Magnetic fabric relationship between Palaeozoic volcanic and sedimentary rocks in the Nízký Jeseník Mts., NE Moravia

Vztahy magnetických vnitřních staveb paleozoických vulkanitů a sedimentárních hornin v Nízkém Jeseníku (Czech summary)

(*6 text*-figs.)

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Anisotropy of magnetic susceptibility (AMS) was used to investigate the fabric of magnetic minerals in Palaeozoic volcanic rocks of the Šternberk-Horní Benešov Belt in the Nízký Jeseník Mts. and in surrounding Lower Carboniferous sedimentary rocks (NE Bohemian Massif). The degree of AMS in the investigated volcanic rocks is relatively high in most specimens, clearly higher than that in recent undeformed volcanic rocks. The orientations of the magnetic fabric elements are near those in surrounding sedimentary rocks west of the Šternberk-Horní Benešov Belt, whose magnetic fabric is no doubt deformational in origin. Consequently, the magnetic fabric in the volcanic rocks investigated is deformational in origin and had at least a part of its deformational history the same as the magnetic fabric of surrounding sedimentary rocks. This conclusion is in agreement with the results of the geological research of the studied area.

Key words: magnetic fabric, volcanic rocks, NE Moravia

Introduction

The preferred orientation of magnetic minerals (the magnetic fabric) in young unmetamorphosed and undeformed volcanic rocks is usually controlled by the lava flow phenomena (for review see Tarling – Hrouda 1993). However, during even weak regional metamorphism the magnetic minerals can disintegrate and reorientate. Consequently, the magnetic fabric of a weakly metamorphosed volcanic rock can be complex, i.e. composed of both the primary (lava flow) and secondary (deformation) components. In general, there is a lack of the criteria how to recognize whether the magnetic fabric under consideration is primary or secondary in origin. The magnetics fabrics conformable to the shapes of volcanic bodies and, better, to the mesoscopic flow fabric elements, if observable, are believed to be primary. On the other hand, the magnetic fabrics conformable to the deformational fabric elements either in the volcanics or in the surrounding sedimentary rocks can be regarded as at least partially deformational (Henry 1977).

The Palaeozoic volcanic rocks investigated occur in the northeasternmost part of the Rhenohercynian Zone of the European Variscides, in the Bohemian Massif called the Sudeticum (Dvořák – Paproth 1969), in the Devonian antiformal Šternberk-Horní Benešov Belt, dividing the Lower Carboniferous sediments of the Nízký Jeseník Mts. into two parts differring structurally. The region west of the Šternberk-Horní Benešov Belt is characterized by well developed slaty cleavage, while the region east of the Belt displays only spaced cleavage or even no cleavage (Orel 1973).

As the magnetic fabric has been extensively investigated in the Nízký Jeseník Mts. by means of the anisotropy of magnetic susceptibility (AMS) in the seventies and early eighties (Hrouda 1976, 1978, 1979, 1979a, 1981; Dvořák – Hrouda 1972, 1975), there is a possibility to investigate the origin of the volcanic rocks in the NE Moravia from the point of view of the relationship of their magnetic fabric to that of the surrounding sedimentary rocks.

Geological setting

Devonian and Carboniferous rock sequences in the Moravo-Silesian region represent the easternmost so far known part of the European Variscides (Matte 1991). The Devonian rocks are divided in two facial developments:

a) the development of the Moravian Karst (prevalently shallow-water limestones with basal clastics on the Proterozoic basement of the Brno unit),

