Dyke Swarm Pattern and Tectonics in the České Středohoří Mts. Volcanic Centre, Ohře (Eger) Rift, Central Europe (Starting Points for Further Research)

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ABSTRACT. Orientation data on the radiating dyke swarm of lamprophyres, semilamprophyres, felsic derivates and common basaltic rocks in the area of the volcanic centre of the České středohoří Mts. obtained from field survey were compared with the newly recognized tectonics inside the superficial volcanic products of the complex. Strike E–W is the most common in all rock groups of the dyke swarm and strike N–S is frequent for dykes of the lamprophyre and semilamprophyre groups. Strikes NNW–SSE and NW–SE to WNW–ESE are present in all groups, too. Faults show the same strike. Orientations of steeply inclined dykes, compared with the strikes of faults, support the idea that the dyke emplacement was controlled by syngenetic regional stress regime using pre-existing rupture systems. No structures induced by formerly supposed diapiric effect of the hypabyssal (essexitic) and/or carbonatitic intrusions were proved. The inclination data of moderately inclined dykes indicate their emplacement into a paired fracture system striking NW–SE and NE–SW to NNE–SSW. A change in regional stress regime is presumed during the development of the dyke swarm.

The radiating shape of the swarm can be explained as the only spatial connection between the hypabyssal intrusions/trachytic vent and dykes (using similar space for magma ascent) – not the structural-genetic one, e.g.: the magma ascent of the dyke swarm rocks was controlled by existing stress regime without application of any updoming and the dyke swarm is radiating in its shape only. Orientations of newly identified faults correspond to the model of the blocky-structure setting inside the rift area.

KEY WORDS: Tectonics, radiating dyke swarm, volcanic centre, the České středohoří Mts., Ohře/Eger Rift.

Introduction

The mountain range of the České středohoří Mts. (CS) represents one of two large Tertiary volcanic complexes developed in the Ohře/Eger Rift (OR) – see Fig. 1. Due to the higher erosion rate caused by the Labe/Elbe River and also due to the tectonic development, this range has been exhumed to deeper levels than the other one, the Doupovské hory Mts. The underlying rocks for superficial products of the CS volcanic complex are

