Results of stress analysis inferred from fault slip data along the Sudetic Marginal Fault (NE part of Bohemian Massif)

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Výsledky napäťovej analýzy z oblasti Sudetského zlomu (SV časť Českého Masívu)

Abstract: The Sudetic Marginal Fault (SMF) separates the Fore-Sudetic block on the NE and the Sudetic block on the SW of Bohemian Massif. The fault slip data along the SMF yielded two different subhorizontal orientations of the maximum stress axes. The NE–SW oriented compression was computed in the Fore-Sudetic block, while the NNW–SSE compression is recorded in the Sudetic block. The faults are predominantly oriented in the NE–SW as well as in NW–SE direction. The dextral and sinistral sense of movement was depicted. The stress fields have operated most probably since Miocene to present day. The SMF most probably represents a barrier between the two different tectonic stress regimes.

Key words: Bohemian Massif, Fore-Sudetic block, Sudetic block, Sudetic Marginal Fault, structural geology, fault-slip data, stress analysis

1. ÚVOD

The research of fault slip data was carried out along the Sudetic Marginal Fault (SMF) in the north-eastern part of Bohemian Massif. The SMF represents a distinctive fault boundary and NW–SE morphotectonic feature. Main purpose of the fault slip data analysis was to obtain the basic information about orientation of the principal stress axes along the SMF.

The previous palaeostress analysis based on the study of fault planes and their kinematics have been performed in the area of Nízký Jeseník and Drahany Uplands (Havíř, 2000, 2002), south of the area of interest. Herein, Havíř (2002) reported the principal compression stress axes in wide range between the WNW–ESE to NNW–SSE during the Neogene. The orientation of recent stresses in the Jeseníky region computed by Havíř (2004) from the focal mechanisms of micro-earthquake events showed the NNW–SSE direction of the compression.

Another papers dealing with analysis of brittle structures concern with statistical evaluation of the measured faults and joints in 2D diagrams only (Grygar & Jelínek, 2003; Štěpančíková, 2005; Štěpančíková et al., 2008; Nováková, 2008).

The recent stress orientation was determined by GPS measurements in wider area of the NE part of the Bohemian Massif (Schenk et al., 2002). GPS data from the Poland part of the SMF shows a sinistral sense of movement or the compression perpendicular to the strike of the Sudetic Marginal Fault (Kontny, 2004).

2. GEOLOGICAL SETTING

The SMF separates the Fore-Sudetic block on the NE and the Sudetic block on the SW. The Sudetic block consists of the Staré Město Group, the Orlice-Śnieżnik complex, the Stronie Śląskie Group, the Velké Vrbno Unit, the Branná Group, and the Keprník Unit. These units/groups are built mainly by phyllonites, gneisses, ortogneisses, marbles, mica schists, metagabbro, erlans, amphibolites, and granodiorites (Žáček et al., 1995). In contrast, the differentially subsided Fore-Sudetic block includes the Vidnava dome of the Žulová Pluton of the Variscan age, representing an apical part of a vast granitic body, which is expressed by an extended gravity low (Cháb & Žáček, 1994). Its Devonian metamorphic cover in the SE is composed of gneisses, amphibolites, quartzites, and marbles. The adjacent Neogene basin is filled with Miocene strata reaching up to 680 m thickness (e.g. Frejková, 1968; Ondra, 1968; Cwojdziński & Jodłowski, 1978; Badura et al., 2004). These deposits overlay the Early Palaeozoic substratum.