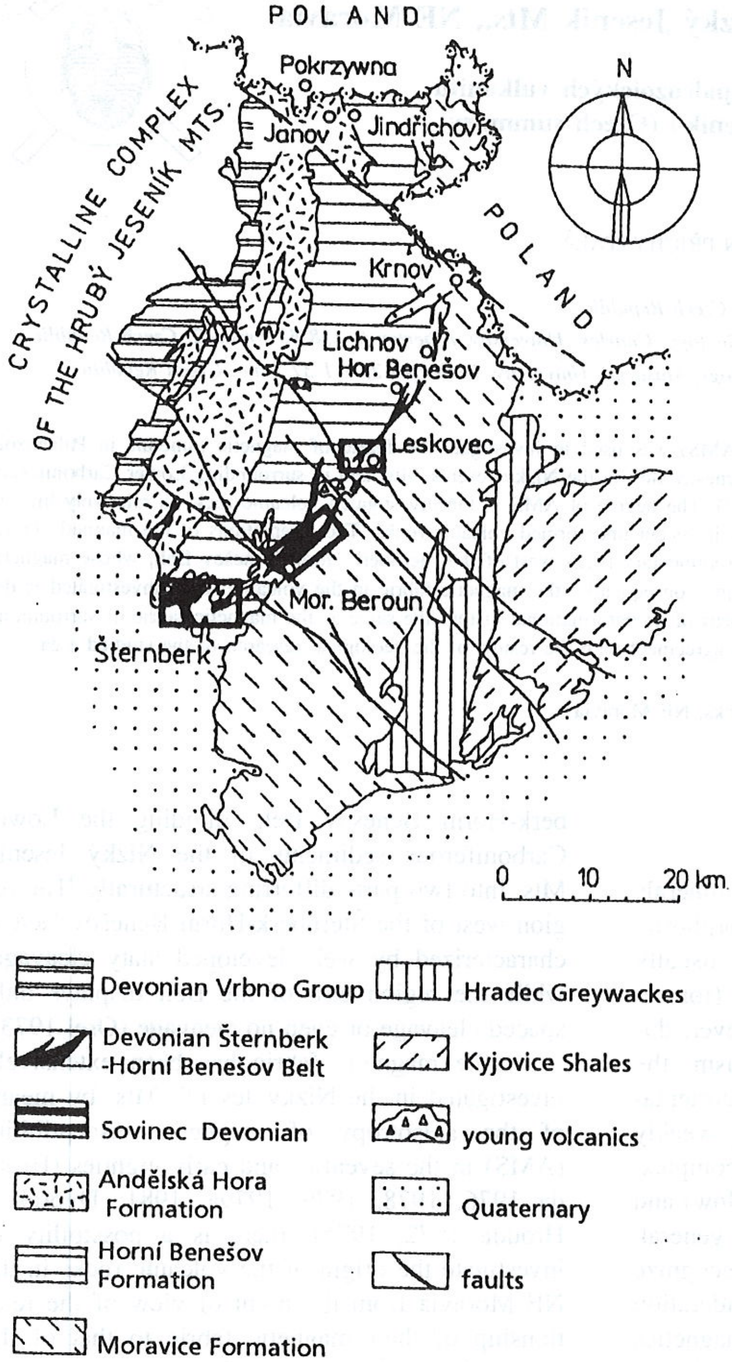


Fig. 1. Geological sketch map of the Šternberk-Horní Benešov Belt and the surrounding areas of the Nízký Jeseník Mts. Oblongs denote the individual sectors investigated

b) the Drahany (basinal) development (submarine spilite – quartz keratophyre volcanism with deeper-water psammitic and pelitic sediments, its basement is not reliably known).

Occurrences of the Devonian to Lower Carboniferous volcanic and sedimentary rocks are concentrated in a few belts trending NNE-SSW. As metamorphism generally grows up from the east to the west and from the south to the north, the best preserved and only weakly metamorphosed volcanic rocks with intercalations of sediments can be studied in the Šternberk-Horní Benešov Belt in the Nízký Jeseník Mts. where the relationship between the Devonian volcano-sedimentary complex and the surrounding Lower Carboniferous flysch formation can also be investigated.

The Šternberk-Horní Benešov Belt is a tectonic zone, in which earlier Devonian to Lower Carboniferous volcanics and pre-flysch sediments crop out among Culm rocks in complicated anticlinorial and klippen structures. Transverse faults divide the Belt into three principal sectors with different erosion levels: southern the Šternberk-Chabičov sector, central the Moravský Beroun sector and northern the Leskovec-Horní Benešov sector. We have sampled the most widespread basic volcanic rocks which have been found in all three sectors of the Belt (for a detailed geological, petrological and geochemical investigation see Přichystal 1990). The basic volcanics include:

Dolerites and Dolerite Porphyries – coarse grained subvolcanic bodies or porphyritic dykes containing pyroxene (titanoaugite), plagioclase (oligoclase), ilmenite, titanite, secondary chlorite and uralite. Subvolcanic bodies have signs of intense dynamic metamorphism that can be explained as a result of their tectonic incorporation into the higher volcano-sedimentary complex.

Spilitic Rocks – they have retained the textures of volcanic rocks, but neither of their minerals, i.e. chlorite, sericite, K-feldspar, albite, hydromicas, calcite, epidote-clinozoisite, titanite, opaque pigment (probably very fine-grained magnetite) can be unequivocally evidenced as primary. The rocks are represented by spilites, amygdaloidal spilites (usually as pillow lavas), the related lithic and vitric tuffs, calcitic hyaloclastics, spilite porphyries and crystal feldspathic tuffs.

Green Schists – they have preserved no volcanic textures and consist of chlorite, epidote, calcite, albite, titanite + actinolite + ilmenite. They usually occur in the vicinity of tectonic zones (overthrusts).

Technique of measurement, data presentation

The AMS of the volcanic rocks investigated was measured with the KLY-2 Kappabridge (Jelínek 1973, 1980) and calculated using the ANISO 14 program (Jelínek 1977). The AMS data of the sedimentary rocks of the Nízký Jeseník Mts. were re-evaluated statistically using the ANISOFT program package (Hrouda et al. 1990).

The intensity of the preferred orientation of magnetic minerals in a rock is indicated by the degree of AMS, $P = k_1/k_3$, where $k_1 \geq k_2 \geq k_3$ are the values of the principal susceptibilities. The character of the magnetic fabric is indicated by the shape factor, $T = 2\ ln(k_2/k_3)/ln(k_1/k_3) - 1$, introduced by Jelínek (1981). If $0 < T \leq 1$, the magnetic fabric is planar, if $-1 \leq T < 0$, the magnetic fabric is linear.

The orientations of magnetic foliation poles and magnetic lineations are presented in the equal-area projection on lower hemisphere.

Magnetic mineralogy

The carriers of magnetism in the investigated rocks were studied by the measurement of the temperature variation of the mean magnetic susceptibility on powder specimens using the CS-2 Apparatus and KLY-2 Kappabridge (Parma – Zapletal 1991, Parma et al. 1993, Hrouda 1994). The results are summarized in Fig. 2.

The values of the mean susceptibility (Fig. 2a) are very variable, probably indicating variable amounts of ferromagnetic minerals in the rocks investigated. The thermomagnetic curves of the specimens with high susceptibility are characterized by higher susceptibilities on the heating curves than on the cooling curves and by the acute decrease in susceptibility between 580 °C and 590 °C (Fig. 2b). This decrease clearly indicates presence of magnetite. However, only the cooling curve is a typical thermomagnetic curve of magnetite. The heating curve shows conspicuous susceptibility increase from 150 °C to 300 °C and continuous, but not acute, susceptibility decrease between 300 °C and 580 °C. This may indicate some changes in the original, perhaps impure, magnetite during heating, giving rise to the relatively pure magnetite indicated by the cooling curve. Consequently, the AMS of strongly magnetic specimens indicates the preferred orientation of magnetite by grain shape.