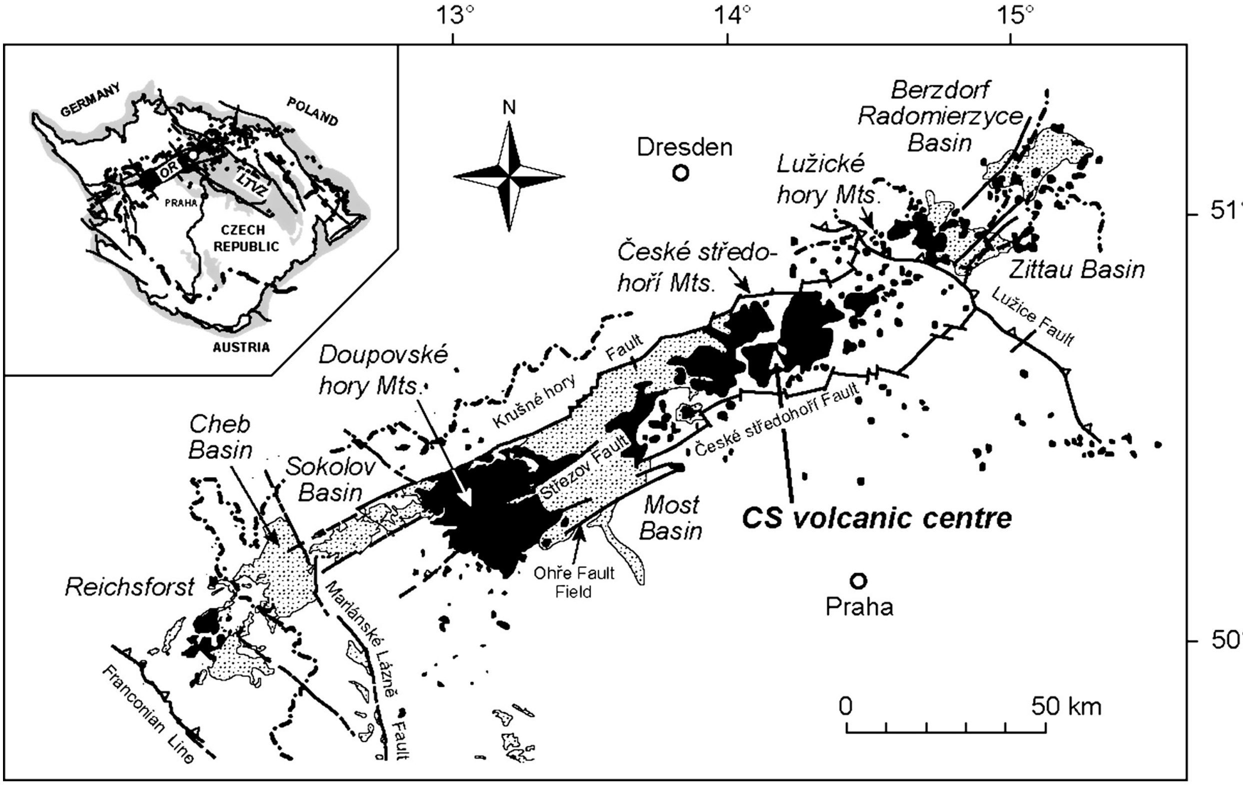

Fig. 1. Location of the České středohoří Mts. volcanic centre in the Ohře Rift (OR) structure. Its position at the junction of the supposed Labe Tectonovolcanic Zone (LTVZ) and the Ohře Rift–*sensu* Kopecký 1978–is shown in the inset map, using the exposed Bohemian Massif contour. Position of the volcanic centre is indicated by the white arrowhead. The main tectonic features, sedimentary basins (dotted) and volcanics (black) represent the Ohře Rift structure on the main figure. The sub-parallel NE-SW-striking fault systems limiting the OR graben structure can be followed from the Mariánské Lázně Fault to the Lusatian (Lužice) Fault only.

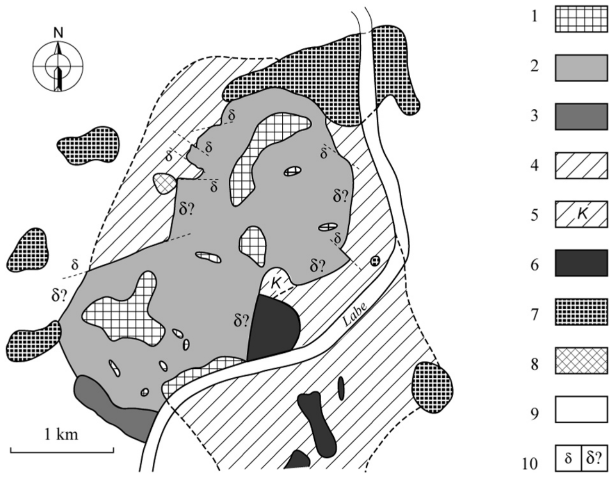

Fig. 2. Geological sketch-map of the internal part of the volcanic centre. 1 – trachyte and phonolite intrusions, 2 – trachytic breccia (crater vent), 3 – mondhaldeite breccia (dyke), 4 – contact metamorphism of Cretaceous sediments, 5 – quartzites, 6 – monzodiorite (rongstockite) and essexite, 7 – nepheline basanite and olivine nephelinite vents, 8 – trachybasalt intrusion, 9 – Cretaceous sediments (sandstones and marlstones) and superficial volcanic products, 10 – probable tectonic limitation of the trachytic breccia body (higher and lower probability).

mostly represented by Late Cretaceous sediments and rocks of the Krušné hory/Erzgebirge Mts. Crystalline Complex.

