Orientations of the principal palaeostresses in the Western Bohemia seismoactive region and their comparison with the recent stresses

Orientace hlavních paleonapětí v seismicky aktivním regionu západních Čech a jejich srovnání s recentními napětími

(6 figs)

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The palaeostress analyses based on the fault striae data were carried out in the Western Bohemia seismoactive region. The results of these analyses were compared with the recent orientations of the principal stresses determined from focal mechanisms of micro-earthquakes. The fault striae data were obtained mainly from the late-Variscan granites. No data for the palaeostress analyses were found in the post-Variscan (Tertiary) sedimentary cover.

Five groups of solutions were determined. In the case of two solutions (solution A: NE-SW compression and NW-SE extension; solution D: NW-SE compression and NE-SW extension), the fault planes were orientated similarly to nodal planes of the focal mechanisms of the recent micro-earthquakes. During the Late Cretaceous to the Tertiary, the sense of shear movements along the active fault planes connected with solution A was opposite with respect to the recent faulting. The geometry of the active faults connected with the palaeostress field D was also similar to recent faulting including the sense of the shear. Thus, in the Western Bohemia seismoactive region, some of the recently active fault planes may represent reactivated pre-existing structures formed during earlier tectonic stages (palaeostress fields represented by solutions A or D).

Key words: Western Bohemia region; faults; striae; palaeostress analysis; recent stress

1. Introduction

The study area is located in the seismoactive Western Bohemia region, an area with strongest recent seismo-tectonic activity in the Bohemian Massif. The most significant epicentral area (Nový Kostel area) occurs to the north of the Cheb Basin, close to the intersection of the Eger and Cheb-Domažlice Grabens. In the past, the micro-earthquake occurrence in the Western Bohemia was interpreted as linked to the recent tectonic activity of the Mariánské Lázně Fault System at the eastern limit of the Cheb-Domažlice Graben (see Bankwitz et al. 2003).

In the Western Bohemia region, the recent regional NW-SE maximum compression and NE-SW maximum extension were determined using various methods (Antonini 1988, Brudy et al. 1997, Dahlheim et al. 1997, Fischer 2002, Havíř 2000, Peška 1992, Slancová – Horálek 2000, Sonnleitner 1993, Vavryčuk 2001). However the geometry of pre-existing structures results earlier tectonic movements under pre-recent stress state. In general, orientation of principal axes of the palaeostress field can significantly differ from the orientations of recent principal stresses.

In the western part of the Bohemian Massif, the palaeostress analyses were previously carried out in the region to the SW and NE of the recently seismoactive area (Adamovič – Coubal 1999, Coubal – Adamovič 2000, Peterek et al. 1997). In the recently seismoactive area, the orientations of principal palaeostresses were investigated only using the geometry of depocenters of the Tertiary sediments in the Cheb Basin (Špičáková et al. 2000).

The aim of this study is to present results of palaeostress analysis from fault populations in the Western Bohemia region and to correlate post-Variscan palaeostresses with the recent stresses. Finally, the stress field evolution in this seismoactive region was interpreted. The palaeostress analysis reported in this study was focused on the Cheb Basin and its surroundings and on the area along the Mariánské Lázně Fault System (Fig. 1). Fault striae data were measured mainly in the late-Variscan granite plutons (the Karlovy Vary pluton and the Smrčiny pluton, Fig. 2) and at a few sites also in the crystalline units northwards of the Cheb Basin (Fig. 2). In addition, several other regions near the Mariánské Lázně Fault System to the S of seismoactive area were studied (Fig. 3). Here, the fault striae data were also measured predominantly in the late-Variscan granite bodies (the Bor pluton and the Kladruby pluton including Sedmihoří stock, Fig. 3) and at a few sites also in the Cadomian intrusions (Lestkov composite pluton and small granite body in the Moldanubian unit, Fig. 3).

In the study area, the post-Variscan sedimentary cover is represented only by the Tertiary sediments deposited mainly in the Eger Graben and the Cheb-Domažlice Graben. But no reliable data were obtained from the Tertiary sediments of the Cheb Basin and from sedimentary cover of the Bor pluton. That is why the palaeostress analyses reported in this study are based mainly on the fault striae data measured in the late-Variscan granites.

2. Geological and structural setting

In the study area, the Variscan crystalline basement comprises rocks of the Saxothuringian Zone, the Moldanubian Zone and the Teplá-Barrandian Zone of the Bohemian Massif (Fig. 1). The gneisses and mica schists of

Fig. 1 Geological map of the Western Bohemia region. a) Map of the position of the western part of the Bohemian Massif in the central Europe within the Variscan Belt. b) Geological map of the western part of the Bohemian Massif with areas cited in the text: Kv – Karlovy Vary Pluton – Nejdek part; Ky – Kynžvart granite body; Sm – Smrčiny Pluton; Sv – Svatava crystalline area; VSP – Vogtland-Saxonian Palaeozoic Complex; ML – Mariánské Lázně Ophiolite Complex; ChB – Cheb Basin; Bo – Bor pluton; Kl – Kladruby pluton; Sp – Sedmihoří stock; Le – Lestkov composite pluton.

the Svatava and Smrčiny crystalline units and the phyllites of the Vogtland-Saxonian Palaeozoic Complex represent the Saxothuringian units in the study area. The Moldanubicum of Bohemian Forest formed by high-grade metamorphic rocks occupies the southwestern part of the studied area. To the E, medium-grade crystalline rocks of the Teplá-Barrandian Zone pass into the low-grade Proterozoic rocks. Small metamorphosed and deformed Cadomian plutonic bodies (i.e. the Lestkov composite pluton) occur in the western part of the Teplá-Barrandian Zone along the West Bohemian fault zone.

