# Principal Directions and Asymmetrical Zoning of Cenozoic Volcanics in the Lužické hory Mts. and the Adjacent Area, N Bohemia

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*ABSTRACT. The North Bohemian Cenozoic Alkaline Sub-Province exhibits prominent features of linear and zoned distribution of volcanics known already for a long time. Nevertheless, quantitative evaluation of this striking phenomenon is meanwhile almost missing. An attempt in this respect is proposed for an ENE peripheral, NNW–SSE-oriented cross section of the main volcanic belt in the northernmost part of the Czech Republic.*

*The studied cross section reveals a leading role of the SSW–NNE-striking fault system in the continuation of the Ohře Rift and a marked zoning in the direction perpendicular to it. The vicinity of the belt axis is characterized by the accumulation of large bodies of phonolites and trachytes. With the increasing distance from the axis, the amount as well as the size of these light rocks drops gradually to zero and the composition of basaltic rocks becomes simpler. The zoning is rather asymmetrical: its NNW flank is broader and petrographically simpler, the SSE one is narrow, more diversified in its composition and gradually passes into a second parallel zone. The role of the Lužice Fault and the WNW–ESE-striking hypothetical Labe Tectonovolcanic Zone is rather weak.*

*KEY WORDS: Bohemian Massif, alkaline volcanism, basaltic rocks, phonolites, trachytes, faults, linear and zoned distribution.*

## Introduction

For more than 150 years already, North Bohemia has been enjoying a world-wide reputation as one of most typical regions of alkaline volcanic products. It forms the eastern branch of the European Cenozoic Volcanic Alkaline Province termed as the North Bohemian Sub-Province, where its volcanics cover approx. 1000 km$^2$. Their occurrences split into several segments in a 250 km long, WSW–ENE-trending belt confined to a tectonic unit known as the Ohře (Eger) Graben or Rift (Vaněčková et al. 1993, Christensen et al. 2001, Fig. 1). This lineament shows an undulating course in longitudinal cross-section, marked by alternations of faults, mostly volcanic, and predominantly sedimentary saddles. They are as follows: Reichsforst fault⇒Cheb–