The CS volcanic complex is composed of bimodal volcanics. Phonolitic-type rocks represent subvolcanic forms, basaltic-type rocks constitute the superficial volcanic products (incl. volcaniclastics) and their subvolcanic forms are developed in minority, compared to the superficial products.

The CS volcanic centre is situated near the Roztoky village, in the Labe River cut between Ústí nad Labem and Děčín. Kopecký (1978) interpreted its position as the junction of the OR and the Labe Tectonovolcanic Zone (LTVZ), specifically the intersection of their prominent but merely presupposed deep-seated structures: the Central Rift Fault and the central fault of the LTVZ. This idea is used on the inset map in Fig. 1, but without the presupposed central structures due to their problematic existence (see below). Volcanic centre of CS can be described as the area of concentrated volcanic bodies of deepest known position. Its internal part (Fig. 2) is represented by a large trachytic breccia body and essexite/monzodiorite stocks (the Roztoky Intrusive Centre of some authors) and is “surrounded” by other volcanic bodies of subvolcanic position.

One of the characteristic features in the area of the volcanic centre is the presence of a dyke swarm of lamprophyres and semilamphrophyres penetrating the country rocks. The radiating shape of this swarm and geochemical affinity of the dyke rocks to the hypabyssal intrusions induced an idea of causal structural relationship between the dyke swarm emplacement and the emplacement of hypabyssal intrusions (Hibsch 1936), i.e., the mechanism of magmatic diapirism. A theory of hidden carbonatitic magmatism in the volcanic centre (Kopecký 1987) also employed the same mechanism of the swarm emplacement, and cone sheets and ring dykes were supposed to be present here.

The CS volcanic complex used to be shown almost free of any faults on older maps. Faults in the Cretaceous sediments were recognized during the survey in 1960s but the volcanics were supposed to be almost unaffected by tectonics at that time. The definition of the OR (Kopecký 1978) brought an idea of deep tectonic setting of the region; nevertheless, these supposed structures were not well defined by their superficial manifestations, especially in the area covered by the complex itself. In addition, the existence of these deep-seated structures (in the sense of their definition) is problematic in the area of the CS, compared to the new results of deep borehole data interpretation (Mlčoch 2002) – see also the discussion in Cajz (2001) – termination and/or modification of rift-related tectonics along the Lusatian Fault and Mariánské Lázně Fault.

Geological setting

Volcanic centre

The centre evidences polyphase magma emplacement, development of crater vents and tectonic movements. Cretaceous sandstones and marlstones, exhumed from the overlying superficial volcanics, are penetrated by basaltic intrusions (basanites to nephelinites and tephrites to trachybasalts) representing mostly subvolcanic or sub-superficial parts of the crater vents. A possible crater lake is developed in the northern part of the volcanic centre. These vents produced material of superficial volcanic products belonging to two lower lithostratigraphic units (Cajz 2000). Hypabyssal stock intrusions are of essexite/monzodiorite composition. A body of trachytic breccia is developed here, 3.5 km by 1.5 km in size. It was first described as a usual volcanic vent (Hibsch 1899). Later it was interpreted as a product of alkaline metasomatism of Cretaceous sediments and crystalline basement rocks caused by hidden carbonatitic intrusion (Kopecký 1987). The intrusions of massive trachytes and phonolites are developed as smaller bodies inside the trachytic breccia itself – see Fig. 2. Several other bodies of phonolite are present around the above mentioned volcanics. Magmatic rocks of the hypabyssal intrusions and some of dykes have been dated to 33–16 Ma by K-Ar method (Ulrych and Balogh 2000). Sodalite syenite stocks to laccoliths have been reported from places farther from the volcanic centre.