The thermomagnetic curves of the specimens with low susceptibility (Fig. 2c) are characterized by much higher susceptibilities on the cooling than on the heating curves. (The cooling curve is not shown in Fig. 2c for the scale reasons.) This probably indicates creation of a new magnetic mineral during heating the rock. The heating curve, in its initial part up to 150 °C, shows hyperbolic course similar to that of paramagnetic minerals. Above 150 °C the susceptibility irregularly decreases up to 580 °C and then relatively rapidly decreases to 600 °C. This rapid decrease probably indicates presence of magnetite. Between 600 °C and 700 °C, the susceptibility further slowly decreases. The resolution of the rock susceptibility into the paramagnetic and ferromagnetic components, made by the method by Hrouda (1994), has shown that the rock susceptibility of the weakly magnetic specimens is mostly carried by paramagnetic dark silicates, but the contribution of the magnetite cannot be neglected. Consequently, the AMS of weakly magnetic specimens indicates the complex magnetic fabric, represented by dark silicates and magnetite.

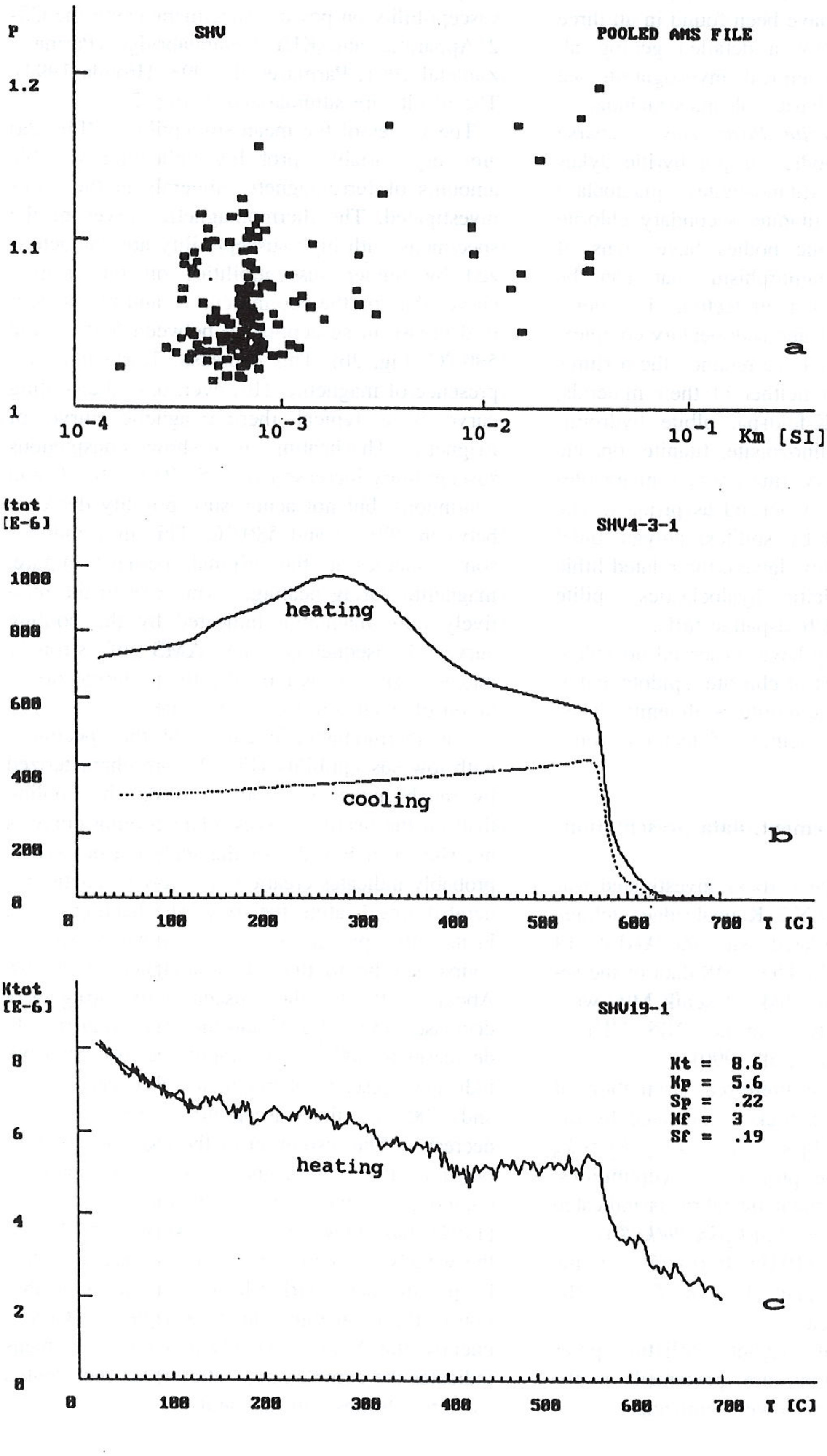


Fig. 2. Susceptibility and its thermal variation in the volcanic rocks investigated
a – plot of the degree of AMS *vs* mean susceptibility; *b* – an example of the thermomagnetic curve of a specimen with high susceptibility (amygdaloide spilite); *c* – an example of the thermomagnetic curve of a specimen with low susceptibility (metabasalt)

The magnetic minerals in the sedimentary rocks of the Nízký Jeseník Mts. are represented by magnetite, hematite and paramagnetic phyllosilicates (Hrouda 1979). However, the amount of magnetite (and hematite) is very low, so that its contribution to the total AMS is much less than that of phyllosilicates (Hrouda – Jelínek 1990, Hrouda et al. 1993).