3. METHODOLOGY

The concept of the palaeostress analysis is the premise that meso-scale structures can be related to larger regional structures; the both scales, meso and regional, and reflect the same dynamics and kinematics (Angelier, 1994). Stress reconstruction based on analysis of such meso-scale fault slip data was done along the SMF. The fault slip data included direction of the fault

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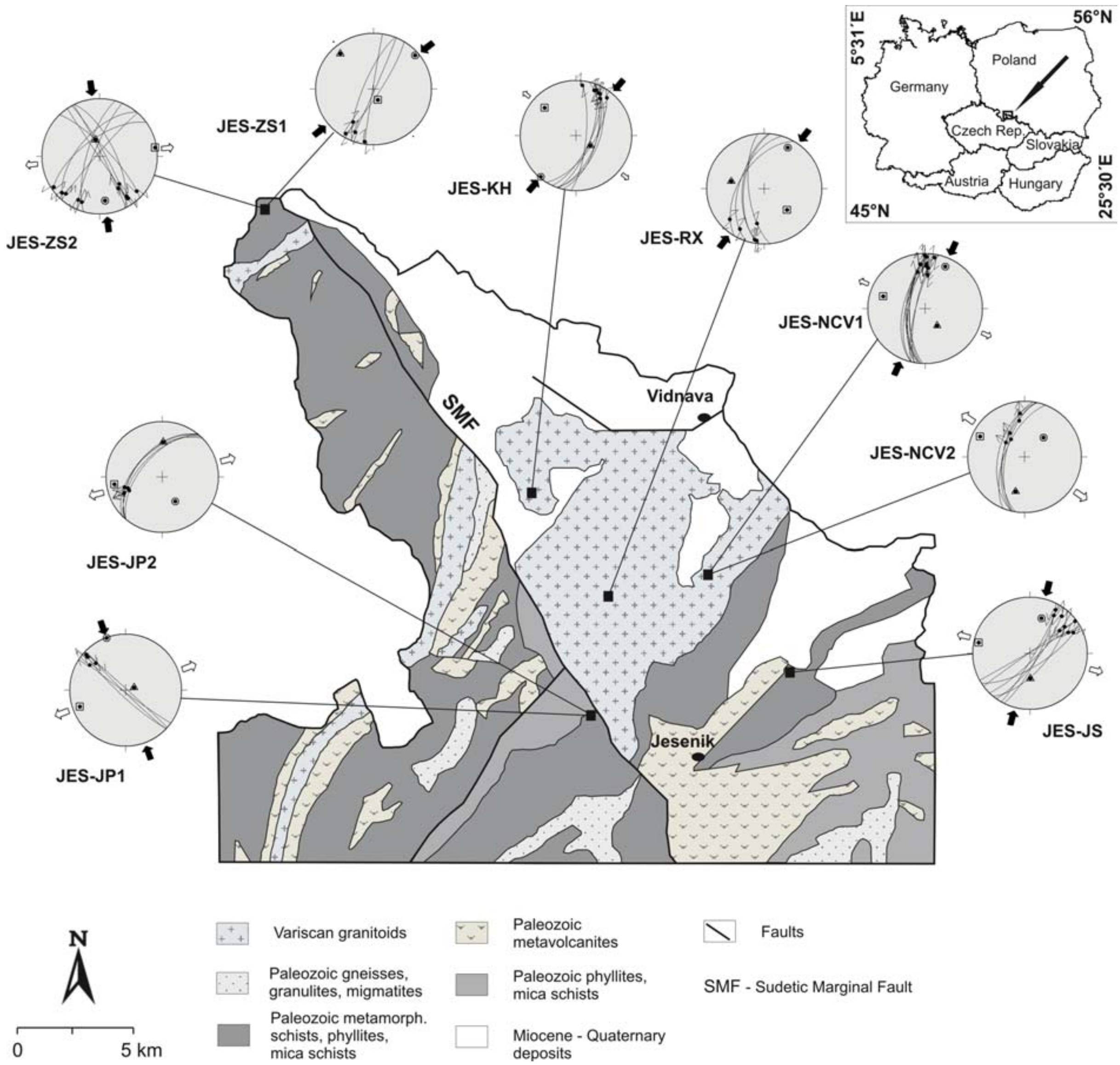