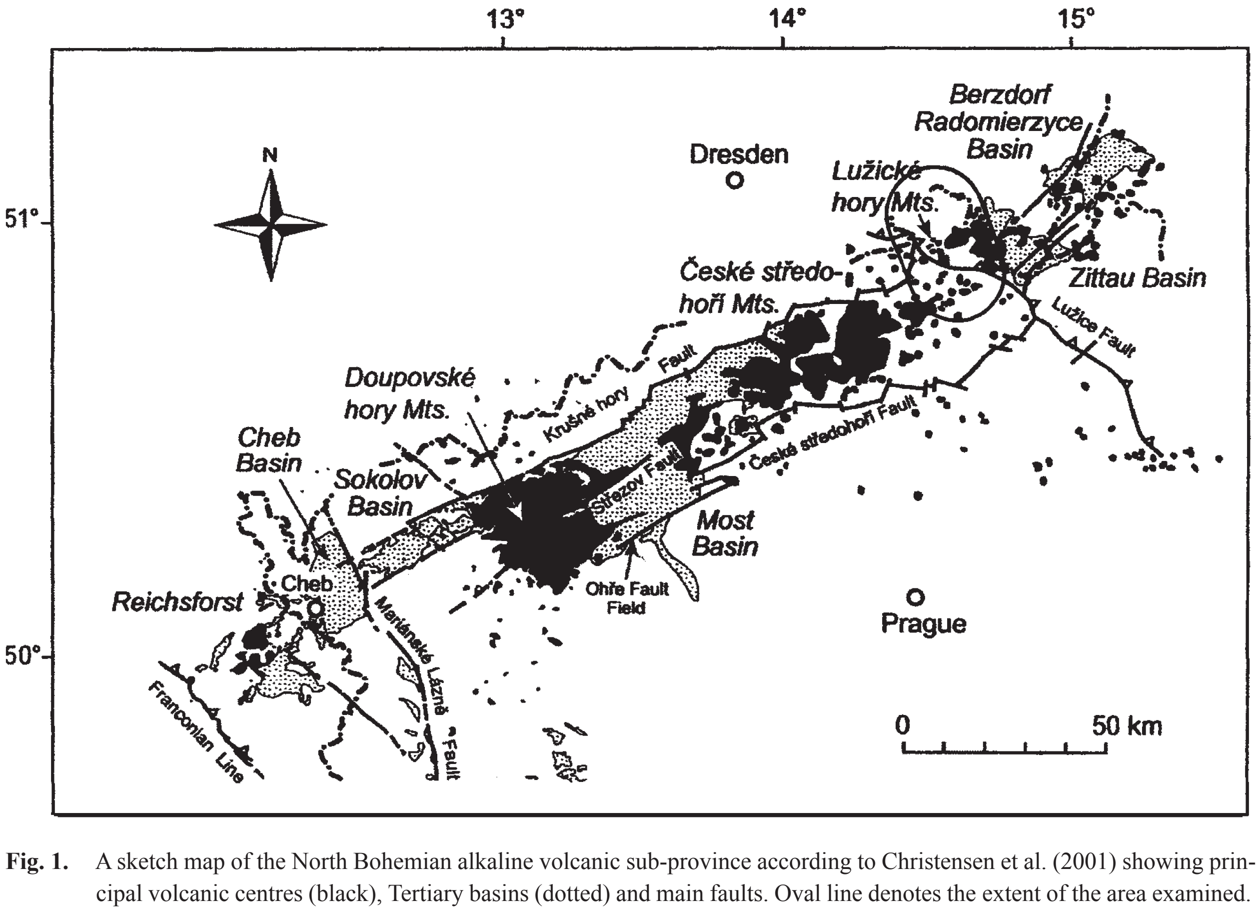


**Fig. 1.** A sketch map of the North Bohemian alkaline volcanic sub-province according to Christensen et al. (2001) showing principal volcanic centres (black), Tertiary basins (dotted) and main faults. Oval line denotes the extent of the area examined.

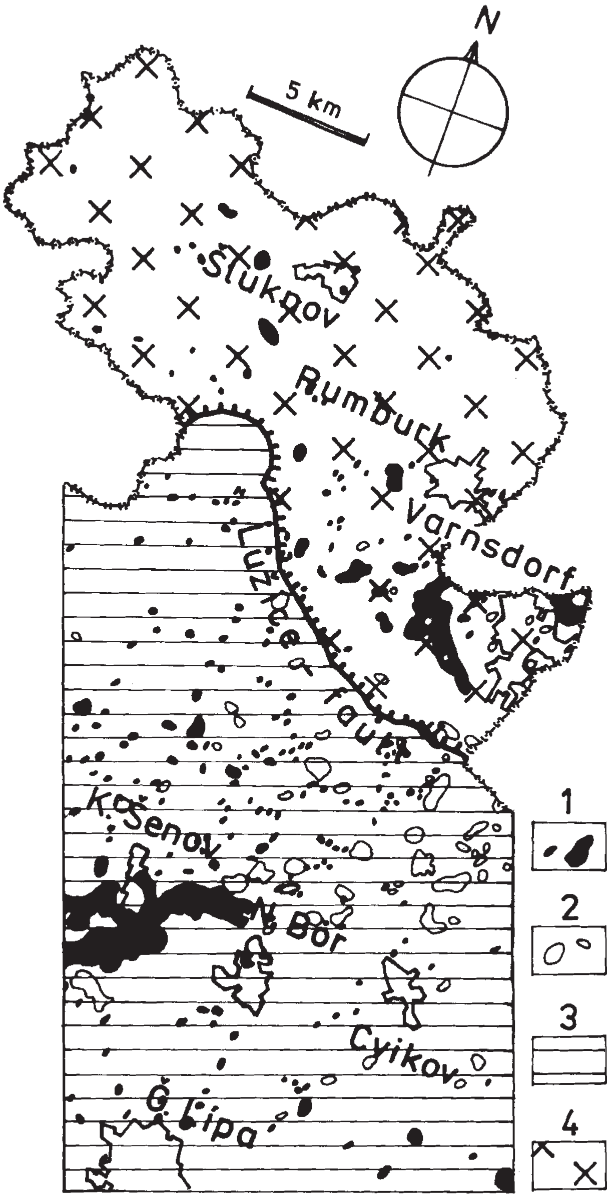


**Fig. 2.** Synoptic geological map of the area examined. 1 – basaltic rocks, 2 – phonolites + trachytes, 3 – Cretaceous sediments, 4 – granitoids of the Lusatian pluton.

Sokolov saddle ⇒ Doupovské hory fault ⇒ Chumutov–Žatec saddle ⇒ České středohoří fault ⇒ Ploučnice River saddle ⇒ Lužické hory fault ⇒ Berzdorf–Radomierzyce saddle. This structure reflects the wavy ceiling of a deep-seated magmatic plume. Two tectonic zones cut obliquely the Ohře lineament: the Cheb–Domažlice Graben and the Labe Tectonovolcanic Zone with the Lužice Fault (Ulrych et al. 1999).

The linear as well as zoned distribution of volcanics did not escape from the attention of former scholars. Nevertheless, no quantification of these phenomena has been hitherto given, the study of Kühn (1990) being a limited attempt in this respect. A more complex analysis is now proposed for the Lužické hory Mts. segment in a NNW–SSE-orientated cross-section perpendicular to the Ohře lineament in the northernmost part of the Czech Republic between the towns of Česká Lípa and Šluknov. The reason for the selection of this cross-section lies in the fact that many new data on geology, petrography, geochemistry, volcanology and geophysics have been collected here during the last two decades.

## Geology

The area examined has the form of a strip 42 km long in the NNW–SSE direction and 16.5 km wide on average. Its areal extent is 691 $km^2$. It contains roughly 300 individual volcanic bodies several tens of $m^2$ up to more than 1 $km^2$ in size. From orographic point of view, the central and substantial part of the area belongs to the Lužické hory Mts. with the highest phonolite peak of Luž (793 m) situated exactly on the Czech/German border.