The area of the volcanic centre was mapped in detail and new results were obtained. A large depression in post-Cretaceous relief was described on the area of 2,000×800 m with the depth of at least 200 m, filled with volcaniclastic material of subaquatic slides and terrestrial debris flows (Cajz 1992). This depression is situated in the approximate prolongation of the Zubrnice Fault. The altitude and stratigraphic positions of Cretaceous sediments in the depression and its environs vary considerably. The large body of the trachytic breccia (a possible vent of younger explosive volcanism, though no corresponding superficial volcanic products have been found) was interpreted to be limited and/or modified by fault structures – see Fig. 2.

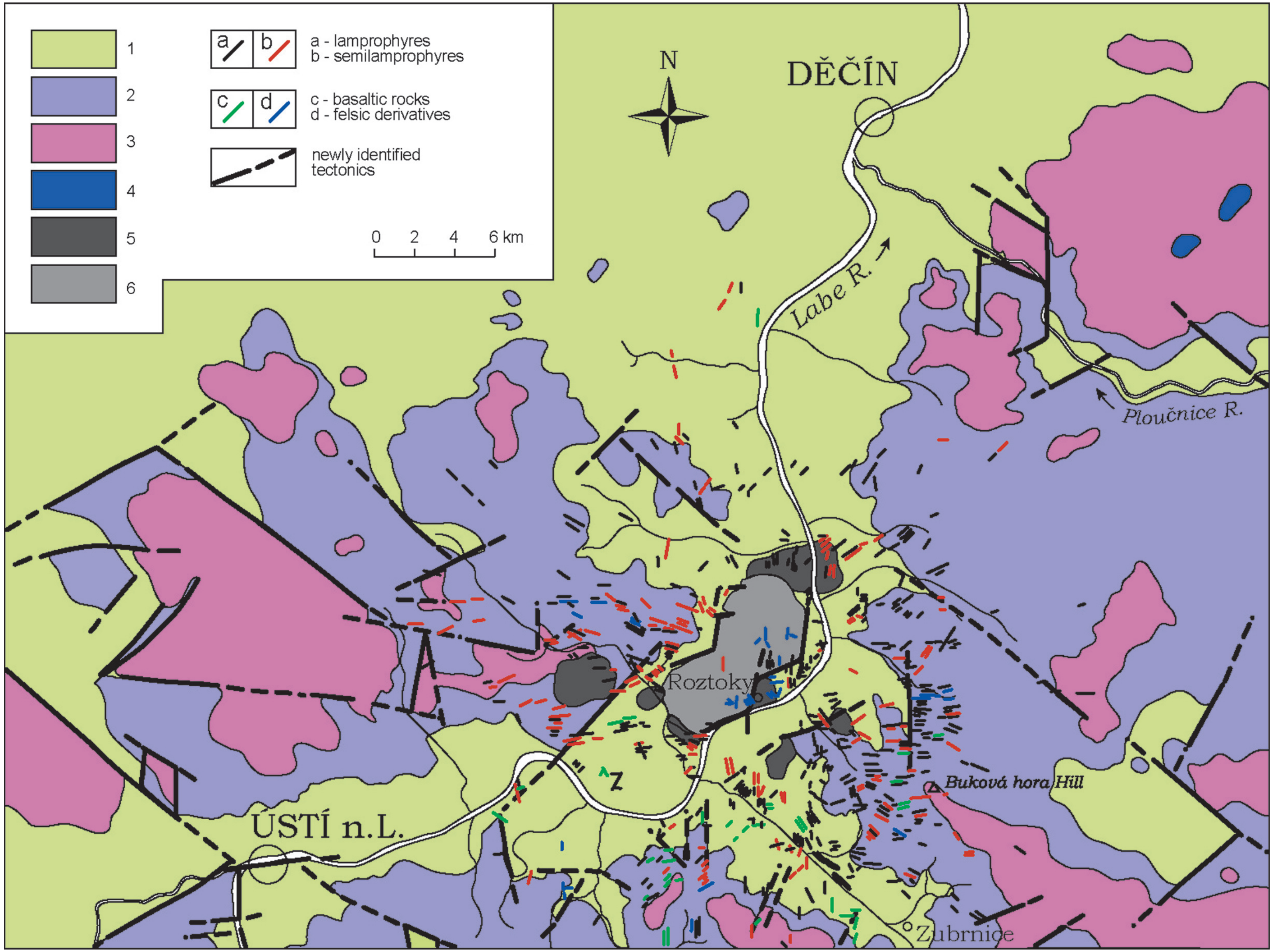

Fig. 3. A map of the dyke swarm distribution and new-ly identified faults in the surroundings of the CS volcanic centre with the volcanic complex lithostratigraphic units: 1 – Cretaceous sediments, 2 – "basanite" rift fill (Ústí Fm.), 3 – "tephrite" composite volcano (Děčín Fm.), 4 – "basanite" upper effusives (Dobrná Fm.), 5 – subvolcanic bodies of solid rocks of the centre (see Fig. 2 for detail), 6 – crater vent filled with trachytic breccia. The intrusions of trachytes and phonolites are not specified.

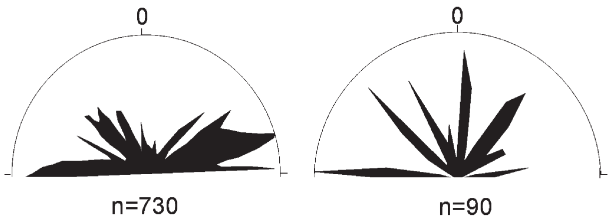

Fig. 4. Rose diagram of the older known tectonic structures in the area of CS (left) – (influence of the marginal rift fault systems is determinative) compared with the rose diagram of newly detected faults in superficial volcanics (right).

Faults

The detailed field survey of the CS complex employed lithostratigraphy of superficial volcanics (Cajz 2000) and revealed faulting inside the volcanic complex (see Fig. 3). Mostly vertical movements on the faults can be identified. Nevertheless, strike-slip component cannot be neglected.

