

**The east-alpine earthquakes and the seismicity associated
with the contact zone between the bohemian massif
and the carpathians**

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RIASSUNTO - I terremoti che hanno origine nella regione alpino-orientale si propagano verso nord attraverso il massiccio Boemo pressoché asismico, con attenuazione di energia anomalamente piccola. Questa energia è guidata nelle zone che sono in corrispondenza della struttura del blocco profondo del massiccio Boemo. A contatto della zona fra il massiccio Boemo ed il sistema dei Carpazi sismicamente attivo sembra esservi una barriera per l'energia. La zona di contatto si è formata su blocchi della crosta insediati più profondamente ed è notevole per anomalie gravimetriche e geomagnetiche. Tale zona è divisa a nord-ovest dalla zona di faglia di Lednice, che è sismicamente inattiva, e, a sud-est, dalla parafora Peripiennina, una zona di faglia pronunciata che penetra attraverso la crosta terrestre ed è caratterizzata, nel lato più profondo dell'arco Carpatico, da una sismicità relativamente alta. Il lato esterno della parafora Peripiennina mostra una linea di inversione dei vettori di induzione di Wiese straordinariamente pronunciata, il che corrisponderebbe all'effetto di un conduttore a corrente elettrica lineare con l'asse giacente parallelamente alla parafora Peripiennina a 20-30 km di profondità.

Questa zona anomala di conduttività elettrica differisce chiaramente dal campo di conduttività largamente esteso e tettonicamente orientato in questa parte del continente Europeo.

SUMMARY - Earthquakes originating in the east-alpine region are propagated northwards through the seismically relatively quiescent Bohemian Massif with anomalously slow attenuation of their energy. The latter is guided in the zones corresponding to the deep blok structure of this tectonic unit. A kind of barrier appears for the energy of east-alpine earthquakes at the contact zone between the Bohemian Massif and the seismically active system of the Carpathians. The

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contact zone is built up of deeper seated blocks of the crust and is conspicuous by gravimetric, geomagnetic and geoelectric anomalies. It is separated from the Bohemian Massif in the north-west by the zone of Lednice, a deep fault zone which is seismically inactive, and from the inner West Carpathians in the south east by the Peripieninian lineament, a pronounced fault zone penetrating through the crust and characterized, mainly on the inner side of the Carpathian arc, by a relatively high degree of seismicity. The outer side of the Peripieninian lineament displays a strikingly pronounced line of inversion of Wiese induction vectors, which would correspond to the effect of a linear electric current conductor with the axis lying parallelly to the Peripieninian lineament in a depth of 20-40 km. This anomalous zone of electric conductivity differs clearly from the widely extended and tectonically oriented conductivity field in this part of the European continent.

INTRODUCTION.

The aim of the present paper is to demonstrate more in detail different types of seismic activity and a peculiar form of propagation of seismic energy generated in the east-alpine foci through the Bohemian Massif. In the same time a quite different behaviour will be shown as regards the propagation of the energy of east-alpine earthquakes into the Carpathians.

Facts known from seismological observations will be presented with some results of explosion seismology and geophysical synthesis available for the region in question. Special attention will be paid to the contact zone between the Bohemian Massif and the West Carpathians, as this zone has been subject to extensive geophysical investigation.

Our region of interest represents a part of Central Europe situated (Fig. 1) south of the practically aseismic Paleozoic Polish platform PP. It contains the tectonic unit of the epi-Variscan Bohemian Massif BM (including in the north-west the adjacent Saxo-Thuringicum ST) with a minor degree of seismic activity, and two seismically active young zones shaped substantially during the period of the Tertiary folding, i.e. the East Alps EA and the western part — the West Carpathians — of the Carpathian system CS, encircling the Pannomian (Carpathian) basin PB. The development of the last named units is still going on.

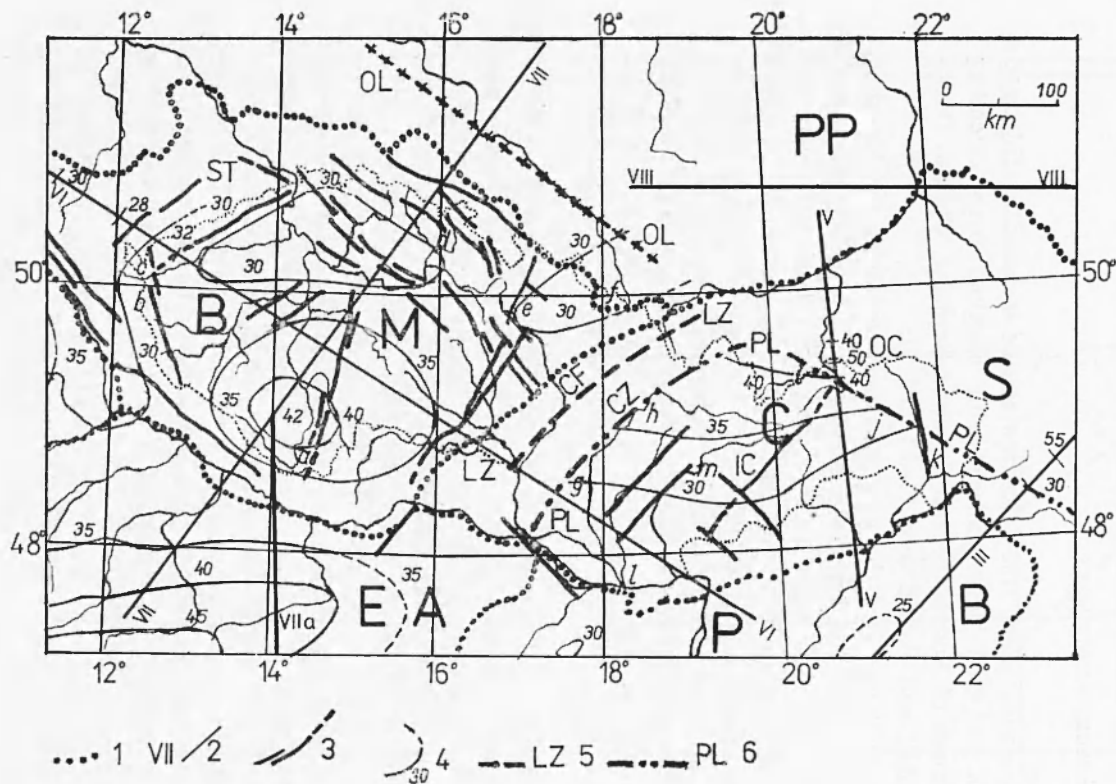


Fig. 1. Region of the Bohemian Massif and the West Carpathians: 1 — boundaries of tectonic units; 2 — international deep seismic sounding profiles; 3 — surface fault systems; 4 — depths of the Moho; 5 — Lednice zone; 6 — Peripieninian lineament; OL — Odra (Oder) line; BM — Bohemian Massif; ST — Saxo-Thuringicum; EA — East Alps; CS — Carpathian System; PB — Pannonian basin; PP — Polish Paleozoic platform; OC — Outer Carpathians; IC — Inner (Central) Carpathians; CF — Carpathian foredeep; CZ — contact zone between the Bohemian Massif and the Carpathians; (a—f)—epicentral areas in the Bohemian Massif; (g—l)—epicentral areas in the West Carpathians.