As demonstrated by the synoptic geological sketch map in Fig. 2, the area, divided by the Lužice (Lusatian) Fault, a first-order regional geosuture, consists of two entirely different units: the Lusatian pluton represented by several granitoids and their dyke conduct in the NE part and by sediments (mostly sandstones) of Upper Cretaceous (on the surface usually Coniacian) age in the NW sector. Subordinate discontinuous tectonic lenses of Proterozoic metasediments and Permo-Carboniferous or Jurassic sediments occur along the Lužice Fault.

Numerous Tertiary volcanic bodies of Upper Oligocene to Lower Miocene age pierce granitic rocks as well as Cretaceous sediments, regardless of the course of the Lužice Fault. Some of them are intrusive bodies such as plugs, necks, fillings of volcanic chimneys or dykes. Nevertheless, erosively destructed lava sheets, partly overlying Oligocene sediments, are also representative for this area. The compositional range of volcanics is considerably wide as is demonstrated in the next chapter.

## Petrography and geochemistry

Based on 114 chemical rock analyses supported by thin-section examination, volcanic rocks were classified according to TAS diagram of IUGS (Le Maitre ed. 2002) – see Fig. 3. The following sources of chemical data were used: Fediuk 2000 (32 analyses), Kühn 1990 (26), Shrbený and Macháček 1973 (22), Shrbený and Macháček 1974 (3), Shrbený 1989 (17), Ulrych and Pivec 1997 (1), Ulrych et al. 1990 (1), archives of the Czech Geological Survey (12).

Fig. 3. reveals a pronounced bimodality of the rock series which splits into basaltic and phonolitic + trachytic groups. A subordinate number of plots (4) show a transitional character that, however, reveals a markedly higher affinity to the basaltic group. Analogous characteristics can be derived from the AFM diagram in Fig. 4.

As for the group of phonolites + trachytes, it should be stressed that the Lužické hory Mts. sector of the North Bohemian Volcanic Sub-Province represents one of the largest accumulations of such rocks not only in the Czech Republic but also in European scale. Approximately one-third of them can be classified as trachytes but they gradually pass into prevailing phonolites in which the sum of alkalis reaches up to 16 %. Among foids, nepheline is usually present; some local phonolites contain

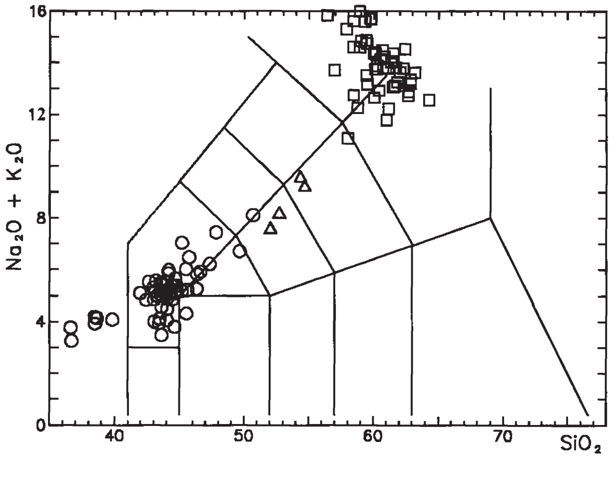


**Fig. 3.** $SiO_2$ vs. $Na_2O + K_2O$ diagram with the IUGS classification grid (Le Maitre ed. 2002) and with 114 plots of volcanics from the area examined. Circles = basaltic rocks, triangles = transitional rocks, squares = phonolites + trachytes.

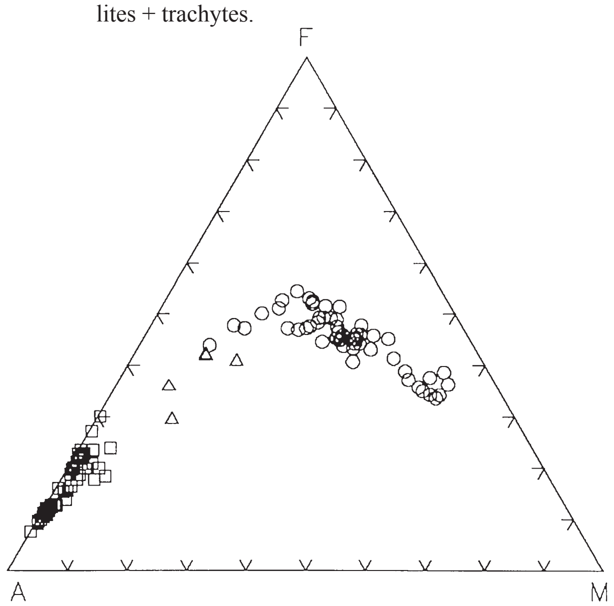


**Fig. 4.** Ternary AFM diagram with 114 plots of volcanics from the area examined. For explanation of symbols see Fig. 3.