Magnetic fabric

The results of the AMS investigation of volcanic rocks are summarized in Figs. 3 to 6. The degree of AMS is variable, ranging from very low to relatively high. The majority of specimens show the degree of AMS moderate, between $P = 1.05$ and $P = 1.1$, i.e. clearly higher than that characteristic of undeformed volcanic rocks (Fig. 3). The ellipsoids of the magnetic fabric range from moderately prolate to very oblate; the majority is clearly oblate. There are no significant differences between the sectors investigated.

The magnetic lineations and magnetic foliation poles are relatively well clustered within the individual sectors and only slightly different between the sectors (see Figs. 4a, 5a, 6a). In the southern Šternberk-Chabičov sector, the magnetic foliations mostly dip E, the magnetic lineations mostly plunge SE under gentle angle (Fig. 4a, b). In the localities where the mesoscopic spaced cleavage is observable, the magnetic foliation is approximately parallel to this cleavage.

In the sedimentary rocks west of the Šternberk-Chabičov sector, characterized by very well developed slaty cleavage, the magnetic foliation is oriented homogeneously like the slaty cleavage, while the bedding tends to create an imperfect girdle in its poles (Fig. 4c). Consequently, the magnetic foliation is parallel to the cleavage and shows virtually no relationship to the bedding. The magnetic lineations are parallel to the strike of the magnetic foliations and to the cleavage/bedding intersection lines (Fig. 4d). In the sedimentary rocks east of the Šternberk-Chabičov sector, cleavage is only poorly developed and the magnetic foliation is parallel to the bedding (Fig. 4e). The magnetic lineation is approximately parallel to the strike of the bedding (Fig. 4f).

In the volcanic rocks of the Moravský Beroun sector, the magnetic foliations dip in average ESE under variable, mostly moderate angle (Fig. 5a). The magnetic lineations show bimodal distribution. One mode is characterized by the SSE plunge under moderate angle, the other mode shows the plunge NE also under moderate angle (Fig. 5b).

The sedimentary rocks west of the Moravský Beroun sector display both the slaty cleavage and bedding, but in the localities investigated both the bedding and cleavage dip SE (Fig. 5c) and one cannot decide, from general view shown in Fig. 5c to which of the fabric elements mentioned the magnetic foliation is nearer. The detail analysis of the individual specimens has however shown that the magnetic foliation is parallel to the cleavage. The magnetic lineations are parallel to the bedding/cleavage intersection lines (Fig. 5d). In the sedimentary rocks east of the Moravský Beroun sector both bedding and cleavage can be observed. The magnetic foliation is parallel to the bedding and the magnetic lineation is parallel to the bedding/cleavage intersection lines (Fig. 5e, f).