The rocks of the Saxothuringian Zone dip southeastwards under the Teplá-Barrandian Zone (Tomek et al. 1997) separated by the Mariánské Lázně Ophiolite Com-

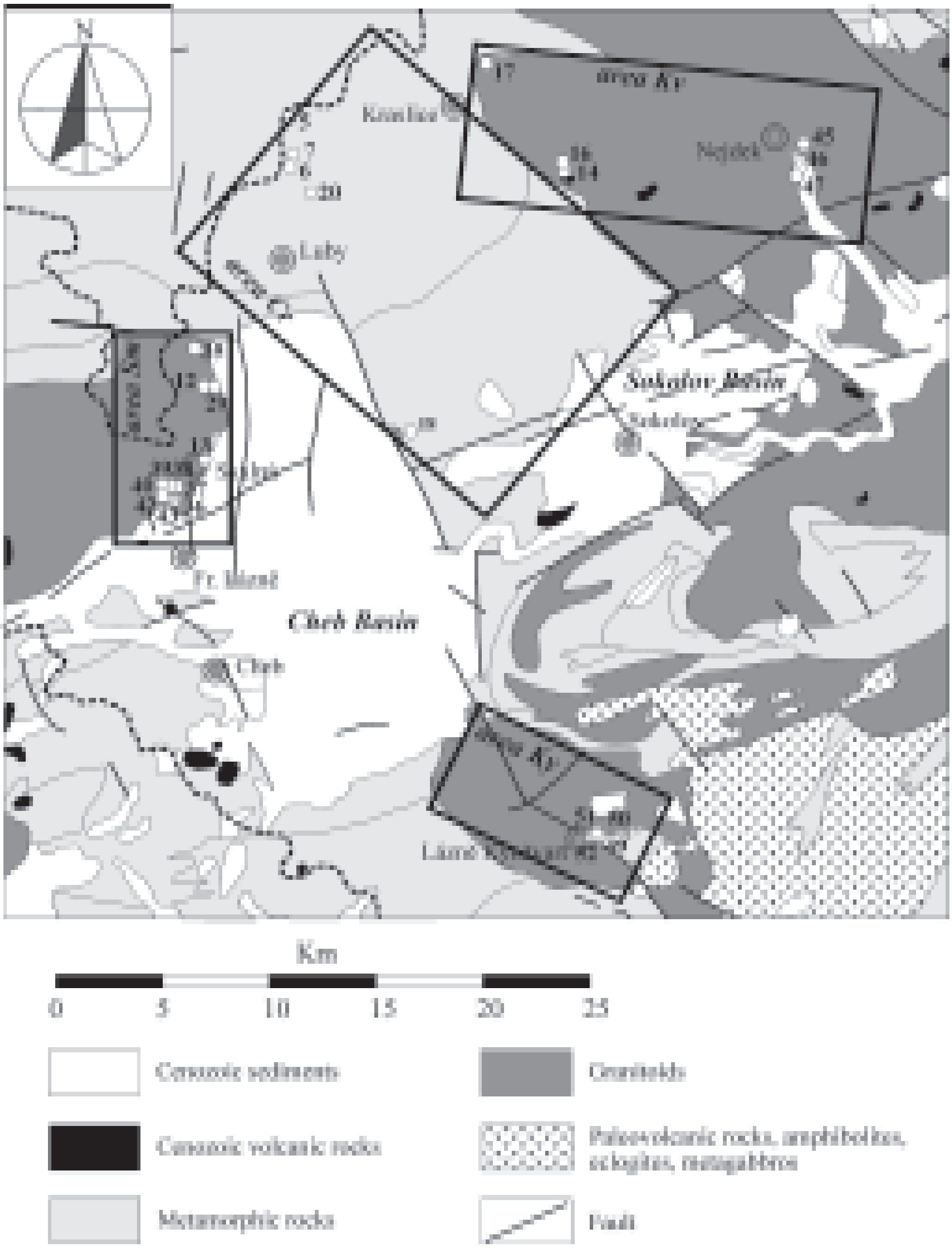

Fig. 2 Map showing positions of the areas examined in the northern part of the study area: area Kv – Nejdek part of the Karlovy Vary pluton; area Ky – Kynžvart granite body; area Sm – eastern margin of the Smrčiny pluton; area Cr – the bodies of quartzites and orthogneisses in the crystalline basement; white circles – sites where the fault striae data were measured (see text for more information).