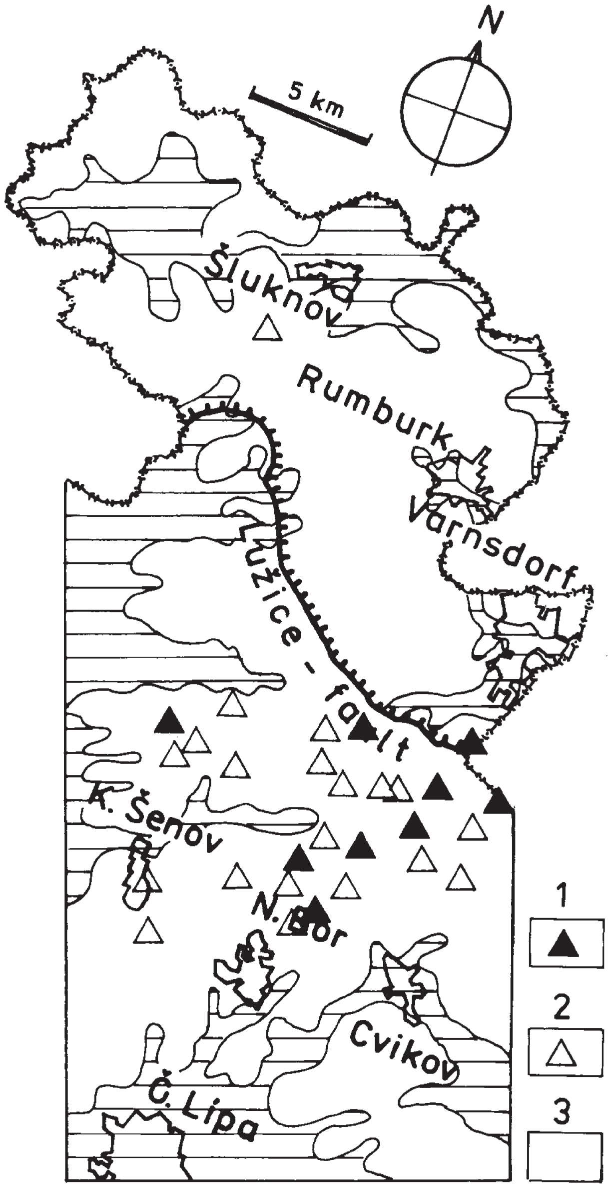


**Fig. 5.** Geomorphological characteristics of the area examined. 1 – peaks over 700 m a.s.l., 2 – peaks 600 to 700 m, 3 – lowlands below 400 m.

mineral of the sodalite group and frequently a certain admixture of analcime. No leucite has been found.

Fediuk (2000) pointed to the fact that an abruptly different trend line is symptomatic for the plot cluster of phonolites + trachytes compared to that for basaltic rocks.

A substantially larger scatter of plots in the TAS diagram characterizes the group of basaltic rocks. Absolute majority of these rocks plot to the classification field of basanites + tephrites. Using the auxiliary criterion of normative olivine content, most of the samples contain less than 10 % ol and must be ranked within tephrites. Other types of basaltic rocks occur in subordinate amounts only. On one hand, they are represented by foidites which invariably contain nepheline + melilite and can be classified partly as olivine melilite nephelinites, partly as olivine melilitites (polzenites). On the other hand, basaltic rocks more acidic than tephrites and basanites include rare basalt *s.s.* and somewhat more frequent trachybasalts, basaltic trachyandesites and trachyandesites. With the increasing $SiO_2$ content, the $Na_2O/K_2O$ ratio decreases; as a result, trachyandesites can be specified as shoshonites. As in the group of phonolites + trachytes, the main foid of the basaltic rock is nepheline, often accompanied or replaced by analcime, while sodalite mineral is extremely rare and leucite is entirely absent.

The proportion of pyroclastic rocks among light volcanics equals zero, and is rather low in basaltic rocks – below 10. Intrusive rocks of plutonic appearance, known from the Doupovské hory Mts. and mainly from the České středohoří Mts., are entirely absent.