SEISMICITY OF THE BOHEMIAN MASSIF.

1. *Autochthonous earthquakes.*

The Bohemian Massif (the Saxo-Thuringicum included) is dislocated in Bohemia and NW-Moravia-Silesia with marginal parts extending to the territories of Austria, Federal Republic Germany, German Democratic Republic and Poland (cfr. Fig. 1 and 2).

In the south-west and the west it is separated from the Mesozoic Bavarian plate by a number of faults directed *NW-SE*. In the north-west and the north its boundary is covered by Triassic sediments and mighty Quaternary deposits. In the north and north-east the Odra fault line OL represents its boundary with the Polish Paleozoic platform PP. In the south-east and the south the Bohemian Massif is bordered by the Alpine-Carpathian Neoidic fold-belt, the Neogene foredeep on which is situated over the submerged parts of the Massif. In the case of the West Carpathians it is the Carpathian foredeep CF and the contact zone CZ.

Tectonically the Bohemian Massif represents a complicated horst-like blok structure of the ancient European plate affected by the pre-Cabrian and Calledoniam orogenies with various forms of volcanism; the development of the Massif culminated in the Variscan orogeny during the Late Paleozoic. Its individual structural units were subject to a sequence of uplifts along steep systems of faults. The stabilization taking place since the end of the Variscan tectonic era (about in the Middle Permian) was the reason that the Bohemian Massif was exposed to a long-lasting denudation and peneplanation of its surface. The inner consolidation in the almost vertical fault zones continued until the Neogene. Then the effect of the Alpine orogeny resulted in the first place in the pressure, directed from the south to the north, which led, mainly at the periphery of the Bohemian Massif, to the forming of radial faults and a re-juvenation of some fault zones established earlier. This was often connected with neovolcanic activity (Miocene), in the first place along the *SW-NE* fault system at the southern border of the Ore Mountains (Krušné hory, Erzgebirge) and the *NW-SE* faults along the *NE*-margin of the Massif. A lifting up of the Bohemian Massif as a whole and

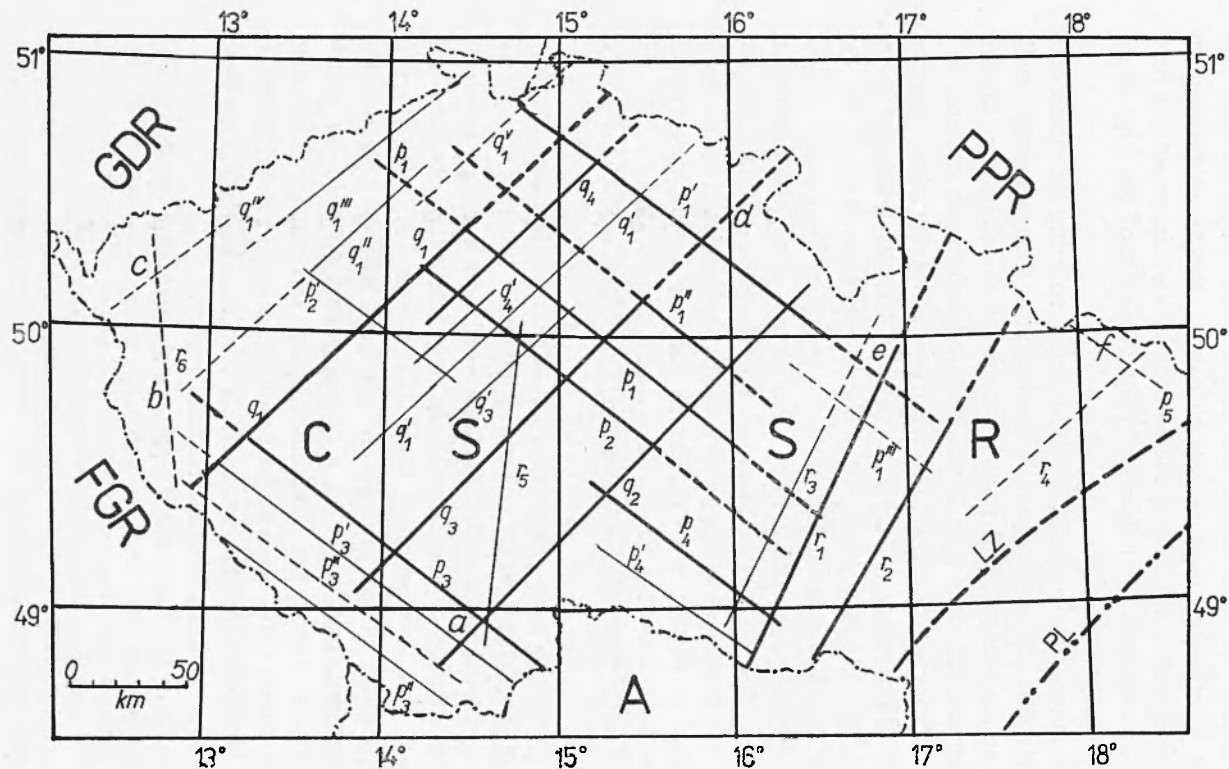


Fig. 2. Axes of zones of higher seismic mobility in the Bohemian Massif: p—SW-NE belts; q—NE-SW belts; r—radial belts; LZ — Lednice fault zone; PL — Peripieninian lineament, A — Austria, FGR — Federal Republic Germany, GDR — German Democratic Republic, CSSR — Czechoslovak Socialist Republic; PPR — Polish Popular Republic; heavy lines — axes with determined dispersion; light lines — axes without determined dispersions; dashed lines — supplements derived from data of the Friuli main shock on 6 May, 1976.

sedimentation in the inner depressions in South-, NE- and North Bohemia are characteristic for this youngest period of evolution.

With regard to earthquakes, the alpine pressure, in general, can be seen as a primary cause of autochthonous shocks originating in the Bohemian Massif. In this sense the autochthonous seismic activity here may well be considered as «induced» by the evolution of the Alps continuing until the present time.

The earthquake catalogue of Czechoslovakia, covering the epoch 460-1956, reveals that the observations of earthquakes, though mostly small, originated at the margins and in the interior of the Bohemian Massif, were much more frequent than it was believed before. At present, this fact is also confirmed by a high number of micro-earthquakes recorded in the stations Pruhonice ($49^{\circ} 59.3' N$, $14^{\circ} 32.5' E$) and Kásperske Hory ($49^{\circ} 07.8' N$, $13^{\circ} 34.8' E$), many of which have been located in the central part of the Bohemian Massif.

