and Vepor Units (Central Western Carpathians, Slovakia). The basement of the underlying Vepor Unit is dominated by Carboniferous granitoids and Lower Paleozoic schists . The overlying Gemer Unit consists mainly of Lower Paleozoic volcano-sedimentary complexes. Both units are overlain by the Late Paleozoic to Mesozoic cover sequences. The GVCZ is characterized by an alternation of ENE–WSW trending lithological complexes from the bottom to the top and from the NW to the SE these are: (1) the Carboniferous Vepor basement granite, (2) Lower Palaeozoic garnet-bearing schists of the Hladomorná Dolina Complex, (3) phyllites, metaconglomerates and metaarcoses of the Vepor Permian Cover, (4) Ochtiná Nappe.

The region was strongly deformed during the Alpine orogenic event of Cretaceous age, but relics of a Variscan metamorphic amphibolite-facies fabric are locally preserved in the Vepor and Gemer basement. Three deformational fabrics of Alpine age are reported from the GVCZ. A first prograde greenschist to amphibolite-facies metamorphic foliation is subsequently overprinted by a second, lower grade metamorphic cleavage. Both of these fabrics are then folded with large scale open folds with subhorizontal axes and locally associated with a steep discrete axial-planar cleavage. The first fabric resulted from the northward thrusting of the Gemer Unit over the Vepor Unit, the second lower grade cleavage is associated with the subsequent exhumation of the Vepor Unit along large-scale detachment and the last fabric results from the large-scale folding due to the continuous indentation of the Gemer Unit, which also led to the formation of the Trans-Gemer Shear Zone.

Numerous magnesite and/or talc ore deposits, some of which are of economic importance, are present in metasedimentary sequences of Carboniferous age in Gemer and Vepor Units. The origin of these deposits remains unknown. Nevertheless, Mg-enriched shear zones develop in the Carboniferous granitoids of the Vepor Unit. The shearing associated with income of Mg leads to the formation of Mg-chlorite–muscovite–quartz phyllonites as well as Mg-chlorite–kyanite-bearing shists. Compared to the composition of granitoids, these rocks are depleted in alkalies and enriched in magnesium, iron and manganese, which is most likely related to the influx of fluids along the shear zones. In contrast, shear zones developed within chloritoid-kyanite schists of the Veporic Permian cover, display a different type of metasomatic alteration, characterized by a strong Fe-enrichment. The unusual enrichment in either Mg or Fe may suggest either heterogenous fluid composition or two separate metasomatic events in the studied area. However, the spatial relationship of the two distinct fluids to two distinct deformation fabrics may imply that the formation of these metasomatic rocks is associated with the different stages of the polyphase Cretaceous evolution of the studied area. The Mg-metasomatism could be associated with the prograde metamorphic evolution of Vepor Unit during the northward thrusting of the Gemer Unit, whereas the Fe-enrichment observed in chloritoid-kyanite schists, strongly affected by the second Alpine deformational fabric, could be associated with the subsequent exhumation of Vepor Unit. Petrological analysis of these rocks suggests that the mineral assemblages developed at 350–450 °C and 3–4 kbar for both metasomatic events.

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Mapping with VLF tool – gold investigation case study that yielded unexpected structural minutiae

Szymon Ostrowski

Polish Geological Institute – National Research Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland.

The VLF method (acronym stands for Very Low Frequency) is one of the geophysical survey method employing electromagnetic (EM) radiation and electromagnetic effects for recognition of shallow subsurface. In VLF survey the EM waves of frequency between 15 and 30 kHz, which are emitted by high-power radio transmitters principally constructed for long distance (usually military or governmental) radio communication are used. Application of the signal for the geophysical surveys is actually free-ride opportunity. The method was developed in late sixties and seventies of XX century, and is still used, although its current importance as a survey method is still diminishing (for extensive explanation of technique see: Milsom 2003).

The VLF survey method is sensitive to changes in electrical properties (primarily resistivity) of the subsurface, down to some teens of meters (the depth of penetration of VLF radiation into the rock medium), and works best, when sharply dipping sheet-like object of contrasting resistivity is present. Above description suggests an obvious applications for the VLF method – it might be used for mapping of strongly mineralized dykes or ore-bodies and faults and fracture networks performing as water conduits. In fact the main applications of the VLF method are confined to groundwater investigations (especially in connection with fractured aquifer; e.g. Goldman and Neubauer 1994) and mineral prospecting for vein deposits. Some attempts were made to apply the VLF method for environmental surveys, e.g. mapping leakages from waste deposits (Kowalska *et al.*, 2012). The VLF method finds only marginal applications in research concerning structural geology, which is probably caused by the fact, that the VLF is usually performed on isolated sections as supplementary method for other survey methods. The VLF results while being unitless (e.g. outcome of differential equation) or unintuitive (e.g. imaginary component of phase shift) are extremely difficult for interpretation and ambiguous when presented only as measurements on separate lines.

The author had the opportunity to apply the VLF method for surveying the site of gold-bearing vein in Khasagt Range, Gobi–Altai Province, Mongolia. The surveyed area consists of metamorphic (mainly gneissic) and magmatic (granite and diorite) complex hosting numerous quartz veins, some of which are gold-bearing. The original task of the survey was to recognize the zones of increased mineralization in the quartz vein known for its sub-commercial gold grades, and identification of other possible gold-bearing targets near-by. The idea of the survey was, that the mineralized vein, as containing minerals of electron conductivity (basically pyrite) should produce electric contrast against host-rock and show an effect on the VLF results.

Since the recognition of the area had to be very detailed, uncommon survey pattern was projected. The VLF measurements were taken every 10 m along the lines spaced at 100 m, perpendicular to the strike of the known vein. The area of approximately 2 sq. km was covered with the survey. Such dense measurement enabled the data set to be regarded as aerial grid and in effect to compose map of the VLF anomalies. The map of in-phase parameter was used for further considerations.

The quality of the obtained results was excellent, as proved by its coherence and similarity of the results obtained for two different frequencies. However the original assumptions failed to be working. The grades of conductive minerals in the vein was too low to yield an effect on the VLF measurements. Also in arid conditions of Gobi–Altai with huge topographic relief, one cannot expect the fissure sets to be efficient water conduits. Surprisingly, very coherent and prominent pattern of VLF anomalies, independent of local topography, was present on the resultant maps. The location of known vein coincides exactly with negative in-phase anomaly, suggesting that the host-rock is more conductive than massive quartz vein in bulk. Moreover, at least four elongated zones of negative anomaly to the south of the vein were detected, oblique to the vein strike, unknown previously from the field. The direction of this unidentified anomalies also was not noted as an structural direction before, neither in the area of survey nor in the surrounding part of Khasagt Range.

Author speculates, that series of oblique anomalies described above, might represent series of secondary narrow quartz veins or fissure network. The presence of such structural features might give some hints for understanding of the pattern of gold occurrence in this part of Khasagt. Gold occurrence is not confined to any of numerous generations of quartz known from the area, and is apparently random within quartz veins. It might be possible, that gold mineralization is connected with tectonic structure unobserved previously, but prominent on the VLF anomaly map and occur in quartz veins on their intersection with the feature.

Although presented speculation might be erroneous and its proving would need much more observations and surveys, the presented case study had shown, that properly devised and conducted VLF survey might bring valuable preliminary information concerning structural features that are hard to identify otherwise.

References

GOLDMAN, M. & NEUBAUER, F. M., 1994. Groundwater exploration using integrated geophysical techniques. *Surveys in Geophysics*, 15 (3): 331–361.

KOWALSKA, A., KONDRACKA, M. & MENDECKI, M. J., 2012. VLF mapping and resistivity imaging of contaminated Quaternary formations near to "Panewniki" coal waste disposal (Southern Poland). *Acta Geodynamica et Geomateria- lia*, 9 (168): 473–480.

MILSOM, J., 2003. Field Geophysics. *Wiley*, 1–232.

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Structural position of Late Cretaceous sedimentary complexes of Belice Unit (Považský Inovec Mts., Slovakia)

Ondrej Pelech[1], Marián Bošanský[2], René Putiška[2], Ivan Dostál[2], David Kušnirák[2] & Jozef Hók[1]

[1] *Department of geology and paleontology, Natural Sciences Faculty, Comenius University in Bratislava, Mlynská Dolina, 845 04 Bratislava, e-mail: pelech@fns.uniba.sk*

[2] *Department of applied and environmental geophysics, Natural Sciences Faculty, Comenius University in Bratislava, Mlynská Dolina, 845 04 Bratislava*

The Považský Inovec Mts. is one of the horst structures situated in the NW portion of Central Western Carpathians. It is composed of the Tatric crystalline basement rocks and its sedimentary cover of Late Paleozoic–Mesozoic age which is overlain by thin-skinned Mesozoic nappes of the Fatric and Hronic. The Belice Unit (Ivanička *et al.*, 2011) represents mainly a Late Cretaceous sedimentary succession cropping out in the northern and southern portion of the Považský Inovec Mts. This unit is considered to be an extension of the South Penninic Zone in the Western Carpathians known as the Vahic (Plašienka *et al.* 1994). However, due to a number of uncertainties the Penninic provenance of the Vahic rock complexes is disputable (Ivanička *et al.*, 2011).

One of the key questions itself is an emplacement of the Belice Unit sediments within structure of the Tatric crystalline. The Late Cretaceous sedimentary formations in the northern portion of the Považský Inovec Mts. are usually located in 100–500 m thin lenses between the crystalline basement complexes. Reliable place for study of structural relationships between the Belice Unit and surrounding crystalline basement is the locality Hranty in the northern portion of the Považský Inovec Mts. The Belice Unit at this locality is forming relatively thin body built by carbonaceous flysch deposits with beds of breccia composed of clasts of crystalline basement. This area was selected for the study using electrical resistivity tomography (ERT). Measurements of electrical resistivity tomography took place on 4 profiles in the electrode arrangement dipole-dipole over the structure of Belice Unit known from previous field work. Interpretation of the 2D inverse model was based on the contrast between the resistivity properties of the crystalline basement rocks and the Late Cretaceous sediments of Belice Unit. Visualization of 4 profiles into the 3D model helped to clarify overall geometry and the structural position of the Belice unit in this location. Intervals of resistivity values of the Late Cretaceous flysch and crystalline basement were obtained on the basis of parametric measurements on type localities. The resistivity values ??were substantially different so the determination between the lithologically distinct complexes appears to be reliable. The internal structure of the body can't be defined on the basis of available information due to its substantial complexity. Geophysical survey shows that the Late Cretaceous sequences do not form larger rock body that increases its volume with depth. This is confirmed by the combination of longitudinal and transverse ERT profiles. On contrary it forms approximately 90 m thick wedge shaped and folded rock body bounded from the top and bottom by the crystalline basement complexes (Fig. 1). Such information are in conjunction with observations from the other occurrence of the Belice Unit in the southern portion of mountain range. The borehole (the Jašter locality) penetrated the fault contact of the Belice Unit with underlying Tatric granites. Recent investigation along with previous knowledge shows that Belice Unit sedimentation didn't start with Oxfordian–Tithonian radiolari-

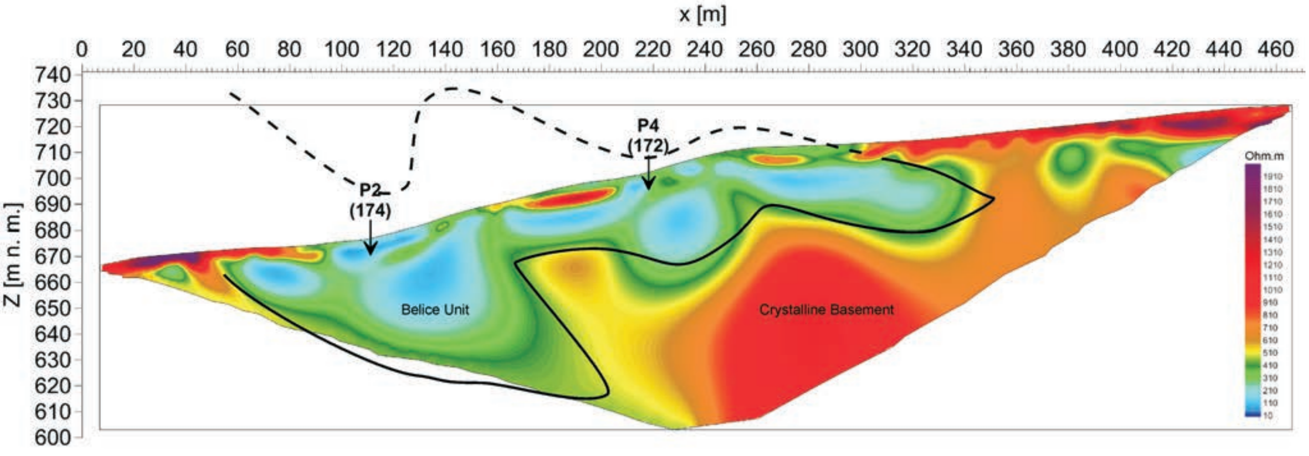

Fig. 1. Interpretation of the folded structure of the Belice Unit in the longitudal Profile 1 showing contrast between the Late Cretaceous formations and the Paleozoic crystalline basement complexes.

tes (the Lazy Fm.) and begun as late as in Late Cretaceous (Ivanička *et al.*, 2011). The radiolarites along with other olistoliths, including Late Paleozoic basalts of Tatric provenance (Putiš *et al.*, 2006) form blocks in Late Cretaceous olistostrome which terminates the syn-orogenic sedimentation in the external portion of Central Western Carpathians. Structural position, stratigraphic and sedimentological character suggests that the Belice Unit is not a remnant of an oceanic realm and its affiliation with South Penninic is highly controversial.

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References

PLAŠIENKA, D., MARSCHALKO, R., SOTÁK, J. & PETERČÁKOVÁ, M., 1994. Origin and structural position of Upper Cretaceous sediments in the northern part of the Považský Inovec Mts. Part 1: Lithostratigraphy and sedimentology. *Miner. Slov.*, 26: 311–334 (in Slovak with English summary).

PUTIŠ, M., SULÁK, M., GAWLICK, H. J. & BOJAR, A. V., 2006. Infratatricum of the Považský Inovec Mts. (Western Carpathians): Geodynamic evolution of continental margin in the vicinity of the oceanic Penninicum. *Miner. Slov.*, 38: 7–28 (in Slovak with English summary).

IVANIČKA, J., KOHÚT, M., OLŠAVSKÝ, M., HAVRILA, M., HÓK, J., KOVÁČIK, M., MADARÁS, J., POLÁK, M., RAKÚS, M., FILO, I., ELEČKO, M., FORDINÁL, K., MAGLAY, J., PRISTAŠ, J., BUČEK, S., ŠIMON, L., KUBEŠ, P., SHERER, S. & ZUBEREC, J., 2011. Explanatory notes to the Geological map of Považský Inovec Mts. and SE portion of Trenčianska kotlina Basin, M = 1 : 50 000. *State geological institute of D. Štúr, Bratislava*, p.1–389 (in Slovak with English summary).

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The origin of atoll shaped garnets in the Teplá Crystalline Complex, Bohemian Massif

Vít Peřestý, Martin Racek & Ondrej Lexa

Institute of Petrology and Structural Geology, Faculty of Science, Charles University in Prague, Albertov 6, 128 43, Prague 2, e-mail: vit.peresty@natur.cuni.cz

Atoll shaped garnets commonly occur in the metapelites of the Teplá Crystalline Complex, which was affected by polyphase deformation and metamorphism. Most of garnets reflect prograde metamorphism and development of a subvertical foliation S_2 and commonly exhibit cores rich in inclusions of biotite, chlorite, muscovite, plagioclase and quartz. Their atoll shapes were formed later during retrogression related to the origin of a subhorizontal cleavage S_3. Garnets show continuous textural variations from inclusion free grains located in the microlithons through garnets with inclusion-rich cores to biotite and/or chlorite rich aggregates surrounded by thin garnet rims within the cleavage domains of S_3. Inclusion free garnets are chemically strongly zoned with continuously decreasing Ca and Mn content from the core to the rim, while Mg and Fe content increases. Garnets with inclusion rich cores are charecterized by chemical changes in the zoning profile, when Mn and Ca content in the core decreases, while xMg ratio increases to values similar to the most external garnet rim. Inclusion free rim has similar prograde composition profile as have rims of the inclusion free grains, and also as have isolated rims of atoll garnets. PT pseudosection modelling of inclusion free grains revealed near isobaric metamorphic history of garnets from ca. 500°C in the garnet core to more than 600 °C in the garnet rim at ca. 6–7 kbar. We interpret atoll garnets as being developed by secondary non-isochemical decomposition of the garnet core. Destabilisation of garnet cores occurs first at peak temperature conditions and localises to the place with largest gradient in chemical potential between non-equilibrium chemical composition of the core and equilibrium composition of the garnet rim. High chemical gradient is best pronounced in the least diffusive Ca component, whose equilibrium concentration differs between core and rim about 20 mol%. This is reflected by diffusion-driven modification of the Ca and Mn rich cores and can be observed only in inclusion rich garnets, where the cores can effectively communicate with the matrix along grain boundaries. The retrograde part of the clockwise PT path follows grossular isopleth, leading to relative stability of the garnet rim during exhumation. Moreover, Mn, Mg and Fe form thin retrograde rim of slightly increased Mn content and decreased xMg, omitting the breakdown of the remaining atoll-shape garnet by intracrystalline diffusion. At the same time, the garnet cores are partially or completely decomposed and replaced by biotite/chlorite agregates. Position of atoll shaped garnets corresponds to a few km wide D_3 detachment zone developed between rheologically strong low-grade superstructure and weak high-grade infrastructure. Such a zone is prone to focused fluid flow, which enhance open system chemical changes in garnets in touch with S_3 cleavage domains. Fluid activity allows outflow of Ca^{2+} from dissolved garnet core, and inflow of K^+ and H_2O to produce micas in the centre of the atoll. Finally, the source of fluids is expected to come from the progressing dehydration reactions in the underlying high-grade rocks.

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Combined analysis of faults and deformation bands reveals the Cenozoic structural evolution of the southern Bükk foreland (Hungary)

Attila Petrik[1,2], Barbara Beke[1,2] & László Fodor[2]

[1] *Eötvös University Budapest, Department of Physical and Applied Geology H-1117, Budapest Pázmány Péter sétány 1/C Hungary, e-mail: petrik.atus@gmail.com , barbara.beke@gmail.com*

[2] *MTA-ELTE Geological, Geophysical and Space Science Research Group, Hungarian Academy of Sciences at Eötvös University, Budapest, Hungary, e-mail: lasz.fodor@yahoo.com*

The study area is located in the eastern part of the North Hungarian Paleogene basin (NHPB). It is bordered by the Mid-Hungarian Shear Zone in the south, the Bükk Mts. in the north, while the western and eastern borders are poorly defined. It is made up of sediments of a Late Eocene–Early Oligocene transgressive and a Late Oligocene–earliest Miocene regressive cycle. Post-19 Ma evolution belongs to the evolution of the extensional Pannonian Basin system. The first rock suites of the basin fill are extended rhyolitic and dacitic pyroclastic rocks produced by many eruptions of late Early to Mid-Miocene times (Lukács and Harangi, 2002). The thick Late Miocene (Pannonian) sedimentary unit consists of lacustrine marlstone, followed by basin floor sandy turbidites, clayey slope deposits, sandy deltaic and variegated fluvial suites (Magyar *et al.*, 1999).

75 outcrops were involved to examine the stress field evolution. In 4 sites (Early and Late Oligocene, Late Miocene porous sandstone, conglomerate) we sampled deformation bands for the purpose of making thin section and cathodoluminescence analysis. Structural analysis was complemented by generalized subsidence model based on borehole and calibration data. Geological cross sections and 2D seismic profiles were also investigated to depict the main NE to ENE trending structures and to reconstruct the eroded parts of the top of Mid-Miocene and Pannonian sediments extrapolating from preserved formation tops.