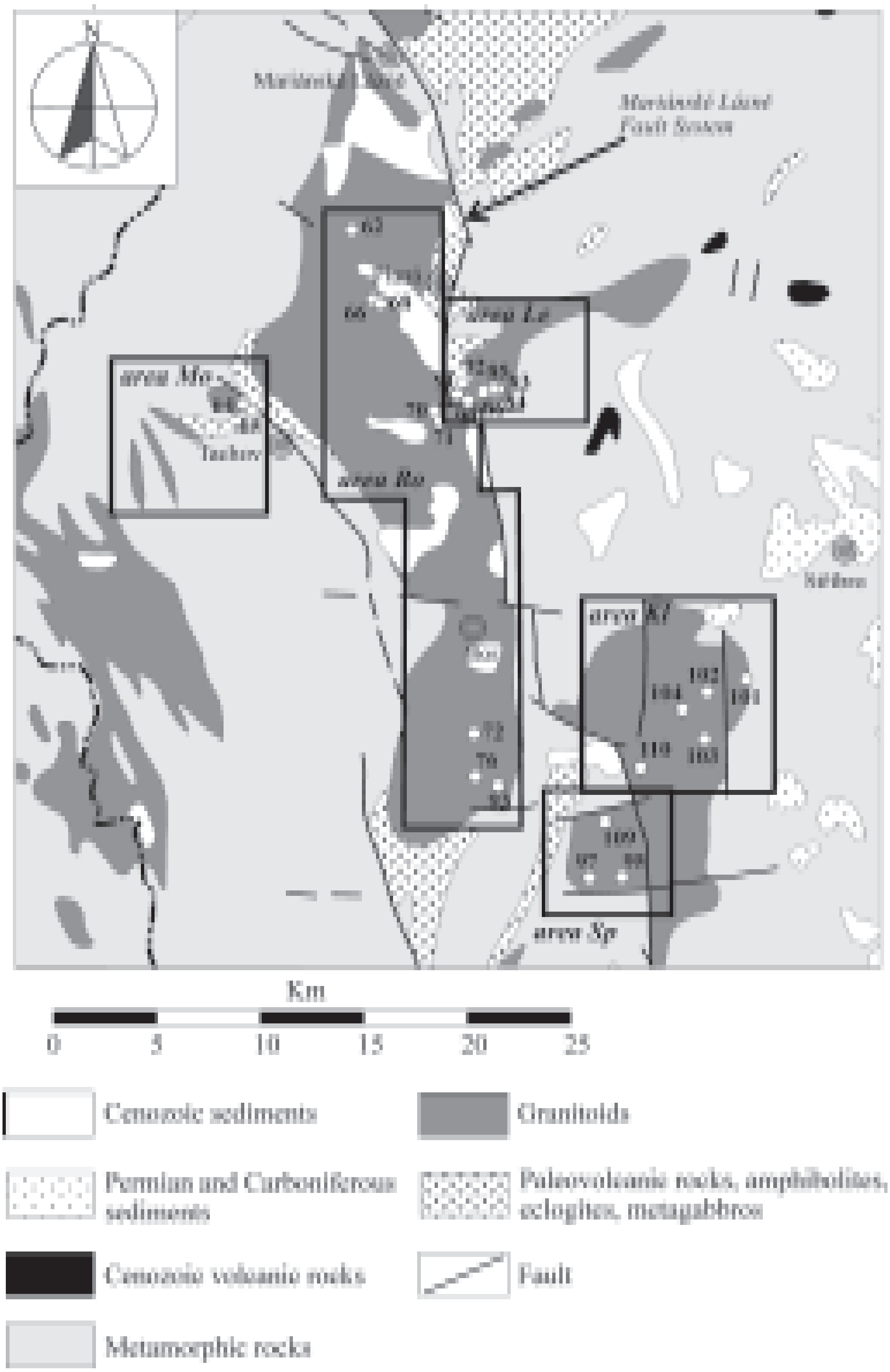

Fig. 3 Map showing positions of the areas examined in the southern part of the study area: area Bo – Bor pluton; area Kl – Kladruby pluton except of the Sedmihoří Stock; area Sp – Sedmihoří Stock; area Le – Lestkov composite pluton; area Mo – small granite bodies in the Moldanubian Zone near Tachov; white circles – sites where the fault striae data were measured (see text for more information).

plex along a tectonic contact trending ENE-WSW. The Tirschenreuth-Mähring ductile shear zone represents the boundary of the Saxothuringian Zone against the Moldanubian Zone (Zulauf 1993). The boundary of the Teplá-Barrandian and the Moldanubian Zones is formed by a NNW-SSE trending shear zone (the Bohemian quartz lode according to Cháb et al. 1997, Mísař et al. 1983; the West Bohemian shear zone according to Zulauf 1994).

Large late-Variscan granite plutons intruded episodically the crystalline basement during several phases. Older granite bodies were emplaced during the Viséan, the emplacement of the younger granites took place during the Westphalian up to the Stephanian (Cháb et al. 1997, Mlčoch 1997, Siebel et al. 1997). In the northern part of the studied area, the granites of the Karlovy Vary Pluton and the Smrčiny (Fichtelgebirge) Pluton intruded the Saxothuringian crystalline rocks (Mlčoch 1997). To the S, some plutons seem to be associated with the major Variscan shear zones, e.g., The Bor pluton, which crops out near the West Bohemian shear zone (Siebel et al. 1997). The late-Variscan granitoids in the western part of the Bohemian Massif are largely unaffected by late Variscan tectonic events (Siebel et al. 1997). Trzebski et al. (1997) interpreted that the emplacement of these granite bodies occurred postkinematically with respect to the Variscan shear deformation. On the other hand, the plutonic bodies were affected by several post-Variscan faulting events.

During the Cenozoic, two grabens filled with Cenozoic sediments and products of volcanic activity developed in the Western Bohemian region (Fig. 1b). The ENE-WSW Ohře (Eger) graben is developed along the eastern escarpment of the Krušné hory Mts. In the Ohře graben, the age of deposited fluvial and lacustrinne sediments ranges from the Middle Eocene to the Lower Miocene, and only in the Cheb Basin the Pliocene sediments are developed (Malkovský 1979, 1987). The tectonic activity of this graben was connected with intra-plate volcanism. The most significant phase of volcanic activity occurred during the Oligocene-Lower Miocene, younger volcanic phases occurred in the Pliocene. The Quaternary products of the volcanic activity are situated near the intersection of the Ohře zone and the Cheb-Domažlice graben (Kopecký 1978, Ulrych et al. 1999). The NNW-SSE Cheb-Domažlice graben cuts across the Ohře zone in the area of the Cheb Basin. The age of the relics of continental sediments deposited in the Cheb-Domažlice graben ranges from the Oligocene to the Pliocene. The eastern limit of the Cheb-Domažlice graben is formed by the Mariánské Lázně fault.

The fault zones were repeatedly reactivated. In the past, the relationship between the recent seismotectonic activity in the Western Bohemia region and the recent tectonic activity of the Mariánské Lázně fault system was commonly considered (Bankwitz et al. 2003). In the Nový Kostel epicentral area northwards of Cheb Basin, clusters of micro-earthquake epicentres are significantly aligned along the NNW-SSE to N-S line (for instance Fischer – Horálek 2003, Horálek et al. 2000, Skácelová et al. 1999) and indicate the existence of NNW-SSE to N-S tectonically active zone (Počátky-Plesná zone according Bankwitz et al. 2003), oblique to the Marianské Lázně fault.

3. Applied methods of palaeostress analysis

The palaeostress analysis presented in this study was based on the study of geometry of fault planes with striations (strike of dip and dip of the fault plane, azimuth and plunge of the striation, sense of the slip, confidence value for sense of the slip). At most part of sites, a small number of fault striae data was found, insufficient for reliable stress analysis at the individual site in respect of heterogeneity of these data. The palaeostress analyses were thus applied to the whole data sets comprising all measurements in the specified areas.

Several methods of palaeostress analysis based on fault striae data exist. The correct determination of the palaeostress state requires the homogeneous data set corresponding to one common deviatoric stress. In the case of the heterogeneous fault striae populations, the separation of these data sets is necessary.

The graphical method of Angelier and Mechler (1977) represents the very simple method convenient to easy determination of the approximate orientations of principal palaeostress axes. In some cases, this graphical method was applied for determination of the approximate results also in this study. Principle of this method is to define the area of all possible orientations of the σ_1 axis (or the s_3 axis respectively) which theoretically satisfy to whole homogeneous set of data.

The numerical methods provide more detailed determination of the palaeostress state in the form of a reduced stress tensor defined by Angelier (see Angelier et al. 1982). The reduced tensor has four degrees of freedom. Three angular variables describe the orientations of principal stress axes σ_1, σ_2 and σ_3, fourth variable is the shape ratio ϕ defined by Angelier (1975) as $\phi=(\sigma_2-\sigma_3)/(\sigma_1-\sigma_3)$. The numerical methods of the palaeostress analysis are based on the inversion using minimizing function (see Angelier 1984, 1990).