In the northern, Leskovec-Horní Benešov

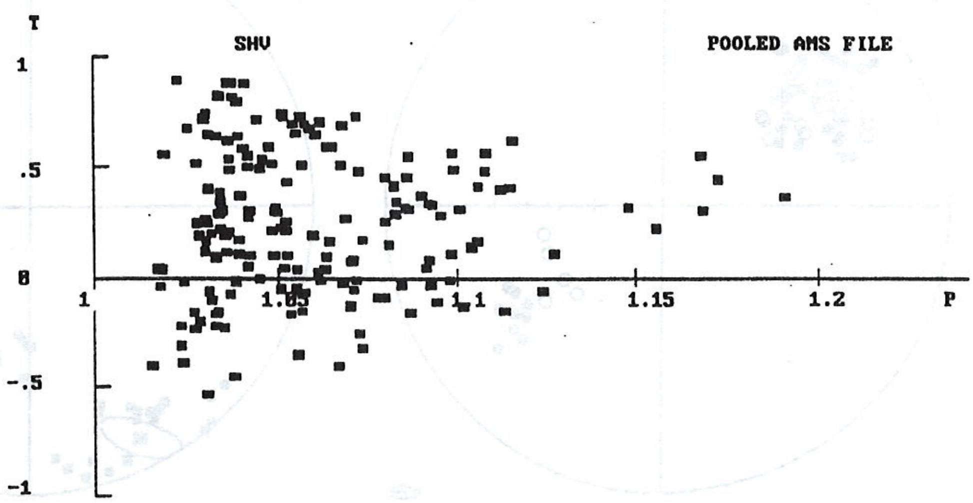
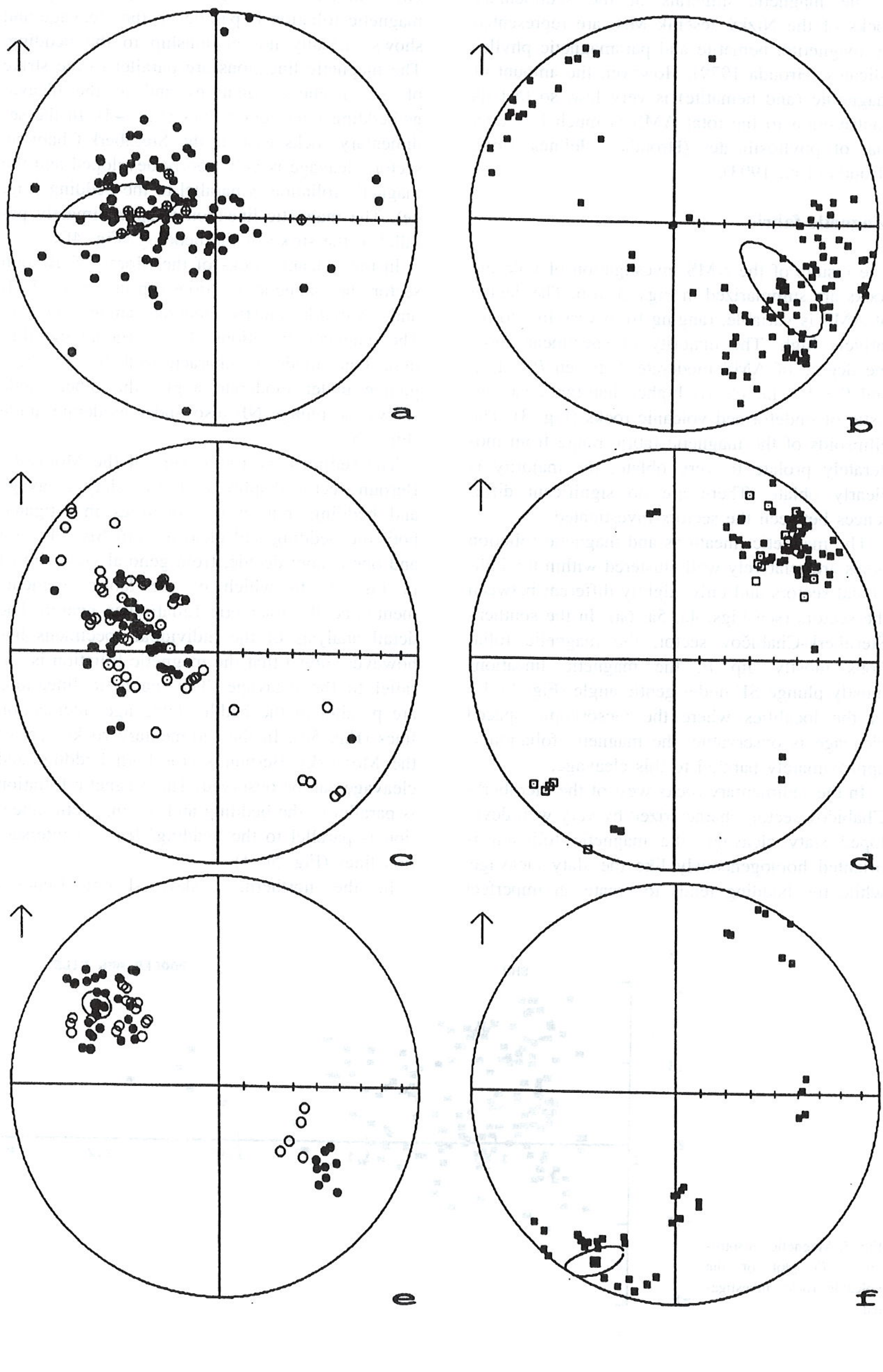


Fig. 3. Magnetic anisotropy (P-T) plot of the volcanic rocks investigated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sector, the magnetic foliations of the volcanic rocks dip E under moderate angle and the magnetic lineations plunge SE under moderate angle, tending to create an imperfect girdle oriented NW-SE (Fig. 6a, b). In the sedimentary rocks west of the sector, the magnetic foliation is near the slaty cleavage, striking in average N-S and being either almost horizontal or dipping gently to steeply E (Fig. 6c). The magnetic lineations are sub-horizontal, trending in average N-S (Fig. 6d). In the sedimentary rocks east of the sector, the magnetic foliations are clearly nearer the bedding than the cleavage, striking in average NE-SW, and the magnetic lineations trend NE-SW (Fig. 6e, f).

Magnetic fabric origin

It has been shown in the preceding section that the bulk susceptibility of the volcanic rocks investigated is an order-of-magnitude lower than the susceptibility of young volcanic rocks of the same chemical composition. It has also been shown that the carriers of magnetism are mostly phyllosilicates generated in the process of weak regional metamorphism. The degree of AMS in many specimens is clearly higher than that typical of undeformed volcanic rocks. The magnetic foliation is well defined in each of the three sectors investigated and is near the mesoscopic spaced cleavage in the volcanics, if developed. The magnetic lineation is also relatively well clustered, mostly oriented in the direction of the dip of the magnetic foliation. In each of the three sectors investigated the magnetic foliation is near the magnetic foliation and slaty cleavage in sedimentary rocks occurring west of the Šternberk-Horní Benešov Belt and not very much related to the magnetic fabric in sedimentary rocks east of the Belt. The magnetic lineations in the sedimentary rocks are in general perpendicular to those in volcanic rocks.

From the above observations one can conclude that the magnetic fabric in the volcanic rocks investigated is not primary, but rather secondary in origin, affected by ductile deformations associated with the slaty cleavage formation in the sedimentary rocks west of the Šternberk-Horní Benešov Belt.

Tectonic implications

The magnetic fabric in the volcanic rocks investigated shows close relationship to that in the sedimentary rocks west of the Šternberk-Horní Benešov Belt. Hrouda (1976, 1979, 1993) showed that the magnetic fabric of those rocks is clearly deformational in origin, formed by the ductile deformations associated with the generation of the slaty cleavage in the course of the fold and thrust tectonics of the final stages of the Variscan collision (for details see Cháb 1986, Rajlich et al. 1987, Čížek – Tomek 1991). These deformations are represented predominantly by strong shortening perpendicular to the cleavage and subordinately by simple shear along the cleavage dip direction. It is likely that the volcanic rocks were incorporated into the thrust sheet structure of the region investigated. It is also probable that the Šternberk-Horní Benešov Belt creates a thrust sheet as well, or even a klippen, structurally belonging to the group of the thrust sheets creating the region west of the Belt.