8 stress fields (Fig.1) were determined in the studied area by means of field structural observations, deformation band analysis and seismic profile interpretation. **The field (D1)** is predominantly NE–SW compression but less typically NW–SE extension also occurred. This phase is mainly characterized by NW–SE trending conjugate reverse faults in association with folds. The age of this stress field is uncertain but it predates the latest Oligocene–earliest Miocene post-sedimentary tilting event. **The field (D2)** was divided in two events (Fig.1); they are similar in the direction of the horizontal stress axes but different in style. The **D2a** of NE–SW extension is characterized by fractured pebbles which indicate syn-diagenetic deformation. Dilation deformation band in Late Oligocene sandstone proves syn-sedimentary extension (sample W5-2 on Fig. 1). Conjugate NW–SE disaggregation bands and initial cataclastic type deformation bands (A1 and A2) indicate early extension because deformation mechanism involved grain rotation in unconsolidated matrix and only minor cataclasis. The **D2b** is basically a NW–SE compression with NE–SW trending conjugate reverse faults and oblique dextral strike slip faults. This compression is associated with blind north vergent reverse faults and folding and impingement of Paleogene sediments on elevated highs. **The D3** is characterized by E–W compression and perpendicular extension marked by E–W trending normal faults and cataclastic type deformation bands (A4 on Fig. 1). This deformation was active in earliest Miocene and resulted in syn-sedimentary thickening of the lowest volcaniclastic level. The **D4 field** shows NE–SW extension with NW–SE trending conjugate faults and joints. This stress field was responsible for syn-sedimentary thickening of the early Middle Miocene volcanoclastic level. This phase reactivated formerly created deformation bands and induced more intense cataclasis along them. The **D5 field** of WNW–ESE extension induced the formation of prominent, map-scale faults with ENE–WSW strike which could be sinistral faults (Tari 1988). On seismic profiles most of the NNE–SSW trending normal faults dip to the WNW and were responsible for southward thickening of Mid Miocene formations. The **D6 field** was a NE–SW to ENE–WSW compression. N–S trending dextral and E–W trending sinistral strike-slip zones characterize this stress field together with NW–SE trending conjugate reverse faults and small folds. This can be tied to the late Sarmatian to early Pannonian inversion of the Pannonian Basin. The **D7 field** is a NNW–SSE extension in which the most significant structures are ENE–WSW trending normal faults. They induced the thickening of early Pannonian clastics in the hanging wall. Important subsidence occurred in the Vatta-Maklár Trough where more than 700 m thick Lower Pannonian sediments were deposited. The **D8 field** is characterized by NW–SE compression and perpendicular extension with WNW–ESE trending dextral and NE–SW trending reverse faults: this could be a late Pannonian phase.

Based on deformation mechanism in deformation bands, their displacement and burial depth history the following trend can be drawn. The earlier the deformation band in the deformation history, the less destructive band type occurred (Fig. 2). The more indurated rocks show more cataclastic deformation. The more cataclastic rocks are more capable to evolve into a discrete slip surface. The most evolved cataclastic deformation bands (S3) is the youngest and probably indicates the most significant burial depth. The strongly cataclastic deformation mechanism itself could suggest 1–3 km overburden, although cataclastic deformation can occur in shallower burial depth less than 1

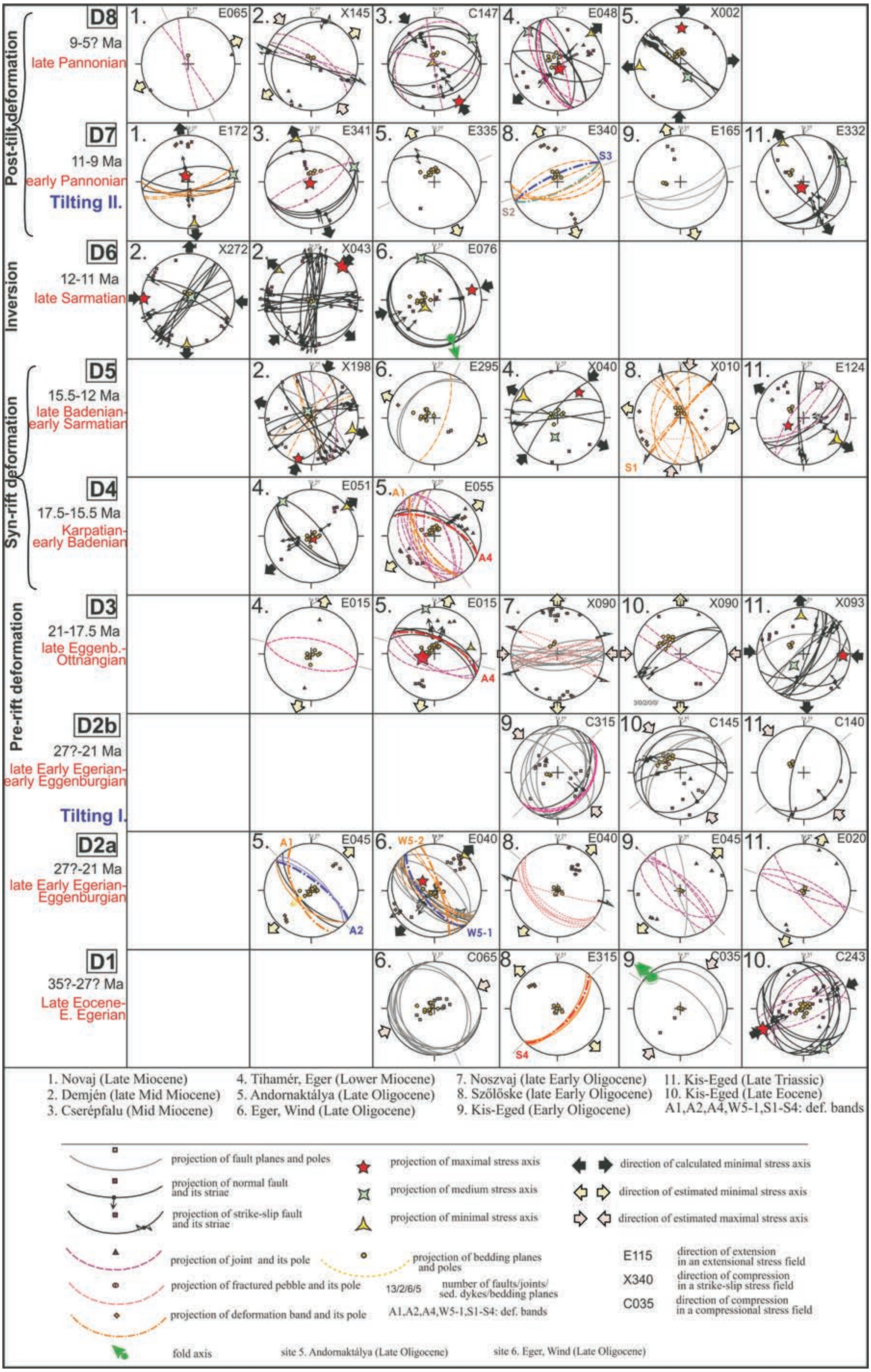

Fig. 1. The summary table of stress fields and main deformation phases.

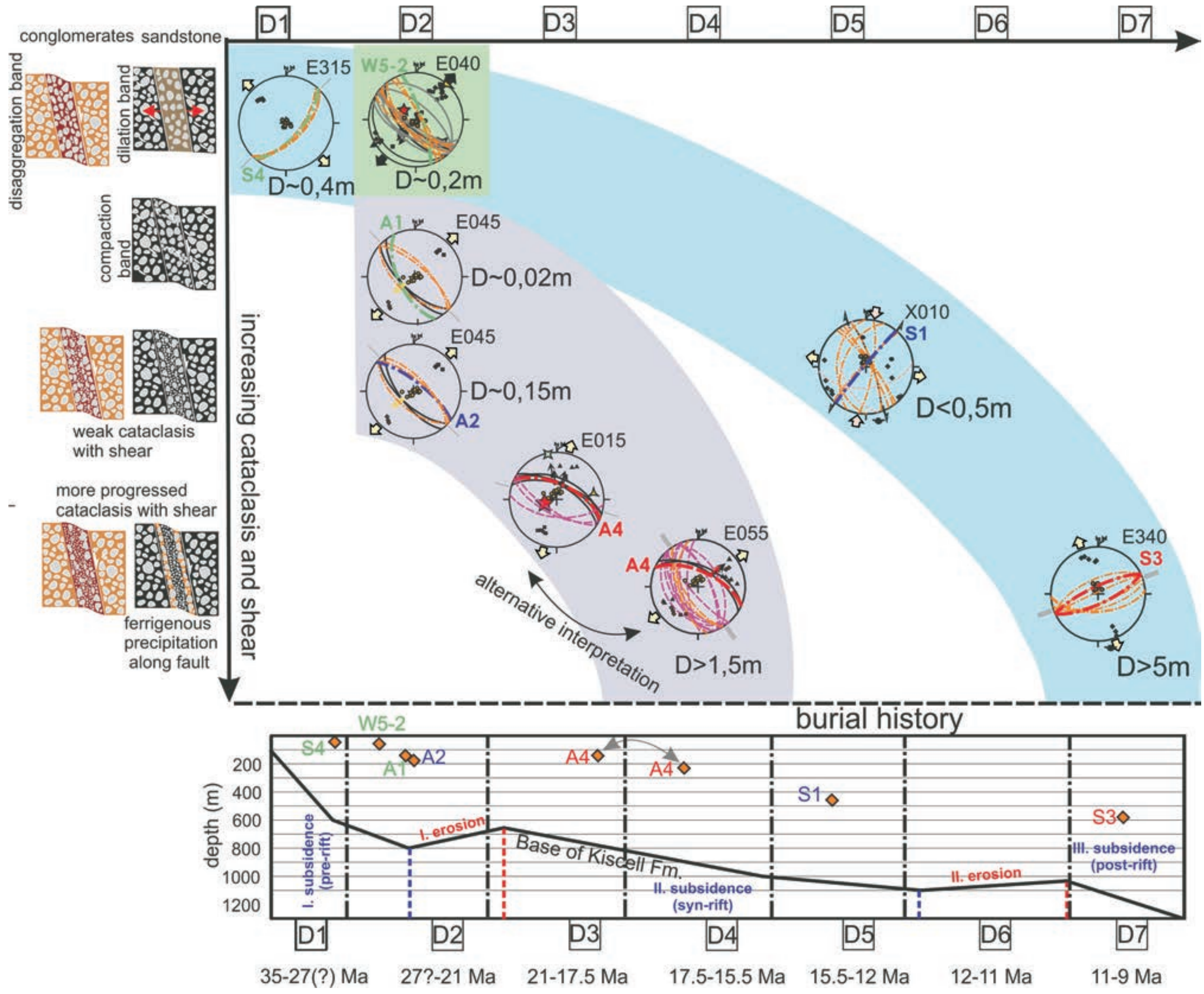

Fig. 2. The evolution of deformation bands with respect to displacement and burial depth. Thickened black line indicates the burial depth of the base Oligocene. Black dotted lines indicate the end of deformation phases. The orange diamonds indicate the burial depth of deformation bands at the time of their formation. The blue dashed lines show the end of main subsidence periods while the red ones indicate the erosional periods.

km, (Fossen *et al.*, 2007). The subsidence modelling predicts 600–800 m of cover at the presumed time of cataclastic deformation. In summary, going from D1 to D7 deformation phase the burial depth is increasing in line with the deformation mechanism of bands (Fig. 13). Concerning the displacement along the bands, the less destructive type of deformation bands (S4, W2, A1, A2) indicates less displacement (Fig. 2). Within the cataclastic type bands, the more developed the cataclasis, the greater total displacement can be observed. The youngest and most cataclastic band (S3) indicates the greatest displacement and probably the most significant burial depth. However, in case of the S4 and S1 transitional type deformation bands, the displacement is not increasing in time which can be explained by different deformation mechanism.

Reference

FOSSEN, H., SCHULTZ, R., SHIPTON, Z. & MAIR, K., 2007. Deformation bands in sandstone – a review. *Journal of the Geological Society*, 164: 755–769.

LUKÁCS, R. & HARANGI, S., 2002. Petrogenesis of the Miocene silicic magmas in the Pannonian Basin: A case study in the Eastern Bükkalja Volcanic Field, Northern Hungary. *Geol. Carpathica*, 53: 13–14.

MAGYAR., I., GEARY, D.H. & MÜLLER, P., 1999. Paleogeographic evolution of the Late Miocene Lake Pannon in Central Europe. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 147: 151–167.

TARI, G., 1988. Strike-slip origin of the Vatta-Maklár trough. *Acta Geol. Hungarica*, 31: 101–109.

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Anisotropy of rock ruptures – experimental study

Tomáš Proisl & Rostislav Melichar

Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlarska 2, 611 37 Brno, Czech Republic, e-mail: 327940@mail.muni.cz

Joints and faults are the most common brittle structures, which disrupt the continuity of the rocks. This lower rocks cohesion has its origin in less strength of joint or fault surfaces in comparison to unfractured rock. Joints are usually considered to be isotropic but this point of view may be used only in the first approximation but it is very simplified in fact. Although it is evident that joints and faults surfaces should be anisotropic only few papers are focused on this problem (Grasselli & Egger, 2003; Kulatilake *et al.*, 1995, 1999). We tried to testify and quantified idea of shear strength anisotropy of such fractures.

Real joint and fault surfaces from the Brno massif were used for this study. Samples were taken by manual drilling machine in the Vranov quarry, where we can find well exposed granitoids with numerous fractures of different types. There were drilled 16 drill cores in minimum through one selected fracture, as samples were tested in sixteen different directions (Proisl 2011, 2013). To keep original orientation, samples were marked to show "zero" direction. It was chosen randomly in case of joints or corresponds to striation on faults surfaces. Samples were tested at shear tensile machine Matest A129. Shear strength were obtained under fixed normal stress component equal to 22 MPa. Resultant shear strengths were plotted in spider diagrams.

Strength pattern of real joints showed typically one peak of shear strength while other directions we characterized by lower strength level (see Fig. 1A). This type of strength pattern might be explained by presence of more or less noticeable steps on joint surfaces. Tested faults brought completely different picture of results. Two types of fault strength pattern were recognized. The first one was typical by the lowest values of shear strength observed in directions parallel to fault striation regardless of the sense of movement and by weak maximum strength in directions perpendicular to striation (Fig. 1B), which was preliminary expected. Faults with the second pattern indicate different strength in direction of striation due to asymmetrical structures on fault surface. Both pattern types have tendency to show some weak peaks in oblique directions, which were sometimes higher then strengths in perpendicular directions. This result of testing was much unexpected and indicates some unknown strength behavior of striated planes.

References

GRASSELI, G. & EGGER, P., 2002. Constitutive lawfor the shear strength of rock joints based on threedimensional surface parameters. *International Journal of Rock Mechanics & Mining Sciences*, 40 (1): 25–40.

KULATILAKE, P. H. S. W., SHOU W., HUANG G., T. H. & MORGAN, R. M., l995. New Peak Shear Strength Criteria for Anisotropic Rock Joints. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 32 (7): 673–697.

KULATILAKE, P. H. S. W., UM, J., PANDA, B., & NGHIEM, N., 1999. Development of new peak shear – strength criterion for anisotropic rock joints. *Journal of Engineering Mechanics*, 125 (9): 1010–1017.

PROISL, T., 2011. Strength of selected jointed rocks in Moravia. *MS, Přírodovědecká fakulta Masarykovy univerzity*, *Brno*, K-VZ-2011-PROI.

PROISL, T., 2013. Anisotropic shear strength of ruptures. — *MS, řírodovědecká fakulta Masarykovy univerzity. Brno*. K-VZ-2013-PROI.

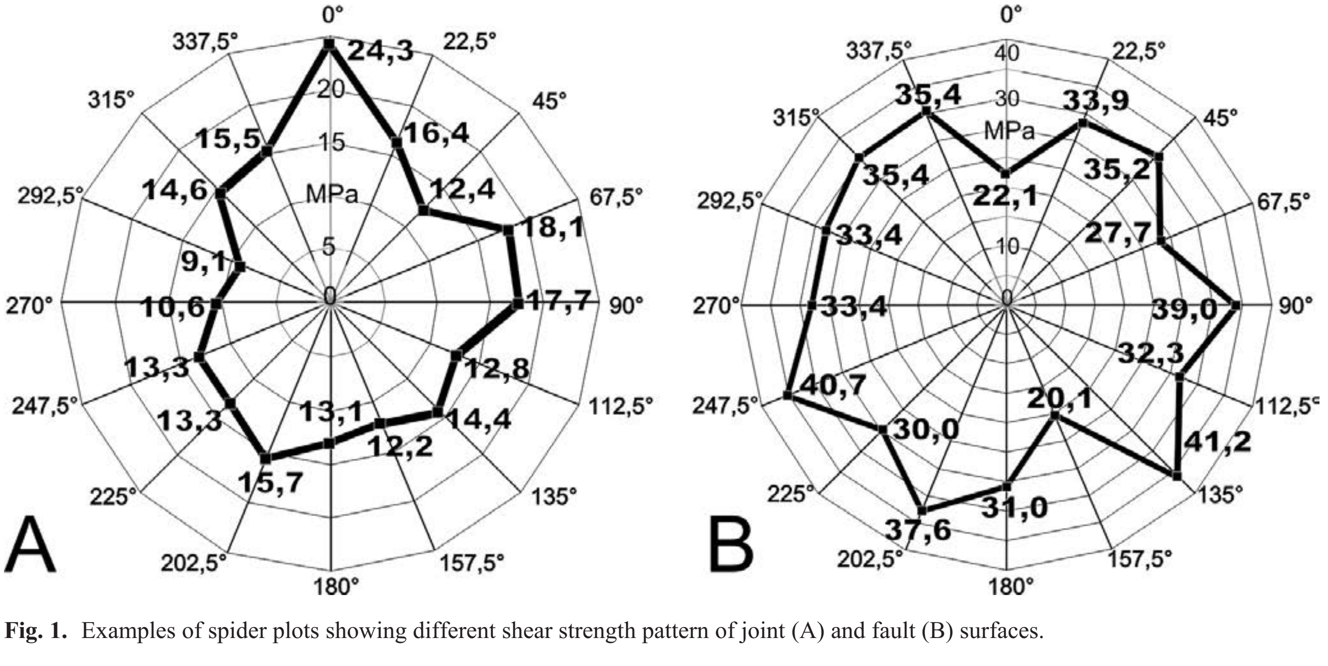

Fig. 1. Examples of spider plots showing different shear strength pattern of joint (A) and fault (B) surfaces.

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Insight into the main structural and tectonic elements of the southwestern part of Jordan

Omar Radaideh & Rostislav Melichar

Department of Geological Sciences, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic, e-mail: o.sabbah@ymail.com

A combined study of structural field work based on paleostress analyses and remote sensing data has been conducted to provide more insight into the structural and tectonic deformation of the east margin of the Dead Sea transform in the southwestern part of Jordan. Analysis of digital elevation model (DEM) and Landsat Thematic Mapper images provide means of recognizing and characterizing linear morphological features and drainage patterns over the area. Statistical analysis of morphological lineaments (Fig. 1A) shows four major populations in the WNW–ESE to ENE–WSW, NE–SW, NW–SE and ~ N–S directions, drainage orientation analysis (Fig. 1B) shows similar trends suggesting that the flow direction of the drainage system in this area is influenced by the lineaments directions. A detailed field survey was carried out in Precamprian to Cenozoic outcrops that allowed gathering a significant dataset of fault-slip data. By using the multiple stress inversions in 9D-space (Melichar and Kernstockova, 2011), a number of 174 local stress tensors with sub-vertical and sub-horizontal kinematic axes were determined from measured faults; most of them reveal a predominance of strike-slip regimes relatively to the normal and reverse ones. The summarized inversion results (Fig. 1C) reveal a series of clustered with three dominant maximum horizontal stress (σ_1) trends (ENE–WSW, NW–SE, NE–SW and N–S) and fits well the inferences derived from remote sensing. These trends are associated with the cumulative strain resulted from the total acting stresses affecting the Arabian Plate over through geological time and could be related to the Syrian Arc stress field (SAS), and with the 105-km sinistral displacement along the Dead Sea Transfom and the opening of the Red Sea (Dead Sea stress Field/DSS).

References

MELICHAR, M. & KERNSTOCKOVA, M., 2011. 9D space – the best way to understand paleostress analysis. *Trabajos de Geología*, 30: 69–74.

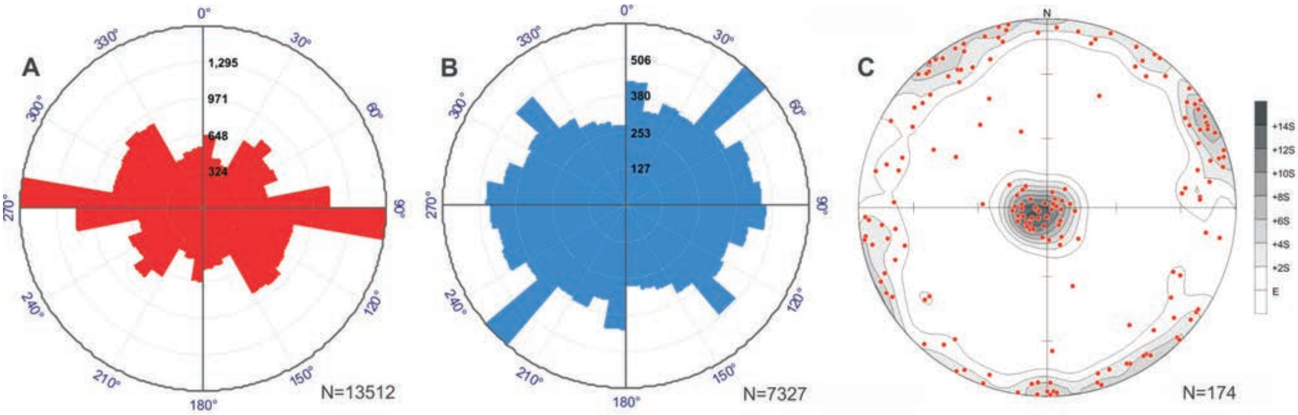

Fig. 1. Equal area projection and Rose diagrams: (A) Rose diagram showing the orientation of lineaments data set, (B) Rose diagram of the stream directions, (C) equal area projection for ó-azimuths of stress tensors. The scale bar indicates the number of data points centered within a 1% counting circle.