Relative to the geological setting of the complete volcanic complex, the tectonic movements are pre-volcanic, syn-volcanic (with different cross-cutting relations to the individual lithostratigraphic units) and post-volcanic. The rose diagrams (Fig. 4) show comparison of all known faults from the area of the CS and newly recognized faults inside the complex.

Dyke swarm generations

The dykes mostly penetrate the Cretaceous country rocks (sandstones and marlstones), and the volcanics of the lowermost lithostratigraphic unit (*sensu* Cajz 2000) – see Fig. 3. The radiating dyke swarm is composed of more than 800 dykes of different magmatic rocks (Hibsch 1936) in the close surroundings of the volcanic centre. Geochemical characteristics of the dykes have been recently studied by Ulrych and Balogh (2000), who distinguished weakly alkaline and strongly alkaline series of the dyke rocks. They also subdivided the dyke rocks into four groups and evaluated their relative frequencies (the local/historic names of rock types are used here for comparison with older research):

Lamprophyres (58 %) – camptonite, monchiquite, mondhaldeite
Semilamprophyres (28 %) – gauteite, bostonite
Felsic derivatives (9 %) – tinguaite (tinguaite porhyry), syenite porphyry
Basaltic rocks (5 %) – nephelinite, basanite, tephrite, etc.

The distribution of the dykes was described to be concentrated at the distance of 2–4 km from the centre (>50 %) and their presence was encountered mostly within 7 km from the centre (98 %). Felsic derivatives were found to be developed closer to the centre itself than the other groups. Radiometric studies by the same authors (Ulrych and Balogh 2000) confirmed the existence of younger and older semilamprophyres, as defined by Hibsch (1936) from field observations.

Geochemical similarity of the dykes to the essexitic (and syenitic) hypabyssal intrusions and the shape of the swarm have led to the idea of the structural-genetic dependence of the dyke swarm on the ascent of these magmas. Žežulková (1985) published first the possibility of tectonic influence on the dyke swarm, evaluating the strikes of about 50 dykes from a part of this area.