The grouping of historical focal areas occurs along the reactivated fault zones in the peripheral parts of the Bohemian Massif. In the interior of the Massif an accumulation of the foci appears in the areas *a* — *f* plotted in Fig. 1: *a* — the South Bohemia basins, *b* — Czech great quartz lode, *c* — the Cheb (Eger) basin and Vogtland, *d* — the Upa (Aupa) valley region, *e* — the border zone Moravia-Silesia, *f* — the Opava region.

Apart from the great earthquake of 1872 near Gera at the NW boundary of the Massif with epicentral intensity reported 8° of the international macroseismic scale, the effects of which were relatively small in the interior of the Massif, the top intensities observed are mostly below 7° , i. e. magnitudes $M \leq 5$ (see Kárník, V., 1968, Part I, pp. 48-50). Groups of earthquakes are not rare. Swarms occur in the region *a*, and are world-known as a typical phenomenon in the region *c* with $I_0 \text{ max} = 7^{\circ}$. During the last hundred years this activity culminated in this region round 1910. Some of these swarms included several hundreds of shocks. This points out the weakness of couplings between individual blocks of this tectonically heavily fractured region.

All shocks in the Bohemian Massif are shallow with depths mostly less than 10 km.

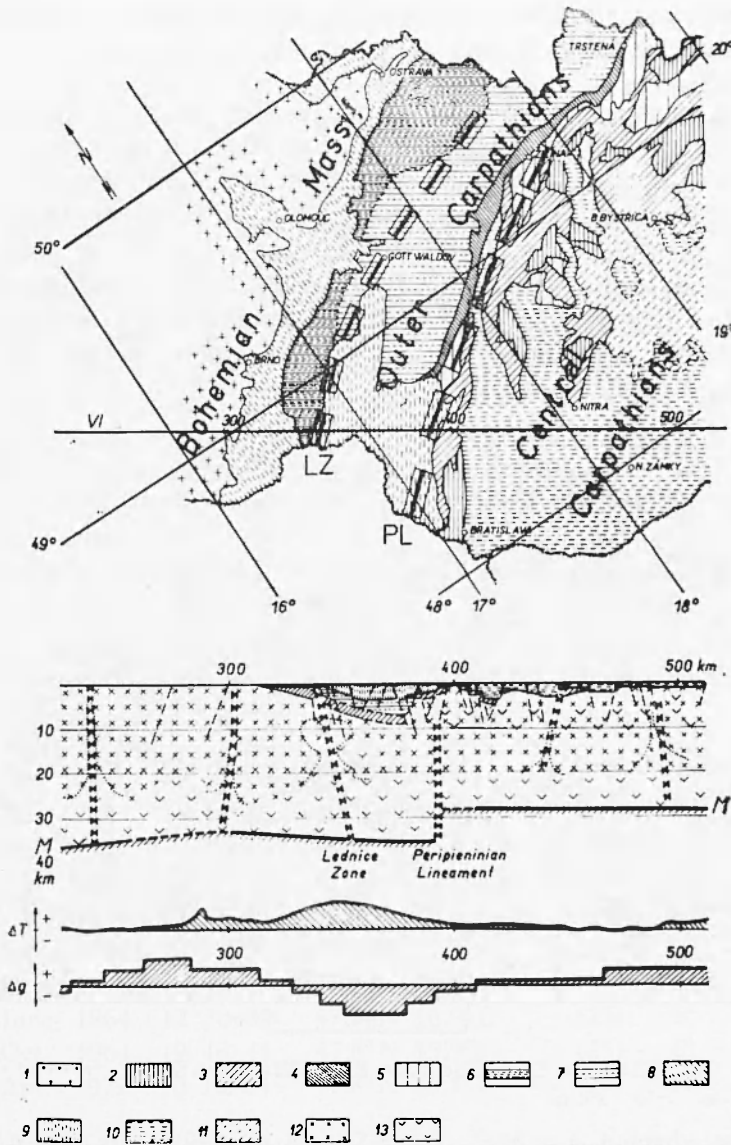


Fig. 3. Contact zone between the Bohemian Massif and the Carpathians: top — geological scheme; middle — structural cross-section, showing sedimentary, granitic and basaltic crustal layers and deep fault zones ascertained by DSS; bottom: ΔT = anomaly of total geomagnetic field T ; Δg = Bouguer gravity anomaly, ΔT and Δg given in arbitrary units; 1 — formations of the Bohemian Massif; 2 — granite; 3 — Mesozoic of the Inner Carpathians; 4 — cliff (Klippen) belt; 5 — Paleogene; 6, 7 — Flysch belts; 8, 9 — Neogene, 10 — Tertiary filling of the inner basins; 11 — neovolcanics; 12 — granite layer; 13 — basaltic layer.

2. Anomalous propagation of the east-alpine earthquakes through the Bohemian Massif.

An important role in the seismic mobility is to be ascribed to the major earthquakes generated in the East Alps and propagated to the north and north-west throughout the Bohemian Massif. Most of them are coming from the sharply distinguished seismogenetic fault zone which proceeds across the superficial geological structures from the Carnic and Julian Alps in NE Italy toward the northeast along the valley of the rivers Mur, Mürz and Leitha and ends at the Danube in the contact area with the West Carpathians Várník, V., 1968 e1971; Sieberg, A., 1932 and cf. F.g. 4).

