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ON THE GENESIS OF GRANITES IN THE ERZGEBIRGE MTS., G.D.R.

(Figs. 5, Tab. 1)

Abstract: The Fichtelgebirge-Erzgebirge anticline — a type area of the Saxothuringian zone Central European Variscides — has an intense granitoid magmatism which is traditionally regarded palingen-anatectical.

Special isotope geochemical investigation results, however, point to a possible mantle relation of the Erzgebirge granites. The very low initial Sr isotope ratios of the Erzgebirge granites and the $\delta^{18}O$ values (Ehrenfriedersdorf granite) are found especially significant. Additionally, certain geochemical specialization effects in the granites (fluorine, alkali distribution) plead for relations to the upper mantle. Of the possible models of a mantle-related granite formation in the Erzgebirge Mts. a diapirism model is favoured according to which with the beginning of the Variscan orogenesis a mantle diapir became active in Central Europe. Melts of probably intermediate composition were given off the mantle arching into the crust, where the crust segment of the Erzgebirge anticline — and here, above all, the east part — was subjected in particular.

The model conception is generally motivated by new results of research in the lithosphere development. According to them a continuous sial formation process below the lithosphere and the repeated removal of sialic-intermediate melts into the crust in form of a diapirism is realistic. For confirmation of such a model several geologic, petrologic and geophysical observations and arguments can be stated.

Резюме: Антиклиналь горных цепей Фихтелгебирге и Эрцгебирге — типовая область Саксотюрингской зоны варисцид Средней Европы имеет интенсивный гранитоидный магматизм, который традиционно считается палингенно-анатектическим.

Но результаты специального геохимичесого исследования изотопов указывают на возможность генетического отношения гранитов Эрцгебирге к мантии. Очень низкие первичные отношения изотопов Sr в гранитах Эрцгебирге и значения $\delta^{18}0$ (эренфридерсдорфский гранат) имеют особое значение. Кроме того, определенные геохимические следствия специализации в гранитах (распределение фтора и щелочей) свидетельствуют также о отношениях к верхней мантии. Из возможных моделей образования гранитов связанного с мантией в горной цепи Эрцгебирге поддерживается модель диапиризма, согласно которой варисцийский орогенезис начался мантийным диапиром в Средней Европе. Выплавки вероятно переходного состава выходили из мантии перекрывающейся сводом в кору, где сегмент коры эрцгебирской антиклинали, прежде всего ее восточная часть, была особенно подвергнута этому процессу.

Концепция модели обычно мотивирована новыми результатами исследования развития литосферы. Согласно этой концепции непрерывный процесс образования сиаля под литосферой и повторяемое движение сиалическо-переходных выплавок в кору в форме диапаризма являются реалистическими. Подтверждением такой модели служить ряд геологических, петрологических и геофизических исследований и аргументов.

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Introduction

Up to the end of the seventies it was undisputed that the granites of the Erzgebirge anticlinal zone — as all other granites of the Central European Variscides, too — were formed palingen-anatectically (e. g. Lange et al., 1972). Since the beginning of the eighties, however, different geologists more and more have shown hesitation against this traditional model of formation, basing on isotope-geochemical and other indications (Rösler—Werner, 1979; Dahm u. a. 1982, 1984; Leeder, 1983).

With the increasing number of investigation results of a modern geochemical and geochronological research of Erzgebirge granites, those opinions have been confirmed which argue against a pure crustal genesis and which consider the influence of the upper mantle in the formation of Erzgebirge granites. The different models discussed recently of a possible mantle relation of Erzgebirge granitic magmas (subduction, mantle diapirism, influence of fluids and heat from the upper mantle), however, show the problems of a mantle — controlled formation model of granitic melts on ensialic basement.

For decision, on the one hand further investigations and altogether a more complex treatment are obviously necessary. On the other hand, this question can not be solved for the Erzgebirge Mts. only. The author tries therefore to consider some essential aspects of present knowledge on lithosphere development, and for confirmation and verification of a model for formation of the Erzgebirge granites he makes also use of results of geologic and geophysical and petrology research of the depth.