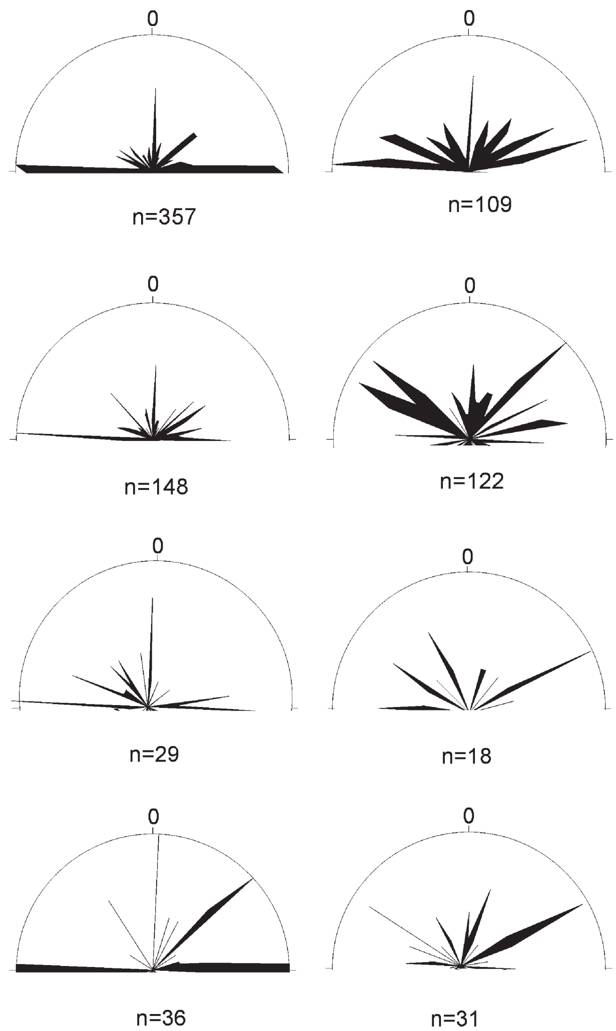

Fig. 5. Rose diagrams of the dyke swarm. Left column – data taken from older maps, right column – newly measured data. Row 1 – lamprophyres, row 2 – semilamprophyres, row 3 – felsic derivatives, and row 4 – basaltic rocks.

Fieldwork and methods

During the detailed field survey (scale 1:10,000), data on the orientations of the dykes were collected. A new survey of the volcanic complex showed the presence of numerous previously unknown faults developed in superficial volcanic products (Cajz ed. 1996, Cajz 2001). In addition, the study of small tectonic phenomena (Adamovič and Coubal 1999, Coubal and Adamovič 2000) indicates an important role of tectonics, which needs to be clarified. This motivated a new evaluation of the dyke swarm emplacement. In the first stage of this research, structural data for the dyke swarm obtained from the detailed field survey were compared with the older ones, taken from the maps, and with

	Strike data from older maps	Newly measured strike data
lamprophyres	90° » 0° , 45° »› 110–135°	90° › 75°, 110–115° › 0°, 65° » 20°, 35°, 130°, 155°
semilamprophyres	90° » 45° , 0° » 105° , 135° › 160°	45°, 110–130° » 80°, 65°, 90° › 0°, 20°, 155°
felsic derivatives	90° › 0° » 110–120°, 135–145° › 80°	60° » 90°, 120°, 150° › 20°
basaltic rocks	90° » 45° › 0° » 145°	65° › 20° » 90°, 105°, 120°, 150°
faults		35° , 0° , 80–90° › 150° › 130°

Tab. 1. A table showing preferences in each group of dyke rocks, compared for both data sets (strikes from older maps vs. newly measured strikes).

the newly recognized brittle structures inside the superficial volcanic products of the CS complex, using the same method to clarify their possible relationships.