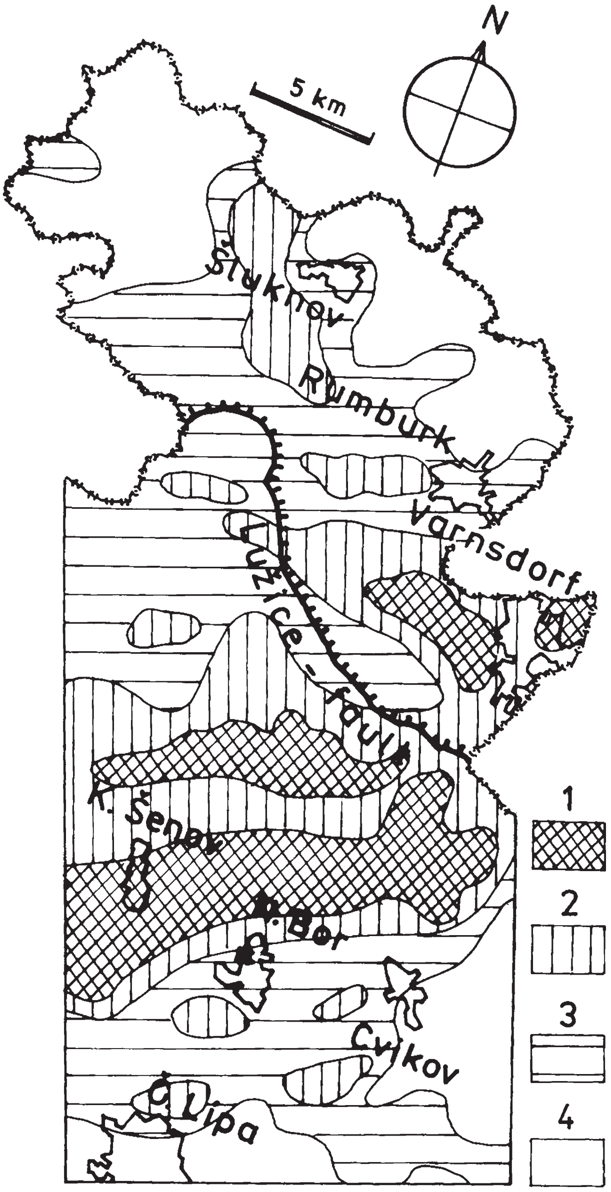


**Fig. 6.** Areal proportion of all volcanics. 1. >20 %, 2. 10–20 %, 3. 1–10 %, 4. <1 %.

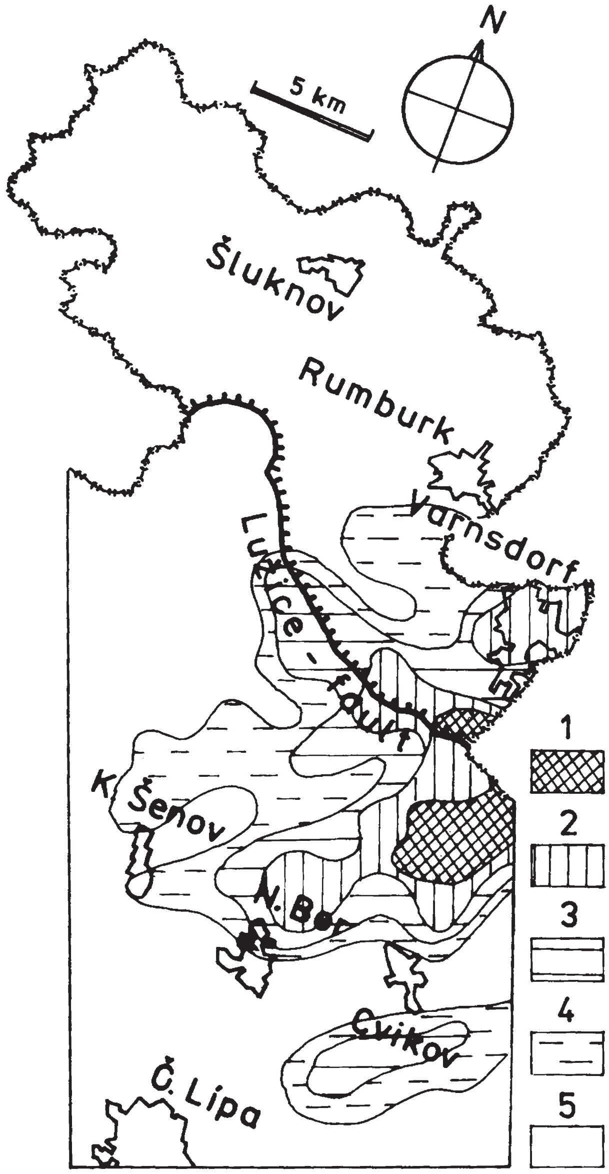


**Fig. 7.** The proportion of light volcanics (phonolites + trachytes) among all volcanics. Values in percent. 1. >60 %, 2. 40–60 %, 3. 20–40 %, 4. 1–20 %, 5. 0 %.

## Distributional characteristics of the volcanics

The distribution of volcanic rocks all over the area examined is uniform neither in their geomorphology nor in the quantity and size of the bodies, in mineral composition or geochemical properties. Linear and zoned arrangement can be demonstrated by various patterns based on quantitative or semi-quantitative evaluations. The following seven cartograms (Figs. 5 to 11) illustrate the results of selected ones.

The first of them (Fig. 5) deals with geomorphologic features. It shows that a conspicuous and almost continuous mountain range runs from WSW towards ENE in the prolongation of the Ohře Rift, being unaffected by the Lužice Fault at all. The range consists of many hills higher than 600 m or 700 m, the position of which is shown in the cartogram; all of them are exclusively volcanic, mostly phonolitic or trachytic. This range represents the very volcanic axis of this area. Perpendicular to it, the surface generally descends to both sides (to NNW and to SSE as well) into lowlands with altitudes often below 400 m. Volcanic bodies occur less frequently here, and light volcanics (phonolites and trachytes) disappear completely.

Fig. 6 shows the proportion of volcanic rocks in the whole geological context. The proportion was evaluated from geological maps 1 : 50,000 using a circular counter of the area equal to 1 % of the total extent of total area examined (for this scale, 1 % of 391 $km^2$ represents a circle with the diameter of 59.4 mm). A conspicuous wide belt with the density of >10 % of volcanics occupies an analogous position as the mountain range in the preceding cartogram in Fig. 5. Densities characterizing the NNW as well as the SSE flanks of the strip studied with subordinate disturbances gradually decrease to below 1 %.