Geologic and temporal position of granites in the Erzgebirge Mts.

The Fichtelgebirge-Erzgebirge anticline is a part of the Saxothuringian zone within the Central European Variscides (Kossmat, 1927; Stille, 1951).

The anticlinal zone shows an extensive granitoid magmatism which can be subdivided into a pre-Variscan cycle (predominantly orthogneisses) and a Variscan cycle. The dominating Variscan granitoid magmatism occurs at the end of the Variscan structure forming processes.

The morphologically intensely structured Variscan Erzgebirge pluton can be separated into three SE-NW directed partial plutons with some local apical intrusions in each pluton (Tischendorf et al., 1965; Lange et al., 1972). The intrusion level is high-plutonic to subvolcanic, from which in the West Erzgebirge Mts. the apical ranges are already eroded, whereas in the Central and East Erzgebirge Mts. only some of the highest intrusions are reached by erosion.

The Variscan granite magmatism of the Erzgebirge Mts. is traditionally attributed to two intrusive complexes:

1. Older complex (OG, mountain granites after Laube, 1876; Upper Carboniferous intrusive complex after Herrmann, 1967);

2. Younger complex (YG, Erzgebirge granites after Laube, 1876; Lower Permian intrusive complex after Herrmann, 1967).

In the different intrusive complexes there are partly extended still several intrusive phases in the meaning of Koptev-Dvornikov (1952) (Herrmann, 1967; Lange et al., 1972). This division of the intrusive complexes into intrusive phases, however, has partly to be modified on the basis of recent mapping (Dahm, 1984). Neither K/Ar datings (Haake, 1972) nor Rb/Sr analyses (Gerstenberger et al., 1984) could yield statistically proved age differences between the younger and the older complex. According to the later Rb/Sr datings all Variscan granites are of Upper Carboniferous age (cf. Tab. 1).

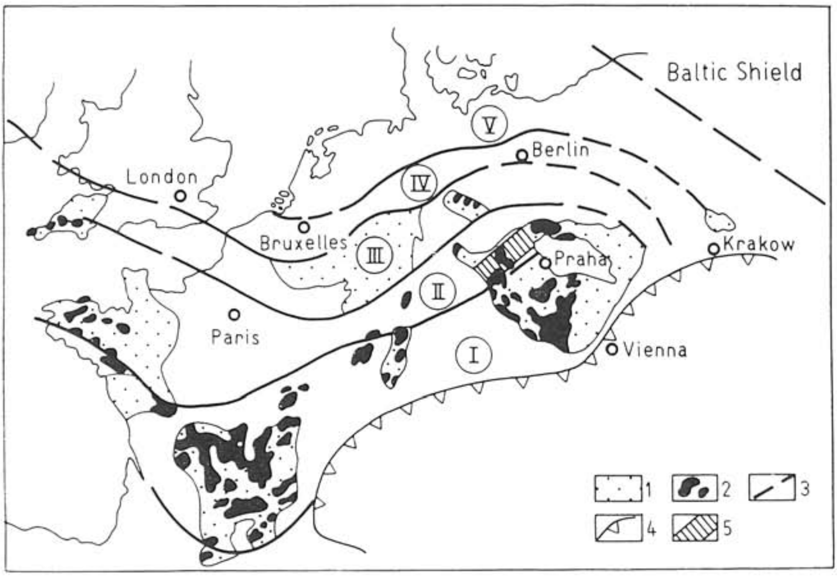

Fig. 1. Zonal division of Central European Variscides in the sense of Kossmat (1927) et Stille (1951).
Explanations: 1 — Paleozoic-consolidated basement; 2 — Variscan granites; 3 — boundaries of geotectonic zones; 4 — alpidic overthrusting; 5 — geotectonic position of the Erzgebirge Mts.; I — Moldanubian zone; II — Saxothuringian zone; III — Rheno-Hercynian zone; IV — Subvariscan zone; V — foreland.