Recently, Rajlich (1990) presented a hypothesis of the development of the N-S to NNE-SSW trending, dextral wrench zone in the Moravo-Silesian Culmian basin during the Westphalian

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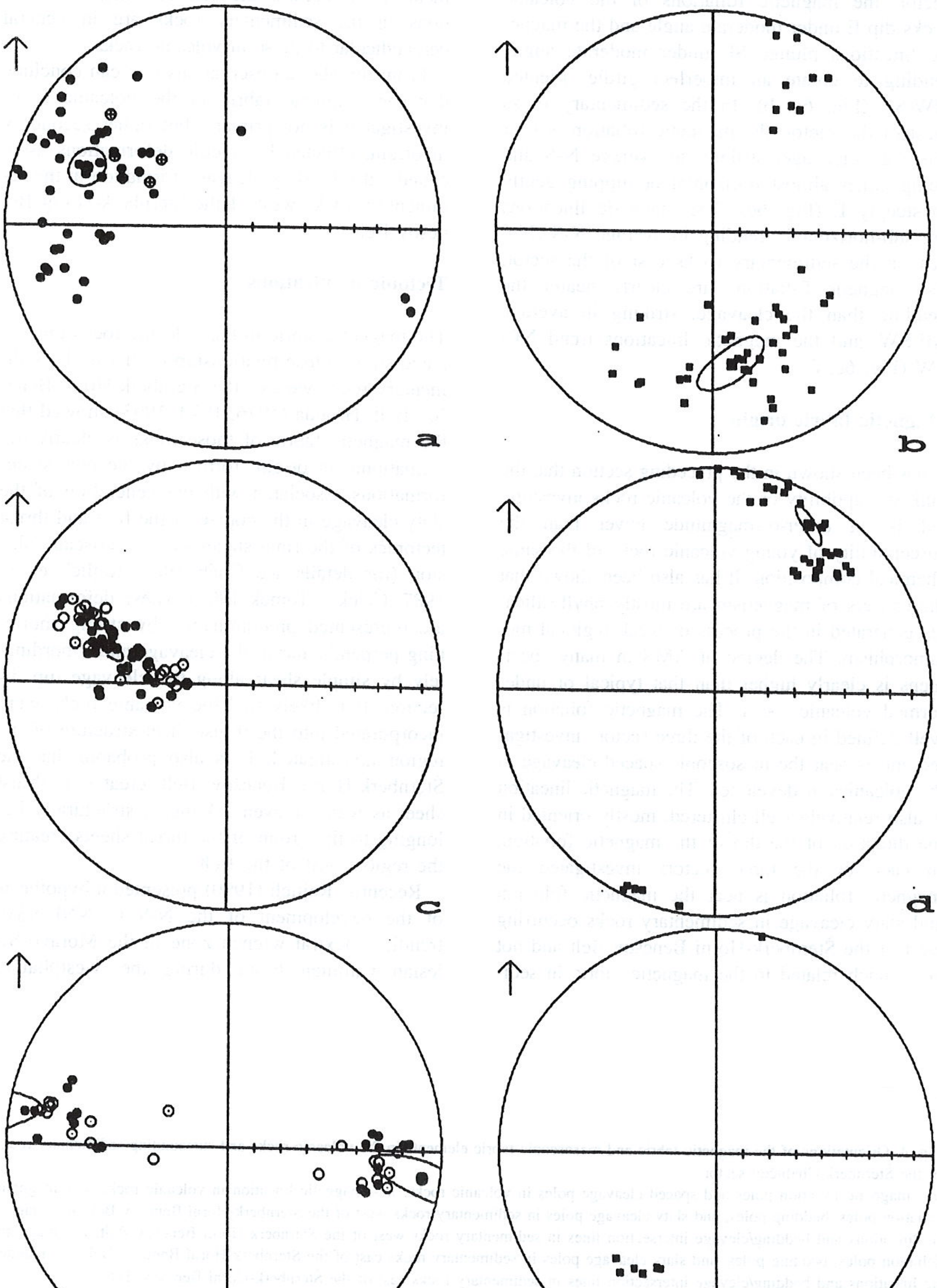
Fig. 4. Orientations of the magnetic fabric and mesoscopic fabric elements in the volcanic rocks and surrounding sedimentary rocks in the Šternberk-Chabičov sector
a – magnetic foliation poles and spaced cleavage poles in volcanic rocks; *b* – magnetic lineation in volcanic rocks; *c* – magnetic foliation poles, bedding poles, and slaty cleavage poles in sedimentary rocks west of the Šternberk-Horní Benešov Belt; *d* – magnetic lineations and bedding/clevage intersection lines in sedimentary rocks west of the Šternberk-Horní Benešov Belt; *e* – magnetic foliation poles, bedding poles, and slaty cleavage poles in sedimentary rocks east of the Šternberk-Horní Benešov Belt; *f* – magnetic lineations and bedding/clevage intersection lines in sedimentary rocks east of the Šternberk-Horní Benešov Belt
Small closed circles and squares denote the magnetic foliation poles and magnetic lineations of individual specimens, respectively. (Large symbols denote the respective fabric elements derived from the mean susceptibility tensor.) Elliptic confidence regions delineate the areas in which the directions of the mean tensor are located on the likelyhood level of 95%. Open circles, circles with dots, and circles with crosses denote the bedding poles, cleavage poles in sediments, and spaced cleavage poles in volcanics, respectively. Squares with dots denote the intersection lines between the cleavage and bedding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(Asturian) transpression, followed by transtension of the area. One of his arguments for the existence of the zone were the NNE-SSW oriented magnetic lineations in the sedimentary rocks of the Nízký Jeseník Mts. revealed by Hrouda (1979).