Fig. 1. Simplified geological map (according to the geological map of Czech Geological Survey, 1998). The observed localities are marked in black squares. Diagrams represent fault planes and sense of movement with computed compression stress axes (black arrows). For additional information see text and Tab. 1
Obr. 1. Zjednodušená geologická mapa (podľa mapy Českej geologickej služby, 1998). Lokality sú označené čiernymi štvorcami. Diagramy reprezentujú zlomové plochy so zmyslom pohybu a s vypočítanými napätiami (kompresia je znázornená čiernymi šípkami). Ďalšie informácie pozri text a Tab.1

plane, sense of movement and the quality of the displacement measurement. Direction of the movement or the fault slip were given by slickenside, striae and the other kinematic criteria that are summarized in e.g. Hancock (1985), Petit (1987), Marko (1993), Angelier (1994) and Doblas (1998).

The stress analysis required a critical kinematic analysis of faults during the field work, based on the evaluation of slickenside surfaces. At the outcrop scale a lot of the brittle structures might be observed, however not all of them were suitable to determine the sense of movement. Thus, only the fault planes with a clear sense of movement were computed. Alternating polished, rough facets and Riedel shears kinematic indicators were applied for determination sense of movement in the granite rocks of the Žulová Pluton. Mineral accrecionary steps were observed only in the Palaeozoic limestones. Fault slip data were collected from the 4 localities, situated mainly in the Žulová Pluton of the Fore-Sudetic block and 2 localities in the Palaeozoic rocks of the Sudetic block. Observations were made on the striated fault surfaces.

A wide range of stress analysis methods using fault slip data has been elaborated (e.g. Angelier, 1979, 1989, 1990, 1994; Etchecopar et al., 1981; Michael, 1984; Delvaux and Sperner, 2003). In the presented analysis, the inversion method was used. The method is based on the assumption of Bott (1959) and Wallace (1951) that a slip on a plane occurs in the direction of the maximum resolved shear stress. The data measured from

Tab. 1. The list of the site codes – locality; geographic coordinates; n – number of faults used for stress tensor determination; nT – total number of fault data measured; σ_1, σ_2 and σ_3 – azimuth and plunge of principal stress axes.

Tab. 1. Zoznam lokalít, ich označenie, geografické koordináty; n – počet zlomov použitých pre výpočet napäťového tensora / napätia; nT – celkový počet nameraných zlomov; σ_1, σ_2 a σ_3 – orientácia hlavných napäťových osí.

Site code	Locality	Latitude	Longitude	n	nT	σ_1	σ_2	σ_3	Tectonic regime
JES-JP1	Jeskyně Na Pomezí – cave	N50°14,825'	E017°08,105'	4	17	340/01	074/70	250/14	NNW-SSE compression
JES-JP2	Jeskyně Na Pomezí – cave	N50°14,825'	E017°08,105'	5	17	152/49	002/37	261/15	ENE-WSW to NW-SE transtension
JES-JS	Jeskyně Na Špičáku – cave	N50°17,043'	E017°15,025'	8	25	018/34	179/53	282/10	NE-SW compression
JES-KH	Kaní hora Mt	N50°19,902'	E017°04,842'	7	13	220/03	125/64	312/26	NE-SW compression
JES-NCV1	Nová Červená Voda	N50°18,150'	E017°11,380'	10	19	025/17	146/59	287/25	NE-SW compression
JES-NCV2	Nová Červená Voda	N50°18,150'	E017°11,380'	5	19	044/50	194/36	295/15	ENE-WSW to NW-SE transtension
JES-RX	Ralux	N50°18,308'	E017°07,377'	5	12	029/16	283/41	134/44	NE-SW compression
JES-ZS1	Złoty Stok	N50°26,490'	E016°53,025'	4	26	050/07	318/16	159/73	NE-SW compression
JES-ZS2	Złoty Stok	N50°26,490',	E016°53,025'	10	26	174/25	339/65	79/6	NNW-SSE compression

fault planes and fault slips, including the sense of movement, were inverted to compute four parameters of the reduced stress tensors: the principal axes are σ_1 (maximum compressional stress axis), σ_2 (intermediate stress axis), σ_3 (minimum stress axis) and the ratio of the principal stress differences:

$$R = (\sigma_2 - \sigma_3) / (\sigma_1 - \sigma_3)$$ (Angelier, 1989, 1994).