As far as the older granites (OG) are concerned, it is a matter of varieties of biotite-monzogranites to leucocratic monzogranites of hypidiomorphic-grained structure (Lange et al., 1972). The younger granite complex (YG) is completely composed of leucocratic syeno- to monzogranites. The granites of the younger complex are characterized by a high geochemical specialization of elements F, Li, Rb, Sn and Be (Tischendorf et al., 1972; Lange et al., 1972). With the younger granites, the wel-known Sn-W-Li deposits of Erzgebirge Mts. are associated.

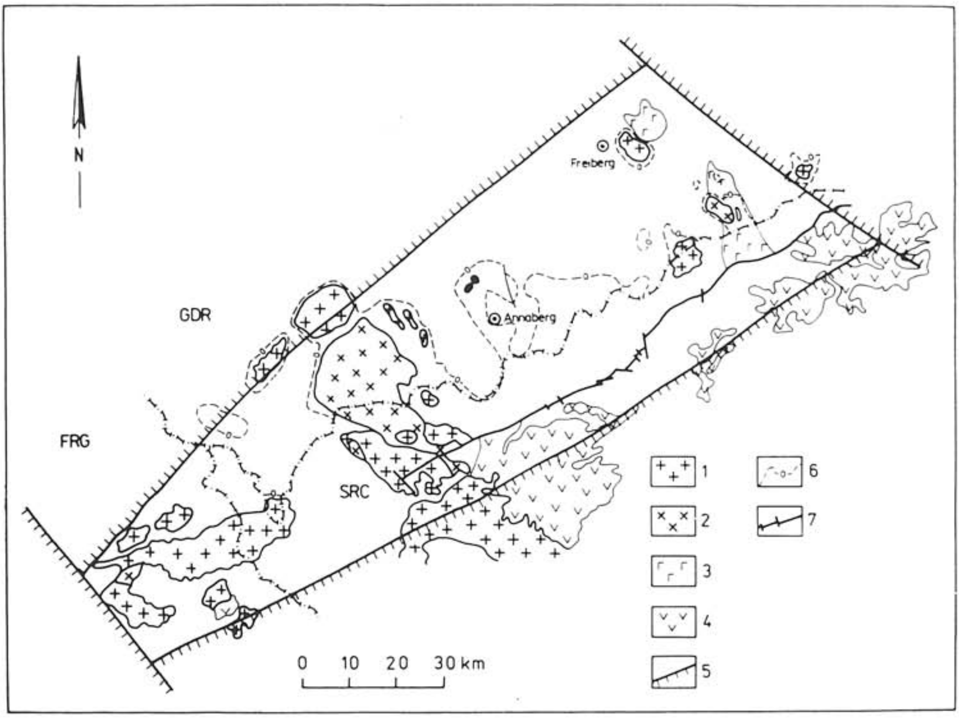

Fig. 2. The Fichtelgebirge-Erzgebirge anticlinorium with the Variscan granitoid rock (simplified after Baumann-Tischendorf, 1978).
Explanations: 1 — older granites (OG); 2 — younger granites (YG); 3 — Variscan volcanic rock (porphyry); 4 — post-Variscan volcanic rock (basalts, phonolithes); 5 — lineaments; 6 — O m-isobath of the Erzgebirge pluton; 7 — Erzgebirge fault.

Indications of a possible mantle relation at the formation of the Erzgebirge granites from geochemical point of view

Besang (1976) had already determined an extremely low initial ratio $^{87}Sr/^{86}Sr$ for the tin granites of Fichtelgebirge Mts. (cf. Tab. 1). For those of the granites of the Erzgebirge Mts. — both for the YG and for the OG — also Sr isotope ratios were obtained which allowed the conclusion that the initial material of granitic melt cannot have had a longer development in the crustal range.