The ranges of all four variables of reduced stress tensor are finite, thus it is possible to take the finite group of tensors, which uniformly cover all possibilities. This fact is used by robust method based on the testing of all possible reduced tensor configurations against fault striae data (e.g. Gephart – Forsyth 1984, Gephart 1990, Hardcastle – Hills 1991). In this study, the program BRUTE3 (Hardcastle – Hills 1991) was used for test of all possible reduced tensor configurations against measured data and for selection of the acceptable tensors, which satisfy the limits. The first limiting factor was minimum value of the resolved shear stress, which has to achieve or exceed the limit following from the Coloumb criteria: $\sigma_t = C+\mu.\sigma_n$ (σ_t and σ_n are value of shear stress and normal stress respectively, C is cohesion and μ is coefficient of friction). C and μ describe the properties of the discontinuity and not the properties of rock mass, because the reactivation of pre-existing faults is assumed. Second factor was maximum limit 25° for angular difference θ between the rake of maximum resolved shear stress and the rake of the measured striations. For test by program BRUTE3, each principal axis of tested tensors was reoriented by 10° increments, value of shape ratio ϕ was changed in range 0.1–0.9 by 0.1 increments. The program cannot test the extreme cases of uniaxial compression and uniaxial extension.

The selection of numerous acceptable solutions for sub-groups of analysed data allows to separate the heterogeneous data. This separation was performed by the program SELECT (Hardcastle – Hills 1991). The selected acceptable orientations of principal stress axes were contoured and for each principal axis the relevant eigenvector of orientation matrix was computed as the most probable orientation. The mean value of the angular difference θ between the rake of maximum resolved shear stress and the rake of the measured striations was also computed. The "best" solutions are reduced tensors with least mean value of θ.

The results of palaeostress analyses were compared with the results of analyses of the recent principal stresses based on the focal mechanisms of micro-earthquakes in the epicentral area Nový Kostel (Havíř 2000, 2003).

4. Results of palaeostress analysis

The orientations of the meso-scale fault planes with striations were measured in the nine areas (Figs 2 and 3): In norther part of the study area, three areas were examined in the Variscan granite plutons (area Kv – Nejdek part of the Karlovy Vary pluton; area Ky – Kynžvart granite body north-westwards of Mariánské Lázně; area Sm – eastern margin of the Smrčiny pluton) and one area in the metamorphic rocks north of Cheb Basin (area Cr). Other five areas are located to the S: three areas in the bodies of Variscan granites (area Bo – Bor pluton; area Sp – granites of the Sedmihoří stock; area Kl – granites of the Kladruby pluton except of the Sedmihoří stock) and two areas in the pre-Variscan intrusions within the crystalline rocks of the Moldanubian Zone (area Mo – small granite body NW of Tachov) and of the Teplá-Barrandian Zone (area Le – southwestern part of the Lestkov composite pluton).

The observed faults with striation were formed by straight smooth planes. The slickenside indicators were mostly represented by scratches and/or crystal fibres. The crystal fibres are among the best kinematic indicators (Doblas 1998). In the cases of well-developed crystal fibres, the determination of the sense of slip movements along the fault plane was highly confident. Along some planes, the Riedel fractures or synthetic hybrid fractures were developed.

The computed results of the palaeostress analysis were divided into five groups of solutions (A-E; Fig. 4). In the case of the solutions A, the axis of σ_1 (maximum compression) is NE-SW, the axis of σ_3 (maximum extension) is NW-SE. Both axes are sub-horizontal or only gently plunging. These solutions were determined in major parts of the areas situated in the late-Variscan granites (areas Kv, Ky, Sm, Bo, Kl).

Similar result is represented by the solution B (Fig. 4). The σ_3 axis is orientated NW-SE or NNW-SSE, the σ_1 axis is steeply plunging towards SW or WSW. The solution B was determined only from faults measured at the site 36 at the eastern margin of the Smrčiny pluton (area Sm). Faults corresponding to this solution were not observed at other sites. Considering this fact, the palaeostress field represented by solution B has probably only local significance.

Solutions C are represented by the N-S σ_1 axis and the E-W to WNW-ESE σ_3 axis. Both axes are sub-horizontal to moderately plunging. These solutions were determined in the Karlovy Vary pluton (areas Kv and Ky) and at the eastern margin of the Smrčiny pluton (area Sm). In spite of similarity of these solutions with the solutions of group A, there are several sites where both solutions were determined and where the faults with striations related to these two solutions form heterogeneous data set, not corresponding with one common stress state. Thus the solutions C cannot be product of regional variability of the orientations of principal palaeostresses, but they represent a different tectonic stage.

In the case of solutions D, the axis of maximum compression σ_1 is NW-SE, the axis of maximum extension σ_3 is NE-SW, and both axes are sub-horizontal to gently plunging (Fig. 4). These solutions were determined in all areas in the southern part of the study area, in the late-Variscan granites (areas Bo, Kl and Sp) and in the pre-Variscan intrusions (areas Le and Mo). On the other hand, these solutions were not found in the Karlovy Vary and Smrčiny plutons.

The last group of solutions (group E) contains only one solution determined at site 64 in a small pre-Variscan granite body NW of Tachov (Figs 3 and 4). In this case, the sub-horizontal maximum compression is NE-SW and maximum extension is sub-vertical.

Only several faults with striations were found in the quartzites and orthogneisses of the crystalline units northwards of Cheb Basin (in the Svatava crystalline area and in the Vogtland-Saxonian Palaeozoic complex, Fig. 1). This heterogeneous, poor-quality set was insufficient for palaeostress analysis. At the site 18, the faults can be correlated with the solution C measured elsewhere. However, kinematic indicators found were not reliable to determine the sense of movement along these fault planes. Two different solutions of the palaeostress analysis are possible in this case (Fig. 5). One of the two possible solutions (solution Cr/A2) corresponds well to the solution of group C.