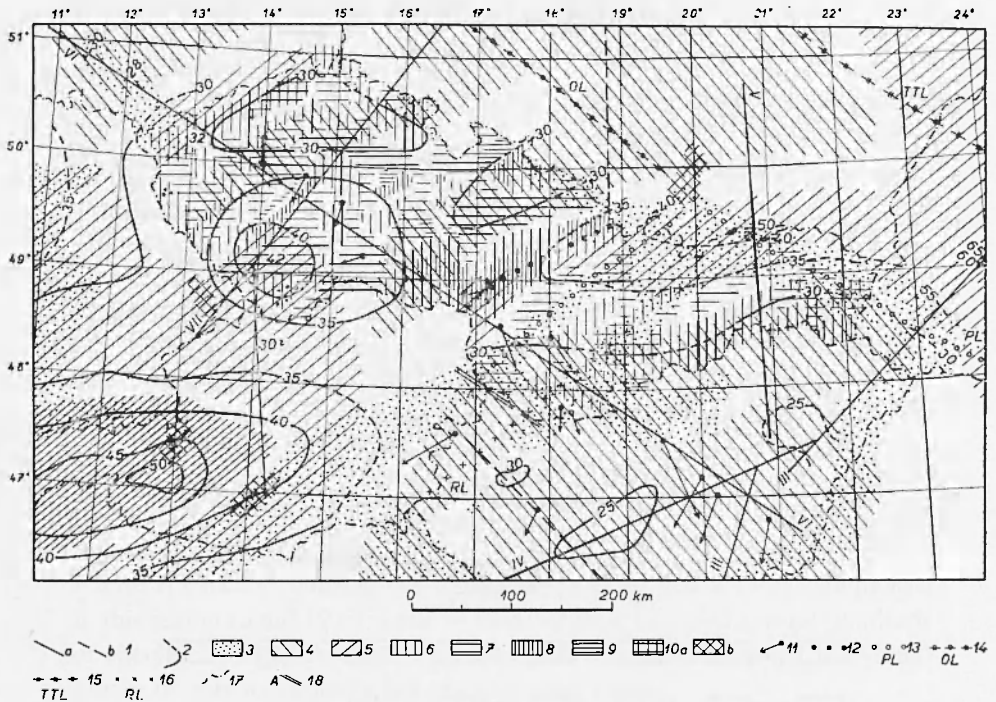


Fig. 4. Distribution of some geophysical fields in Central Europe: 1a, b — deep seismic sounding profiles; 2 — depths of the Moho; 3 — seismically active zones; 4 — positive gravity anomalies; 5 — negative gravity anomalies (denser hatching signifies $|\Delta g| \geq 100$ mgl); 6 — positive geomagnetic anomalies; 7 — negative geomagnetic anomalies; 8 — zones of high positive geomagnetic anomalies; 9 — zones of high negative geomagnetic anomalies; 10a — areas of high geomagnetic anomalies in neovolcanic belts in Czechoslovakia; 10b — anomalous geomagnetic zones in Austria and Poland; 11 — magnetotelluric induction vectors along international profile VI (see also Fig. 6); 12 — fault zone of Lednice; 13 — Peripieninian lineament; 14 — Odra (Oder) lineament; 15 — Tarnqvist-Teisseyre lineament; 16 — Raab line; 17 — state frontiers; 18 — deep reflecting seismic interfaces suggested in (Zatopek, A., 1957).

Since the times of E. Suess Suess, E., 1885 it became known that their macroseismic fields. These are anomalously elongated toward the north and north-west. Consequently, the pear-like shape of the macroseismically shaken area is asymmetric with the focus situated in the south-eastern part of the field. If the earthquake reaches the Bohemian Massif, the decrease of macroseismic intensities with epicentral distance becomes in general unusually small, much smaller than at the corresponding distance in the Carpathians or even in the Alps themselves. In this way strong east-alpine earthquakes penetrate macroseismically far over Dresden in Saxony, i. e. to epicentral distances over 400 km.

A number of earlier authors, e. g. Heritsch, F.; Kautsky, F.; Schwinner, R.; Mifka, V., Trapp, E., tried to find an explanation of this anomaly; unfortunately, due to a relatively small number of available observational data, some erroneous results, especially for the kind of propagation in the Bohemian Massif, have been obtained, cf. Zátapek, A., 1948a; 1948b.

During the last four decades many thousands of observational data have been collected from the Bohemian Massif in the Geophysical Institute of the Academy of Sciences Prague, Czechoslovakia, as regards the following earthquakes occurred in the north-eastern part of the East Alps:

No.	Date	UT (h, m, s)	h (km)	I_0 (MSK)	M
1	25 July 1927	21 35 30	47.5° N 15.5° E	36 ⁽¹⁾	7° 5.4
2	8 Oct. 1927	19 49 00	48.1° N 16.4° E	28 ⁽²⁾	7.9° 5.6
3	8 Nov. 1938	03 11 34	47.9° N 16.4° E	25-28 ⁽²⁾	7° 5.3
3'	8 Nov. 1938	03 23 15	47.9° N 16.4° E		4.5°
4	18 Sep. 1939	00 14 37	47.8° N 15.9° E	(25)	7° (5.2)
5	2 Dec. 1963	06 49 09	47.9° N 16.4° E	(25)	6.5° (5.0)
6	30 June 1964	12 30 02	47.7° N 16.0° E	(25)	5° (4¼)
7	27 Oct. 1964	19 46 11	47.8° N 15.9° E	(25)	6° (4¾)
8	16 Apr. 1972	10 10 04	47.8° N 16.1° E	(25)	7.5° (5.5)

⁽¹⁾ After Kárník 1968; ⁽²⁾ after Zátapek, 1948 a; (...) depths assumed by the author; magnitudes M calculated after Kárník, 1968, Part I, p. 48.

Except the aftershock No. 3' his ensemble of earthquakes revealed striking similarities of the individual macroseismic fields. Shocks No. 1-4 have been studied by the present author on a basis of almost 3000 reports from 1029 localities situated in the Bohemian Massif

Zátopek, 1948 a, b under use of graphical and numerical statistics. Characteristic results are as follows:

a) Intensities of observations in a distance range from about 70 to 420 km distributed over the Bohemian Massif region vary irregularly and do not indicate any regular decrease with epicentral distance.

b) The density of points of observation is very variable, but the general pattern preserves a clearly pronounced stability for all the cases studied. Repeatedly certain areas are covered densely with observations while in the neighbouring zones the density of observation is very small. This fact does not depend on the epicentral distance in the given range of distances and is not directly related to the density of population.

c) In the south-east, near the contact of the Bohemian Massif with the Carpathians the observations become scarce and practically disappear in the south-east of the line LZ — the so-called zone of Lednice — plotted in Fig. 1. The adjacent zone CZ, a contact zone between the Bohemian Massif and the Carpathians appears as a barrier for the energy of alpine earthquakes. We shall see that this zone is conspicuous by geophysical effects.

d) The observations reappear at the south-western edge of the Little Carpathians, but the intensities decrease very rapidly toward the north-east, along the south-western branch of the fault zone *PL*, associated with the Peripieninian lineament, geologically known as an important disturbed zone, separating the Outer Carpathians OC (Fig. 1) from the Inner (or Central) Carpathians IC. This rapid attenuation of the energy penetrating into the Carpathians suggests the idea of a seismic barrier at the NE end of East Alps Zátopek, 1957.

e) By means of graphical statistics applied to the set of observation points two systems of straight lines of regression *p* and *q*, represented in Fig. 2, were derived as axes of the zones including the majority of observation points. The directions found correspond to average main tectonic directions of the Bohemian Massif. Apart of them an accumulation of observations was found along axes denoted in Fig. 2 with *r*—*s*. This system corresponds to the radially disturbed zones of graben-character.

f) Though the pattern found coincides in general with the known

superficial fractured zones, its geological explanation in some cases, e. g. for the densely covered zone p_2 , is not evident and must be attributed to deeper seated factors.

After elimination of the influence of density of population, the densely covered zones, in view of their statistical stability, were physically interpreted as zones of higher seismic mobility. The anomalous higher energy in this interpretation is provided in greater epicentral distances by waves guided at a deeper-seated quasi-horizontal discontinuity, slowly nearing to the surface in the north; from this interface the energy is transported to the surface along steeply falling deep dislocations. Therefore, on the surface, the statistically found axes of densely covered zones indicate a scheme of the deep block structure of the territory in consideration. The geologically-territorial meaning of the scheme plotted in Fig 2 was explained in detail in Zátopek, 1948 a.