It follows from a mathematical modelling of the AMS behaviour in a transpression zone (Hrouda 1994a) that the magnetic foliation in the above mentioned wrench zone would be expected very steep up to vertical and the magnetic lineation should be nearly horizontal, oriented NNE-SSW, if the deformations associated with the zone formation were penetrative enough to affect the volcanic rocks of the Šternberk-Horní Benešov Belt. However, the magnetic foliations in the volcanic rocks investigated strike N-S to NE-SW and dip moderately E to SE and the magnetic lineations are oriented mostly NW-SE, plunging SE. Consequently, the magnetic fabric does not support the Rajlich (1990) hypothesis.

In this respect, it should be explained, at least qualitatively, why the magnetic lineations in the volcanic rocks are oriented almost perpendicularly to those in the sedimentary rocks west of the Šternberk-Horní Benešov Belt, even though the main components of the magnetic fabrics of both the rock types are considered to have been formed during the same process, i.e. the slaty cleavage generation associated with fold and thrust tectonics. The analyses of the deformational development of the area have shown that the sedimentary rocks under consideration were first shortened vertically and relatively strong magnetic foliation developed parallel to the bedding (Hrouda 1979, 1991). Later, slaty cleavage generated mostly at oblique angle with respect to the bedding and the associated magnetic fabric overprinted strongly the previous magnetic fabric. This non-coaxial superposition of the two predominantly planar magnetic fabrics has given rise to the less planar magnetic fabric whose magnetic lineation is parallel to the bedding/cleavage intersection lines (Hrouda 1976). This magnetic lineation is typical intersection lineation and cannot be regarded as the stretching lineation.

The volcanic rocks did not evidently undergo the deformation corresponding to the vertical shortening of the sediments. Their weak primary (flow) magnetic fabric was strongly overprinted by the deformation associated with the slaty cleavage generation and no intersection magnetic lineation generated. Consequently, the susceptibility ellipsoid reflects in its form the shape of the strain ellipsoid of the deformation associated with the slaty cleavage generation. The ellipsoid shape ranges from moderately prolate to clearly oblate which implies either pure shear combined with flattening or simple shear combined with flattening as representing the strain associated with the slaty cleavage generation. As the magnetic lineation (direction of the rock lengthening) is oriented parallel to the dip line of the thrust sheets evidenced by Cháb (1986), Čížek – Tomek (1991) and Rajlich et al. (1987), one can hypothesize that the deformation that formed the magnetic fabric of the volcanic rocks was simple shear combined with flattening associated with creation and motion of the thrust sheets.

Conclusions

The investigation of the magnetic fabric in the volcanic rocks of the NE Moravia has drawn the following conclusions:

1. Magnetic fabric in the volcanic rocks investigated is relatively homogeneous, slightly differing in individual sectors
2. Magnetic foliation is roughly parallel to the cataclastic foliation, implying deformational origin of magnetic fabric
3. Magnetic foliation in volcanics is parallel to the magnetic foliation and slaty cleavage in the sedimentary rocks west of the Šternberk-Horní