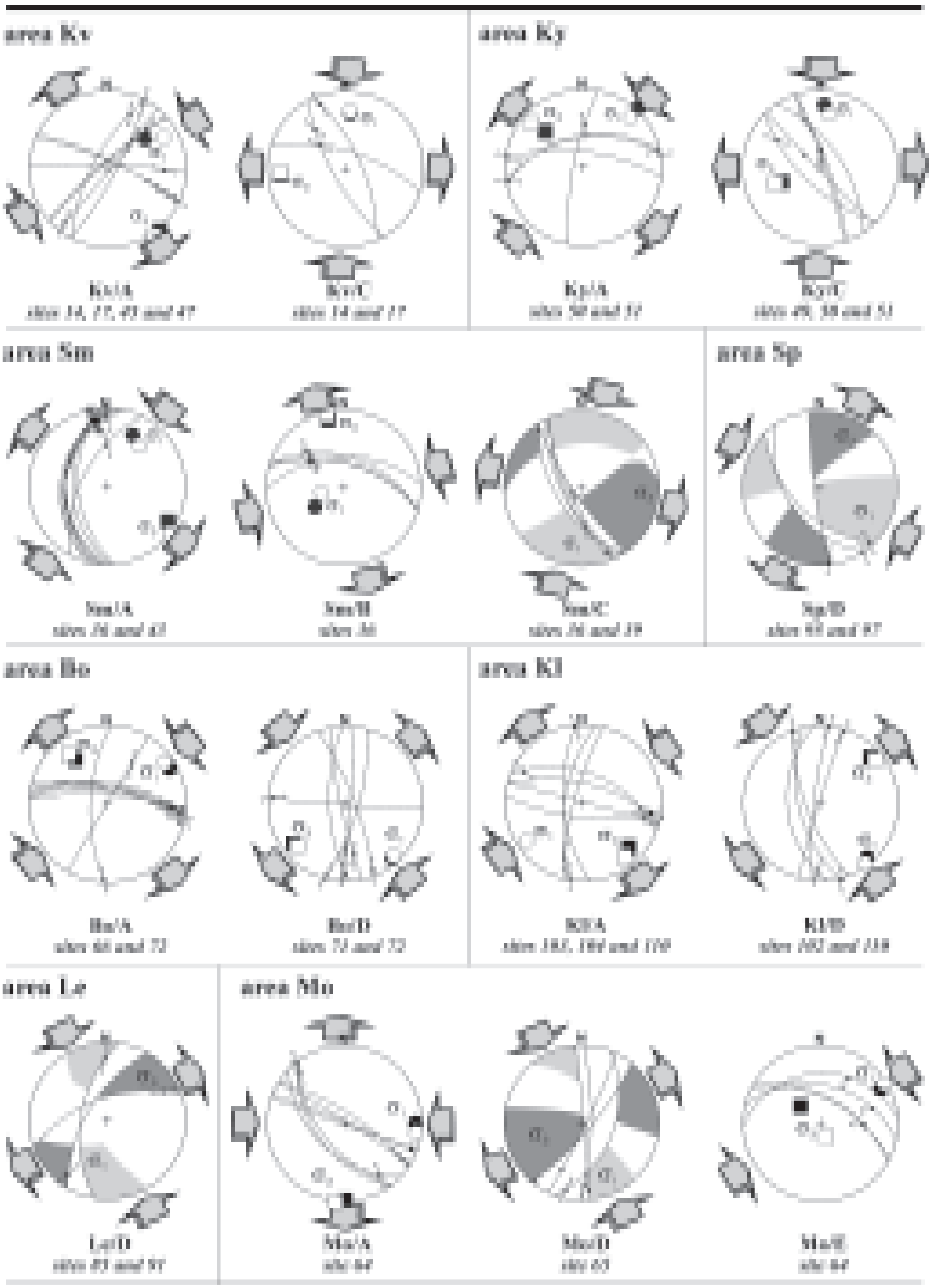

Fig. 4 Calculated orientations of the principal palaeostresses (Lambert projection, lower hemisphere): white circle – eigenvector of the all acceptable orientations of the σ_1 axis; black circle – best solution of the σ_1 axis; white square – eigenvector of the all acceptable orientations of the σ_3 axis; black square – best solution of the σ_3 axis; grey area – acceptable orientations of the σ_1 axis and the σ_3 axis, respectively, determined using simple graphical method of Angelier – Mechler (1977); great circles – fault planes used for stress analysis; grey arrows – orientations of principal horizontal stresses.

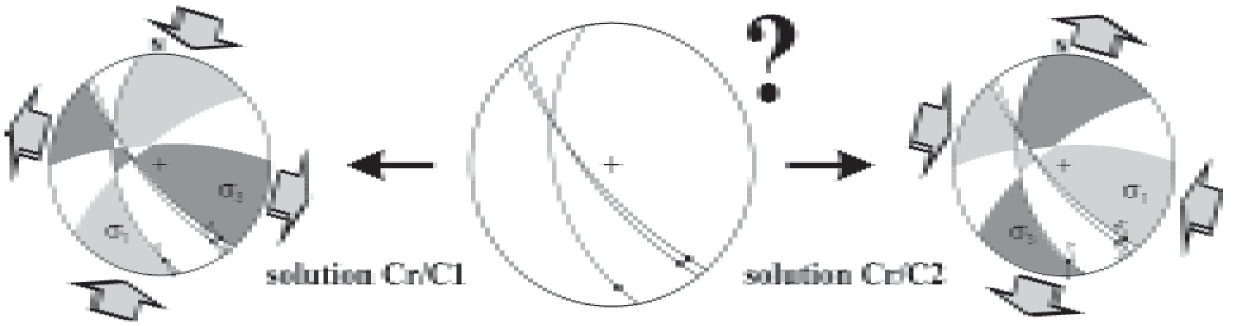

Fig. 5 Diagrams of two possible solutions (Cr/C1 and Cr/C2) of graphical stress analysis of faults measured in orthogneisses at site 18, between Kopanina and Horní Častkov (Lambert projection, lower hemisphere): grey area – acceptable orientations of the σ_1 axis and the σ_3 axis respectively determined using simple graphical method of Angelier – Mechler (1977); great circles – fault planes used for stress analysis; grey arrows – orientations of principal horizontal stresses.