These results have been confirmed and completed with a micro-seismic analysis on a basis of a about 4000 observations referring to the earthquakes No. 6, 7 and 8 Babska, V., Ruprechtová, L., Zenklová, O., 1965; Babuska, V., Ruprechtová, L., 1965. In Babuska, V., Ruprechtová, L., 1965 the independence of the density of observations from the density of population was ensured by introduction of a normalized observation-point density in a unit area.

In a map representing the density of observations in Babuska, V., Ruprechtová, L., 1965 for the shocks No. 1 - 7 the highest densities are accumulated along the axis p_2 , plotted in Fig. 2 and running over Praha along the river Sázava, and along p_4 in the direction $NW-SE$, continuing then north-wards in the southern part of r_1 (the Boskovice furrow). Another concentration occurs at the crossings (p_1, q_3) and (p_1'', q_2) the Labe (Elbe) fault system and that of Iron Mountains (železné hory)). Further concentrations appear at the crossing (p_3, q_2, r_5) (basins in South Bohemia) continuing northwards along r_5 and toward the north-west along the range of šumava (Böhmerwald). Areas of higher densities along q_1 in the direction $NE-SW$ (running through densely faulted zones at the Barrandian NW -margin) and at the crossing (p_1', q_4) (in the zone of the fault system of Lužice in the north of the Czech Cretaceous table). Changes of the frontiers associated with the period of World War II are responsible for the reduced number of observations available in the zones q_1^{III} and q_1^{IV} (fault zone systems in the south-east of the Ore Mountains (Krušné hory)).

Interesting is the relationship of the calculated zones of higher mobility with the position of foci catalogued in Kárník, V., Michal, E., Molnár, A., 1957 (p_3, q_2, r_5) mentioned above. Along q_2 there is a number of foci situated in the region of the Bohemian-Moravian Highlands with a concentration at Jihlava (Iglau). Along the zones p_3 , and also a parallel one lying on the Bavarian side, a number of foci is reported. Relatively many epicentres are located along r_6 (statistical representation of the Czech great quartz lode) with an accumulation in the region \dot{u} . As already indicated, a high number of foci is accumulated in the Ore Mountains (Krušné hory) region near the zones q_1^{III} and q_1^{IV} and their crossing with r_6 in the swarm region c . The group d of epicentres in North Bohemia finds itself at the extremities of the zones q_3 and q_4 , respectively. Many of historical shocks are situated along p_1 , including in the south-east the active region e . In Central Bohemia historical foci are associated with the rather complicated (p, q)-configuration in the NW-part of p_2 . A number of shocks was observed at Kutná Hora (Kuttenberg) closely at the intersection (p_1, q_3). At least a part of them, similarly as in the case of Jihlava (Iglau), may be related to the ore mining in the both places. Some historical shocks lie also along the r_1 and r_2 , respectively.

In papers (Babuška et al., 1965; Babuška, V., Ruprechtová, L., 1965) dealing with shocks No. 5 - 6 the authors detected an anomalous increase of instrumental magnitudes M_{LH} occurring for the stations situated W-NW of the focus, i. e. a tendency analogous to the macroseismic anomaly. This azimuthal dependence of instrumental magnitudes emphasized specific conditions in the deep structure of the Bohemian Massif affecting the propagation of surface waves even at relatively distant stations ($\Delta_{\text{max}} = 22.7^\circ$). The tendency of increasing magnitudes may be observed for the stations situated in the Hercynian and Caledonian parts of Europe.

As for the aftershock No. 3' and the earthquake No. 8, the distribution of observations fits fully the scheme given in Fig. 2, too.

3. Distribution of observations of the main shock of Friuli, Italy, May 6, 1976, in Bohemian Massif.

Several times in the history (Kárník, V. et al., 1957) the Bohemian Massif was macroseismically shaken by major earthquakes (with magnitudes going over 6 magnitude units) originated in the southern units of the East Alps, namely in the Carnic and Julian Alps, respectively.

The shock named above was macroseismically felt far in the north off the Bohemian Massif. In this unit it was observed with top intensities in a few cases reaching 6⁰ MSK (Procházková, D. et al., 1977). According to Italian seismologists (Giorgetti, F., 1976) the parameters of the shock were 46° 17' N, 13° 07' E, $H=20\ 00\ 09$ UT, $I_0=10^0$ MSK, $M=6.4$, $h=7-8$ km; after C.S.E.M. 46.36° N, 13.28° E, $I_0=9^0 - 10^0$ MSK and $M=6.7 - 7$.

Already the first information proved the transverse character of the macroseismic field with anomalously small attenuation toward the north (typical also for strong historical earthquakes occurred in this region), similar to the cases dealt with in II, 3.

In Czechoslovakia the collection of information covered the whole area, where observable effects could be expected (Giorgetti, F., 1976; Kárník, V. et al., 1977); thus, apart of positive also negative reports have gathered. The former ones were available in 2588 cases from 459 localities. The analysis has been done and published (e. g. (Giorgetti, F., 1976; Kárník, V. et al., 1977; Kárník, V. et al., 1976)).

In the present paper only the distribution of observations in the Czechoslovak territory after (Giorgetti, F., 1976) is considered in relation to the scheme given in Fig. 2. The inclusion of the said set of points caused practically no noticeable change in the statistical (p, r, s)-scheme; in a number of cases it was possible to extend, complete or make more accurate some regression lines as derived for shocks No. 1-4. These supplements are expressed in Fig. 2 by dashed lines.

The epicentral distance range for Bohemia and Moravia falls between 270 and 540 km, i. e. considerably more than for No. 1-4. In Slovakia the shock was felt only in Bratislava and Kúty, close to the south-western end of the Peripieninian lineament PL and the Lednice zone LZ, respectively (Figs. 1-5). There are no observations south-east of LZ.

The comparison of the density distribution of points with those found in (Zátopek, A. 1948 a) and (Babuška, V., Ruprechtová, L., 1965) shows in all cases maximum densities in the Neogene South Bohemia basins (neighbourhood of the (p_3, q_2, r_3)-intersection, focal area a), in Central Bohemia the fractured area closed by the zones (p_1, q_1, p_2', q_1), cf. II, 2, and in the middle of the zone q_1^{III} along the fault zone in the south-east of the Ore Mountains (Krušné hory); systems q_1^{II} , q_1^{IV} , q_1'' and q_1 are well characterized in all cases and so p_1' , p_1'' and partly p_1 (the last in its NW-part; in the SE-part the covering is rather poor); the zone p_2 , very strongly pronounced for shocks No. 1-8; zones