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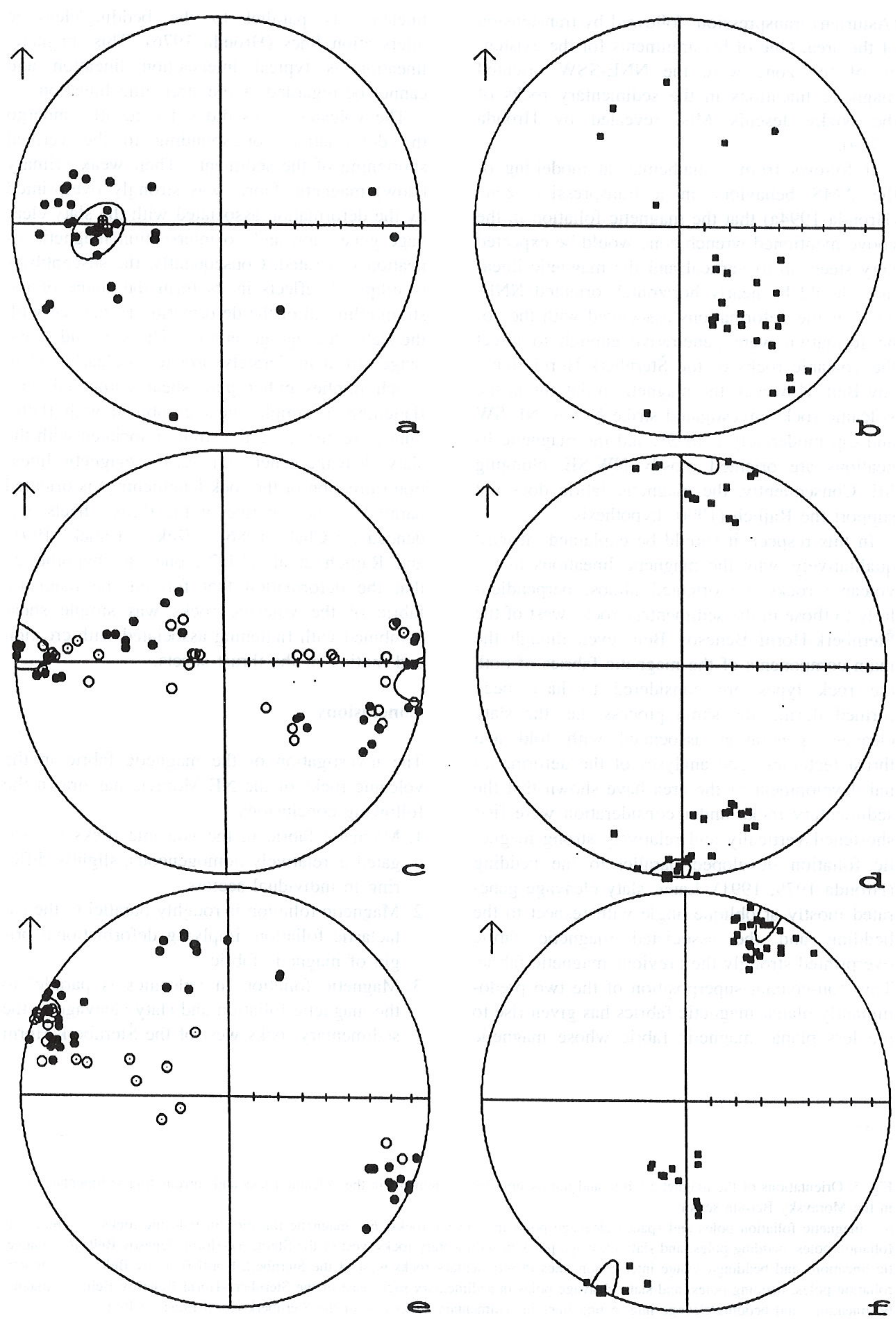
Fig. 5. Orientations of the magnetic fabric and mesoscopic fabric elements in the volcanic rocks and surrounding sedimentary rocks in the Moravský Beroun sector
a – magnetic foliation poles and spaced cleavage poles in volcanic rocks; *b* – magnetic lineation in volcanic rocks; *c* – magnetic foliation poles, bedding poles, and slaty cleavage poles in sedimentary rocks west of the Šternberk-Horní Benešov Belt; *d* – magnetic lineations and bedding/clevage intersection lines in sedimentary rocks west of the Šternberk-Horní Benešov Belt; *e* – magnetic foliation poles, bedding poles, and slaty cleavage poles in sedimentary rocks east of the Šternberk-Horní Benešov Belt; *f* – magnetic lineations and bedding/clevage intersection lines in sedimentary rocks east of the Šternberk-Horní Benešov Belt
For legend see Fig. 4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Benešov Belt; magnetic lineation is approximately parallel to the dip line in volcanics and to the strike line in sediments

4. The formation of the magnetic fabric in volcanic rocks was associated with the slaty cleavage generation in sediments west of the Šternberk-Horní Benešov Belt
5. Deformations associated with slaty cleavage generation are represented mostly by shortening perpendicular to the cleavage and partially also by simple shear parallel to the cleavage (indicated by dip-parallel magnetic lineation)
6. These deformations were associated with creation and motion of the thrust sheets in the final stages of the Variscan collision.

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Fig. 6. Orientations of the magnetic fabric and mesoscopic fabric elements in the volcanic rocks and surrounding sedimentary rocks in the Leskovec-Horní Benešov sector

a – magnetic foliation poles and spaced cleavage poles in volcanic rocks; *b* – magnetic lineation in volcanic rocks; *c* – magnetic foliation poles, bedding poles, and slaty cleavage poles in sedimentary rocks west of the Šternberk-Horní Benešov Belt; *d* – magnetic lineations and bedding/clevage intersection lines in sedimentary rocks west of the Šternberk-Horní Benešov Belt; *e* – magnetic foliation poles, bedding poles, and slaty cleavage poles in sedimentary rocks east of the Šternberk-Horní Benešov Belt; *f* – magnetic lineations and bedding/clevage intersection lines in sedimentary rocks east of the Šternberk-Horní Benešov Belt

For legend see Fig. 4

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Vztahy magnetických vnitřních staveb paleozoických vulkanitů a sedimentárních hornin v Nízkém Jeseníku

Pomocí magnetické anizotropie byla studována vnitřní stavba magnetických minerálů v paleozoických vulkanických horninách šternbersko-hornobenešovského pásma Nízkého Jeseníku a v okolních spodnokarbonských usazených horninách. Ukázalo se, že stupeň anizotropie ve zkoumaných vulkanitech je u většiny vzorků dosti vysoký, podstatně vyšší než u recentních nedeformovaných vulkanických hornin obdobného složení.

Orientace magnetické foliace a magnetické lineace jsou ve vulkanitech podobné jako v okolních sedimentárních horninách, které se nacházejí z. od šternbersko-hornobenešovského pásma a jejichž magnetická vnitřní stavba je nepochybně deformačního původu (magnetická foliace je rovnoběžná s klivážovou břidličnatostí a magnetická lineace s průsečnicemi kliváže a vrstevnatosti). Z toho plyne, že magnetická vnitřní stavba ve zkoumaných vulkanitech je převážně deformačního původu a měla přinejmenším část své deformační historie stejnou jako magnetická vnitřní stavba okolních spodnokarbonských sedimentů. Výsledky studia magnetické anizotropie jsou v dobré shodě s výsledky posledních geologických výzkumů předmětného území.