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A general comparison between the Paleostress methods

Omar Radaideh & Rostislav Melichar

Department of Geological Sciences, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic. E-mail: o.sabbah@ymail.com

Several techniques with different algorithms have been developed for determining paleostress states from fault slip datasets. All of them rely on the Bott's (1959) assumption that slip on a plane occurs in the direction of the maximum resolved shear stress, and objectively estimate the principal stress axes (σ_1, σ_2, σ_3) besides the stress ratio, but do not yield information about the absolute values of stress. In order to choice of the best fitting techniques, many paleostress inversion methods are compared through analyses of artificial homogeneous and heterogeneous fault-slip data with known stress solutions. In this context, we used different commercial computer programs including Win-Tensor v.4 (Delvaux, 2012), Tectonics FP 1.7.5 (Reiter and Acs, 1996–2003), T-Tecto v3 (Žalohar, 2009), Mark 2011 (Melichar and Kernstockova, 2011), as well as MIM Package (Yamaji and Sato, 2005), the last three programs have functions for numerically faults separation into homogeneous subsets with their precise stress tensors. Consequently, we obtained many of result solutions of different inversion techniques such as Right Dihedra, Numerical Dynamic Analysis, Gauss inversion, and P-T inversion methods. The results were then checked for accuracy and consistency (Fig. 1), and we found considerable consistency between the results of different methods but generally, the best fit of principal axes orientations with respect to fault orientations were represented by the multiple inversions in 9D-space method, Mark program.

References

BOTT, M.H.P., 1959. The mechanics of oblique slip faulting. *Geological Magazine*, 96: 109–117.

DELVAUX, D., 2012. Release of program Win-Tensor 4.0 for tectonic stress inversion: statistical expression of stress parameters. EGU General Assembly, Vienna, 2012. {In}: *Geophysical Research Abstracts*, 14: 5899.

MELICHAR, M. & KERNSTOCKOVA, M., 2011. 9D space – the best way to understand paleostress analysis. *Trabajos de Geología*, 30: 69–74.

REITER, F. & ACS, P. 1996–2003: Tectonics FP – a computer program for structural geology.

YAMAJI, A. & SATO, K., 2005. MI viewer, Version 4.10. *Division of Earth and Planetary Sciences*, Kyoto University. Kyoto.

ŽALOHAR, J., 2009. T-TECTO 3.0 Professional. Integrated software for structural analysis of fault-slip data. – Department of Geology, SI-1000 Ljubljana, Slovenia.

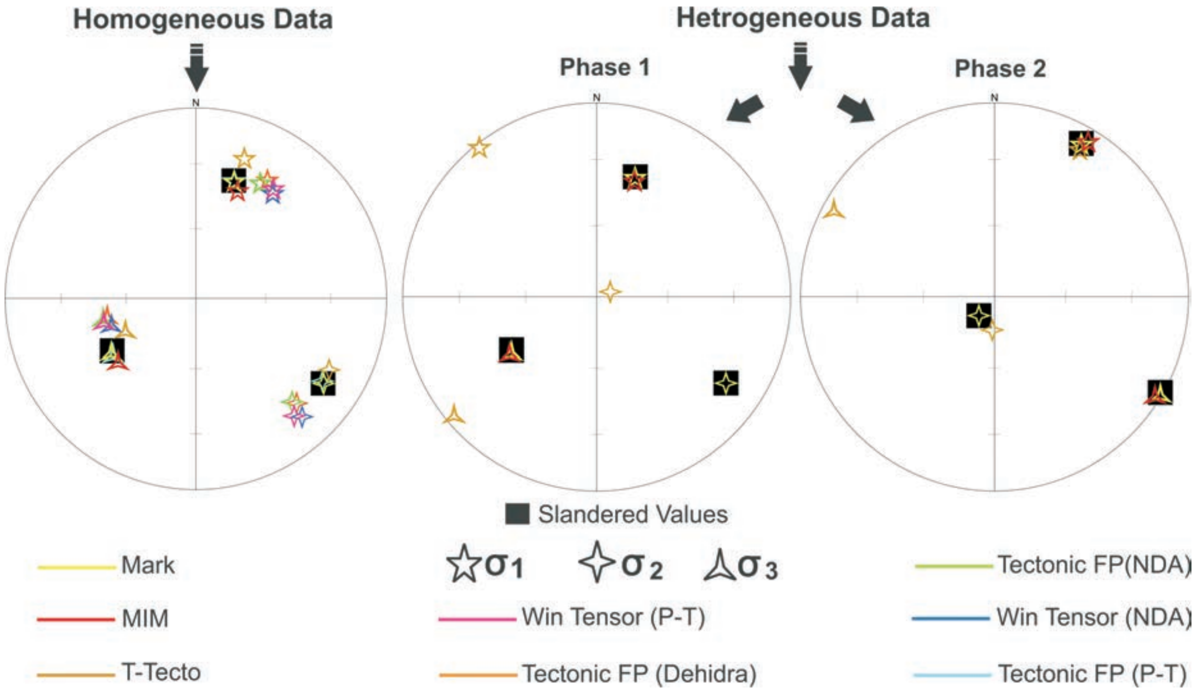

Fig. 1. Stereoplots showing results of different paleostress programs.

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Tectonic deformation of Miocene rocks in the frontal part of Polish Outer Carpathian foreland fold-and-thrust belt (Tarnów–Rzeszów region)

Marta Rauch

Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Wrocław, Podwale St. No. 75, PL-50-44 Poland, e-mail: ndrauch@cyf-kr.edu.pl

The Polish Outer Carpathians is a northern part of a foreland-verging thrust-and-fold belt which formed in Oligocene–Miocene times (Książkiewicz, 1977; Pescatore & Ślączka, 1984). This part of belt is composed of Upper Jurassic–Lower Miocene flysch-dominated rocks (Książkiewicz, 1977; Oszczypko, 2006). The Carpathian Foredeep is a foreland basin that formed during the Miocene due to lithospheric flexure of the European Plate in front of an advancing Outer Carpathian orogenic belt (Krzywiec, 2001). Its Miocene sedimentary fill is overridden from the south by the Outer Carpathian thrust sheets (Sieniawska *et al.*, 2010). The Miocene strata of the foredeep were partly deformed at the Carpathian orogenic front and incorporated in the Outer Carpathian belt (especially east of Cracow) as the thrust slices being the external part of this belt which are called Zgłobice Unit (Kotlarczyk, 1985). Sedimentation in the Carpathian Foredeep lasted to the Middle Miocene, the Sarmatian (Oszczypko, 2006) or even later to the Pannonian (Olszewska, 1999).

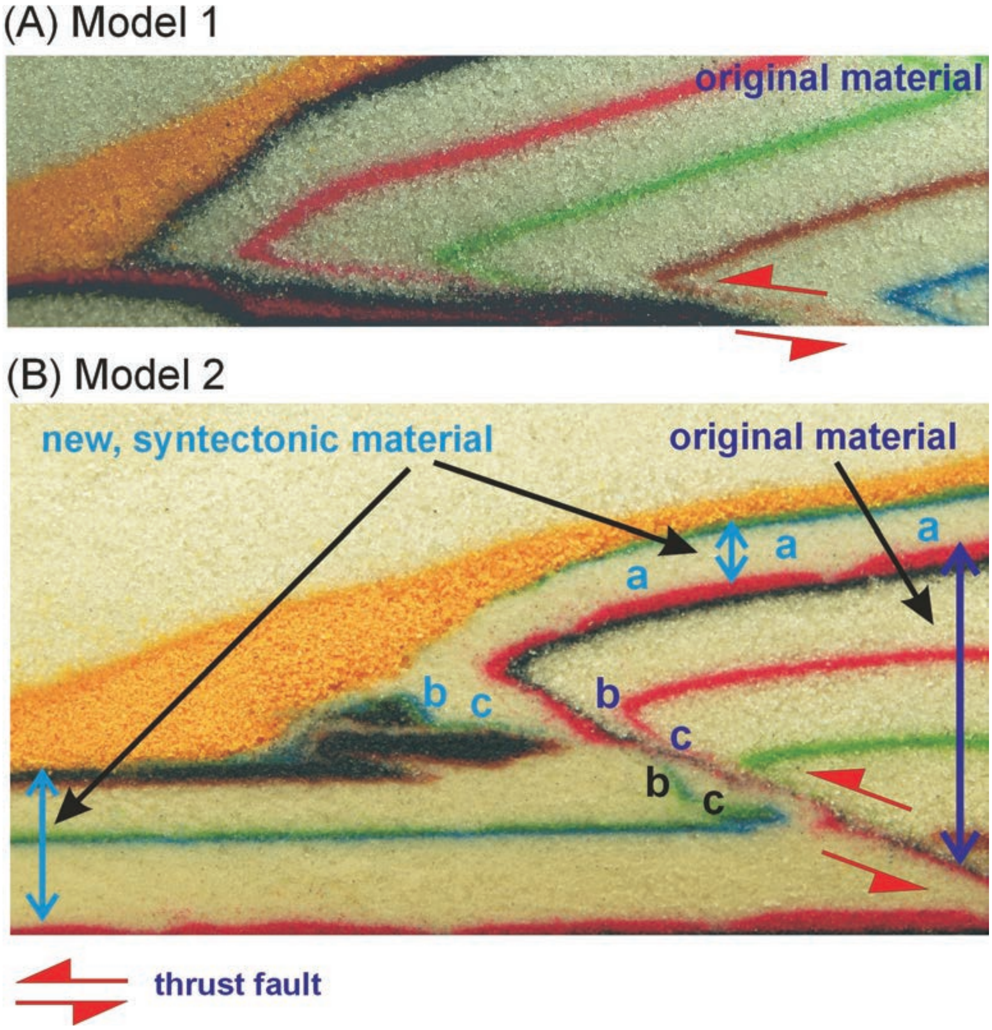

Fig. 1. Cross-sections of the two models, which cut the experimental stack of slices, are showing the frontal slices of these models: (A) Model 1 is showing the deformation of the original horizontal layers and (B) Model 2 is showing the deformation of the original layers together with the new, syntectonical deposited layers. For explanation of the markers a, b and c see text.

The study area is located in the zone of the Carpathian orogenic front between Tarnów and Rzeszów. The aim of the present investigation is to determine the character of the tectonic deformation of the Miocene strata which were genetically connected with the Carpathian Foredeep basin. The transgressive Miocene marine sediments, which covered the rocks of the Carpathian nappes, preserved locally in the form of isolated patches (Żytko *et al.*, 1989).

Basing on the results of the field investigation, the Miocene strata in the vicinity of the Rzeszów, within so-called Rzeszów Embayment (Gonera, 1980) are lying nearly horizontally on the rocks of the Skole nappe. These Miocene strata are only slightly deformed, they are cut by few thrusts and strike-slip faults. In the vicinity of the Tarnów, the Miocene rocks of the southern part of the Carpathian Foredeep are strongly folded and cut by numerous faults. The Miocene strata are vertical or horizontal, and these horizontal ones are in an overturned position (Zgłobice near Tarnów).

The present paper shows the results of the two experiments (Fig. 1) which were performed in the Laboratory of Analogue Modelling, in the Institute of Geological Sciences Polish Academy of Sciences. The experimental material was quartz sand. During the experiments, the original horizontal layers were deformed in the compressional regime (Fig. 1A). Additionally, during second experiment (Fig. 1B) the influence of the synorogenic sedimentation were tested. This investigation was extended the results of Sieniawska *et al.* (2010). These author's modelled a fragment of the Polish Carpathian orogenic front and tested the influence of the synorogenic sedimentation in front of an active fold-and-thrust wedge that rested on top of a weak ductile detachment horizon, thereby examining the dynamics of growth structures.

Both, the original and new, syntectonic layers of the experimental material are involved in the active thrusting and folding. However, the new layers deposited on the top of the hanging wall of the active thrust are not deformed or only slightly deformed (Fig. 1B, see "a" marker). I observed the same slightly deformation or even absence of any deformations within the Miocene rocks in the vicinity of the Rzeszów, within the Rzeszów Embayment. The Miocene sediments were lying on the top of the Skole nappe there and they were thrusted together over the Miocene strata of the Carpathian Foredeep.

The layers within the zone of the thrust fault and close to it are deformed, they are tilted from the normal position (Fig. 1, see "b" and "c" markers). The layer located there are steely deeping (see "b" marker) or slightly deeping but overturned ("c" marker). At Zgłobice in the vicinity of Tarnów, there are the overturned, nearly horizontal Miocene strata and the vertical strata also. The results of the experiments suggest that the syntectonic deposited layers, located in front of the active thrust were strongly deformed into the stack of slices, the same like westward of the Tarnów (see Kirchner and Połtowicz, 1974).

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References

GONERA, M., 1980. Osady mioceńskie w Zalesiu koło Rzeszowa. *Kwartalnik Geologiczny*, 24 (2): 299–310.

KIRCHNER, Z. & POŁTOWICZ, S., 1974. Budowa geologiczna obszaru między Brzeskiem a Wojniczem. *Rocz. Pol. Tow. Geol.*, 44: 293–320.

KOTLARCZYK, J. 1985. An outline of the stratigraphy of Marginal Tectonic Units of the Carpathian orogen in the Kraków Przemyśl area. In: Kotlarczyk J. (Ed.). *Geotraverse Kraków-Baranów-Rzeszów-Przemyśl-Komańcza-Dukla. XIII Congress Carpatho-Balkan Geological Association, Guide to Excursion*, 4: 21–32, Wydawnictwo Geologiczne, Warszawa.

KRZYWIEC, P. 2001. Contrasting tectonic and sedimentary history of the central and eastern parts of the Polish Carpathian foredeep basin – results of seismic data interpretation. *Marine and Petroleum Geology*, 18: 13–38.

KSIĄŻKIEWICZ, M., 1977. The tectonics of the Carpathians. In: *Geology of Poland*. *4: Tectonics*. Geological Institute, Warszawa, 476–669.

OLSZEWSKA, B. 1999. Biostratygrafia neogenu zapadliska przedkarpackiego w świetle nowych danych mikropaleontologicznych [Neogene biostratigraphy of the Carpathian Foredeep in light of the new micropaleontological data]. *Prace Państwowego Instytutu Geologicznego CLXVIII*, 9–28.

OSZCZYPKO, N. 2006. Late Jurassic–Miocene evolution of the Outer Carpathian fold-and-thrust belt and its foredeep basin (Western Carpathians, Poland). *Geological Quarterly*, 50: 169–94.

OSZCZYPKO, N., KRZYWIEC, P., POPADYUK, I. & PERYT, T., 2006. Carpathian Fore-deep Basin (Poland and Ukraine): its sedimentary, structural and geodynamic evolution. In: Golonka, J. & Picha J. (Eds). The Carpathians and Their Foreland, Geology and Hydrocarbon Resources *AAPG Mem.*, 84: 293–350.

PESCATORE, T. & ŚLĄCZKA, A., 1984. Evolution models of two flysch basins: the Northern Carpathians and Southern Apennines. *Tectonophysics*, 106: 49–70.

SIENIAWSKA, I., ALEKSANDROWSKI, P., RAUCH, M. A. & KOYI, H. 2010. Control of synorogenic sedimentation on back and out-of-sequence thrusting: insights from analog mo- deling of an orogenic front (Outer Carpathians, southern Poland). *Tectonics*, 29 (TC6012): 1–29.

ŻYTKO, K., ZAJĄC, R., GUCIK, S., RYŁKO, W., OSZCZYPKO, N., GARLICKA, I., NEMČOK, J., ELIÁŠ, M., MENČIK, E. & STRÁNIK, Z., 1989. Map of the tectonic elements of the Western Outer Carpathians and their foreland. In: Poprawa D & Nemčok J. (Eds.), *Geological Atlas of the Western Outer Carpathians and their Foreland*. Państwowy Instytut Geologiczny Warszawa/GUDŠ Bratislava/UUG Praha.

Geologia Sudetica, 2014, 42: 80–81.

Statistical analysis of a bulk chemical composition of orthogneisses, migmatites and metarhyolites from the Orlica–Śnieżnik Dome, West Sudetes

Aleksandra Redlińska-Marczyńska

Institute of Geology, Adam Mickiewicz University, Maków Polnych 16, 61-606 Poznań, e-mail: aleksandra.redlinska-marczynska@amu.edu.pl

The Orlica–Śnieżnik Dome (OSD) is one of the crystalline units in the West Sudetes, correlated with the Saxothuringian or Moldanubian zone of the European Variscides (*e.g.* Franke & Żelaźniewicz 2000; Aleksandrowski & Mazur, 2002). The dome is composed of various types of amphibolite phacies gneisses, by tradition named the Śnieżnik and Gierałtów gneisses, enclosing high grade rocks, and metasedimentary series. Details of both pre- and Varsican evolution of the OSD are debatable, mainly because of complex structural relationships between rocks, and strong overprint of latest stage of shear deformation. The geochemical signature obtained from the metasedimentary series (= Młynowiec–Stronie Formation) suggests that its protolith developed as subsiding rift basin succession on the gneissic basement between 530–470 Ma ago, and acid metavolcanic rocks (= leptites) from the same formation originated ca. 500 Ma (*e.g.* Murtezi, 2006; Jastrzębski *et al.*, 2010, Skrzypek *et al.*, 2011). Geochemically, both types of gneisses seem to be almost identical (peraluminous normal granites) and coeval in origin (ca. 500 Ma) and metamorphism (ca. 340 Ma) – *e.g.* Turniak *et al.*, 2000; Lange *et al.*, 2005; Bröcker *et al.*, 2009. Nevertheless, there are obvious differences in structural record of gneisses, and if taken as the main criterion, the gneisses can be undoubtedly subdivided into simple deformed L-S tectonites, with single mylonitic foliation and elongation lineation (= Śnieżnik Gneiss Formation), and multiple deformed group of rocks with at least 2 foliations, intrafolial folds, porphyroblasts and/or leucosome segregations (Gierałtów Gneiss Formation) – *see* Redlińska-Marczyńska & Żelaźniewicz (2011).

Hereby, a set of 24 own geochemical samples from various gneisses[1], together with 25 archived gneiss samples (Lange *et al.*, 2005) and 15 samples of 'massive leptites' (Murtezi, 2006) has been subjected to univariate statistical analysis (*i.a.* min., max., mean & standard deviation, Spearman's rank correlation, variation). The main goal was to examine if there are geologically important relationships between the OSD rocks, if sample's selection follow our earlier, structural classification (Redlińska-Marczyńska & Żelaźniewicz, 2011). The most distinctive results can be summarized as follows:

1. Correlation matrixes revealed that the Śnieżnik Formation is homogeneous magmatic suit of rocks – there are 165 very strong[2] and 265 strong correlations between pairs of constituents (430 in totals). The Śnieżnik Formation and the leptites are stronger related to each other (238 pairs) than the Śnieżnik and Gierałtów formations with each other (only 180 pairs). To compare: the Gierałtów Formation alone gives 176 statistically meaningful correlations pairs, which stands less than a half of total sum of correlated pairs form the Śnieżnik Formation alone. The matrix designed for massive leptites alone revealed in total 260 pairs of statistically meaningful dependencies.

2. Correlation applied to variation analysis revealed that 2 separate mineral phases (Fe-Mg and Mg-Mn) must have fractionating compatible elements within the Śnieżnik Formation, while only one phase (Ti-Mg) within the Gierałtów Formation. Moreover, dissimilar substituents in feldspars can be recognized in the Śnieżnik Formation (Cs, Ba, Sr, and REE in the alkali feldspar, while Ba, Sr, and Eu in plagioclase), and the Gierałtów Formation (Sr and Ga in plagioclase, and Rb and Tl in alkali feldspars).

3. Plotting points coming from *in situ* chemical analyses of porphyroclasts from the Śnieżnik Formation complement the trend on Harker's variation diagrams constructed for K, Ca, Na, and Ba, indicating that the chemistry of gneisses have been controlled by crystal fractionation (*see* Rollinson, 1993). The chemical composition of leptites is compatible with the curvature negative trends, identifying the latest degree of fractionation. On a contrary, the plotting points from the Gierałtów Formation do not fit the pattern.

Geochemistry of gneisses (and leptites) selected carefully in accordance with structural classification, show that the Śnieżnik Formation and leptites from the Młynowiec–Stronie Formation are comagmatic, while the Gierałtów Formation stands out clearly as the heterogeneous suite of rocks. Nearly all previous geochemical data from the OSD obtained from the variety of gneisses are interpreted to indicate no differences between gneissic suites. Results presented here confirm our earlier research (Redlińska-Marczyńska & Żelaźniewicz, 2011) and point out the importance of structural record in the geological interpretations and classifications.

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[1] ICP and ICPMS methods applied in the Activation Laboratories Ltd. Canada (own samples and cited papers).