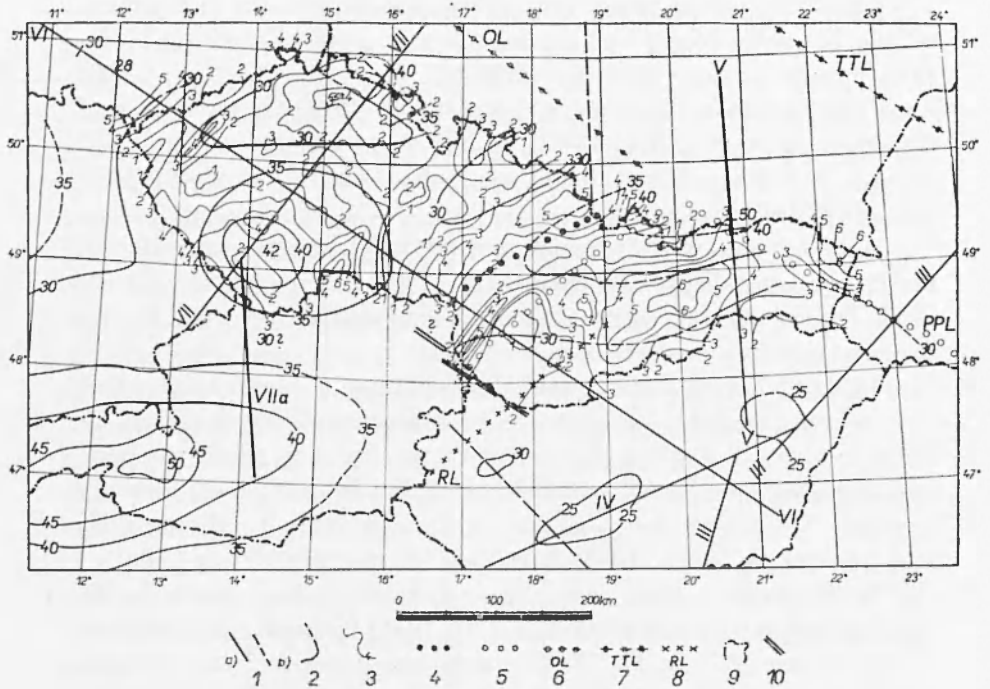


Fig. 5. Distribution of isolines of derivations of the vertical (in arbitrary units) in the Czechoslovak territory: 1a, b — deep seismic sounding profiles; 2 — isolines of depths of the Moho; 3 — isolines of reduced deviations of the vertical; 4 — fault zone of Lednice; 5 — Peripienian lineament; 6 — Odra (Oder) lineament; 7 — Tornqvist-Teisseyre lineament; 8 — Raab line; 9 — state frontiers; 10 — supposed zone reflecting seismic energy of east-alpine earthquakes downwards.

r_1 , r_2 , r_5 and r_6 are clearly indicated, though with comparatively small numbers of observations (in the eastern part it was possible to trace mobile zones p_5 and r_4 in the active region f , see II, 2); striking is the small density of observations along p_4 , and the southern part of r_1 , where (cf. II, 2) for shocks No. 1-7 the highest densities were found. Surprising is the case of Friuli the appearance of areas («shadow zones») with observations missing: a belt running on the northern side of p_1 from r_2 toward the north-west and then along q_3 to the south-west up to p_3 ; another empty area finds itself in the neovolcanic region of NW-Bohemia, and a third one occupies a part of the Cretaceous Table in NE-Bohemia in the north-east of p_1 .

Except the Carpathian foredeep CF (Fig. 1), the main shock of Friuli did practically not penetrate into the Carpathians.

4. *Macro seismic field of other major European earthquakes in the Bohemian Massif.*

Two earthquakes of 20 th century with foci situated west of the Bohemian Massif yielded a possibility to examine their macro seismic effects and distribution observations with regard to the scheme of the mobile zones represented in Fig. 2:

a) the «Middle-European» earthquake of 16 November 1971, $48^{\circ} 11' N$, $8^{\circ} 35' E$, $I_0 = 8^0$ MCS (Sieberg, A., 1932), (cf. also (Zátopek, 1948 a).

b) the earthquake in SW-Germany of 27 June 1935, $48^{\circ} 03' N$, $9^{\circ} 28' E$, $I_0 = 8^0$ MCS (Hiller, W., 1936).

The focal depth of shocks was estimated (Kárník, V., 1971) to be between 15-42 km. Both earthquake emphasize, along the fault zones indicated in Fig. 1 (in the peripheral parts of the Bohemian Massif in the west, north and south), a similar shape of the area shaken. In the interior of the Bohemian Massif, the western part of Bohemia was afflicted macroseismically with higher intensities grouped along the axis q_1 between the intersection with p_2 and p_1 , respectively. Also the surroundings of the intersection (p_3 , q_2 , r_3), i. e. the region of the South Bohemian basins, were macroseismically shaken, but not the zone q_2 itself. For the case b) almost all observations are situated in q -zones of West Bohemia, then along p_3 , the NW-part of p_2 and along p_1'' ; isolated observations lie also at the southern end of r_1 .

It is thus possible to conclude that also in cases of extra-alpine sources the seismic energy was led by the same system of tectonic discontinuities as found for the east-alpine earthquakes. A further study of the selective way, in which the observed phenomena occur, may contribute to a better understanding of the behaviour of tectonic structures.

CONTACT ZONE BETWEEN THE BOHEMIAN MASSIF AND THE CARPATHIANS

1. *Generalities.*

The West Carpathians (Fig. 1) joining the East Alps at the river Danube between Vienna and Bratislava. Their main range proceeds in an arc, concave to the south, gradually in SW-NE, W-E and NW-SE.

directions approximately up to the meridian 23° E, where the East Carpathians begin (Fig. 1, 4-6).

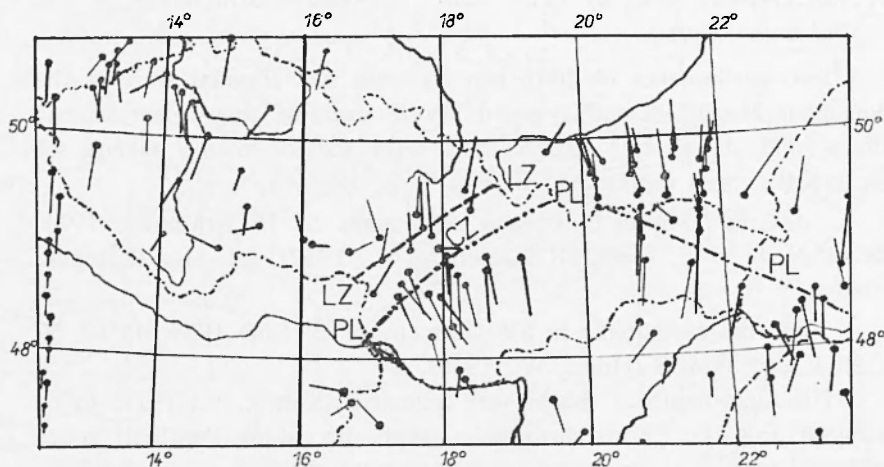


Fig. 6. Distribution of Weise induction vectors in the region: Note the inversion within the contact zone CZ and along the eastern branch of the Peripieninian lineament PL.