A set of 1430 data was processed: 1160 data on dykes and 270 data on tectonic structures. Of this number, 750 directional data were taken from older papers and 680 new ones were used (for closer information on number of dykes in each rock group in both data sets see Fig. 5). Altogether 590 dykes were confirmed by the field survey but only 280 dykes provided data on their strikes and 46 dykes were exposed enough to show their dip angles. All the data on dyke orientations were statistically evaluated as for the rock type. Ninety newly recognized tectonic structures were evaluated using the rose diagrams.

Structural data on faults and dykes were computer-processed using the StereoNett PC program, and the rose diagrams were drawn for the evaluation of their strikes. The measured data of dips were evaluated using the great-circle and pole-density diagrams.

Results

The dykes of the swarm have mostly the character of thin bodies. Dyke thicknesses range from about 10 cm to more than 10 m, but vary around 1 m on average. Their length can be usually followed for several tens of metres. A large number of dykes (52 %) did not provide directional data as the rock type could be identified from debris only. Data on dyke strikes were often deduced using morphological criteria in the field (43 % of all used data), because there was no possibility to measure at the outcrop. More than 85 % of all measured dykes are steeply inclined; the majority reaches 80–90°. The limit of 75° was used to distinguish between almost vertical dykes and moderately inclined ones. The vertical dykes were evaluated as for their strike only. Strikes of dyke groups from the whole area were compared, differentiating between the data taken from older maps and the newly measured data (Fig. 5, Tab. 1).

Lamprophyres and semilamprophyres show a similarity of strikes in the two data sets and the felsic derivatives strikes are different from the former in both data sets. The dykes of basaltic rocks, the emplacement of which is supposed to be connected with the formation of superficial volcanic products, are closer to the groups of lamprophyres and semilamprophyres. The differences between rock groups are wider in the set of newly measured data. The higher simplicity of the swarm distribution drawn on older maps seems to be caused by possible idealization. This is supported also by the recent field observations.

Nevertheless, the strike of 90° is one of the most common in all rock groups, and the strike of 0° is frequent in the lamprophyre and semilamprophyre groups. Strikes of 150–155° and 105–130° are present in all groups, too. The comparison with the newly recognized fault strikes (see the table above) shows a high degree of similarity.

Moderate dip angles (<75°) were obtained from 46 dykes of the swarm. Their orientation is visible on Fig. 6. Formerly (Kopecký 1987), they were supposed to represent ring dykes and cone sheets connected with the intrusions of the internal part of the centre. This statistical evaluation shows development of paired systems in strike intervals 105–130° and 20–40°. These strikes are represented in all dyke groups as well as in the data set of faults. The moderately dipping dykes are supposed to have made use of a tectonic paired fracture system for their emplacement. Data from brittle structures were collected for the evaluation of the stress field.

The relatively wide difference between the felsic rocks group and the groups of lamprophyres and semilamprophyres can be caused by different regional stress regime, employed during their emplacement. The smaller difference between lamprophyres and semilamprophyres is more problematic to explain due to the existence of semilamprophyres of pre-, syn- and post-lamprophyre age (Hibsch 1936, Ulrych and Balogh 2000).

Only two bodies are supposed to represent sills, having a higher thickness and being related to specific vents, not to the bodies of hypabyssal intrusions and/or the trachytic breccia.

Discussion and open questions

The analysis of structural data of the dyke swarm in the vicinity of the CS volcanic centre and the newly recognized tectonic structures in a wider area around the centre show a close genetic connection between these two phenomena. The origin of ruptures and faults can be due to the effect of stresses preceding the syn-magmatic stress fields. The significant coincidence in the courses of ruptures emplaced by dykes and courses of faults indicates their mutual relationship. The swarm is radiating in its shape only: no structural-genetic connection between the swarm emplacement and the magma ascent of the hypabyssal intrusions and/or trachytic breccia-filled crater vent was proved.