[2] Spearman's rank correlation is considered very strong if correlation coefficient r_s (±) 0.7, and strong if r_s (±) 0.7 (*vide* Rollinson, 1993).

References

ALEKSANDROWSKI, P. & MAZUR, S., 2002. Collage tectonics in the northeasternmost part of the Variscan Belt: the Sudetes, Bohemian Massif. In: J.A. Winchester *et al.* (Eds.), Palaeozoic Amalgamation of Central Europe. *Geological Society, London, Special Publications*, 201: 237–277.

BRÖCKER, M., KLEMD, R., COSCA, M., BROCK, W.,

LARIONOV, A. N., & RODIONOV, N., 2009. The timing of eclogite-facies metamorphism and migmatization in the Orlica–Śnieżnik complex, Bohemian Massif: constraints from a geochronological multi-method study. *Journal of Metamorphic Geology*, 27: 385–403.

FRANKE, W., ŻELAŹNIEWICZ, A., 2000. The eastern termination of the Variscides: terrane correlation and kinematic evolution, in: Franke,W. (Eds.), Orogenic processes: Quantification and Modelling in the Variscan Belt. *Geological Society of London, Special Publications*, 179: 63–86.

JASTRZĘBSKI, M., ŻELAŹNIEWICZ, A., NOWAK, I., MURTEZI, M. & LARIONOV, A., 2010. Protolith age and provenance of metasedimentary rocks in Variscan allochthon units: U-Pb SHRIMP zircon data from the Orlica–Śnieżnik Dome, West Sudetes. *Geological Magazine*, 147: 416–433.

LANGE, U., BRÖCKER, M., ARMSTRONG, R., ŻELAŹNIEWICZ, A., TRAPP, E. & MEZGER, K., 2005. The orthogneisses of the Orlica–Śnieżnik complex (West Sudetes, Poland): geochemical characteristics, the importance of pre-Variscan migmatisation and constraints on the cooling history. *Journal of Geological Society of London*, 162: 973–984.

MURTEZI, M., 2006. The acid metavolcanic rocks of the Orlica–Śnieżnik Dome (Sudetes): their origin and tectono-metamorphic evolution. *Geologia Sudetica*, 38: 1–38.

REDLIŃSKA-MARCZYŃSKA, A. & ŻELAŹNIEWICZ A., 2011. Gneisses in the Orlica–Śnieżnik Dome, West Sudetes: a single batholitic protolith or a more complex origin? *Acta Geologica Polonica*, 61: 307–339.

ROLLINSON, H., 1993. Using Geochemical Data: Evaluation, Presentation, Interpretation. Harlow, UK: *Longman*, 352p.

SKRZYPEK, E., SCHULMANN, K., ŠTÍPSKÁ, P., CHOPIN, F., LEHMANN, J., LEXA, O. & HALODA, J. 2011. Tectono-metamorphic history recorded in garnet porphyroblasts: insights from thermodynamic modelling and electron backscatter diffraction analysis of inclusion trails. *Journal of Metamorphic Petrology*, 29: 473–496.

TURNIAK, K., MAZUR, S. & WYSOCZAŃSKI, R., 2000. SHRIMP zircon geochronology and geochemistry of the Orlica–Śnieżnik gneisses (Variscan belt of Central Europe) and their tectonic implications. *Geodinamica Acta*, 13: 393– 312.

Geologia Sudetica, 2014, 42: 82.

Rock fabric control of the failure pattern – a case study on the sedimentary rocks from the southern part of the Holy Cross Mountains, Poland

Barbara Rybak-Ostrowska & Andrzej Konon

Faculty of Geology, University of Warsaw, Żwirki i Wigury 93, 02-089 Warszawa, Poland, e-mail: barbara.rybak@uw.edu.pl, andrzej.konon@uw.edu.pl

The strike–slip fault pattern has been investigated within the Permian–Miocene cover to the south of the Upper Palaeozoic Holy Cross Mountains fold belt. During field studies, the dextral strike–slip component was observed along faults that cut rocks buried at shallow depths up to 2 km. The study was focused on the fault zone analysis with particular emphasis on the microstructure of small scale structures within the damage zones associated with the slip surfaces. The analysis has displayed two of the main mechanisms of fault development with regard to rock fabric (I and II).

I. Deformation of cemented, low-porosity, medium- and thick-bedded carbonate Jurassic rocks occurs primarily by fracturing, veining and pressure solution that preceded the fault initiation and propagation (Crider &Peacock, 2004). The faults propagate by segmented slip surfaces, usually connected by calcite-filled dilational jogs (Segall & Polard, 1980; Sibson, 1989). The faults and the surrounding shear fractures are usually associated with calcite mineralization, with bulk within the main fault. The slip surfaces show mineral lineation, striation or/and different types of steps resulting from the development of shear fractures.

II. Deformation of high porosity carbonate rocks and sandstones is primarily dominated by shear band formation. The structures has been classified kinematically as compactional shear bands (after Aydin *et al.*, 2006). The shear bands have been divided into two types (IIa and IIb), based on their composition, grain size, porosity and cementation of the rocks:

– disaggregation zones (IIa), localised within highly porous, poorly consolidated, coarse grained, thick-bedded calcirudites of Miocene age,

– cataclastic bands (IIb), occurring in porous, thick-bedded sandstones of Triassic and Cretaceous age.

The disaggregation zones exhibit a discrete shear-related reorganization of the grains that causes porosity reduction relative to the host rock. The cataclastic bands occur as thin, up to few mm wide isolated structures or in clusters. They exhibit grain fracturing, comminution and matrix development that resulted in porosity reduction in relation to the host rock. The presence of these structures facilitated the initiation of faults that propagated by the failure of the individual bands or clusters and formation of slip surfaces along or within them (e.g. Aydin & Johnson, 1983, Hesthammer & Fossen, 2001, Nicol *et al.*, 2013). The faults developed within the calcirudites are segmented with rough slip surfaces that exhibit only discrete grooves and are intersected with R-shears. The faults developed within sandstones are segmented or continuous (more mature faults), usually associated with a thin layer of fault rock represented by cataclasites. The slip surfaces are highly polished, striated and grooved, intersected with R-shears.

Microstructural evidence indicates that the development of the strike-slip fault zones at shallow depths is strongly controlled by the rock fabric of sedimentary rocks that facilitated the failure pattern. Evidence of pressure solution coupled with interpreted presence of significant amounts of calcium carbonate-rich fluids penetrating only the faults zones developed within low-porosity carbonate rocks suggest that pressure solution was a common deformation mechanism in the host rock during faulting, which probably influenced the fluid source that precipitated calcite.

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References

AYDIN, A. & JOHNSON, A.M., 1978. Development of faults as deformation bands and as slip surfaces in sandstone. *Pure & Applied Geophysics*, 116: 931–942.

AYDIN, A., BORJA, R.I. & EICHHUBL, P., 2006. Geological and mathematical framework for failure modes in granular rocks. *Journal of Structural Geology*, 28: 83–98.

CRIDER, J.G. & PEACOCK, D.C., 2004. Initiation of brittle faults in the upper crust: a review of field observation. *Journal of Structural Geology*, 26: 691–707.

FOSSEN, H., SCHULTZ, R.A., SHIPTON, Z.K. & MAIR, K., 2007. Deformation bands in sandstone: a review. *Journal of the Geological Society*, *London*, 164: 755–769.

HESTHAMMER, J. & FOSSEN, H., 2001. Structural core analysis from the Gullfaks area, northern North Sea. *Marine and Petroleum Geology*, 18: 411–439.

NICOL, A., CHILDS, C., WALSH, J.J. & SCHAFER, K.W., 2013. A geometric model for the formation band clusters. *Journal of Structural Geology*, 55: 21–33.

SEGALL, P. & POLLARD, D.D., 1980. Mechanics of Discontinuous Faults. *Journal of Geophysical Research*, 85 (B8): 4337–4350.

SIBSON, R., 1989. Earthquake faulting as a structural process. *Journal of Structural Geology*, 11: 1–14.

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Mineralogical inheritance in partially molten rocks: implication for fabric resetting in granitoids

Karel Schulmann[1,3], Pavlína Hasalová[1,2], Anne Sophie Tabaud[3], Kryštof Verner[1] & Emilien Oliot[2]

[1] *Center for Lithospheric Research, Czech Geological Survey, Klárov 3, 118 21, Prague 1, Czech Republic, e-mail: schulmann.karel@gmail.com; pavlina.hasalova@geology.cz; krystof.verner@geology.cz*
[2] *School of Geosciences, Monash University, Clayton, 3800, VIC, Australia*
[3] *EOST, Institute de Physique de Globe, UMR 7516, Université de Strasbourg, 1 rue Blessig, 67084, Strasbourg, France, e-mail: oliot@unistra.fr; as.tabaud@unistra.fr*

During orogenic processes continental crust experience significant partial melting. Repeated thermal pulses or fluctuation in water content can even cause multiple anatectic events that result in complex intrusion suits. There are numerous studies regarding chronology of such intrusions or origin of the magmas. However, there is lack of microstructural characteristic of such remelting/infiltration processes. How do we distinguish the newly derived melt from the inherited magmatic crystals? What is the resulting microstructural appearance of such "mixed" granite? And importantly how does new melt presence impact on fabric recorded in these granites?

We investigate extensive granitoids complex in the Vosges Mountains in Eastern France. This complex reveal two main generations of magmatic rocks. The first event occurred at ca. 340 Ma, is associated with extensive Mg-K magmatism and is related to building of thick orogenic root and subsequent exhumation of deep crust to shallower crustal levels. These granitoids intruded all crustal levels. The second magmatic event occurred at ca. 325 Ma and affected exclusively the mid-crustal level. This magmatic event produced large quantity of felsic anatectic melts which further pervasively intruded and compositionally and texturally reworked previously formed magmas.

The detailed field and microstructural observations revealed a transition from granites that has been completely reworked by the infiltrated melt to granites that preserve former magmatic assemblage and have only incipient amount of the new melt (Fig. 1). The new from melt crystallized material form narrow, fine-grained pathways along grain boundaries or cuts across pre-existing magmatic grains. With increasing amount of the newly crystallized material the original magmatic xenocrysts are resorbed and show highly corroded shapes. The early formed feldspar and quartz grains have strong compositional zoning, with cores reflecting original magmatic composition and rims showing later multiple melt overgrowths. Original magmatic feldspars, biotite and Fe-oxides have different composition then the new phases crystallizing in the partially molten granite. The anisotropy of magnetic susceptibility (AMS) study shows that the original Vosges granitoids fabric was either preserved or completely reworked by the growth of new magnetic phases. The degree of fabric reworking corresponds to the proportion of the newly crystallized material.

We suggest, that the new melt pervasively migrated through the older granitoids resulting in mixture of inherited "xenocrysts" and of new from melt derived crystals. The interaction between new magma and previously crystallized magmatic rock results in variety of granite textures and fabrics. These reflect different degree of equilibration between the bulk rock and the passing melt.

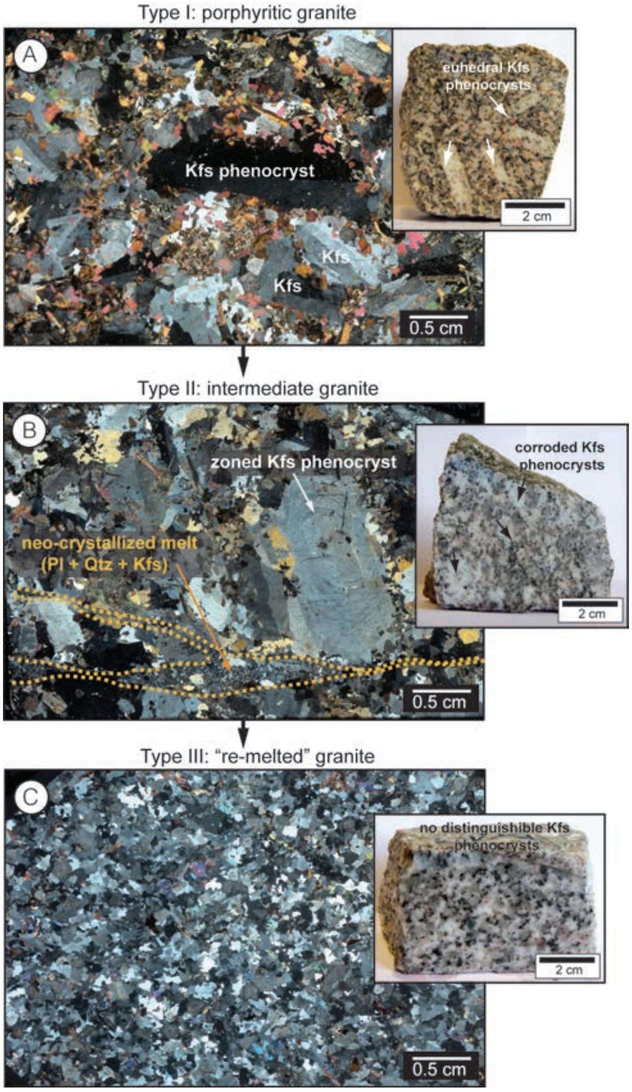

Fig. 1. Textural changes in the Vosges granitoid with increasing degree of pervasive melt intrusion at microscale. (A) Original porphyritic granite; (B) Intermediate granite with original phenocrysts being strongly corroded by newly crystallized material; (C) Fine-grained, completely reworked granite dominated by newly crystallized melt wit occasional relics of original phenocrysts.

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Zechstein limestone (Ca1) joint orientation analysis in mining shafts of "Polkowice-Sieroszowice" copper and silver mine (SE Poland): field study results

Tomasz Selerowicz[1], Andrzej Głuszyński[2] & Mateusz Niedbał

[1] *KGHM CUPRUM sp. z o.o. Centrum Badawczo-Rozwojowe, ul. Gen. Wł. Sikorskiego 2-8, 53-659 Wrocław, e-mail: tselerowicz@cuprum.wroc.pl*

[2] *Polish Geological Institute - National Research Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland, e-mail: andrzej.gluszynski@pgi.gov.pl*

The density and geometry (strike and dip) of fractures are important factors, which need to be considered when a new part of mine is going to be established. The stability of a mining heading is reduced when it is cut by dense fracture zones or fractures that are oriented parallel to the heading. Last papers on the problem of joints in copper and silver mines in Fore-Sudetic Monocline has been published more than 3 decades ago (Salski, 1975; 1977; Salski & Kijewski, 1976; Dumicz & Don, 1977). Since that time new mining areas have been excavated, which allowed continuing the research.

The field study comprised of measurements of strike and dip orientation of fractures, density and geometrical relationship between fractures in the Zechstein limestone (Ca1). During the field work more than 3900 measurements in 11 sites of the "Polkowice-Sieroszowice" mine have been collected.

The southern part of the mine is characterized by relatively dense network of faults with range of displacement and length. Single faults are grouped in faults zones trending NW–SE, and W–E. Towards the north faults gradually disappear, but fracture density generally remains similar in both northern and southern part of the mine.

In "Polkowice" area two main directions of fractures with strikes orientation of NNE–SSW and SE–NW can be observed. Besides small maximum of NE–SW and ESE–WNW directions can be also measured. In "Sieroszowice" area main directions of strikes are NE–SW and SE–NW but the range of strikes orientations are much wider probably due to overlapping of different fracture generations.

Towards the north the 5–10° clockwise rotation of the fracture system is observed. In the most northern part of the mine, where the Jakubów monocline occurs, new sets of fractures have been observed. The orientation of these fractures is more complex probably due to local bending.

In the vicinity of faults with the throw larger than 10 m, the fracture zones with high density of fractures (few fractures in 2–3 m interval) are present. These fracture zones are generally parallel or oblique to faults.

Zones of very high density of fractures (few dozens in 5–10 m interval) have been also documented. Such zones are parallel to the main fault zones and may represent initial stage of fault formation.

The research confirmed previous results (Salski,1975b) from the southern part of the mine that fractures with steep dip angles dominates in the limestones (Ca1). More than 60% of fractures have dip steeper than 85° and around 95% of fractures are within the interval of 65–90° dip angle.

Besides of steep fractures, the fractures with more gentle dip angle of 10–30° have been also observed. They are much less common, but occur in the whole area. The length of those fractures usually does not extend more than several meters. They are generally filled by gypsum-calcite mineral veins. On the fracture surfaces, slickensides have been observed, which indicates the movement between the fracture sides. The strike of the fractures are generally oriented NW–SE. However, curved planes of strike can sometimes be seen.

Field study in "Polkowice-Sieroszowice" mine provided new data on the orientation of fractures measures in the area previously not available for research. The data is mostly correlated with previous results obtained by other authors in the southern part of the mine.

References

DUMICZ, M. & DON, J., 1977. Analiza strukturalna monokliny przedsudeckiej w rejonie Polkowic. *Acta Univ. Wratis*, 378, *Prace Geol.-Miner.*, 6: 279–297.

SALSKI, W., 1975a. Tektonika okolic Lubina. *Biul. Inst. Geol.*, 287: 61–178.

SALSKI, W., 1975b. Zmiany układu spękań w cechsztyńskich skałach węglanowych monokliny przedsudeckiej. *Kwart. Geol.*, 19/3: 583–595.

SALSKI, W., 1977. Rozwój tektoniczny obszaru miedzionośnego monokliny przedsudeckiej. *Rocznik PTG*, 47 (1): 27–48.

SALSKI, W., KIJEWSKI, P., 1976. Wpływ eksploatacji na rozwój spękań w obrębie filarów technologicznych w kopalniach LGOM-u. *Prace Naukowe Instytutu Geotechniki Politechniki Wrocławskiej*, 16: 199–219.

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Structural conditions of landslides development in the Biała Wisełka Valley (Silesian Beskid, Outer Carpathians)

Rafał Sikora

Polish Geological Institute – National Research Institute, Upper Silesia Branch, e-mail: rafal.sikora@pgi.gov.pl

The Vistula River source area is situated on the western slopes of the Barania Góra – Malinowska Skała ridge (Barania Góra Range, Silesian Beskid). The basement of this ridge is building by rocks of the Silesian Unit of the Flysch Carpathians. In this area Silesian Unit is composed by thick-bedded coarse grained sandstone of the Lower Istebna Beds. The Lower Istebna Beds are overlying by medium to thick-bedded sandstones of the Upper Godula Beds, interbedded by shales and thin-bedded sandstones. The Malinów Conglomerate are in their upper part (Burtan 1972, 1973; Nescieruk & Wójcik 2000). These rocks are monoclinally lying to the SW or SE at an angle 10–30°. About 170 landslides was recognized in this area as the results of cartographic works of the **Landslide Counteracting System (SOPO)**. Many of these landslides are recognized as the complex, translational – rotational types of mass movements and are characterized by large range areas, high altitudes of the main scarps and different altitudes of the minor scarps (Sikora & Piotrowski 2013a, b). Most of displacements occurred consequently or obliquely to the beds dip. Structural research included an analysis of lineaments on the basis of the Digital Elevation Model (DEM), aerial radar photography, topographic maps and the measurements joints, faults and bedding planes in outcrops. They were made especially in the Biała Wisełka Valley. Preliminary results of these analyzes show the relationships between development of the landslides scarps, the directions of transport of rock masses and existing discontinuities in the massif. Morphology of the Vistula River source area shows numerous lineaments. The most pronounced of these extend to ENE–WSW direction. Lineaments in the Biała Wisełka Valley corresponds to position of the highest scarps (up to 30 meters) of the landslide, which is situated on northern slope of the valley. Strike of landslide scarps reflects one of the joint sets – parallel to regional scale folds axis (Mastella & Konon 2002). Large displacements on the surfaces of scarps suggest the existence of listric fault. The main scarp was a main fault surface at the same time. The minor scarps are result of faulting, slumping and sliding blocks of the hanging wall. Tectonically transport of rock masses was generally to S along the failure surfaces (shear planes) on different discontinuities (faults, joints, bedding planes) mainly in thin-bedded intervals of the Upper Godula Beds. This direction links to extensional stress axis ($\sigma3$). Tension cracks were created at the foot of highest scarps (perpendicular to the $\sigma3$ direction). Gravitational movements were also connected with erosive activity of Biała Wisełka river and regional seismic activity. The Vistula region is one of the most active areas in Polish part of the Outer Carpathians. On this area were earthquakes of $M>4.3\pm0.4$ in the 15th and 19th centuries (Pagaczewski 1972, Rączkowski 2007). The differences in the development of each of precipitates rocks were also significant. Highly anisotropic Upper Godula Beds were weighted down by the overlying thick-bedded and more homogeneous Lower Istebna Beds which resulted in toppling and falling of large size blocks in the upper part of the landslide (Sikora & Piotrowski 2013c, d). Some of landslides in adjacent area contains caves in colluviums. Among these pseudokarst caves are the longest ones in the Polish part of the Outer Carpathians (e.g. Wiślańska Cave and Miecharska Cave). Their origin is related to fracture of Silesian Unit rocks and the mass movements (Tomaszczyk 2005, Margielewski & Urban 2000, Margielewski *et al.* 2008). The scale of these phenomena shows the catastrophic processes of the landslide movements and their significant relationship to the structural conditions of the region.