Because of the high Rb/Sr ratios of the total rock samples of YG, their initial Sr isotope ratios can be determined only with a greater statistical error than of OG. However, it can be stated unambiguosly, that the $(^{87}Sr/^{86}Sr)_i$ of YG with sufficient statistical security are lower than those of OG. Basing on the $(^{87}Sr/^{86}Sr)_i$ data of OG and YG and including $\delta\ ^{18}O$ and element concentration data, Gerstenberg et al. (1984) developed a model according to which the magmas of OG have assimilated certain parts of upper crustal

Table 1

Selected parameters of a geochemical-geochronologic investigation of granites in the Fichtelgebirge-Erzgebirge anticlinal zone (after Dahm, Gerstenberger et Geissler, 1984)

	Fichtelgebirge Mts. (after Besang et al., 1976)	West Erzgebirge Mts.		Central Erzgebirge Mts.	East Erzgebirge Mts.	
		Kirchberg (OG)	Eibenstock (YG)	Ehrenfriedersdorf (YG)	Niederbobritzsch (OG)	Altenberg (YG)
Rb-Sr age (Ma)	295	307±4	313±2	319±3	317±5	307±2
temporal classification (after Odin, 1982)	Stephanian	Westphalian	Namurian	Namurian	Namurian	Westphalian
$(^{87}Sr/^{86}Sr)_i$	0.694	0.7068 ±0.0011	0.7025 ±0.0029	0.7009 ±0.0052	0.7068 ±0.0003	(0.6914 ±0.0103)
Eu anomaly		slightly negative	strongly negative	strongly negative		

material (gneisses), whereas the YG have been generated from non-contaminated magmas.

The analyses of the rare-earth elements showed a distinct negative Eu-anomaly in all cases. This points to a depth origin of the magmas or a longer fractional crystallization processes. Very low initial Sr isotope ratios and intense negative Eu-anomalies are obviously typical of the younger granites (tin granites).

By means of detailed investigations of the granites in the Ehrenfriedersdorf tin deposit (Central Erzgebirge Mts.), further indications for a supposed origin of these granites from the upper mantle range could be obtained (Stiehl et al., 1985). A mean $\delta_{SMOW}{}^{18}O$ value for the granite of $+7.4 \pm 1.0$ ‰ suggests an origin from a juvenile magma, considering the mean δ ^{18}O index. The Ehrenfriedersdorf granite differs distinctly in its δ ^{18}O value from typical anatectic granites.

The discussion about a possible mantle relation of Erzgebirge and other Variscan granites is still being encouraged by element-geochemical observations. In this context, the specialization effects of the Erzgebirge granites are remarkable. Whereas in general the elements which are evidently concentrated in the Erzgebirge granites (F, Sn, Li, Rb, Be) are regarded "granitophile" and thus — corresponding to the anatectic conception — also typically crustal, investigation results of ultrabasic and alkali enriched rock force to a partial revaluation. In these unambiguous mantle derivated apart from accumulations of Nb, Ta, P (which are concentrated in many ore-bearing granites, too, as is well-known) one can find partly extreme F concentrations. E. g. A o k i et al. (1981) state 3000—8500 ppm F for phlogopites of kimberlites. In the sense of L e e d e r and numerous other authors (cf. e. g. L e e d e r, 1981; 1983), flourine is a typical mantle element. Especially flourine, however, a very great importance is attributed for specialization of granitoid rock and for the efficacy of mineralization processes (T i s c h e n d o r f, 1969). Basing on similar considerations, R ö s l e r and W e r n e r discuss the participation of subcrustal material in the formation of specialized Erzgebirge granites already in 1979. Moreover, in the Saxothuringian and Rheno-Hercynian zone of Central European Variscides a remarkable spatial correspondence in the alkali specialization of granitoid rock on the one hand, and basic magmatites of the Variscan early stage (with unambiguous mantle origin) on the other hand, can be determined. This could point to genetic relations.