Stress orientation pattern (reduced stress tensor) was determined using the analytical stress method (Angelier, 1989, 1994) with the TENSOR software package (Delvaux, 1993; Delvaux & Sperner, 2003). The TENSOR contains the Shear program (Rotational optimization) which represents the inverse method. The inversion is performed using an iterative procedure, by testing a great number of different stress tensors around each of the axes and by testing different values of R, with the aim to minimize a misfit function. The simplest misfit function to minimize is the slip deviation between the observed slip direction and the theoretical shear stress on the plane (Delvaux, 1993; Delvaux & Sperner, 2003).

4. RESULTS OF STRESS ANALYSIS

The geometry and orientation of the fault system is close related to the pre-existing joint pattern within the Žulová Pluton (c.f. Grygar & Jelínek, 2003; Štěpančíková, 2005; Štěpančíková et al., 2008). The results of the fault slip analysis are partly affected by superposing fault planes on pre-exist brittle structures. Eventhough 9 tensors from the 86 measured fault slip data have been defined. The results of stress analysis can be divided into 2 following groups.

The NE–SW oriented maximum compressional stress axis σ_1 is the most frequent. The faults are NNE–SSW oriented with predominantly dextral strike-slip sense of movement. The dominant tectonic regime is transpressive. The faults classified to this deformational stages were observed mainly in the granite rocks of the Fore-Sudetic block (e.g. the localities with site codes: JES-KH, JES-RX, JES-NCV1, JES-JS) with the exception of the Złoty Stok locality (JES-ZS1) situated on the edge of the Sudetic block (Tab. 1; Fig. 1).

The NNW–SSE oriented maximum compressional stress axis σ_1 is less frequent and the localities are situated in the Sudetic block, i.e. on the SW side of the SMF (e.g. the localities with site codes: JES-ZS2, JES-JP1). The NW–SE fault planes show generally dextral strike-slip sense of movement (Tab. 1; Fig. 1).

Besides the prevailing strike-slip tectonic regime the transtension regime was determined. The NE–SW to NNE–SSW oriented fault planes are characterized with oblique normal sense of movement (e.g. the localities with site codes: JES-JP2, JES-NCV2) (Tab. 1; Fig. 1).

5. DISCUSSION AND CONCLUSIONS

The observed fault planes are predominantly oriented in the NE–SW and in the NW–SE direction with dominant strike-slip movement. The fault structures represent the youngest tectonic features within the Žulová Pluton. According to Maluski et al. (1995) the age of the Žulová Pluton is the Late Carboniferous. Therefore the brittle structures are Post-Carboniferous and younger than joint systems. The Žulová Pluton is bounded by the SMF against the Sudetic block as well as against the Neogene sediments of the Vidnava Basin. The N and NW margin of the Žulová Pluton is also tectonically limited against the Neogene sediments. According to Frejková (1968) the age of tectonic activity of the faults restricted the Neogene sediment of the Vidnava Basin is Early Miocene. It is possible to determine tectonic activity of the NE–SW and NW–SE faults to post Early Neogene in age.

Two main directions of the maximum compressional stress axis σ_1 were computed (the NNW–SSE and NE–SW). The NE–SW orientation of the compression prevails. The NE–SW oriented compression was recorded within the Fore-Sudetic block, i.e. on the NE side of the SMF. The NNW–SSE oriented compression was recorded within the Sudetic block only.

The results of the GPS measurements along the SMF show the recent tectonic activity generated by the NE–SW oriented compression (Kontny, 2004). These data are in a good accordance with the results of the orientation of the compressional stress axis σ_1 obtained from fault slip data within the Fore-Sudetic block. On the other hand, the stress pattern measured at the localities within the Sudetic block indicates the NNW–SSE oriented maximum compressional stress axis σ_1. Similar position of compressional axis was computed for micro-earthquake events at the Jeseníky region within the Sudetic block (Havíř, 2004). Orientation of the stress in the Sudetic block is related to ongoing convergence of the Western Carpathians and the Bohemian Massif (Jarosiński, 2005). The stress field has been active since Miocene to the present day (Kováč, 2000).