5. Comparison between determined palaeostresses and recent stresses

In the western part of the Bohemian Massif, the NW-SE orientation of the recent maximum compression was determined at many sites using earthquake focal mechanisms (Antonini 1988, Dahlheim et al. 1997, Fischer 2002, Havíř 2000, Slancová – Horálek 2000, Sonnleitner 1993, Vavryčuk 2001), borehole breakouts and hydrofracturing method (Brudy et al. 1997, Peška 1992). Exceptional NNE-SSW orientation of the maximum horizontal compression is reported only from the Plzeň basin by Peška (1992). In the seismoactive Western Bohemia region, the focal mechanisms of micro-earthquakes from the epicentral area Nový Kostel (north of Cheb Basin) indicate the maximum compression moderately plunging to SE and sub-horizontal NE-SW maximum extension (Havíř 2000, 2003, Fig. 6). This is consistent with the results obtained by others (for instance Slancová – Horálek 2000, Sonnleitner 1993, Vavryčuk 2001).

Only the solutions of group D from the southern part of the study area are similar to the recent orientation of principal stresses. Other solutions significantly differ from the recent orientation of stress axes. In the case of the common solutions A, the orientations of maximum compression and maximum extension are "replaced" with respect to the recent orientations.

The comparison of the measured fault geometries with the geometry of nodal planes of micro-earthquakes shows their similarity in the cases of fault striae data used for determination of solutions A (with the exception of sense of movement) and D (including the sense of movement). It indicates that similarly orientated faults may have been activated both during tectonic events connected with palaeostresses A and D and during recent tectonic movements in the Western Bohemia region.

6. Discussion and conclusion

The results of the palaeostress analysis indicate several stages of brittle faulting in the Western Bohemia region. Five different orientations of the principal palaeostresses (solutions A-E) were distinguished.

In respect of the late-Variscan age of the granites faulted during tectonic movements connected with analysed palaeostresses, the faulting connected with analysed palaeostresses has to be younger (post-Variscan, only in the case of the oldest deformation may be still late-

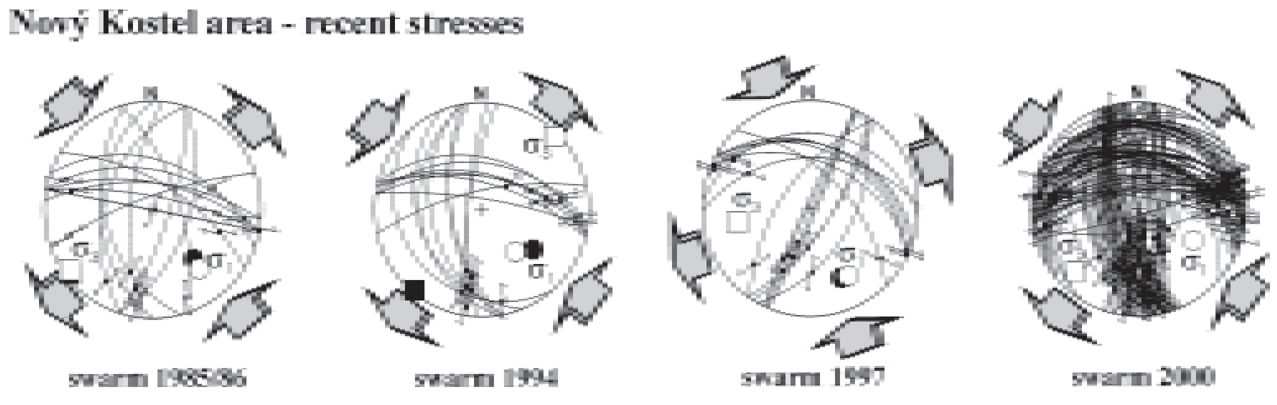

Fig. 6 Orientation of the recent principal stresses in the epicentral area Nový Kostel (Western Bohemia) determined for four micro-earthquake swarms (according Havíř 2000 and Havíř 2003): white circle – eigenvector of the all acceptable orientations of the σ_1 axis; black circle – best solution of the σ_1 axis; white square – eigenvector of the all acceptable orientations of the σ_3 axis; black square – best solution of the σ_3 axis; great circles – nodal planes of the focal mechanisms used for stress analysis; grey arrows – orientations of principal horizontal stresses.

Variscan). In the study area, no other evidence was found, which could allow determination of the age of these palaeostresses more exactly. The results of palaeostress analysis presented in this study can be compared with palaeostress analyses carried out in other regions of the western part of the Bohemian Massif, where brittle deformation of the Mesozoic and the Tertiary sediments was investigated by Adamovič – Coubal (1999), Coubal – Adamovič (2000) and Peterek et al. (1997).

Peterek et al. (1997) shows several tectonic stages connected with N-S to NE-SW orientation of the maximum compression and E-W to NW-SE orientation of maximum extension. The Late Cretaceous to Early Paleogene age of strike-slip deformations in the Variscan granite bodies related to the NNE-SSW compression were supposed by Peterek et al. (1997). Adamovič – Coubal (1999) have determined the Late Cretaceous NE-SW compression, the Eocene NNW-SSE compression and the Miocene NE-SW compression in the northern part of the Bohemian Massif (Most basin). The significance of the Late Creataceous to Palaeogene approximately N-S compression is demonstrated by the uplift of basement over the Upper Cretaceous sediments along the Frankonian Lineament (see Zulauf – Duyster, 1997) or on the northern margin of the Bohemian Cretaceous basin (Coubal 1990). Therefore, I interpret the Late Cretaceous to Tertiary age of at least part of the strike-slip deformations corresponding with the solutions A and C. Some of these deformations can be related also to the Miocene stage assumed by Adamovič – Coubal (1999).

Peterek et al. (1997) found only the Pre-Permian and the Permo-Triassic stages of the faulting corresponding to the NW-SE compression and NE-SW along the Western Border fault zone of the Bohemian Massif. However, the Miocene stage of the NW-SE compression has been distinguished in the northern Bohemia region (Adamovič – Coubal 1999, Coubal 1990; Coubal – Klein 1992). On the basis of orientations of main depocentres in the Cheb basin, Špičáková et al. (2000) supposed the NW-SE compression and NE-SW extension during the deposition of the Pliocene sediments. Similar orientations of the principal stresses are characteristic also for the recent stress field in the Western Bohemia region (e.g., Havíř 2000, Slancová – Horálek 2000, Vavryčuk 2001). Thus the solutions D (NW-SE compression, NE-SW extension), determined in the studied region, are comparable not only to the recent stress field but also to the palaeostresses related to different stages (both late-Variscan and post-Variscan) in other regions in the western part of the Bohemian Massif.