Hypotheses of a mantle relation of granitic melts and foundation of the diapirism model

Different authors challenge a possible mantle relation of the Erzgebirge granitoid rock with reference to the continental development of the Fichtelgebirge-Erzgebirge anticlinal zone in the Variscan belt. After T i s c h e n d o r f (1985) the postkinematic Erzgebirge granites are intrusive granites of the continental crust which were formed by complete anatexis of deep-crustal rock in the stage of the progressive Variscan tectogenesis.

At the same time different possibilities of a relation of Erzgebirge granites to the upper mantle are being discussed:

1. indirect mantle relation

The granitic melt is generated in the crust by influence of heat and fluida from the upper mantle (among other L e e d e r, 1983).

2. "direct" mantle relation

The granites represent the differentiation product of intermediate magmas. The intermediate magma is lead off the range of the upper mantle. The latter process is linked either with the subduction or subfluence of the oceanic crust (W e t z e l — S c h ü t z e, 1985; S t i e h l et al., 1985), or a mantle diapirism is supposed (D a h m 1985; D a h m et al., 1982, 1984).

The hypothesis of the mantle diapirism based on the idea that differentiation processes in the mantle lead to accumulation of incompatible, specifically light material quantities below the lithosphere. The mantle is arching up and these sialic melts of mean intermediate composition are delivered into the crust. Within the crust, these intermediate mantle magmas can differentiate themselves further up to monzogranites.

Such a hypothesis considers on the one hand the geochemical mantle indications which cannot be ignored in their totality, though the significance of some criteria is still being in discussion.

On the other hand, such a hypothesis explains a mantle-related granite formation on ensialic, i. e. continental basement. The continental development of the Variscan Central Europe is proved by geologic and geochemical-magmapetrological observations (Rösler — Werner, 1979) and thus, the idea of a Central European subduction zone at Variscan period presents itself not very realistic, too.

The "compromise hypothesis" of an indirect mantle relation, however, cannot conclusively explain the geochemical mantle indications (by volatiles, e. g., the initial ratio $^{87}Sr/^{86}Sr$ can be lowered only partially and not to mantle values), and it does not explain why a spacious mantle degassification of crustal and mantle granites often occur in close neighbourhood.

In the following, the hypothesis of the mantle diapirism is explained in general, and after that (Pkt. 5) special hints and observations which can confirm this model conception — related to the Central European area in the Variscan belt — are given. In the summarizing representation of the present paper the differentiation process of intermediate parent magmas to acid (monzogranitic) melts in the crust will not be regarded in particular since the existence of such a process is acknowledged by most petrologists.

The *foundation* of the mantle diapirism hypothesis is derived from new geochemical-petrologic results concerning the world-wide intensively treated problem of the crust-mantle development.

A still wide-spread opinion, after which the formation of sialic melts in the mantle should not be possible in general (e. g. Wyllie et al., 1976), should be denied. The following facts and arguments are to be used:

1. It is undoubted that a primary sial formation at the beginning of geologic history could take place only in the mantle.

2. It is furthermore known in general that in the further crust development sialic magmas were formed by recycling and subduction processes (fusion of continental and oceanic crust).

3. Many results of geochemical and petrologic research, however, point to the acceptance that the whole crust development has been fundamentally determined by supply of juvenile sialic magmas from the mantle.

From the temporal analysis of variations of several isotopes (Sr, Nd, Hf, ...) it becomes probable that the crust has not been generated uniquely, but it must have been *grown step by step* (Hurley, Moorbath, Wasserburg, De Paolo, Tatsumoto et al.,).

A polyphase crust formation process, however, cannot be explained by recycling processes only, since in the course of crust development a volume growth and a strong *irreversibility* are given. Above all, the crust formation process underlies a significant material trend: the lithophile components (e. g. potassium) increase in the course of development, but the mafic components (e. g. iron, magnesium) decrease. This "felsification" of the crust which was found world-wide (Ronov, Veizer, Engel, Rogers, ...) points at a repeated primary material supply of the mantle and the reflections of corresponding mantle differentiation processes in the crust.