References

BURTAN, J., 1972. Szczegółowa mapa geologiczna Polski w skali 1: 50000 arkusz Wisła. *Wyd. Geol.*, Warszawa.

BURTAN, J., 1973. Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1: 50000 arkusz Wisła. *Wyd. Geol.*, Warszawa.

MARGIELEWSKI, W. & URBAN, J., 2000. The type of initiation of mass movements in the Flysch Carpathians studied on the base of structural development of the selected crevice type caves (southern Poland). *Prz. Geol.*, 48: 268–274.

MARGIELEWSKI, W., SZURA, CZ. & URBAN, J., 2008. Jaskinia Miecharska Cave (Beskid Śląski Mts., Outer Carpathians) the largest non-karst cave in the Flysch Carpathians. *Zacisk* 26, 7–13.

NESCIERUK, P., WÓJCIK, A., 2000. Szczegółowa Mapa Geologiczna Polski w skali 1: 50 000 arkusz Wisła (1028) – reambulacja CAG, Warszawa.

PAGACZEWSKI, J., 1972 - Catalogue of earthquakes in Poland in 1000–1972 years. Mater. *Pr. Inst. Geofiz. PAN*, 51: 3–36.

RĄCZKOWSKI, W., 2007. Landslides hazard in the Polish Flysch Carpathians. *Studia Geomorph. Carpatho-Balcanica*. XLI, 61–75.

SIKORA, R. & PIOTROWSKI, A., 2013a. Mapa Osuwisk i Terenów Zagrożonych Ruchami Masowymi gmina Wisła w skali 1: 10000. CAG, Warszawa.

SIKORA, R. & PIOTROWSKI, A., 2013b. Objaśnienia do Mapy Osuwisk i Terenów Zagrożonych Ruchami Masowymi gmina Wisła w skali 1: 10000. CAG, Warszawa.

SIKORA, R. & PIOTROWSKI, A., 2013c. Blokowiska w koluwiach wybranych osuwisk w obszarze źródłowym Wisły (Beskid Śląski). [W:] *V Polska Konferencja Sedymentologiczna POKOS 5*: Głębokomorska sedymentacja fliszowa (red. Krobicki M., Feldman-Olszewska A.). Żywiec, maj 16-19. PIG – PIB, Warszawa: 224–225.

SIKORA, R. & PIOTROWSKI, A., 2013d. Zagadnienia osuwiskowe w rejonie Baraniej Góry (Beski Śląski).). [W:] *LXXII Zjazd Polskiego Towarzystwa Geologicznego*: Wyzwania geologii regionu górnośląskiego w XXI wieku, przewodnik wycieczek terenowych (red. Krobicki M., Sikora R.). Wisła, wrzesień 19-21. PIG – PIB, Warszawa: 98–105.

TOMASZCZYK, M., 2005. Correlation between orientation of pseudokarst caves and joints in NE part of Silesian Beskid Mts. (Outer Carpathians). *Prz. Geol.*, 53: 168–174.

Geologia Sudetica, 2014, 42: 86–87.

Structural reconstruction of a fractured fluid reservoir using single quartz grains of drilling chips

Ágnes Skultéti, Tivadar M. Tóth, Krisztián Fintor & Félix Schubert

University of Szeged, Department of Mineralogy, Geochemistry and Petrology, H-6722 Szeged, Egyetem street 2, Hungary, e-mail: skulteti.agi@gmail.com

In several places, because of the intense deformation, shear zone rocks behave as an excellent fractured fluid reservoir. Therefore the petrographic and structural characterization of the shear zone formations is very important. Nowadays the investigation of the shear zone rocks usually carries out using only a few surface outcrop and drill core specimens, which provide only diffuse informations and draw down with high costs. Our samples were obtained from a newly bored geothermal well located inside the Mecsekalja Shear Zone, in the South Transdanubian region of Hungary. The Szentlorinc-1 well with the drilling chips brought to the surface from around 2 km depth providing an exclusive chance to investigate the shear zone beneath.

The drilling chip collection includes only a few small rock grains unsuitable for traditional petrographic evaluation; more than 80% of the material consists of tiny (< 1 mm) single quartz grains. Quartz is one of the most common minerals in the Earth's crust, and is stable across a wide range of temperature and pressure conditions. As its microstructure is sensitive to diverse deformation mechanisms, quartz may provide valuable information regarding the structural evolution of many different rock types.

Using Raman microspectroscopy, single quartz grains and monomineralic domains characterized by different deformation conditions can be identified and separated. Three microstructurally extreme quartz grain types were discrimi-

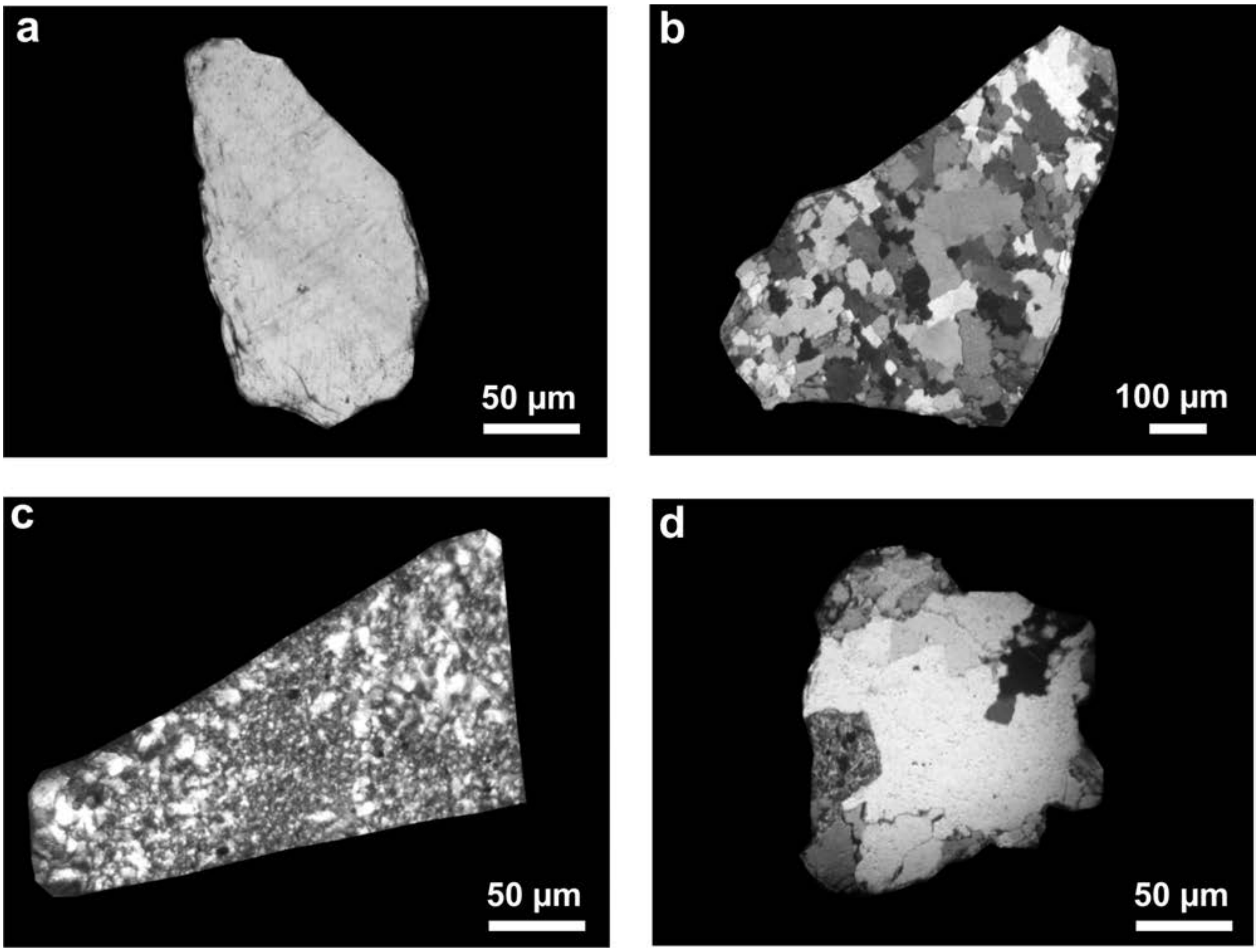

Fig. 1. Characteristic quartz grain types in the analyzed samples. (a) Quartz grain with undulose extinction (type 0: T0), (b) quartz grain with subgrains (type 1: T1), (c) quartz grain with small, undeformed recrystallized grains (type 2: T2), and (d) transitional quartz grain with heterogeneous microstructure.

nated from a subsurface shear zone: grains with undulose extinction (T0), grains with subgrains (T1), and grains with recrystallized grains (T2) (Fig. 1). Moreover, several microstructurally transitional grains were measured which represent combinations of the above extremes. Statistical analysis revealed that the microscopically identified extreme grains possess significantly different spectral attributes, and as such can be divided on the basis of certain variables of their respective Raman spectra. The three extreme quartz grain types were formed by different deformation mechanisms and thus represent distinct deformation conditions. The T0-T1-T2 spectral space can therefore also be considered a virtual deformational space. Although each complex quartz grain measured also appears elsewhere in the deformation process defined by T0-T1-T2 extreme conditions, they together represent a successive deformation path. This combined pathway is assumed to be characteristic for the whole rock volume under study. The computed Raman spectroscopy-based virtual deformational space enabled the determination of the structural evolution of the analyzed shear zone.

Characterization of single quartz grain microstructures using the above technique along the whole well enables localization of the ductile shear zones inside the crystalline complex. This datum was completed with well-log data, which provide information about the brittle deformation. Using these logs brittle shear zones (presumably cataclasite, breccia zones) can be localized along the well. When comparing depths and extensions of the deformed horizons, a coincidence of the brittle and ductile zones becomes clear (Fig. 2). This behaviour may suggest two different evolution schemes. (1) If the firstly evolved ductile shear zones caused softened regions inside the crystalline mass, it could reactivate later in a brittle way due to a tectonic event independent of the early one. (2) Provided, these structures formed due to the same tectonic event, these zones may represent a detachment fault. These structures develop as the result of continental extension, when the middle and lower continental crust deformed in a ductile way is uplifted to the brittle upper crust. As a consequence, ductile and brittle deformation overlaps along the same shear zones (Lister and Davis, 1989). These large scale faults usually divide crystalline blocks of significantly different metamorphic evolutions in the footwall and the hanging wall (metamorphic core complexes), what is a well-known phenomenon in the metamorphic basement of SW Transdanubia, close to the studied well.

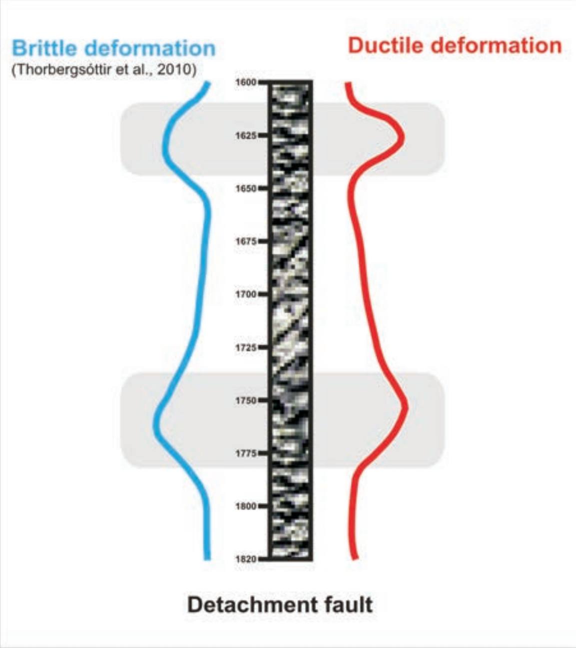

Fig. 2. Ductile and brittle shear zone localizations along the Szentlorinc-1 well.

References

LISTER, G.S. & DAVIS, G.A., 1989. The origin of metamorphic core complexes and detachment faults formed during Tertiary continental extension in the northern Colorado River region, U.S.A. *Journal of Structural Geology*, 11: 65–94.

THORBERGSÓTTIR, I. M., TULINIUS, H., ÁDÁM, L., GUDMUNDSSON, G., HALLDÓRSDÓTTIR, H. B., TRAUSTASON, S., HU, Z. & YU, G., 2010. Geothermal Drilling for Space Heating in the Town of Szentlorinc in SW Hungary. *Proceedings World Geothermal Congress*, Bali, Indonesia.

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Thrust structures in Trangoška syncline, Low Tatras, Slovakia

Ľuboš Sokol & Rostislav Melichar

Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic

The Trangoška syncline (Kettner 1927) is a structure of the Triassic sedimentary rocks which belongs to autochtonous or parautochtonous cover of Tatricum unit of the Central Western Carpathians. These rocks are preserved in a tectonic zone of E–W direction cutting granitoids and metamorphic rocks of Tatricum crystalline unit. The sedimentary record started in the Lower Triassic with basal clastic rocks such as quartzite, arkose and "Werfenian" shale. These rocks are covered by limestone and dolomite. Southern contacts with crystalline rocks are usually transgressive but northern contacts are formed by significant fault structures (Fig. 1).

Strike of the Mesozoic sediments bedding has mostly E–W direction with deviations near fault zones. Dip of these sediments is variable and they dip mostly to N. In the central part of Trangoška structure occurs zone of overturned bedding with dip to SSE (Fig.1 – cross-sections e–f).

Although the Trangoška structure was considered to be a syncline (Kettner, 1927; Zoubek, 1937), we presume that it is simple stratigraphic sequence overthrusted by granitoids during alpine orogeny. Evidence for this thrust was found in the eastern part of the structure, where observed crystalline rocks are thrusted over Werfenian shales along mylonite zone. Some small shear zones were found in foliated limestone from central and western part of Trangoška structure. Dip of mylonite foliation is 17° to NW and dip of foliated limestone is around 25° to S with sense of movement top-to- NW. Samples from these outcrops showed us very strong deformation under the green-schist facies conditions.

The Trangoška tectonic zone was later reactivated in younger deformation phases (Nemčok & Štéc 1989) which created the recent form of structure. Very significant is mostly south dipping normal fault which forms most of the northern border of central and eastern part of structure and creates brittle cataclasite zones and carbonate breccia. This normal fault runs through the Mesozoic sequence in western part of Trangoška structure and splits it in to two parallel limbs separated by gneiss of tatric crystalline basement (Fig.1 – cross-sections a–b, c–d).

Another set of transverse faults separates the western part of structure into blocks. These faults have NW–SE direction with a dip around 60° to SW with components of dextral strike slip and normal fault. The separation into individual blocks makes this part more complex, but allows us to see the structure in different erosional levels.

References

BIELY, A., 1992. Geological map of Low Tatras. State Geological Institute of Dionýz Štúr 1:50 000, Bratislava.

KETTNER, R.,1927. Predběžná zpráva o dosavadních geologických výzkumech v Nízkych Tatrách. Rozpravy České akademie věd a umění, Třída II, 36 (4): 1–19.

NEMČOK, M. & ŠTÉC, M., 1989. Tektonický obraz jaskyne Trangoška. Záverečná správa. Regionálny geologický výskum SSR. IV. Etapa. *Manuscript*, Bratislava, *Archív ŠGÚDŠ.*

ZOUBEK, V. 1937. Dva nálezy rúd v mezozoiku ďumbierskej zóny. *Věstník Stát. Geol. Úst. Československ. Rep.*, 13 (1-2): 211– 231.

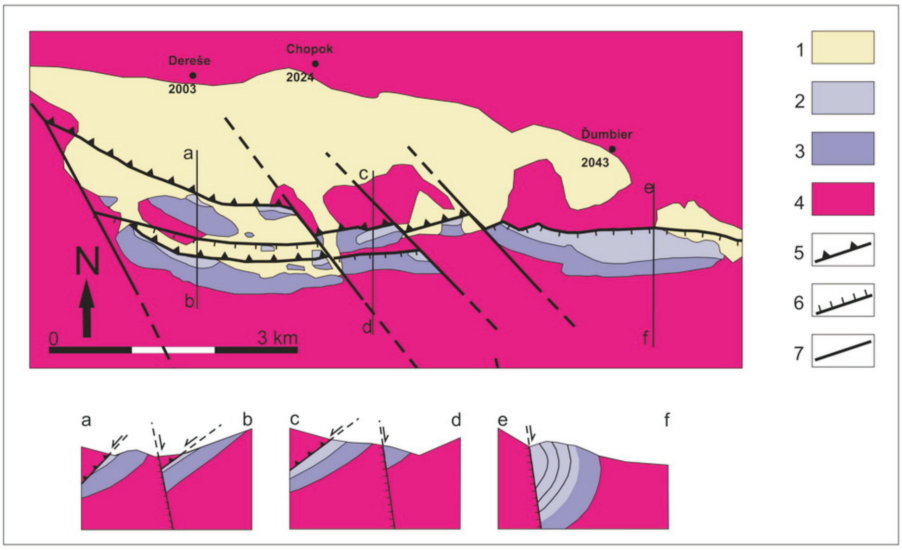

Fig. 1. The simplified geological map (Biely *et al.* 1992, modified) and cross-sections (not in scale) of central and western part of Trangoška structure. 1 – Quarternary sediments; 2 – Triassic limestone, dolomite and carbonate breccia; 3 – Triassic quartzite, arkose and "Werfenian" shale; 4 – Granitoids and metamorphic rocks of tatric crystalline basement; 5 – Nape boundary characterized by mylonitization and deformation under the greenshist facies conditions; 6 – Normal fault characterized by brittle cataclasite zones and carbonate breccia; 7 – Transverse normal faults.

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Quaternary slip at faults in the West Carpathian Foreland: The Upper Morava Basin, Czech Republic

Petr Špaček[1], Jiří Šváb[1], Petra Štěpančíková[2] & Petr Tábořík[2]

[1] *Institute of Physics of the Earth, Masaryk University, Brno, e-mail: spacek@ipe.muni.cz*
[2] *Institute of Rock Structure and Mechanics, Academy of Science of the Czech Rep., Prague*

Increasing demands on safety of nuclear power plants and other critical facilities as well as growing efforts for hazard mitigation in general call for deeper understanding of Quaternary slip history of faults in densely populated parts of the world. Numerous observations suggest that the research related to these issues should include the slowly slipping faults which are characteristic for extra-Alpine Europe, since also these are capable of producing strong earthquakes in relatively long seismic cycles.

In the northeastern part of the Bohemian Massif and its contact with the Outer Western Carpathians a tectonically active crustal domain exists, located approximately between the towns of Trutnov, Svitavy, Zlín, Ostrava and Klodsko and largely coinciding with the central and eastern Sudetes Mts.This region is characteristic by present-day microseismicity as well as historical seismicity concentrated between Sudetic Marginal Fault – Bělá Fault system and southern margin of the Haná Fault zone (line Konice–Kroměříž). The calculated focal mechanisms (very scarce in this weakly active region) indicate combination of strike-slips and steep normal slips on NW–SE to N–E oriented faults. Together with anomalous release of CO_2, likely associated with deeply permeable faults, this indicates a specific state of stress with local permutation of main stress direction from subhorizontal to subvertical orientation.

The reoccuring volcanic activity in Oligo-Miocene, Mio-Pliocene and Plio-Pleistocene (northern part of the active region) and mainly the Pliocene to Pleistocene subsidence in the Upper Morava Basin (UMB; southern part of the region) document the long-term character of tectonic instability with similar deformational style. Up to 60+ m thick succession of fluvial or fluvio-lacustrine clastics of Early-Middle Pleistocene age lies beneath the fluvial terraces, filling narrow intra-basin grabens in UMB. Based on the offset between these anomalous accumulations and the Early-Middle Pleistocene fluvial terraces, minimum cumulative vertical throw of around 100 m is estimated for some faults (or fault sets) in Quaternary.

Recently, we started a detailed study at one of the major faults of the UMB with length of 30+ km and pronounced morphology, the NW–SE trending Kosíř fault. In a 30 m long and 4–6 m deep trench across the fault segment terminating the Tertiary basin against the Late Carboniferous shales (locality Stařechovice near Prostějov) we exposed a unique profile in the upper part of the >17 m thick succession of sediments accumulated at the foot of the fault scarp. The sequence of several generations of Quaternary loess and colluvia on top of the bedrock is disrupted by a numerous steep (60–80°), SW dipping faults and minor antithetic faults (Figure), both exhibiting prevailing normal slip ranging from <1 cm to 1.6 m. These faults form a splay-like system resulting in the stepwise shape of the basin margin revealed by electric resistivity tomographic profiles. Both syn- and post-sedimentary faults are present and the clear basinward increase of their age is indicated. Fault slip-related colluvial wedges were not observed in the exposed profile.