In the Western Bohemia seismoactive region, the faults with planes orientated similarly to nodal planes of the recent micro-earthquakes were pre-recently active during the tectonic stages connected with the palaeostresses represented by solutions A and D. In the case of the Late Cretaceous and/or the Tertiary palaeostress field A (NE-SW compression, NW-SE extension), the orientations of the fault planes is comparable to the nodal planes of micro-earthquakes, but the sense of movements along these fault planes is opposite with respect to the recent faulting. The palaeostress field D (NW-SE compression, NE-SW extension) represents other (probably pre-recent) tectonic activity accompanied by brittle deformation similar to the recent faulting, including sense of the shear movement. That is why not only formation of new faults but also the reactivation of the pre-existing fault planes during the recent faulting along the Počátky-Plesná zone can be supposed. The geometry of some structures formed by these pre-existing fault planes can be related to pre-recent orientations of the principal palaeostresses, including orientations represented by solutions A, which strongly differ from the orientations of the recent stresses.

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References

Adamovič, J. – Coubal, M. (1999): Intrusive geometries and Cenozoic stress history of the northern part of the Bohemian Massif. – Geolines, 9: 5–14.

Angelier, J. (1975): Sur l'analyse de mesures recueillies dans des sites faillés: L'utilité d'une confrontation entre les méthodes dynamiques et cinématiques. – C. R. Acad. Sci. (Paris), 281, sér. D, 23: 1805–1808.

– (1984): Tectonic analysis of fault slip data sets. – J. geophys. Res., 89: 5953–5848.

– (1990): From orientation to magnitudes in palaeostress determination using fault slip data. – J. Struct. Geol., 11: 37–50.

Angelier, J. – Mechler, P. (1977): Sur une méthode graphique de recherche des contraintes principales également utilisable en tectonique et en séismologie: la méthode des diedres droits. – Bull. Soc. geol. Fr., 7, 6: 1309–1318.

Angelier, J. – Tarantola, A. – Valette, D. – Manoussis, S. (1982): Inversion of field data in fault tectonics to obtain the regional stress – I. Single phase fault populations: a new method of computing the stress tensor. – Geophys. J. R. astr. Soc., 69: 607–621.

Antonini, M. (1988): Variations in the focal mechanisms during the 1985/86 Western Bohemia earthquake seqence – correlation with spatial distribution of foci and suggested geometry of faulting. – In Procházková D. (ed.): Induced seismicity and associated phenomena, Proceedings of conference in Liblice, March 14–18, 1988, pp. 250–270.

Bankwitz, P. – Schneider, G. – Kämpf, H. – Bankwitz, E. (2003): Structural characteristics of the epicentral areas in Central Europe: study case Cheb Basin (Czech Republic). – Journal of Geodynamics, 35: 5–32.

Brudy, M. – Zoback, M. D. – Fuchs, K. – Rummel, F. – Baumgärtner, J. (1997): Estimation of the complete stress tensor to 8 km depth in the KTB scientific drill holes: Implication for crustal strength. – Journal of Geophysical Research, 102, B8: 18453–18475.

Coubal, M. (1990): Compression along faults: example from the Bohemian Cretaceous Basin. – Mineralia slovaca, 22: 139–144.

Coubal, M. – Adamovič, J. (2000): Youngest tectonic activity on faults in the SW part of the Most Basin. – Geolines, 10: 15–17.

Coubal, M. – Klein, V. (1992): Development of the Saxonian tectonics in the Česká Lípa region. – Bull. Czech. Geol. Surv., 67, 1: 25–45.