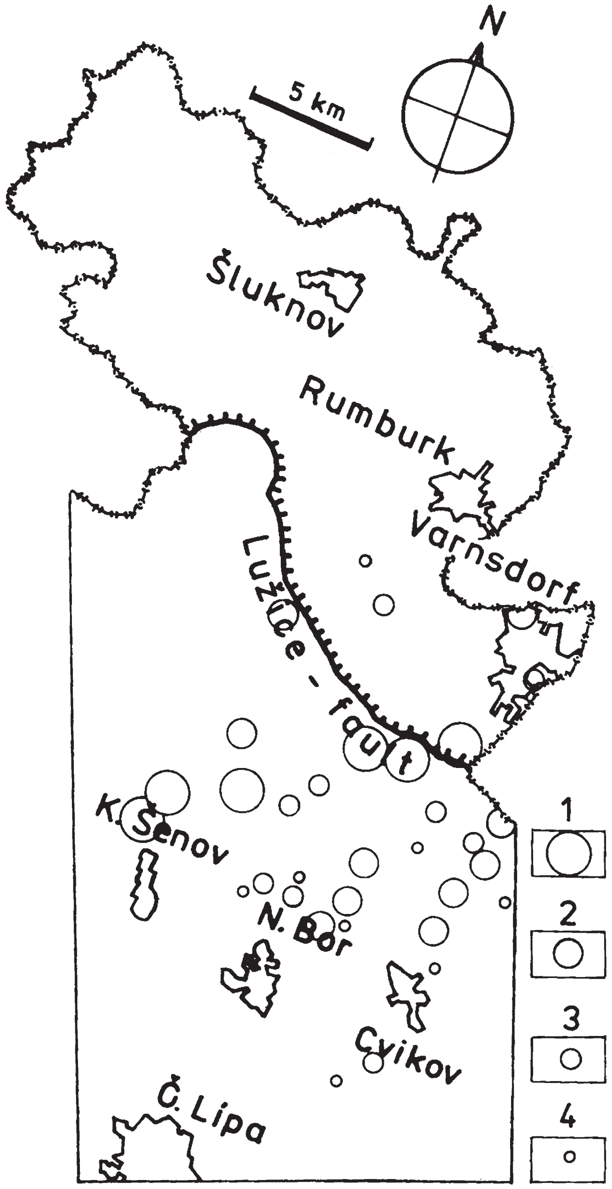


**Fig. 8.** $Na_2O$ : $K_2O$ ratio (wt.%) in light volcanics (phonolites + trachytes). 1. >1.75, 2. 1.50–1.75, 3. 1.25–1.50, 4. <1.25.

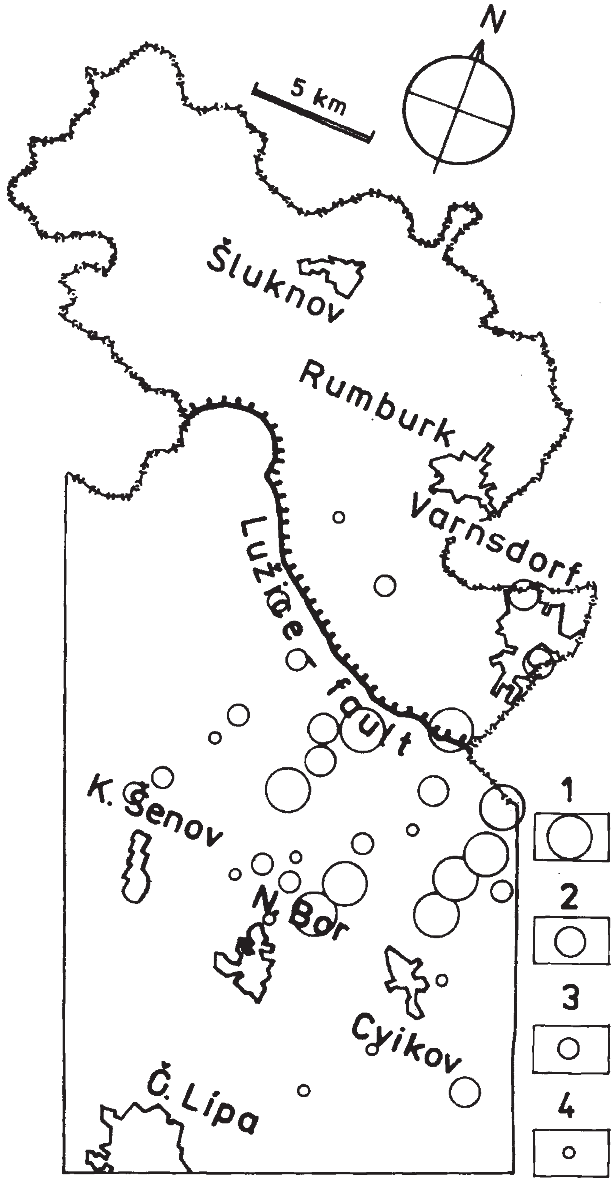


**Fig. 9.** Proportion of normative nepheline in light volcanics (phonolites + trachytes). 1. >25 %, 2. 20–25 %, 3. 10–20 %, 4. <10 %.