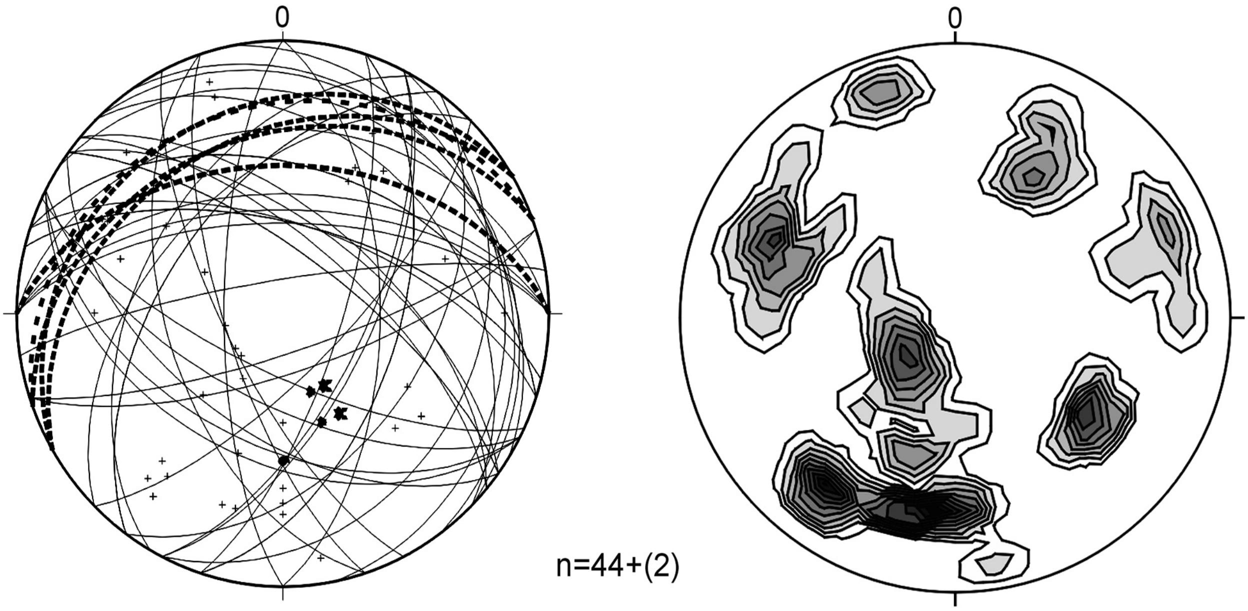

Fig. 6. Evaluation of moderately dipping dykes (<75°), using poles and lower hemisphere projection. Two supposed sills are included in the great circle diagram (dashed circles; four close dashed circles show the variable orientation of trachybasaltic ring segment).

The newly recognized faults do not correspond with the idea of the deep-seated Central Rift Fault of Kopecký (1978). Their orientation is mostly oblique to the presupposed Central Rift Fault and no fault or fault zone was found as a superficial manifestation of this supposed deep structure. The orientations and mutual relationships of the faults better correspond to the model of block structural setting inside the rift than to their derivation from any kind of central structure.

The emplacement of the "radiating" dyke swarm was affected by the regional stress field at the time of magma ascent, which resulted in the opening of pre-existing ruptures and allowed possible ascent of magmas for the formation of dyke rocks. This regime was similar during the emplacement of lamprophyres and semilamprophyres, with the possible exception of younger semilamprophyres (*gauteites II*). A change in the stress regime can be supposed before the emplacement of felsic derivatives.

Some of the moderately dipping dykes seem to have used a paired system of open fractures. This system strikes 105–130°, much like the paired silicified fracture system developed along the Lusatian Fault during the earliest phases of its tectonic history (Coubal, unpubl.). No formation of ring dykes and cone sheets was proved, with the only exception of the trachybasaltic sill – see Fig. 6.

The data on brittle structures are now collected and will be used for further evaluation of the stress fields. Continuation of the structural studies and the identification of successive stress fields and their effects should bring a new idea of the tectonic setting of this part of the Ohře Rift.

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