Tectonic origin of the faults is suggested by evident long-term activity localized in a relatively narrow zone with only meter-scale migration towards the slope. However, rather than representing the marginal fault proper, these structures were likely formed by near-surface, creep-like relaxation of the topographic instability controlled by tectonic slip on the main fault. In such setting, the observed absence of structures typical for surface breaking paleoseismic events is not conclusive. The OSL and AMS dating of the loess horizons is currently being carried out and will allow a detailed reconstruction of sedimentary and deformational processes, including the slip rate which is presently estimated to the order of 0.01 to 0.1 mm/year (assuming the Late Pleistocene age of the top loess horizon).

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Determination of tectonic stress using anisotropy of magnetic susceptibility (AMS) – a case study from the Krosno Beds (Silesian Unit, Polish Outer Carpathians)

Aleksandra Stachowska[1], Piotr Ziółkowski[1], Leszek Jankowski[2] & Anna Wysocka[1]

[1] *Faculty of Geology, University of Warsaw, ul. Żwirki i Wigury 93, PL-02-089 Warszawa, Poland, e-mail: a.stachowska@student.uw.edu.pl, Anna.Wysocka@uw.edu.pl, pziolkow@uw.edu.pl*
[2] *Polish Geological Institute, Carpathian Branch, Skrzatów 1, PL-31-560 Kraków, e-mail: leszek.jankowski@pgi.gov.pl*

Magnetic fabric investigations have been conducted during the master's degree research of the first author. Anisotropy of magnetic susceptibility (AMS) in sandstones from different outcrops of the Krosno Beds (Fig. 1) has revealed the existence of typical "sedimentary" fabrics with palaeocurrent directions, as well as magnetic fabrics, recording various degrees of tectonic involvement.

AMS analysis allows for a three-dimensional study of magnetic fabric in a rock sample. Comparison of values of magnetic susceptibility (MS) in three orthogonal directions (axes k1, k2, k3) enables describing magnetic fabric as an ellipsoid. The ellipsoid shape may be spherical (k1 = k2 = k3), oblate (k1 k2 but k2 k3), triaxial (k1 > k2 and k2 > k3), or prolate (k1 > k2 and k2 k3) (e.g. Tarling & Hrouda, 1993).

Axis orientation of the AMS tensor of sedimentary rocks can be interpreted either as an indicator of palaeoflow directions or as a result of tectonic overprint, which progressively modifies the original sedimentary fabric related

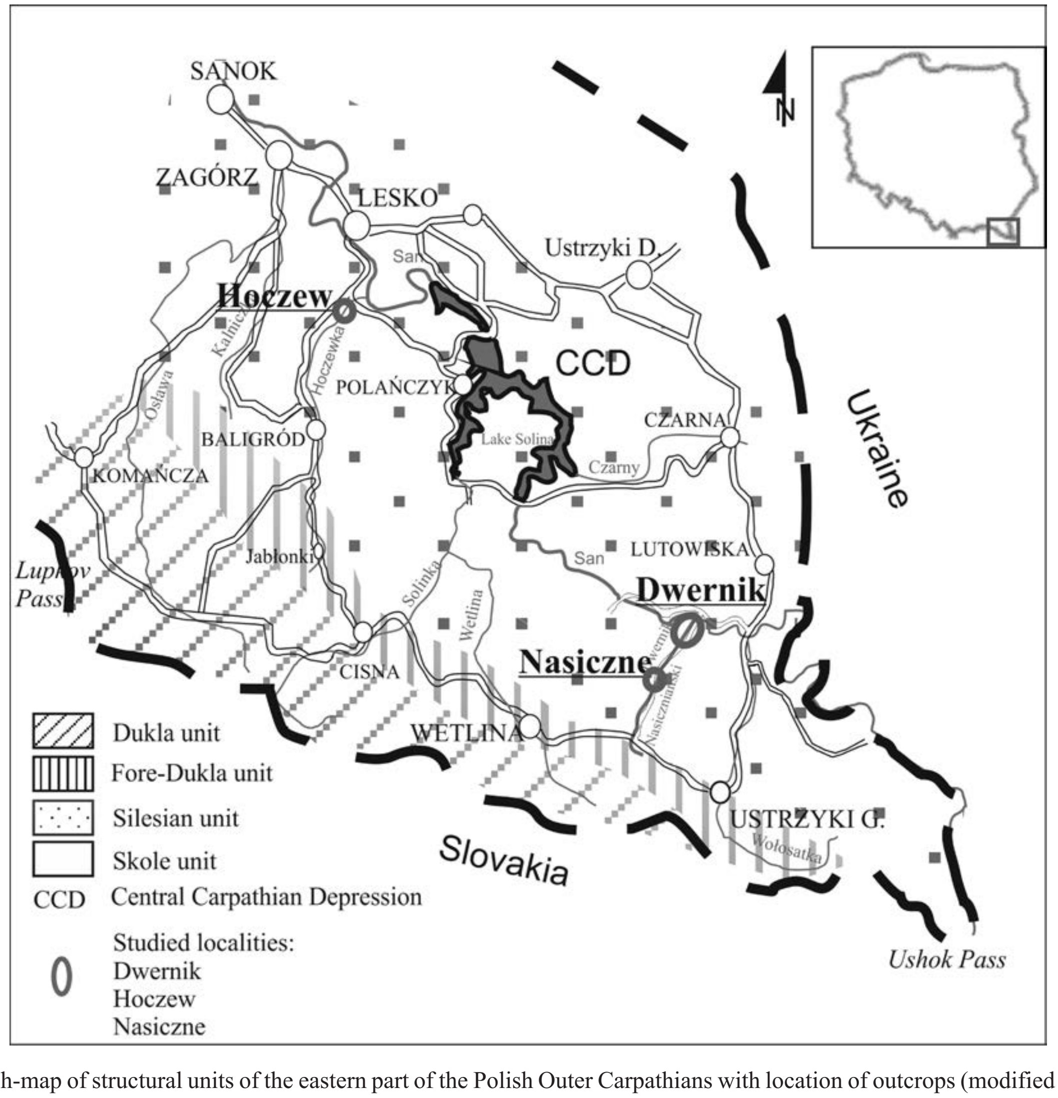

Fig. 1. Sketch-map of structural units of the eastern part of the Polish Outer Carpathians with location of outcrops (modified from Ślączka & Żytko 1978).

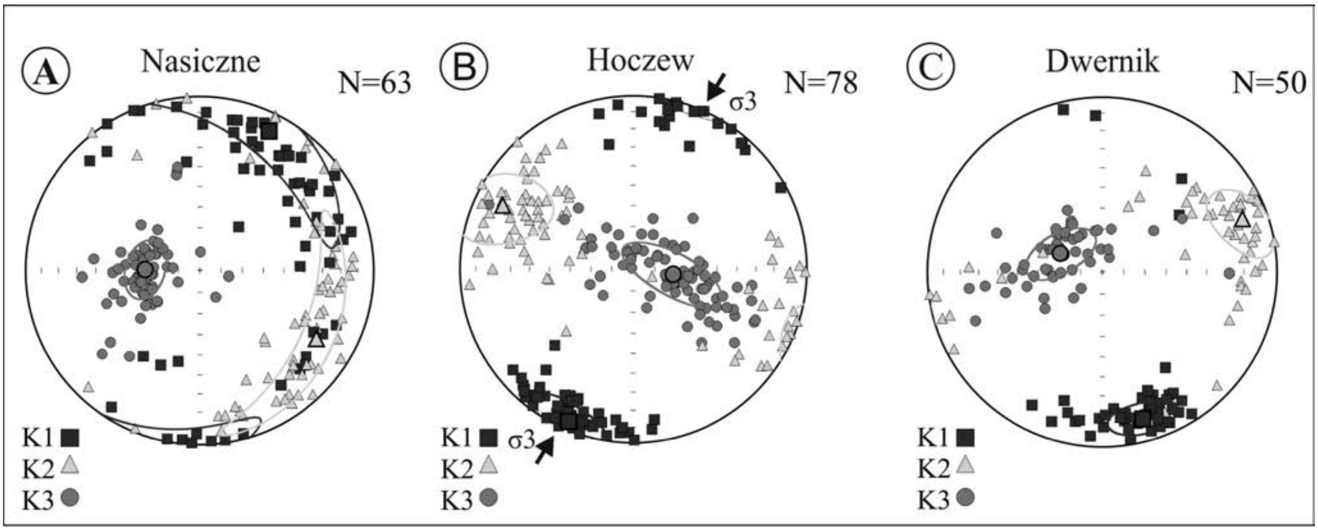

Fig. 2. AMS plots for the studied outcrops, showing three different types of magnetic fabric. Stereographic projection in a tectonic coordinates system. A. oblate shape of the AMS ellipsoid from Nasiczne, B. prolate shape of the AMS ellipsoid from Hoczew, C. triaxial shape of the AMS ellipsoid from Dwernik.

to sedimentation and compaction processes. (Graham, 1966 *fide* Hrouda, 1981). Increasing deformation of the sedimentary rock causes changes in the shape of its magnetic fabric. When analyzing the ellipsoid shape, the magnetic susceptibility axes can be attributed to axes of tectonic stress (*ibidem*). Pares *et al.* (1999) showed that rocks located at a considerable distance from the front of tectonic deformations are characterized mainly by oblate ellipsoids. At a shorter distance, the AMS ellipsoid attains prolate shapes, to become triaxial closest to the deformation front.

During the study, a total number of 190 oriented palaeomagnetic samples (25 × 22 mm) have been collected from three outcrops (Nasiczne, Hoczew, Dwernik). Magnetic susceptibility and its anisotropy were measured using an AGICO's KLY-3 rotating magnetic bridge. The results were analyzed using the ANISOFT42 (Chadima & Jelinek, 2009 AGICO) software.

The measured samples from Nasiczne show magnetic fabric typical of sedimentary rocks. The AMS ellipsoids have oblate shapes and are clearly tilted towards the palaeoflow direction indicated by directional sedimentary structures. No significant directions of stress are recorded in these magnetic fabrics (Fig. 2A). In the remaining outcrops, the primary sedimentary magnetic fabrics have been modified by postsedimentary tectonic stress. Moreover, the rocks from Hoczew show magnetic fabric (prolate shape), whose orientation is almost in line with the position of regional tectonic units (NW–SE). In this case, the prolate shape may indicate the local extension of the NE–SW direction (σ3 axis corresponds to the k1 axis) (Fig. 2B). A different AMS plot was obtained for Dwernik (Fig. 2C). Probably, the rocks occurring in this locality were most susceptible to deformation, as indicated by the triaxial shape of the magnetic fabric.

The research shows that in the case of a stronger tectonic involvement, anisotropy of magnetic susceptibility (AMS) of flysch rocks can be used for determining stress directions. Moreover, detailed lithological-sedimentological studies show that the magnitude of deformation is strongly influenced by bed thickness, grain size, and sedimentary structures within the beds. The results and their interpretation are crucial for the reconstruction of original stress directions in the Silesian sedimentary basin.

References

CHADIMA. M. & JELINEK. V., 2009. Anisoft 42. Anisotropy data browser. AGICO, http://www.agico.com/.

HROUDA. F., 1981. Magnetic anisotropy of rocks and its application in geology and geophysics. *Geofyzika, národní podnik*, Brno, 1–46.

PARES. J. M., VAN DER PLUIJM. B. A. & DINARES-TURELL. J., 1999. Evolution of magnetic fabrics during incipient deformation of mudrocks (Pyrenees, northern Spain). *Tectonophysics*, 307: 1–14.

ŚLĄCZKA. A. & ŻYTKO. K., 1978. Mapa geologiczna Polski w skali 1:200000, arkusz Łupków. *Państwowy Instytut Geologiczny*, Warszawa.

TARLING. D.H. & HROUDA. F., 1993. The magnetic anisotropy of rocks. *Chapman & Hall Press*, London, Glasgow, New York, Tokyo, Melbourne, Madras: 1–213.

WINKLER. A., ALFONSI. L., FLORINDO. F., SAGNOTTI. L. & SPERANZA. F., 1997. The magnetic anisotropy of rocks: principles, techniques and geodynamic applications in the Italian peninsula. *Annali di Geofisica*, 40 (3): 729–740.

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Valley evolution of the Biala Lądecka river – Preliminary results from upper part of the basin

Jakub Stemberk[1] & Petra Štěpančíková [2]

[1] *Department of Physical Geography and Geoecology, Charles University in Prague, Albertov 6, Prague 2, 128 43, Czech republic, e-mail: kuba.stemberk@gmail.com*

[2] *Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, Dpt. Engineering Geology, V Holešovičkách 41, Prague 8, 182 09, Czech Republic*

Biała Lądecka (Biała Kłodzka) river is located in Lower Silesia (Poland) and its valley separates Góry Złote Mts. (Rychlebské hory Mts.) on the northeast from Góry Bialskie Mts. on the southwest. During last year we dealt with geomorphology research in Biala Lądecka river basin, which has a noticeably asymmetrical river basin, probably due to Quaternary tectonic activity of the Sudetic Marginal Fault. According to old research provided in this area by L. Finckh and G. Götzinger (1931), W. Walczak (1954) and A. Ivan (1966), Biala Lądecka river used to flow across the Góry Złote Mts. directly to Oderská nížina Lowland during Pliocene; currently it flows to Nysa Kłodzka Basin. Our research was focused on analysis of all available cartographic materials (geological and topographic maps), available literature and own detail geomorphological mapping of selected landforms. Spatial distribution of these landforms such as gullies, erosion trenches, dellens, alluvial plains, alluvial fans, springs, swamps, river terraces, could potentially indicate recent tectonic activity in the studied area. Moreover, stream network parameters (based on DEM data) such as changes in erosion intensity indicated in longitudinal profiles, slope gradient and Stream Length (SL) index (Hack 1973) for upper river basin were analyzed.

The results will also complete the research focused on tectonics in the adjacent areas, e.g. paleoseismologic studies on the SMF (Štěpančíková *et al.* 2010, 2011), monitoring using dilatometric gauges TM71 installed on the SMF (Stemberk *et al.* 2010), etc. Some of preliminary results will be presented.

References

FINCKH, L. & GÖTZINGER, G., 1931. Erläuterungen zur geologischen Karte des Richensteiner Gebirges, des Neselkoppenkammes und des Neisse-Vorlandes. Wien, 108p.

HACK, J.T.,1973. Stream-profile analysis and stream-gradient index. *U.S. Geological Survey Journal of Research*, 1: 421– 429.

IVAN, A., 1966. Geomorfologické poměry severozápadní části Rychlebských hor. Kandidátská práce, GÚ ČSAV, Brno, 120p.

STEMBERK, J., KOŠTÁK, B. & CACOŃ, S., 2010. A tectonic pressure pulse and increased geodynamic activity recorded from the long-term monitoring of faults in Europe. *Tectonophysics*, 487: 1–12.

ŠTĚPANČÍKOVÁ, P., HÓK, J., NÝVLT, D., DOHNAL, J., SÝKOROVÁ, I. & STEMBERK, J., 2010. Active tectonics research using trenching technique on the south-eastern section of the Sudetic Marginal Fault (NE Bohemian Massif, central, Europe). *Tectonophysics*, 485: 269–282.

ŠTĚPANČÍKOVÁ, P., DOHNAL, J., PÁNEK, T., ŁOJ, M., SMOLKOVÁ, V., ŠILHÁN, K., 2011. The application of electrical resistivity tomography and gravimetric survey as useful tools in an active tectonics study of the Sudetic Marginal Fault (Bohemian Massif, central Europe). *Journal of Applied Geophysics*, 74: 69–80.

WALCZAK, W. 1954. Pradolina Nysy i plejstoceńskie zmiany hydrograficzne na przedpolu Sudetów wschodnich. Polska Akademia Nauk, Instytut geografii, Warszawa, 52p.

Geologia Sudetica, 2014, 42: 93.

Interaction of eclogite with felsic granulite in the orogenic root, Bohemian massif

Pavla Štípská[1,2], Roger Powell[3], Martin Racek[4] & Ondrej Lexa[1,4]

[1] *Center for Lithospheric Research, Czech Geological Survey, 11821 Praha 1, Czech Republic, e-mail: pavla.stipska@geology.cz*
[2] *Ecole et Observatoire des Sciences de la Terre, Institut de Physique du Globe – CNRS UMR 7516, Université de Strasbourg, 1 rue Blessig, F-67084 Strasbourg Cedex, France*
[3] *School of Earth Sciences, The University of Melbourne, Victoria 3010, Melbourne, Australia*
[4] *Institute of Petrology and Structural Geology, Charles University, Albertov 6, CZ-12843 Praha, Czech Republic*

In the Blanský les granulite body, in the Bohemian Massif, in a low-strain zone, a contact is observed where intermediate granulite has been formed by interaction of felsic kyanite-K-feldspar granulite with an eclogite body. This locality is important because such observations are rare; it throws light on how such intermediate granulite may be formed. Whereas partial melt of felsic granulite does appear to intrude the eclogite, the primary mode of generation of intermediate granulite appears to be by diffusion from the melt into eclogite, not by mixing. The primary additions into eclogite in its conversion to intermediate granulite are K_2O and H_2O.

The salient features of the eclogite are garnet with large idiomorphic omphacite inclusions, separated from a recrystallised matrix by a zoned plagioclase moat. The matrix consists of diopsidic clinopyroxene, orthopyroxene, plagioclase, quartz, rutile and minor brown amphibole. There is a continuous transition from this eclogite towards the felsic granulite, involving dramatic textural and mineral assemblage changes. The main consequences of the additions of K_2O and H_2O are the appearance of ternary plagioclase, now with perthitic exsolution, biotite, and also kelyphitic replacement of garnet. From a thermobarometric point of view, ternary feldspar in the same rocks as garnet with grossular-rich cores does not mean that they can be combined to give PT estimates, as has been done in the past. The garnet composition is a relict from the higher P past of the eclogite, while the ternary feldspar grew at intermediate pressure when the eclogite matrix recrystallised.

Zirconium-in-rutile thermometry suggests that at least the metamorphic changes at intermediate pressure, as well as the presence of the ternary feldspar, occurred at temperatures of about 900–950°C . A PT pseudosection of the eclogite is used to suggest that it equilibrated at a pressure of about 20 kbar, and that its recrystallisation occurred at about 12 kbar. A PT pseudosection of an intermediate granulite is used to show that the higher-T features preserved in them formed also at about 12 kbar. Then P-μ and T-μ pseudosections are used to show how the diffusive interaction between the felsic granulite and the eclogite produced the intermediate granulite.

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Quaternary tectonic movements in the Tatra Mts., evidences from cave morphology

Jacek Szczygieł

Department of Fundamental Geology, Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec,
e-mail: j_szczygiel@tlen.pl

The evidence of the movement taking place after the cave formation is a shift in the passages profile. These research focuses on such shifts documented in the Tatra's caves quaternary in the age. Sixteen shifts in eight caves located in all the High-tatric units have been recorded.

Faults sub-parallel to the slopes are spaced from the surface to several tens of meters. The stress analysis showed that those faults are results of the horizontal widening, which usually can be correlated with the slopes orientation. These two factors indicate that these faults formed in the result of the relaxation of the massif. This process may be related to the extension following after the contraction, analogous to the Outer Carpathians (Zuchiewicz, 1998). Can also be caused by extension related to gravity and surface topography. Evidence of this process can be faults where shifts are combined with a 2–3 cm gap.

The faults located under the valley bottoms and / or opposite or obliquely to the slopes are result of rotational uplift of the Tatra Mts. The rotation may cause in various parts of the massif different local stress field. Those faults were developed under transition regime between the extensions of the transtension related to WSW–ENE oriented tension which is consistent with Vojtko *et al.* (2010). Displacements of those faults exhumed pre-existing surfaces: fracture, inter-bed or fault planes. It may indicate that the orientation of the fault plane dependent on the existing structures and not formed at ideal angles relative to the compression principal axes. When the fault plane is rejuvenated, the extensions to the transtension regime determines development of normal dip-slip or oblique-slip faults. Those situations took place especially in the massive limestone but in the thin-bedded limestone too when they are cut by fault. A special case is thin-bedded Middle Triassic limestone of the upper limbs of the major folds dipping steeply to the South. The stress arising from the rotation caused deformation along inter-bed planes, those are the main weakening surfaces in this carbonate complex. The layers steeply inclined toward S had been tilt toward N, which resulted the movement of the layers to each other which is similar to the flexural slip in character.

References

VOJTKO, R., TOKÁROVÁ, E. V. A., SLIVA, U. & PEšKOVÁ, I., 2010. Reconstruction of paleostress fields and revised tectonic history in the northern part of the Central Western Carpathians (the Spišs Magura and Vychodne Tatry Mauntains). *Geologica Carpathica*, 61 (3): 211–225.

ZUCHIEWICZ, W., 1998. Quaternary tectonics of the Outer West Carpathians, Poland. *Tectonophysics*, 297: 121–132.

Geologia Sudetica, 2014, 42: 95.