The next cartogram (Fig. 7) was constructed using an analogous method as cartogram Fig. 6, with the exception that the areal proportion of light volcanics (phonolites + trachytes) among all volcanic was evaluated. The image on this cartogram is not as unambiguous as in the preceding cartogram. The figure shows a general increase in light volcanics towards the ENE. Nevertheless, some linear features can be stated here, too. The most prominent of them has a position resembling the position of main belts in Figs. 6 and 7, namely the Ohře Rift direction. The leading role of this direction is also accentuated by the fact that peripheral sectors of the strip examined are characterized by zero proportion of light volcanics. In spite of this, we must admit that also a less pronounced high-density belt follows the Lužice Fault in its SE part, obliquely to the above mentioned main belt of the Ohře Rift direction.

Striking linear and zoned patterns are shown in Fig. 8. $Na_2O/K_2O$ ratio (wt.%) for analysed phonolites + trachytes is given here in four quantitative categories. The highest category shows a linear contour which coincides with the main volcanic axis indicated by high phonolite + trachyte hills between Kamenický Šenov and Jiřetín; here, it uninterruptedly passes across the Lužice Fault from Cretaceous sediments into granitic rocks of the Lusatian pluton. Perpendicular to this axial zone, the ratio gradually decreases to both sides.

An analogous cartogram is given in Fig. 9. Four quantitative categories are also distinguished here as in the preceding figure. But in this case, the amount of nepheline expressed in the C.I.P.W. norm is presented. The linear distribution of data is definitely as clear as in Fig. 7: the highest values are confined to the ENE part of the cartogram, to the position on the

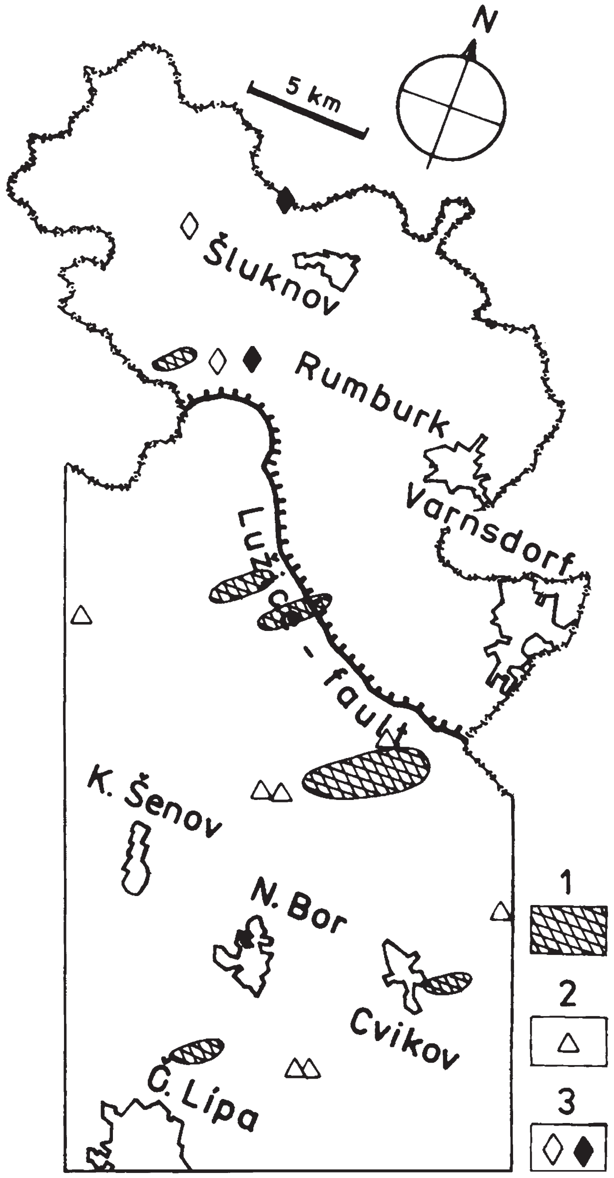


**Fig. 10.** Occurrences of extreme basaltic rocks. 1 – trachybasalts, basaltic trachyandesites, trachyandesites, phonotephrites, 2 – foidites with melilite (melilite olivine nephelinites, olivine melilitites – polzenites), 3 – basanites with lherzolite nodules ± kaersutite xenocrysts (full symbols – extremely abundant).