Dahlheim, H.-A. – Gebrande, H. – Schmedes, E. – Soffel, H. (1977): Seismicity and stress field in the vicinity of the KTB location. – Journal of Geophysical Research, 102, B8: 18493–18506.
Doblas, M. (1998): Slickenside kinematic indicators. – Tectonophysics, 295: 187–197.
Fischer, T. (2002): The August-December 2000 earthquake swarm in NW Bohemia: the first results based on automatic processing of seismograms. – Journal of Geodynamics, 35, 1–2: 59–81.
Fischer, T. – Horálek, J. (2003): Space-time distribution of earthquake swarms in the principal focal zone of the NW Bohemia/Vogtland seismoactive region: period 1985–2001. – Journal of Geodynamics, 35: 125–144.
Gephart, J. W. (1990): FMSI: A fortran program for inverting fault/slickenside and earthquake focal mechanism data to obtain the regional stress tensor. – Computers & Geosciences, 16, 7: 953–989.
Gephart, J. W. – Forsyth, D. W. (1984): An improved method for determining the regional stress tensor using earthquake focal mechanism data: application to the San Fernando earthquake sequence. – J. gephys. Res., 89: 9305–9320.
Hardcastle, K. C. – Hills, L. S. (1991): BRUTE3 and SELECT: Quickbasic 4 programs for determination of stress tensor configuration and separation of heterogeneous populations of fault-slip data. – Computers & Geosciences, 17, 1: 23–43.
Havíř, J. (2000): Stress analyses in the epicentral area of Nový Kostel (Western Bohemia). – Studia geoph. et geod., 44, 4: 522–536.
– (2003): Problem of stress analysis in the Nový Kostel area (W Bohemia): influence of various geometries of active faults. – Geolines, 16: 42.
Horálek, J. – Fischer, T. –Boušková, A. – Jedlička, P. (2000): The Western Bohemia/Vogtland Region in the Light of the Webnet Network. – Studia geoph. et. geod., 44, 2: 107–125.
Cháb, J. – Šrámek, J. – Pokorný, L. – Chlupáčová, M. – Manová, M. – Vejnar, Z. – Waldhausrová, J. – Žáček, V. (1997): The Teplá-Barrandian Unit. – In: Vrána, S. – Štědrá, V. (eds.): Geological model of Western Bohemia related to the KTB borehole in Germany, Journal of geological sciences, Geology, 47, pp. 80–104.
Kopecký, L. (1978): Neoidic taphrogenic evolution and young alkaline volcanism of the Bohemian Massif. – Sbor. geol. věd, Geologie, 31: 91–106.
Malkovský, M. (1979): Tektogeneze platformního pokryvu Českého masívu. – Knihovna ÚÚG 53.
– (1987): The Mesozoic and Tertiary basins of the Bohemian Massif and their evolution. – Tectonophysics 137: 31–42.
Mísař, Z. – Dudek, A. – Havlena, V. – Weiss, J. (1983): Geologie ČSSR, I. Český masív. – SPN, Praha.
Mlčoch, B. (1997): Granitoid plutons of the Saxothuringian Zone. – In: Vrána, S. – Štědrá, V. (eds.): Geological model of Western Bohemia related to the KTB borehole in Germany, Journal of geological sciences, Geology, 47, pp. 58–61.
Peška, P. (1992): Stress indications in the Boheman Massif: reinterpretation of borehole televiewer data. – Studia geoph. et geod., 36: 307–324.
Peterek, A. – Rauche, H. – Schröder, B. – Franzke, H.-J. – Bankwitz, P. – Bankwitz, E. (1997): The late- and post-Variscan tectonic evolution of the Western Border fault zone of the Bohemian Massif (WBZ). – Geol Rundsch, 86: 191–202.
Siebel, W. – Trzebski, R. – Stettner, G. – Hecht, L. – Casten, U. – Höhndorf, A. – Müller, P. (1997): Granitoid magmatism of the NW Bohemian massif revealed: gravity data, composition, age relations and phase concept. – Geol Rundsch, 86: S45-S63.
Skácelová, Z. – Nehybka, V. – Havíř, J. (1999): Seismicity in the area of Western Bohemia. – Explor. Geoph., Remote Sensing & Environ., V, 2/1998: 7–15.
Slancová, A. – Horálek, J. (2000): Analysis of state of stress during the 1997 earthquake swarm in Western Bohemia. – Studia geoph. et geod., 44, 2: 272–291.
Sonnlaitner, M. (1993): Vergleich unterschiedlicher methoden der spannungsinversion von erdbebendaten – am beispiel von erdbeben aus der region Vogtland / westl. Böhmen. – MS Diploma thesis. München.
Špičáková, L. – Uličný, D. – Koudelková, G. (2000): Tectonosedimentary evolution of the Cheb Basin (NW Bohemia, Czech Republic) between Late Oligocene and Pliocene: a preliminary note. – Studia geoph. et geod., 44, 4: 556–580.
Tomek, Č. – Dvořáková, V. – Vrána, S. (1997): Geological interpretation of the 9HR and 503M seismic profiles in Western Bohemia. – In: Vrána, S. – Štědrá, V. (eds.): Geological model of Western Bohemia related to the KTB borehole in Germany, Journal of geological sciences, Geology, 47, pp. 43–50.
Trzebski, R. – Behr, H. J. – Conrad, W. (1997): Subsurface distribution and tectonic setting of the late-Variscan granites in the northwestern Bohemian Massif. – Geol. Rundsch, 86: S64-S78.
Ulrych, J. – Pivec, E. – Lang, M. – Balogh, K. – Kropáček, V. (1999): Cenozoic intraplate volcanic rock series of the Bohemian Massif: a review. – Geolines 9: 123–129.
Vavryčuk, V. (2001): Inversion for parameters of tensile earthquakes. – Journal of geophysical research 106, B8: 16339–16355.
Zulauf, G. (1993): The Moldanubian/Saxothuringian Boundary at the Western Border of the Bohemian Massif – a Polyphase Strike-slip Zone. – Z. dt. Geol. Ges. 144: 68–87.
– (1994): Ductile normal faulting along the West Bohemian Shear Zone (Moldanubian/Teplá-Barrandian boundary): evidence for late Variscan extensional collapse in the Variscan Internides. – Geol. Rundsch., 83: 276–292.
Zulauf, G. – Duyster, J. (1997): Supracrustal intraplate thickening of Variscan basement due to Alpine foreland compression: Results from the superdeep well KTB (Bohemian Massif, Germany). – Tectonics 16, 5: 730–743.

Orientace hlavních paleonapětí v seismicky aktivním regionu západních Čech a jejich srovnání s recentními napětími

V seismicky aktivním regionu západních Čech byly provedeny paleonapěťové analýzy založené na studiu zlomů se striacemi, jejichž výsledky jsou presentovány v tomto článku. Řešení paleonapěťových analýz byla porovnána s orientací hlavních os recentního napětí odvozené z fokálních mechanismů mikro-zemětřesení. Zlomy se striacemi byly analyzovány především v pozdně-variských granitech. V tercierních sedimentech tvořících povariský sedimentární pokryv nebyla bohužel nalezena data vhodná pro spolehlivou paleonapěťovou analýzu.

Bylo rozlišeno pět skupin řešení paleonapěťové analýzy (řešení A-E). Protože zlomy použité k odvození paleonapětí porušují pozdně-variské granity, nalezená paleonapětí musí být mladší (převážně povariská). Přímo ve studovaném regionu nebyly nalezeny další doklady, které by dovolily spolehlivě upřesnit stáří jednotlivých řešení. Přibližné časové zařazení některých řešení bylo proto provedeno na základě porovnání těchto řešení s výsledky paleonapěťových analýz aplikovaných v mesozoických a tercierních sedimentech v jiných regionech západní části Českého masivu Adamovičem – Coubalem (1999), Coubalem – Adamovičem (2000) a Peterekem et al. (1997).

Orientace ploch zlomů, jejichž aktivita souvisela s paleonapěťovými poli odpovídajícími řešením A (komprese SV-JZ, extenze SZ-JV) a D (komprese SZ-JV, extenze SV-JZ), je podobná orientaci nodálních ploch fokálních mechanismů recentních mikro-zemětřesení. Smysl střihu podél zlomových ploch aktivních za působení paleonapětí odpovídajícímu řešení A je opačný oproti současným střižným pohybům podél recentně aktivních zlomů. Stáří řešení A je přibližně řazeno do rozmezí svrchní křídy až tercieru. Geometrie zlomů, jejichž aktivita jeví vztah s paleonapětím odpovídajícímu řešení D, se podobá geometrii nodálních ploch fokálních mechanismů, včetně smyslu střižného pohybu. Některé recentně aktivní zlomy v seismicky aktivním regionu západních Čech tak mohou být representovány nejen novotvořenými strukturami, ale také pre-existujícími reaktivovanými plochami vytvořenými již v průběhu předchozích tektonických pohybů, při působení paleonapětí odpovídajících řešením A nebo D.