Tectonics of the Magura Nappe in the Biela Orava region (Western Carpathians) – preliminary results

Frantisek Teťák, Ivana Pešková. & Martin Kováčik

State Geological Institute of Dionýz Štúr, Mlynská dolina 1, Bratislava, e-mail: frantisek.tetak@geology.sk, ivana.peskova@geology.sk, martin.kovacik@geology.sk

State Geological Institute of Dionýz Štúr is providing geological mapping of the Biela Orava region (Fig. 1) since July 2011. The regional-geological mapping at scale 1:50 000 is planned to accomplish till 2016. The study area is built by the tectono-lithofacial units characteristic for the Magura Nappe. They are the Krynica, the Bystrica and the Rača Units (Fig. 2). They are represented by deep-water flysch sedimentary sequences, predominantly in Paleogene age. The tectonic slices of the **Bystrica Unit** are dipping to the south mostly less than 50°. While towards to the south part of the Bystrica Unit, the tectonic slices are steep dipping. The Krynica Unit is steeply dipping to the north. The southern part of the Krynica Unit was backthrusted over the Pieniny Klippen Belt which resulted in origin of the Oravská Magura ridge. It follows that the Magura Nappe have been formed into the fan like structure. The **Krynica Unit** represents a massive body of tectonic slice. The lover part of the tectonic slice is reduced and along their thrust line is strongly tectonically affected. The Bystrica Unit is formed by several thinner tectonic slices. According to similar lithostratigraphic and tectonic features we can divide it into the four zones: greywacke zone, narrow slices zone, glauconite sandstones zone and zone with the klippen structure. The **greywacke zone** is situated on the south of the Bystrica Unit. It is characterized by abundance of greywacke sandstones. It is composed of several thicker tectonic slices (e.g. Beňadovo, Náveterný vrch Hill and Sochov vrch Hill). The tectonic slice of Beňadovo and the base of the Krynica Unit (thin bedded flysch and red claystones) are folded together on the several places. Three or four thin strongly tectonically affected tectonic slices form the **narrow slices zone** of Bystrica Unit. The slices are only 100 up to 500 m thick, but they contain as well as the Beloveža Formation. The **glauconite sandstones** zone in the northern part of the Bystrica Unit is composed of three tectonic slices. They are 700 – 1500 m thick. The **zone with the klippen structure** occurs near Mútne and Oravské Veselé villages. There are accumulated at least 15 thin tectonic slices with dominance of the Beloveža Formation. The klippen structure is formed by the lenses or strips 10 to 300 m in length built by the sandstones and Łącko marls. The tectonic slices are affected by **system of faults oriented generally in N–S direction**. The fault system is observed particularly in the Novo and Lomná surroundings, in the east of the Malý Kopec Hill close to the Novo village, in the north of Námestovo and in the Pilsko and Babia hora Mts. surroundings. The N–S trending faults are steep dipping predominantly with the vertical sense of movements.

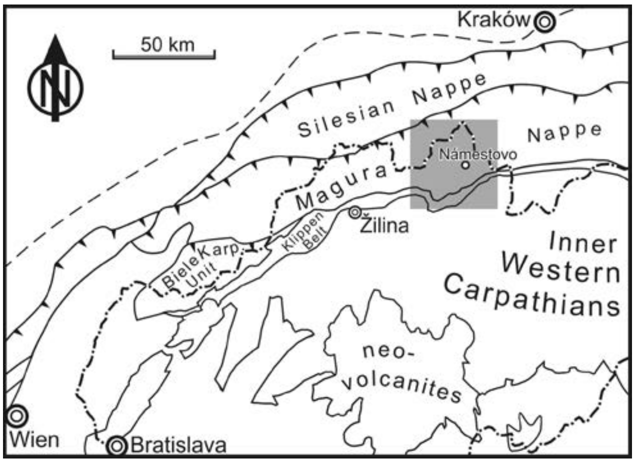

Fig. 1. The simplified tectonic sketch of the western part of the Western Carpathians. The investigated area is displayed by gray rectangle.

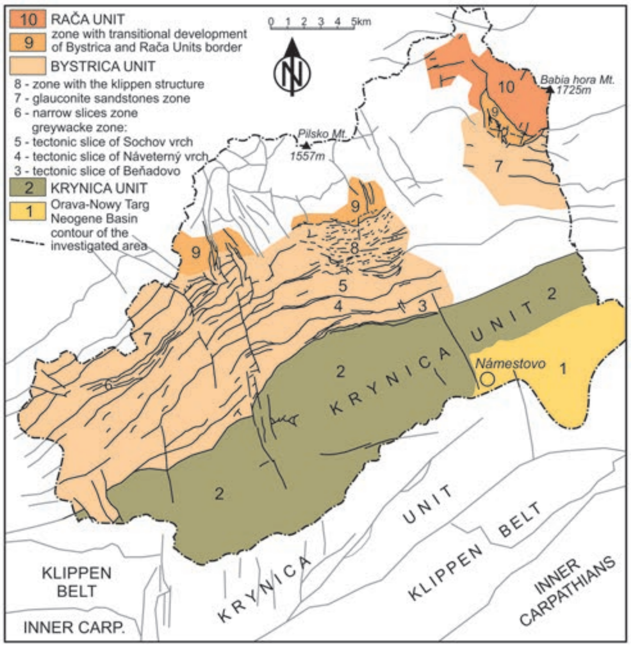

Fig. 2. The tectonic map of the Magura Nappe in the Biela Orava region. Supposed tectonic lines beyond the accomplished area are shown in gray.

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Geological context of landslide occurrence – a case study from Ochotnica valley (Magura Nappe, Polish Outer Carpathians)

Marta H. Tomaszczyk[1,2]

[1] *Polish Geological Institute – National Research Institute, 4 Rakowiecka St., 00-975 Warsaw, Poland,*
e-mail: marta.tomaszczyk@pgi.gov.pl
[2] *Institute of Geology, Faculty of Geology, University of Warsaw, 93 Żwirki i Wigury Street, 02-089, Warsaw, Poland*

Mass movements are frequent phenomena in Polish Outer Carpathian, more than 90% of all landslide in Poland is located there (Długosz, 2011). Latest research during SOPO* programme shows that number of landslides is far more than 25 000 (in 75% of all Carpathian area, excluding e.g. National Parks territory) which accounts for 20% of Carpathian surface.

The aim of the research is to present relation between development of structural landslide and the geological context in the Ochotnica valley. By the term 'structural landslide' author means structural slides running through specific, natural geological surface, which azimuth of movement is strictly related with geological structure (Kleczkowski, 1955). Two groups of factors have influence on evolution of structural landslide: passive and active (Bober, 1984). Active factors are external and internal elements connected with climate, physical processes, and human activity (river erosion, rainfall, melting of snow, earthquakes, land development, reduction in the strength of rocks by changing physical and chemical rocks property) and they affect directly on landslide occurrence and distribution. The passive factors include geological and, resulting them, morphological conditions such as slope aspect; lithology; azimuth and dip of layer, especially folds appearance; presence, type and scale of faults and fractures; thickness of weathering zone (*op. cit.*). The passive factors determinate places where appearance of combination of active factors gives high possibility of landslide occurrence, and they are the issue of this work.

The area of the research is situated in the southern part of Polish flysch Carpathian – Krynicka Subunit and, only a small fragment, Bystrzycka Subunit in Magura Nappe. It contains almost 130 km^2 of Ochotnica river drainage areas'. The region is built of sandstone-shale flysch deposits of turbidite origin. Mechanical characteristic of flysch rocks and complex tectonic affects the development of mass movement. In the examined area more than 500 occurrence of mass movement was describe. More than 90% of them are classified as structural landslide.

Many authors (Kleczkowski, 1955; Mastella, 1975; Bober, 1984; Wójcik, 1997; Zabuski *et al.* 1999; Margielewski, 2004) indicated relation between mass movements and geological structure, but only few (Długosz, 2011) undertook the try to calculate the real effects using mathematical models. To compare landslide distribution with geological factors was built a 3D geological model that contains surface area with map of landslides. Model based on all available data such as geological unit boundary, location of folds, faults and strike/dip measurements that derived from author field work, regional geological maps in 1:50 000 scale and analysis of digital elevation models. A surface area in the model was create from LIDAR data (ISOK** program) which resolution is 1 meter. The field research covers geological and landslides mapping in 1:10 000 scales. Geological mapping contains observation and measurements of lithology, strike/dip orientation, folds and faults occurrence and their parameters, fractures. Landslide mapping include range of landslide body and orientation, height and type of elements of internal morphology (e.g. scarp, trenches, water indications).

The 3D structural model allows using geostatistics analyses to calculate distribution of different parameters such as: consequence ratio (Tomaszczyk *et al.*, 2012), geological formations, density of faults, slope aspect and dip. These final maps were collated to map of landslide occurrence. Proposed methodology allows to define an impact that each parameters have on landslide occurrence and distribution, not only in qualitative way but also quantitative.

* Protection system against landslide risk
** IT system of country protection against extreme hazards (ISOK)

References

BOBER, L., 1984. Rejony osuwiskowe w polskich Karpatach fliszowych i ich związek z budową geologiczną regionu. *Biul. Inst. Geol.*, 340: 115–156.

DŁUGOSZ, M., 2011. Landslide susceptibility in the Polish Carpathians. *Pr. Geogr.*, 320:1–114.

KLECZKOWSKI, A., 1955. Osuwiska i zjawiska pokrewne. *Wyd. Geol.*, Warszawa,

MARGIELEWSKI, W., 2004. Patterns of gravitational movements of rock masses in landslide forms of the Polish Flysch Carpathians. *Prz. Geol.*, 52 (7): 603–614.

MASTELLA, L., 1975. Osuwiska konsekwentno-strukturalne na Podhalu. *Biul. Geol.*, 18: 259–270.

WÓJCIK, A., 1997. Landslides in the Koszarawa drainage basin – structural and geomorphological control (Western Carpathians, Beskid Żywiecki Mts.). *Biul. Państ. Inst. Geol.*, 376: 5–40.

TOMASZCZYK, M.H. & TOMASZCZYK, M., 2012. The relations between geological structure and slope orientation as a context of landslide development. An example from Lubań and Gorc ridge (Gorce, Polish Outer Carpathians). 10 Meeting of Central European Tectonic Studies Group (CETEG). *Min. Slov.*, 44 (1): 109.

ZABUSKI, L., THIEL, K. & BOBER, L., 1999. Landslides in the polish Carpathian flysch. Geology – modelling – stability calculations., IBW PAN, Gdańsk.

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Possibilities of using geological and geophysical data to create a 3D structural model of Upper Silesia Coal Basin

Marta H. Tomaszczyk[1], Marcin Stano[2] & Łukasz Jasiński[1]

[1] *Polish Geological Institute – National Research Institute, 4 Rakowiecka St., 00-975 Warsaw, Poland, e-mail: marta.tomaszczyk@pgi.gov.pl*

[2] *Department of Fundamental Geology, Faculty of Earth Sciences, University of Silesia, 60 Będzińska Street, 41 – 200, Sosnowiec, Poland, e-mail: marcin.stano@us.edu.pl*

Upper Silesia Coal Basin is one of the most important places in geological map of Poland because of energy resources potential, not only coal but also methane (e.g. Coal Bed Methane) and tight gas (Kwarciński *et al.*, 2008). It is also a region liable for peculiar anthropopression, because of long and intensive using of subsurface space. Therefore, a detailed study on geological structure of USCB is essential task for Polish Geological Survey. Nowadays, multidimensional modelling and visualization of geological data permit fundamental advances in Earth Sciences. Recently 3D geological modelling is mostly used in hydrocarbon issues but there is huge potential and possibilities to use it in other fields of interest (Xue *et al.*, 2004; Kaufmann *et al.*, 2008).

Upper Silesia Coal Basin is a homogenous part of Upper Silesia Block built of lithological and facies varied Carboniferous rocks (Buła *et al.*, 2008). Lithostratigraphic profile starts from clastic rock with flysch character (kulm). Later the sedimentation changes to molasses, coal-bearing facies, and first paralic and then limnic (*op.cit.*). USCB, as a part of USB, is divided to few main tectonic Units: Moravian–Silesian Fold and Thrust Belt, Upper Silesia Through, Upper Silesia Fold Belt, Rzeszotary Horst and Liplas Graben (Buła *et al.*, 2008). The borders of USCB determine range of coal-bearing rock of Upper Carbon and regional Fault Zones. In the east, it borders with Małopolska Block along Cracow–Lubliniec Fault Zone and probably continues to north with Odra Fault Zone. West border is complicated and runs along Moravian–Silesian Fault Zone. In the south, it contacts with Brno Block along Hana Fault Zone and continuous to Pery-Pieniny Fault Zone (*op.cit.*).

On USCB area are available two main sources of data: deep boreholes and mine documentations (e.g. short boreholes, maps of coal layer). On USCB drilled more than 5600 deep boreholes, including 1200 boreholes deeper than 1000 m. 57% of USCB area is covered with mine documentations. Only in the southern part, significant number of seismic profiles was done (Jureczka, 2005). 3D geological modelling usually based on continuous information, such as seismic profiles, but some of numeric methods allow creating a mathematically and geometrically correct 3D geological modelling from boreholes, cross section and geological map (Fernadezo *et al.*, 2004, Galera *et al.*, 2003). This kind of 3D models is based on information concluded in 1D boreholes and 2D geological maps and cross section, such as geological unit boundary, location of faults and strike/dip measurements (Kaufmann *et al.*, 2008).

Four research areas were proposed for further analysis: Oświęcim, Pszczyna, Mikołów and Będzin. The differences between them are geological structures, scales of coal production, extent of recognition and source of data. After first step of analysis, that takes into account e.g. coherence, homogeneity, density of data Mikołów area was chosen for further analysis.

The first and most important thing in a geological modelling process is to gather, sort and select usable data. It is fundamental work before building an acceptable model. Selected data need to be processed and reinterpreted in order to create coherent dataset that contains one coordinate system and geological and structural information consistent with current knowledge. One of the main problems in the USCB area is the heterogeneity of data and their interpretations. There is huge variety of recent and older data and only some of them are accurate enough and representative and can be used in 3D modelling (Stano, 2012). Most of older data are only paper form and need to be digitised. In our work, we propose a methodology that provides preparing coherence dataset that can be used in geological modelling and a methodology for creating a structural model. USCB is atypical area, because of very good recognition in Carboniferous strata, and pure in other strata. There is also huge number of data, but with high heterogeneity. That is the reason the USCB needs individual applications.

References

BUŁA Z., ŻABA J. & HABRYN R. 2008. Tectonic subdivision of Poland: southern Poland (Upper Silesia Block and Małopolska Block). *Przegląd Geologiczny*, 56 (10): 912–920.

FERNANDEZ, O., MUNOZ, P., ARBUES, P., FALIVENE, O. & MARZO M., 2004. Three-dimensional reconstruction of geological surfaces: An example of growth strata and turbidite system from the Ainsa basin (Pyrenees, Spain). *AAPG Bulletin*, 88: 1049–1068.

GALERA, C., BENNIS, C., MORETTI, I. & MALLET, J.L. 2003. Construction of coherent 3D geological blocks. *Computer & Geosciences*, 29: 971–984.

JURECZKA, J., DOPITA, M., GAŁKA, M., KRIEGER, W., KWARCIŃSKI, J. & MARTINEC, P., 2005. Geological Atlas of Coal Deposits of the Polish and Czech Parts of the Upper Silesia Coal Basin. 1:200 000. Warszawa.

KAUFMANN, O., MARTIN, T., 2008. 3D geological modelling from boreholes, cross-sections and geological maps, application over former natural gas storages in coal mines. *Computer & Geosciences*, 34: 278–290.

KWARCIŃSKI, J. & HADRO, J., 2008. Coalbed methane in the Upper Silesia Coal Basin. *Prz. Geol.*, 56(6): 485–490.

STANO, M., 2012. Wielowymiarowy model złoża węgla kamiennego kopalni "Knurów-Szczygłowice". MSc thesis. University of Silesia.

XUE, Y., SUN, M. & MA, A., 2004. On the reconstruction of the three-dimensional complex geological objects using Delaunay triangulation. *Future Generation Computer Systems*, 20: 1227–1234.

Geologia Sudetica, 2014, 42: 98.

Predominant processes of forming caves in the Polish part of High Tatra Mts.

Maksymilian Twyrdy

Polish Academy of Science, Podwale, 75, Wrocław, Poland, e-mail: maksymilian.twyrdy@twarda.pan.pl

There are several pseudokarst caves in the High Tatra granitoid core (S Poland). Two genetic types might be distinguished, based on recent, predominant (main) cave-forming process: gravitational-relaxation-tectonic caves (release/tectonic fractures) and weathering-erosive caves. Twelve of thirty-one caves of Polish part of granitoid core are described in this paper and classified into these two types. These, belonging to the gravitational-relaxation-tectonic type of caves, are described in terms of displacement characteristics. Weathering-erosive caves are predominantly formed by surface physical erosion which is shown by their shape. This paper also provides information about tectonic parameters of four new caves (were not named yet), occurred in High Tatra granitoid core: first formed in vertical joint set, on the northern slope of Rysy mountain (called Mała Szpara pod Rysami Cave), which also comprise a main fault zone (according to Grochocka-Piotrowska, 1970). The rest also formed in two crossing, vertically or near-vertically joint sets in Mnich's massif, which one has a several meters faulting displacement.

One of these primary cave-forming processes is jointing, as a result of magma shrinking during melt solidification. Three joint systems occur in High Tatra Mts.: one horizontal set (called L) and two vertical, intersecting sets (called Q and S) (Cloos, 1921). These joint sets intersect to form a non-orthorhombic system, and only rarely perpendicular joint system(s). Fractures are divided into two groups: extension fractures (which apparent in High Tatra morphology features as ridge trenches) and release joints (they are reflecting stress directions in the past, called: "residual stress" (Kieslinger, 1960; Price, 1966). Some of these joints are secondary filled with hydrothermal products, tectonic breccia, cataclasites and/or mylonites. All of these fillings cause a kind of locally weakness of rock structure and thus are creating good conditions to form caves. The most important cracks to forming caves is vertical fracturing of massif because it gives possibility to water erosion, e.g.: rockfalls and gelivation (especially for High Tatras: LGM – Last Glacial Maximum). Gelivation happens also recently, through the snow erosion, so called nival erosion (f.e. Rutkowski, 1974, *unpublished*). The rate of forming weathering-erosive caves depends on: land morphology, mass wasting, temperature amplitudes, forest presence (it reduces erosion speed) and level of insolation. Gaál & Bella (2010) have described geological features of the Slovakian part of High Tatra Mts. They made a discussion about relation between tectonic and weathering processes and presented some examples. I use their conclusions to caves, occuring in the Polish part of High Tatra Mts and gathered information about morphology of these caves, presented by Twyrdy (2014; *unpublished*). I have also considered observations by Wójcik (1961) and assign a predominant cave-forming process to each of these caves. Another case of this paper is showing the correlation between a shape of cave with their predominant cave-forming process, which is clearly observed in High Tatra Mts.

References

CLOOS, H., 1921. Der mechanismus tiefwulkanischer Vorgänge. *Die Umschau*, 27: 40–52.

GAÁL, L. & BELLA, P., 2010. Medzibalvanové jaskyne – terminológia a genetické typy. *Aragonit Journal*, 15 (1): 3–10.

GROCHOCKA-PIOTROWSKA, K., 1970. Fotointerpretacja i geneza struktur nieciągłych w masywie granitowym polskiej części Tatr Wysokich. *Acta Geologia Polonica*, 20 (2): 365–411.

JUREWICZ, E., 2007. Multistage evolution of the granitoid core in Tatra Mountains. Granitoids in Poland, *AM Monograph* No.1, p.307–314.

KIESLINGER, A., 1960. Residual Stress and Relaxation in Rocks. In: *International Geological Congress*, XXI Session, Part XVIII, Kopenhagen, 270–276.

PIOTROWSKI, J. 1978. Mesostructural analysis of the main tectonic units of the Tatra Mts. *Studia Geol. Polon.*, 55: 1–80.

PLAŠIENKA, D. & PROKEŠOVÁ, R. 1996. Towards an evolutionary tectonic model of Križna cover nappe (Western Carpathians, Slovakia). *Slovak Geological Magazine*, 3–4: 279–286.

PRICE, N. J., 1966. Fault and Joint Development in Brittle and Semi-brittle Rock, *Pergamon Press*, 1–186.

RUTKOWSKI, M., 1974. Tektonika Siedmiu Granatów w Tatrach z uwzględnieniem zagadnienia współczesnych ruchów poziomych w szczelinach grzbietowych (niepublikowane). *Archi- wa Instytutu Geologii Podstawowej UW*, Warszawa, 19– 35.

SPERNER, B., 1996. Computer programs for the kinematic analysis of brittle deformation structures and the Tertiary tectonic evolution of the Western Carpathians (Slovakia). PhD Thesis, Tübinger Geowiss. *Arbeiten A27*: 1–120.

TWYRDY, M., 2014 (in press). Pseudokarst caves in the Rybi Potok Valley and the Valley of Five Polish Ponds, High Tatra granitoid massif (S Poland). European General Assembly Conference, 2014, Vienna.

WÓJCIK Z., 1961: Caves in granites in the Tatra Mountains. *Die Höhle*, 2: 75–76.