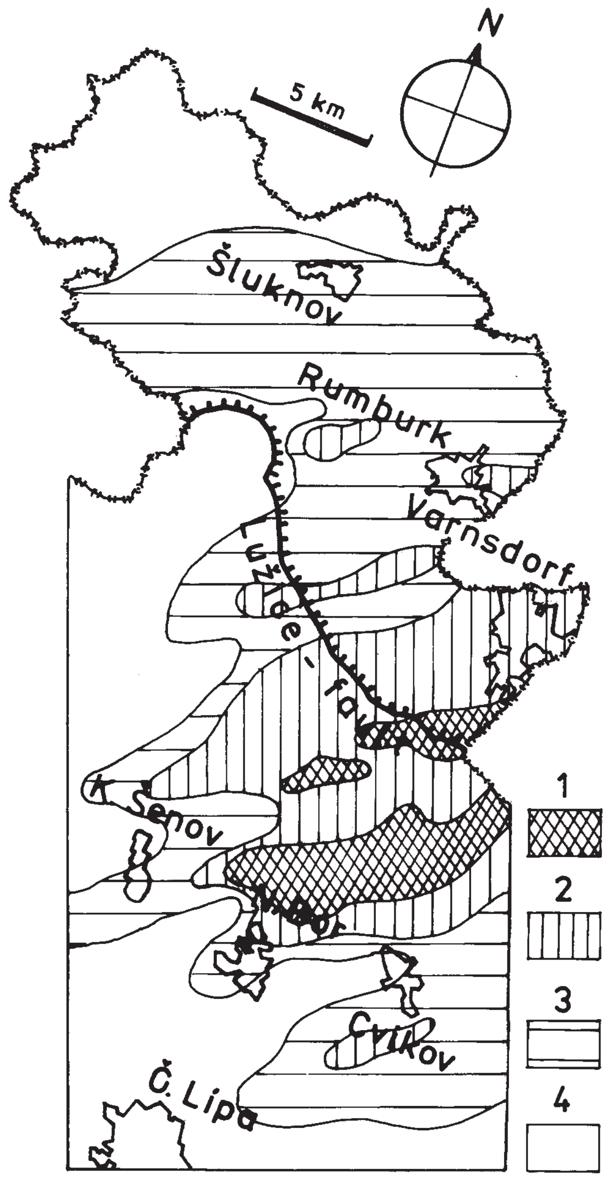


**Fig. 11.** Airborne registered radioactivity in the area examined. Isolines in ppm $U_{equiv.}$ Adapted from Manová in Šalanský (1977).

main volcanic axis. On the other hand, the zoned arrangement of quantitative categories is clearly developed here, showing systematic bilateral decrease with the increasing distance from the main volcanic axis.

The next cartogram in Fig. 10 relates to basaltic rocks. As stated in chapter Petrography, absolute predominance in this group of rocks belongs to tephrites + basanites. Expressed in terms of graphic Gauss distribution, these rocks represent a steep peak of the distribution curve and can be designated as normal or common basaltic rocks of the area examined. Basaltic rocks situated to the left as well as to the right from the strong tephrite+basanite maximum in the TAS diagram in Fig. 2 are present in subordinate quantities only and consequently have the character of extreme members in this region. The role of both of them is illustrated cartographically, the more basic one being represented by melilitic basaltic rocks and the more acidic one comprising trachybasalts to trachynadesites. In addition to that, a third special type of basaltic rocks is present in the same figure, namely basaltic rocks rich (and very rich) in ultramafic xenoliths. The following facts can be deduced from the cartogram: Melilite basaltic rocks occur in the Cretaceous sector of the area only (even though one exceptional dyke of this type cutting granite is known from Hinterhermsdorf in Germany, a few hundred metres behind the WSW boundary of our area). On the other hand, basaltic rocks containing frequent peridotite nodules are confined to the opposite side of the Lužice Fault in the granitic sector. The occurrences of trachybasalts, basaltic trachyandesites and trachyandesites follow the main volcanic axis and – to a lesser degree – also its broader surroundings.

The last cartogram (Fig. 11) reflects the distribution of natural radioactivity in the area studied. It is obvious that the main impact on the result is due to the presence of light volcanics. Therefore, the image of this cartogram is very similar to Fig. 7 showing the proportion of phonolites + trachytes. Also the comment on Fig. 11 can be analogous to that on Fig. 7: conspicuous short linear radioactivity maximum coincides with the ENE part of the main volcanic axis, and two subordinate elevated densities are present: one parallel to the main maximum in the ESE part of the area, the other oblique to the main maximum roughly following the Lužice Fault.

## Conclusions

The area between the town of Česká Lípa and the Czech/German border at Šluknov shows a pronounced tectonic control of the distribution of Cenozoic alkaline volcanics which are ranged into Upper Oligocene to Lower Miocene (Fediuk 1999). This fact is reflected by a wide set of diverse parameters ranging from geomorphology, the amount and size of volcanic bodies to their mineralogy, petrography, geochemistry and geophysics. All cartograms indicate the main volcanic axis running in the direction WSW–ENE (the Ohře Rift lineament), namely in the prolongation of its central fault (Střezov Fault) which displays a horst character.

In a cross-section transverse to this main axis, zoned distribution of volcanics can be stated according to the same parameters as proclaimed for the linear distribution. This zoning is rather asymmetrical due to the interference on its SSE flank by another WSW–ENE-trending belt between Litoměřice and Liberec, keeping track of the České středohoří Fault Zone (not treated in the present study). The responsibility for the zoned arrangement of the volcanics can be attributed to the degree and intensity of tectonic opening of the volcanic feeders from individual magma chambers influenced by the plume activity.

The transverse Lužice Fault exhibits only a limited influence on the distribution of the volcanic field in the strip examined. This statement brings a rather disparate view compared to the conclusions of Kühn (1990). The fact that almost no volcanic occurrence is situated directly on this fault should be also stressed. The Labe Tectonovolcanic Zone, trending along the Lužice Fault, seems to be rather hypothetical in this light.

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