According to the presented data and according to Grünthal (2004) it can be assumed that the stress regime across the SMF changed orientation of the compression vector from the NNW–SSE position within the Sudetic block to the NE–SW within the Fore-Sudetic block. These orientations of the stress pattern remain apparently unchanged from Miocene till recent time. Following these observations the SMF seems to be a distinct barrier between the two different tectonic stress regimes. As the presented data and conclusions are preliminary results of the fault-slip analysis, it is necessary to continue with the collecting and processing additive information.

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Resumé: Sudetský okrajový zlom (SMF) predstavuje výrazné zlomové ako aj morfotektonické rozhranie SZ–JV smeru. Oddeľuje bloky s odlišnou geologickou stavbou – sudetský blok na juhozápade a predsudetský blok na severovýchode SMF. Sudetský blok je reprezentovaný paleozoickými metamorfovanými a magmatickými horninami, na rozdiel od predsudetského bloku, ktorý je tvorený Žulovským granitoidným plutónom variskeho veku a devónskym metamorfovaným obalom. Priľahlá Vidnavská panva je vyplnená miocénnymi sedimentami. Cieľom výskumu bolo určiť smer a charakter zlomov a orientáciu napätia, pri ktorom vznikali. Geometria a orientácia pozorovaných zlomových systémov je komforná s orientáciou preexistujúceho/primárneho puklinového systému v Žulovskom plutóne. Dáta pre výpočet orientácie napätia boli spracované štandardnými metódami štruktúrnej analýzy (napr. inverzná metóda).

Zlomy sú orientované v smere SV–JZ a SZ–JV s dominantným smerne-posuvným pohybom. Napäťovou analýzou boli vypočítané dva smery kompresie s prevládajúcou SV–JZ orientovanou kompresnou zložkou napätia. Menej výrazne je zastúpená kompresia v smere SSZ–JJV. Dominantná SV–JZ kompresia bola zistená na lokalitách, ktoré sa koncentrujú v predsudetskom bloku (JES-KH, JES-RX, JES-NCV1, JES-JS, JES-ZS1). V oblasti sudetského bloku bola zaznamenaná kompresia smeru SSZ–JJV (JES-ZS2, JES-JP1). Na analyzovaných lokalitách prevláda transpresný tektonický režim. Transtenzia je dokumentovaná len na lokalitách JES-JP2 a JES-NCV2.

Frejková (1968) na základe sedimentárneho záznamu z miocénnych sedimentov Vidnavskej panvy zaraďuje aktivitu zlomov SV–JZ a SZ–JV smeru do spodného miocénu. Výsledky GPS meraní poukazujú na recentnú aktivitu SMF realizovanú v napäťovom poli s kompresiou v smere SV–JZ. Smer kompresie je porovnateľný so smerom hlavnej napäťovej osi vypočítanej na lokalitách predsudetského bloku. Orientácia kompresie v oblasti sudetského bloku je SSZ–JJV a zodpovedá kompresii odvodenej z fokálnych mechanizmov (Havíř, 2004). Predpokladáme, že napäťové pole, ktoré generovalo zlomové porušenie pretrváva od obdobia spodného miocénu do recentu. Orientácia kompresnej osi v sudetskom bloku je pravdepodobne odrazom pretrvávajúcej konvergencie Západných Karpát a Českého Masívu (Kováč, 2000; Jarosiński, 2005). Orientácia kompresie v predsudetskom bloku súvisí s orientáciou kompresie v oblasti severoeurópskej platformy (Jarosiński, 2005). Odlišná orientácia napätia v oblasti sudetského a predsudetského bloku môže byť interpretovaná ako funkcia výrazného tektonického rozhrania SMF.