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Tectonometamorphic evolution of the Rehamna dome (Marocco)

Pauline Wernert[1], Francis Chopin[2], Pavla Štípská[1,3], Karel Schulmann[1,3], Michel Corsini[4], Mohamed El Houicha[5] & Jean-François Ghienne[1]

[1] *École et Observatoire des Sciences de la Terre, Institut de Physique du Globe – CNRS, UMR7516, Université de Strasbourg, 1 rue Blessig, 67084, Strasbourg Cedex, France*

[2] *Department of Geosciences and Geography, P.O. Box 68, 00014,University of Helsinki, Finland*

[3] *Czech Geological Survey, Klárov 3, 11000, Prague 1, Czech Republic*

[4] *Geoazur – CNRS UMR6526, Université de Nice Sophia Antipolis, 250 rue Albert Einstein, 06560 Valbonne, France*

[5] *Département de Géologie, Faculté des Sciences, Université Chouaib Doukkali, El Jadida, Morocco*

The Morocco Variscan belt is considered to be the south-western continuation of the European Carboniferous orogen on the NW Gondwana margin. The Rehamna Massif in the west (belonging to the Coastal Block) is composed of Cambrian to Devonian sediments covering Proterozoic basement and shows only weak deformation. The central and eastern Rehamna parts belong to the Central zone of the western Meseta, formed by Devono-Carboniferous intra-continental basins and by underlying Proterozoic basement. These basins are reworked by late Palaeozoic deformation under Barrovian geothermal gradient and are intruded by felsic magmas.

Three main deformation events (D1, D2 and D3) of variable intensity and geometry were identified. The first forms a flat-lying metamorphic foliation S1, which is deformed by WSW–ENE trending F2 folds with associated sub-vertical S2 cleavage, then heterogeneously reworked by NNE–SSW trending F3 folds with an S3 cleavage moderately to steeply dipping to ESE. Crystallization–deformation relationships in the Barrovian sequence show that biotite, garnet, chloritoid and staurolite grew in the S1 subhorizontal fabric, and that chloritoid and staurolite continued their growth during the early stages of the development of the S3 fabric. Andalusite porpyroblasts around granitoid intrusions show either S3 pressure shadows, pointing to the syntectonic nature of the intrusions or are post-tectonic. Crystallization–deformation relationships, combined with mineral chemistry and mineral zoning are combined with pseudosection modelling into P-T-d paths. Based on these P-T-d paths, three main tectonic events have been recognized: 1) Southward thrusting of an Ordovician sequence over the Proterozoic basement, its Cambrian sedimentary cover and the overlying Devono-Carboniferous basin. This event caused subhorizontal shearing and prograde Barrovian metamorphism of the buried rocks. 2) Continuous shortening resulting first in continuation of burial, then in the development of a syn-convergent extrusion of metamorphosed units to form a dome elongated E–W. This was responsible for syn-convergent detachment of the Ordovician upper crustal sequence. 3) The next episode of convergence took place in a ESE–WNW direction orthogonal to the previous one and is characterized by the accretion of the Rehamna dome to the continental basement in the east. Existing Ar/Ar dating shows that the first and the second deformations occurred during the Late Carboniferous to Early Permian (315–290 Ma) and that the third deformation took place during the Early Permian (290–275 Ma).

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Orthogneiss fabric destruction through melt infiltration and overpressure driven cataclasis

Prokop Závada[1], Pavlína Hasalová[2,1,4], Roberto F. Weinberg[4], Martin Racek[3,2], Alice Roberts[4], Jiří Konopásek[5], & Karel Schulmann[2]

[1] *Institute of Geophysics ASCR, v.v.i.; Boční II/1401, 141 31, Prague, Czech Republic*
[2] *Center for Lithospheric Research, Czech Geological Survey, Klárov 3, 118 21, Prague 1, Czech Republic*
[3] *Institute of Petrology and Structural geology, Faculty of Science, Charles University, Prague, Albertov 6, Czech Republic*
[4] *School of Geosciences, Monash University, Clayton, VIC 3800, Australia*
[5] *Department of Earth Science and Centre for Geobiology, University of Bergen, Allégaten 41, N-5007, Bergen, Norway*

The Eger crystalline unit (ECU) consists of high-grade anatectic rocks as gneisses, migmatites, granites and granulites. They are commonly interpreted as felsic orogenic lower crust that was rapidly exhumed (1.1–2.5 mm/year) during the Variscan orogeny at around 340 Ma along the Tepla–Barrandian and Saxothuringian suture zone (Zulauf, 2002). Peak metamorphic conditions for these anatectic gneisses and granulites were estimated at ca. 740–845°C and 14–16 kBar (Kubíková, 2009). The gneisses and migmatites of the ECU differ by increasing volumes of the crystallized melt and range from banded mylonitic orthogneiss with recrystallized monomineralic bands, through stromatic migmatites, inhomogeneous (dirty) diatexites to isotropic granitic gneisses and granites. Field relationships suggest that these rocks are all derived from the same protolith and represent a continuous sequence. In this study, we aim to understand mechanisms driving the gradual breakdown of the orthogneiss mylonites. We use high-resolution cathodoluminiscence, back-scattered diffraction and micrograph imagery together with the element maps.

We suggest that the continuous transition from banded orthogneiss to non-foliated granitic gneisses or granites is caused by two contrasting mechanisms: (1) Pervasive infiltration of melts that migrated through these rocks, where melt passes pervasively along grain boundaries through the whole rock volume changing the macro- and microscopic appearance of the rock, its mineral composition and geochemical whole-rock signature. The textural variations from orthogneiss to diatexite have been interpreted by different degrees of equilibration between the bulk rock and the passing melt. The melt infiltration is heterogeneous and leaves behind the relicts of banded orthogneisses locally preserved as ghost-like structures in newly formed granitic rocks/diatexites. (2) Cataclastic failure evidenced by ubiquitous cracking of K-feldspar and plagioclase grains, rotation of their fragments, wedge-shaped pools of unlike phases (mimicking crystallized melt) in K-feldspar and plagioclase (Fig.1) and later mechanical mixing of quartz, plagioclase and K-feldspar. The brittle failure of such rocks in the presence of melt has not been previously described and we postulate that it was triggered by high melt pressures coupled with the volume increase of the melting reaction together with increased pore pressure due to pervasive melt migration. Finally, we suggest that the migration of melt through the anatectic region producing the “ghost structures” may imply processes in melt sources, where disaggregation and entrainment of the host in escaping melt provides magmas with source rock xenoliths.

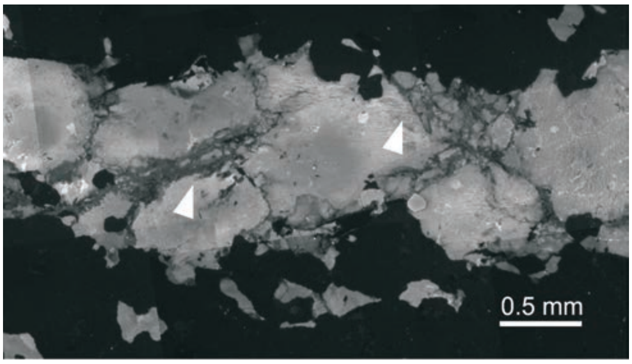

Fig. 1. Cathodoluminiscence image of a K-feldspar band (light grey) in between two quartz ribbons (black). Extensive fragmentation of K-feldspar grains (arrows) along their margins is coupled with melt injection. Crystallized melt is interpreted as the dark grey coatings of the K-feldspar fragments.

References

KUBÍKOVÁ, E., 2009. Redistribuce zikronia v horninotvorných minerálech během vysokého stupně metamorfózy – impli- kace pro krystalizaci metamorfních zirkonů ve felsických granulitech (in Czech). English title: Redistribution of zirkonium in rock forming minerals during high grade metamorphosis – implications for crystallization of metamorphic zircons in felsic granulites. Diploma thesis, Charles University in Prague, 92p.

ZULAUF, G., DÖRR W., FIALA J.,KOTKOVÁ, J., MALUSKI, H. & VALVERDE-VAQUERO, P., 2002. Evidence for high-temperature diffusional creep preserved by rapid cooling of lower crust (North Bohemian shear zone, Czech Republic), *Terra Nova*, 14 (5): 343–354.

Geologia Sudetica, 2014, 42: 101–102.

Rocks deformed in the constrictional regime: L>S to L tectonites in the Orlica–Śnieżnik Dome, the Sudetes, Poland

Andrzej Żelaźniewicz[1, 2], Olga Kromuszczyńska[1] & Natalia Biegała[2]

[1] *Instytut Nauk Geologicznych PAN, Podwale 75, 50-449 Wrocław, Poland, e-mail: pansudet@pwr.wroc.pl*
[2] *Instytut Geologii UAM, Maków Polnych 16, 61-606 Poznań, Poland*

The Orlica–Śnieżnik Dome (OSD), NE Bohemian Massif, contains in its core several gneiss variants with protoliths dated at ~500 Ma. In the western limb of the dome, rodding augen orthogneisses with prominent stretching lineation, mainly L>S tectonites, dominate. In spite of apparently simple mesofabric of the L>S tectonites, these rocks show evidence of multiple deformation on mesoscale and microscale. Scarcity of published results of quartz c-axis fabrics in constrictionally deformed metagranites impedes comparisons of these rocks with other natural examples. Studies of quartz LPOs in rocks deformed in the constrictional regime are seldom and most accounts deal with rocks deformed in the plane or flattening strain regimes that usually develop in planar shear zones.

Microscopic observations of the Spalona augen rodding orthogneisses suggest that the texture formation in these rocks was a protracted, multistage process The quartz c-axis microfabrics show complex yet reproducible patterns that developed under the joint control of strain geometry and temperature. The quartz pole figures are mixed features represented by pseudo-girdle patterns. Quartz grains from quartz ribbons and tails at K-feldspar augens are suitable for micro-s tructural analysis whereas quartz grains from quartzofeldspathic aggregates are less informative, which is likely due to the presence of feldspar grains that recrystallized concurrently in such aggregates. The K-feldspar and quartz rods display shape fabric represented by the triaxial prolate ellipsoid which evolved in the constrictional field with some non-coaxial rotational strain in the general shear regime.

We found that the overall microfabric patterns in gneisses of the Góry Bystrzyckie Mts. are more complex than those obtained by other authors (Cymerman, 1997; Szczepański, 2010) who reported rather simple LPO patterns that were interpreted as mainly type I and type II cross girdles. These were mainly explained by dextral strike-slip shearing in the plane strain and simple shear regime, which develops in a typical shear zone.

In our study the quartz LPOs patterns c-axis orientations in the augen rodding orthogneiss were measured independently for three domains: (1) quartz ribbons, (2) quartzofeldspathic aggregates, (3) pressure shadows at K-feldspar porphyroclasts. Then synoptic diagrams were constructed. In selected samples, quartz c-axis orientations were measured (in the XZ plane) for each of the three distinguished domains separately to check whether their microfabrics are similar or different and to what extent they differ. The pole figures revealed for the quartz ribbons resemble type I cross girdle pattern, which does not agree with the perfect rodding structure of L>>S type gneisses. In spite of the simple constrictional mesofabric, the L>S tectonites show quite complex yet reproducible patterns of quartz c-axis distribution. The microfabrics of the Góry Bystrzyckie gneisses represent a composite feature because of multiple deformation of the rocks and common interplay of strain geometry and temperature during the deformation. They cannot be explained by the model of a shear zone with strain intensity varying across it (Żelaźniewicz *et al.*, 2013).

Because of multiple deformation, the observed quartz LPOs patterns in the rodding gneisses, which are mixed features represented by pseudo-girdle patterns, cannot be utilized as a characteristic identifier of the constrictional regime. However the patterns are compatible with observations made by Sullivan & Beane (2010) in metargilites (amphibolite facies) from California, in which they found microfabrics transitions between true double-girdles and type II cross girdle and small circle girdles around X. Both their and our data are generally consistent with the models of Lister & Hobbs (1980) and Schmid & Casey (1986).

Our study suggests that the texture formation in the studied orthogneisses involved strain partitioning with changing strain rate and kinematics in the general shear regime under temperatures of the amphibolite facies (450–600°C). The estimations agree with those inferred by us from the activity of prism <c> and prism <a> slips and are furthermore compatible with temperature data calculated by a number of authors for the country metasediments. Such

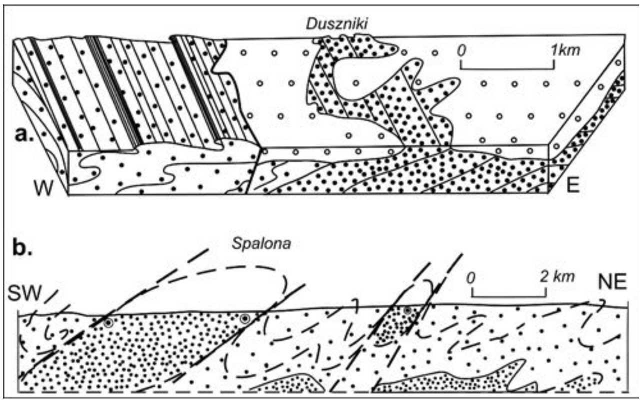

Fig. 1. Tectonic position of rodding augen gneiss bodies in the western limb of the Orlica–Śnieżnik Dome. a – block diagram showing the relationships between the gneisses (dense dots) and mica schists (sparse dots) in the vicinity of Duszniki; b – simplified cross-section through the central part of the Góry Bystrzyckie Mts., showing location of the gneisses in the hinge zones of large-scale folds and the N-ward movement (elongation) which gave rise to opposite strike-slip kinematics at the opposite margins of the Spalona gneiss body (after Żelaźniewicz *et al.*, 2013)

consistencies may suggest that both the metasediments and metagranites were deformed in similar crustal levels.

In the rodding augen orthogneisses, the K-feldspar and quartz rods display shape fabric represented by the triaxial prolate ellipsoid which evolved in the constrictional field with some non-coaxial rotational strain in the general shear regime. Such ellipsoid fits well the observed mesofabric and composite microfabric. It is possible that the strain path started under conditions closer to the plane strain and then changed over to constriction. Such switch can be accomplished in the hinge zone of a large scale fold where the elongation occurs parallel to the fold axis (Fig. 1). Inclined to recumbent folds (F2) of that dimension were identified at the northern tip of the Spalona body in mica schists and gneisses by Żelaźniewicz (1978) (Fig. 1a). It is suggested that the constrictional fabric in the gneisses along with the observed belts of opposite kinematics can be explained by the presence of such folds (Fig. 1b). Opposite sense of shearing found on a small scale within the studied samples can be explained by dominantly coaxial regime in which the inclined objects tend to rotate toward the fabric attractor to reduce an acute angle with it and by different rates of the partitioned strain. On a larger scale, the co-existence of belts with opposite kinematics in the Spalona body can be explained by large-scale folding (Fig. 1).

In the western OSD, more complex strain history was recorded by sheared migmatitic gneisses. We observed that in these gneisses, the fine stretching lineation, expressed by reddish Kfs rods, and parallel with mica lineation was overprinted first by the feldspar-mica lineation and then by the white mica lineation, which all evidence multiple deformation at lowered temperature. The migmatitic gneisses were deformed first at relatively high temperature probably by flattening and then by constriction and coaxial plane strain at general shear regime, when basal and rhomb <a> slip systems operated. The constrictional strain, characteristic of the Spalona augen orthogneisses, was in migmatitic gneisses imposed on the originally planar fabric defined by high-temperature migmatitic layering. The domainal differences in quartz microfabrics recognized in the selected samples are common for the Spalona orthogneisses but uncommon for the sheared migmatitic gneisses. For what was referred to as anatectic orthogneisses, Přikryl *et al.* (1996) also reported the presence of two perpendicular quartz and feldspar fabrics, the succession of the W–E and N–S lineation sets, which agrees with our observations.

We propose that the rodding augen gneisses in the Góry Bystrzyckie Mts. developed in partly or wholly detached bodies which were located in the hinge zones of antiformal folds and bounded by ductile faults. In the eastern OSD, the large-scale, easterly and westerly verging folds was recognized and mapped (Don *et al.*, 2003). In kilometer-scale folds, one can find rodding gneisses (L>S tectonites) in the hinge areas (Międzygórze, Młyńsko, etc). In general, it is proposed that rodding gneisses may serve as a tool for the identification of the large-scale closures of folds developed in the regions which are built of schistose metasediments and metagranites enclosed in them. The constrictional fabric in metagranites may develop in the hinge zones of large scale folds, where the elongation occurred parallel to the fold axes (Fig. 1).

References

CYMERMAN, Z. 1997. Structure, kinematics and an evolution of the Orlica–Śnieżnik Dome, Sudetes. *Prace Państwowego Instytutu Geologicznego*, 156: 3–118.

DON, J., SKÁCEL, J. & GOTOWAŁA, R., 2003. The boundary zone of the East and West Sudetes on the 1:50 000 scale geological map of the Velké Vrbno, Staré Místo and Śnieżnik Metamorphic Units. *Geologia Sudetica*, 35: 25–59.

LISTER, G.S. & HOBBS, B.E. 1980. The simulation of fabric development during plastic deformation, the effects of deformation history. *Journal of Structural Geology*, 2: 355–370 .

PŘIKRYL, R., SCHULMANN, K. & MELKA, R. 1996. Perpendicular fabrics in the Orlické hory orthogneisses (western part of the Orlice–Sněžník Dome, Bohemian Massif) due to high temperature E–W deformational event and late lower temperature N–S overprint. *Journal of the Czech Geological Society*, 41: 156–166.

SCHMID, S.M. & CASEY, M. 1986. Complete fabric analysis of some commonly observed quartz c-axis patterns. *Mineral and Rock Deformation: Laboratory Studies, American Geophysics Union Monography*, 36: 263–286.

SULLIVAN, W.A. & BEANE, R.J., 2010. Asymmetrical quartz crystallographic fabrics formed during constructional deformation. *Journal of Structural Geology*, 32: 1430–1443.

SZCZEPAŃSKI, J. 2010. *Proweniencja i ewolucja tektonometamorficzna serii suprakrustalnej w krystaliniku Gór Bystrzyckich. [Provenance and tectonometamorphic evolution of the supracrustal series from the Bystrzyckie Mts. Crystalline Massif]*. 1–166. Wydawnictwo Uniwersytetu Wrocławskiego; Wrocław.

ŻELAŹNIEWICZ A. 1978. Makroskopowe struktury tektoniczne w metamorfiku polskiej części Gór Orlickich.[Major tectonic structures in the Polish part of the Góry Orlickie]. *Geologia Sudetica*, 13: 67–86.

ŻELAŹNIEWICZ, A., KROMUSZCZYŃSKA, O.& BIEGAŁA, N. 2013. Quartz <c> axis fabrics in constrictionally strained orthogneisses: implications for the evolution of the Orlica–Śnieżnik Dome, the Sudetes, Poland. *Acta Geologica Polonica*, 63: 697–722 .

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Internal Western Carpathian tectonic unit involved in the Klippen Belt structure: the Drietoma Unit – case of study

Ivana Pešková[1], Jozef Hók[2] & Michal Potfaj[1]

[1] *State Geological Institute of Dionýz Štúr, Mlynská dolina 1, 817 04 Bratislava, Slovakia, email: ivana.peskova@geology.sk*
[2] *Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina, pavilion–G, 842 15 Bratislava 4, Slovakia, email: hok@fns.uniba.sk*

The Drietoma unit represents a rock sequence recognizes in the western segment of the Pieniny Klippen Belt (PKB). The lithostratigraphy and tectonic position of the Drietoma unit were contradictory interpreted by various authors since 1969. The specific sedimentary sequences in the stratigraphic range of Upper Triassic (Norian) to Lower Turonian has been originally described as a part of the Manín unit (Began, 1969). Later Rakús (1977) classified mentioned sediments into the Drietoma unit. The younger stratigraphic member, the flych sedimentary sequences (Albian–Turonian), have been interpreted as an integral part of the Drietoma unit. However, there is no evidence about sedimentary or stratigraphy continuity of Upper Triassic to Lower Cretaceous (Berriasian) sedimentary sequences with the Albian–Turonian flysch sediments. Their contact is tectonic.

The position of the Drietoma unit occur between the sedimentary sequences of the internal units of the Western Carpathians on the south and between the integral units of PKB (Kysuca and Czorsztyn unit) on the north. The Drietoma unit is allochthonous tectonic unit thrusted over the tectonic units of the Pieniny Klippen Belt. The Fatricum and the Hronicum tectonic units are in tectonic superposition above the Drietoma unit. The tectonic transport of sediments was generally top to the NW direction. The Drietoma unit is a particular structural element displaced into the area of recent course of PKB from internal or southern zones after the Turonian.

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References

BEGAN, A. 1969. Geologické pomery bradlového pásma na strednom Považí. *Zbor. Geol. Vied, rad Západné Karpaty*, 11: 55–103.

RAKÚS, M. 1977. Doplnky k litostratigrafii a paleogeografii jury a kriedy manínskej série na strednom Považí. *Geol. Práce, Správy 68, Geol. ústav D. Štúra, Bratislava*, 21–38.