The West Carpathians are divided into the Outer (Flysch) Carpathians OC and the Inner (Central) Carpathians IC, separated from each other by the narrow Pieninian cliff (Klippen) fault zone, comprising marine Jurassic and Cretaceous complexes, the Peripieninian lineament PL. This zone is associated with many geophysical effects.

The Outer Carpathians developed as a geosynclinal foredeep during the Late Mesozoic and Paleogene and were filled by Flysch materials of age ranging from the Late Cretaceous to the Oligocene. After intense processes of folding, faulting and forming of nappe structures in the Miocene, the Flysch nappes were thrust over the Neogene of the Carpathian foredeep.

In the Inner Carpathians metamorphic crystalline complexes of the basement (Late Precambrian gneisses and schistes, interspersed with Variscan plutons) were covered by Paleozoic complexes and the sedimentary cover of Mesozoic Formations. This sequence with a part of the basement rocks was intensively folded and faulted during the Late Cretaceous. The newly created nappe formations were displaced to

considerable distances. In the Eocene thick Flysch deposits resulted from the subsidence in the northern part of the Inner Carpathians. Their present structure was mostly created during the transition Paleogene-Neogene with large undulations and subsidences. Crystalline cores of the Inner Carpathians were lifted up. In the Neogene mostly only radial faulting occurred. The Neogene strata find themselves in the Outer Carpathian foredeep CF, in the Pannonian basin PB, and extend from the south into the central part of the Carpathian arc and in the intermontane depressions. Neogene sedimentary rocks are interbedded with Miocene to Pliocene volcanics in Central and South Slovakia, North Hungary and East Slovakia (with a continuation eastwards in the East Carpathians).

2. Seismicity of the West Carpathians.

The seismicity of the West Carpathians (Kárník, et al., 1957; Kárník, that of the East Carpathians (region of Vrancea!). In the West Carpa-V., 1971) is comparable with that of the East Alps, but is lower than thians frequent small shocks are very shallow, often caused by movement of small block, influencing the shape and size of the macroseismic field (Zátopek, A., 1939; Kárník, V., 1960). The highest intensities may exceptionally reach or pass slightly over 9⁰ MSK, i.e. the maximum magnitudes near 6 magnitude units. Many of the active zones are connected with the Peripieninian lineament PL, comprising (Fig. 1) two branches oriented SW-NE and NW-SE, respectively (the latter continues in the Soviet East Carpathians). On the inner side of the Peripieninian lineament in the West Carpathians the epicentres concentrate in the areas denoted in Fig. 1 with *g-k*; *g*-region of the Little Carpathians (Malé Karpaty) and Brezová Mountains (Brezovské pohorie), *h*-region of Žilina, *i*-Spis region, *j*-Vranov region, *k*-Humenné region. Typical small shocks are frequent in the territory of the USSR along the continuation of neovolcanic zone mentioned above. As for other regions may epicentres are scattered in Central Slovakia -- region *m*; very active is the northern boundary of the Pannonian basin, represented in Fig. 1 by the region *l*-Komárno-Budapest. The great Komárno earthquake of 1763 with $I_0=9^0-10^0$ MCS is considered to be the strongest shock in the region of the West Carpathians. Intensities of 9⁰ MCS are attributed to several shocks in the northern part of the region *g*, and of 8⁰-9⁰ to the region *h*. All of the foci in the West Carpathians are situated in densely fractured

zones and/or in neovolcanic areas. The high intensities reported in the region *m*, may be connected with ore mining and thus are mostly of local importance.

The contact zone CZ, where, as shown in part II, 2 of the present paper, also observations of east-alpine earthquakes die out, appears almost aseismic. Observations of shocks bound to regions *g*, *h*, and *l* seem to indicate a higher attenuation of seismic energy in this zone, though the strongest of them display a transverse character of macroseismic field, elongated in the direction NW-SE.

3. *Crustal structure of the region and of the contact zone CZ.*

A simplified scheme of the Moho, resulting from explosion seismology (deep seismic sounding on international and national profiles, evaluation of quarry blasts) is sketched in Figs. 1, 4 and 5. A thin crust is typical for the Pannonian basin PB (minimum thickness 25 km) and the south and south-western part of the West Carpathians; a thick crust is typical for the Bohemian Massif (minimum thickness 25 km) and the south and south-western part of the West Carpathians; a thick crust is typical for the southern part of the Bohemian Massif (maximum thickness 42 km).

The method of continuous profiling, used mostly in Central and East Europe, allows to determine, apart from the depth of the Moho and other crustal discontinuities, also the position and character of pronounced fault zones and to delimit the structural blocks of the crust (Sollagub, V. B., et al., 1972). A satisfactory agreement found on profiles VI and VII with the mobile zones described in paper (Zátopek, A., 1948) may thus be seen as its experimental verification.

In Fig. 3 the contact zone CZ is represented with the adjacent parts of the Bohemian Massif (left) and the southern part of the West Carpathians (right). A jump of 7-8 km was found between the respective levels of the Moho at this contact (about 36 km in the Bohemian Massif and 28-29 km in the West Carpathians) lying in the deep fault zone of the Peripienian lineament PL. Corresponding jumps were stated in the eastern branch of the lineament at its cross-sections with international profiles V (10 km, see Fig. 1) and III (over 20 km, situated in the USSR).

The neighbouring fault zone LZ in the west, i. e. the Lednice zone, was discovered as a zone penetrating down to the Moho, too.

The deeper-seated block structure between LZ and PL proceeds

towards the north-east; at the surface the zone is covered by mighty layers of Neogene sediments and is characterized by a pronounced negative Bouguer gravity anomaly. The surroundings of the Lednice zone LZ and the crystalline in the adjacent part of the Bohemian Massif are conspicuous with the high positive magnetic anomaly, which disappears east in the transition over the Peripieninian lineament. Measurements in a system of national profiles and the evaluation of quarry blasts records it was found that this zone is formed by individual blocks plunged to great depths (36-38 km) varying from block to block. A similar structure was found in some places neighbouring on the Lednice zone from the west below the Carpathian foredeep CF (Beránek, B., 1971; Beránek, B., Zátcepek, A., 1975; Zátcepek, A., 1975).

Relative velocities of vertical component of recent crustal movements growing up to 4 mm/year with either upheavals or subsidences prove a relatively high mobility of the contact zone (Vyskčil, P., Kopecký, A., 1974).

In (Bursa, M., 1969) it was shown that the vectors of the deflections of the vertical after removing the effects of topography exhibit close correlations with the block structure. This can be well observed in Fig. 5 in the SW-part of the Peripieninian lineament PL, where the high gradients of the isolines indicate a local increase in geoid curvature.

Concerning the heat flow in the contact zone an increase was found from about 55 mWm^{-2} in the south-west to about 80 mWm^{-2} in the north-east (Ostrava-Karviná coal basin) (Cermák, V., 1968).

An astonishing phenomenon connected with the contact zone CZ in a peculiar distribution of electric conductivity expressed in the inversion of Wiese induction vectors (Wiese, H., 1965; Praus, O., 1971; Jankowski, J., et al., 1975) within the contact zone CZ on the outer side of the Peripieninian lineament (Fig. 6). This striking behaviour was stated also along the eastern branch of the lineament and could be compared with the effect caused by a linear electric current conductor the axis of which would be situated parallelly to the Peripieninian lineament PL in a depth of 24-40 km (Jankowski, J., et al., 1975)

Broader relationships between the local geophysical fields bound to the contact zone CZ and the corresponding characteristics on a regional scale of Fig. 1 may be estimated in Fig. 4, where the distribution of Bouguer gravity anomalies, seismically active zones, geomagnetic anomalies, Wiese induction vectors along profile VI, and some other informa-

tion are presented together.

In general, the distribution of positive and negative Bouguer gravity anomalies corresponds to the areas with a thin and thick crust, respectively. In the Alps the axis of maximum negative (Makris, J., 1971) anomalies coincides fairly well with that of the outer topography and the relief of the Moho. In the West Carpathians the axis of the maximum negative anomalies follows the Peripieninian lineament along its western branch up to the region of the High Tatra (Ibrmajer, J., 1966). Further to the east this axis and the maximum depths of the Moho are shifting to the north (Ney, R., 1975) off the main mountain range into the Flysch zone of the Outer Carpathians. The Peripieninian lineament is here not accompanied by deep structural mass defects.

In the Inner Carpathians, in general, the regional gravity anomalies indicate, in agreement with deep seismic soundings and the pattern of derivatives of the vertical (Fig. 5), a comparatively uniform thinning of the crust to the minimum of 25 km as found in the Pannonian basin.

It should be mentioned that the principle of isostasy is valid over larger parts of the region studied, but with many local deviations. The Airy model seems to be adequate only on a restricted scale.

In agreement with geological findings (Mahel, M., et al., 1974) and geodetic evidence (Cimbálruik, M., et al., 1967), recent crustal movements with vertical component of velocity over 5 mm/year been ascertained in the Danubian Lowland and show a tendency to grow toward the Pannonian basin.

Epicentral zones are indicated in Fig. 4 by dots. Seismic characteristics of the Bohemian Massif as an active area and the selective propagation of the energy from east-alpine and some other foci in a was confirmed by deep seismic sounding, were analyzed in part II. The stable system of statistically found discontinuities, the existence of which instrumentally assessed higher magnitudes of east-alpine earthquakes in stations situated in the Hercynian and Caledonian parts of Europe is an effect which would pay a further study.

We introduce a few examples of earthquakes associated with the Peripieninian lineament: Dobra Voda (known as Jokeo) 1906 (region *g*), $I_0=9^0$ MCS; zilina 1858 (region *h*), $I_0=8^0-9^0$ MCS; Strazske 1941 (region *k*), $I_0=7^0$. As already mentioned, focal depths in the West Carpathians can rarely be estimated over 10 km. The seismic zone connected with the western branch of the Peripieninian lineament continues in the SW-direction as far as to the Po lowland in North Italy.

With regard to the poor propagation of the east-alpine shocks into the West Carpathians, a «seismic mirror», i. e. a fault zone, indicated in Figs. 4 and 5, was assumed (Zátopek, A., 1957), reflecting the energy coming from the east-alpine foci downwards. Unfortunately, experimental data from this important contact zone between the East Alps and the West Carpathians are missing.

Zones of positive geomagnetic anomalies are often typical for contacts of bigger tectonic units. Such an anomaly (Fig. 3) was already mentioned in the contact zone between the Bohemian Massif and the Carpathians. High magnetic anomalies occur in zones of intensive metamorphism (e. g. in East and Central Bohemia) or are accompanying the zones of young-Tertiary volcanism. The latter ones are often connected with frequent small shocks in the neighbourhood of the eastern branch of the Peripieninian lineament.

The distribution of Wiese induction vectors in the wider region far enough from the contact zone CZ and the Peripinian lineament (cf. Figs. 4 and 6) indicates the presence of an extended and tectonically oriented deep-seated anisotropy of electrical conductivity, which sometimes is considered (Sollagub, V. B., et al., 1972) in connection with the asthenospheric channel of lower seismic velocities.

Concerning geothermal characteristics of the studied region the recently issued paper Cermák, V., Hurtig, E., 1977) yields the most comprehensive information. Inside the Bohemian Massif the heat flow is rather low ($40-60 \text{ mWm}^{-2}$) with a minimum corresponding to the to the maximum crustal thickness and the maximum in the thermal area of North Bohemia. In the Carpathians the heat flow increases from $50-60 \text{ mWm}^{-2}$ in the outer Flysch zone to about 70 mWm^{-2} in the main folded units of the Inner Carpathians and a rapid increase occurs in the central intermontane depressions to 100 mWm^{-2} and more in the Pannonian basin. These results are Conform with the conditions of the model of Ney (Ney, R., 1975), supposing some kind of subduction in the some zone of the Peripieninian lineament.

CONCLUSION.

The existence of a stable statistically derived pattern of zones of higher mobility in the Bohemian Massif, where the energy of earthquakes originated in the north-eastern part of the East Alps is selectively

propagated northwards, was confirmed by further observations. The interpretation of this anomaly by guided waves, leading the energy from a deep interface to the surface along almost vertical fault zones, is supported by the results of explosion seismology conducted in the region. The mobile zones have been identified as surficial indications of deep fault systems reaching in some cases down to the Moho and perhaps partly into the mantle. Some of these zones have been found seismogenetic.

Particular attention has been paid to the contact zone CZ between the Bohemian Massif and the West Carpathians, which is separated in the west from the Bohemian Massif by the Lednice deep fault zone, and the east from the Inner Carpathians by the Peripieninian lineament, which was found to be the most conspicuous feature in the West Carpathians.

Gravimetric, geomagnetic, magnetotelluric and geothermic effects are associated with the contact zone, which is formed by a deep-seated system of blocks situated on the outer side along the Peripieninian lineament. Here jumps of many kilometres occur in the level of the Moho at the transition from the thin crust inside the Carpathian arc to the thick crust outside. A strikingly pronounced line of inversion of Wiese induction vectors within the contact zone, continued eastwards outside the Peripieninian lineament, suggests a particular distribution of electric conductivity in this zone. Seismic activity, associated with the Peripieninian lineament, appears predominantly on its inner side, where, in the western part, some destructive shocks have been catalogued.

A brief description of characteristics of the regional geophysical fields is given for comparison with the more or less small scale character of those connected with the contact zone CZ.

A systematic geophysical study with a complex of methods and a geophysical synthesis appear necessary in all contact zones between individual big tectonic units of the region, which may be considered as one of the clue areas of European tectonics.

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