This hypothesis is confirmed by investigation results of Ronov et al. (1984) after which an extensive equivalent material development can be observed both in variably old clay schists and granitoid rocks and in basalts, i. e. typical mantle rocks.

According to results existing up to now there is partially to be seen a *temporal correspondence of phases with increased mantle differentiation with* *phases of crust formation activity,* too. On the basis of data given by Patchett et al. (1981), Balashov et al. (1984), Pilot (1985) and other authors such exposed phases occur in the mantle and crust development with 3.5 (3.8—3.3) Ga; 2.8 (3.0—2.5) Ga; 1.8 (1.9—1.6) Ga and 0.7 Ga.

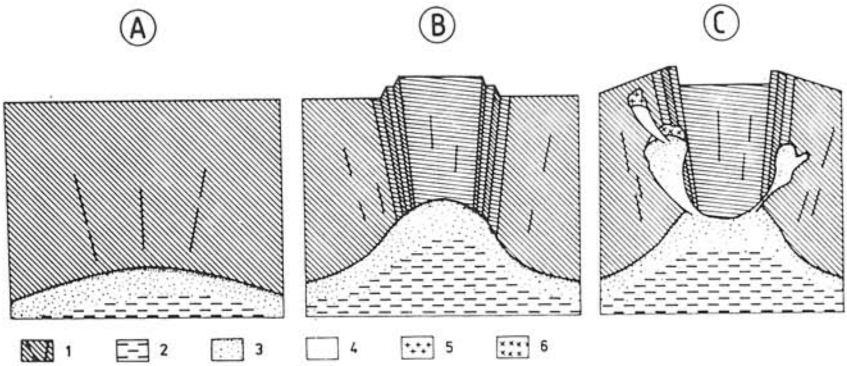

Fig. 3. Hypothesis of mantle diapirism.
Explanations: A — accumulation of lithophile (intermediate) parts of material below the lithosphere. B — extreme uparching and uplift of the crust segment above the diapir top. C — flow of sialic-intermediate melts into the crust and further differentiation up to monzogranitic melts; depression over the diapir top.
1 — lithosphere with fault structures; 2 — asthenosphere; 3 — lithophile (sialic--intermediate) parts of material in the mantle diapir; 4 — granitic melts; 5 — granites; 6 — intermediate magmatic rocks.

The mantle is today strongly differentiated. The world-wide isotope-geochemical and petrologic investigations of mantle magmas and xenolithes in such depth magmas could prove that the mantle both in vertical and in horizontal direction has great inhomogeneities in the material composition. Besides the mantle zones depleted and non-depleted (primitive) with lithophile elements under the continents and in the marginal zone to the oceanic crust there are existing also such mantle areas where fluids, alkali and other lithophile components are concentrated. (For the G.D.R. territory such range were determined e. g. in the area of East Erzgebirge Mts./Elbe valley zone, see point 5). Thus it is in principle proved that *in the upper mantle enrichment processes can take place.*

The existence of mantle zones with concentrations of lithophile components is in general associated with processes of mantle metasomatosis.

It can be started from the legitimate hypothesis that the lithosphere development underlies a *cooling regime.* The increasing material-structural differentiation of the lithosphere, speaks for this, but also calculations of many authors (Sharpe—Peltier, 1979; Mc Kenzie—Weis, 1980; Schubert et al., 1980; Stacey, 1980; Turcotte, 1980; Sleep—Langan, 1981) show that the heat flow at the earth surface exceeds the international radiogenic heat production and the earth cooled down for 140—

340 °C in the last 3 Ga. Accordingly, the lithosphere should grow downwards step by step. The lithosphere is indeed thicker in old shield regions than in young crustal units or in oceanic areas. The positive correlation between lithosphere thickness and age is significant (Kono — Amano, 1978). If such a crystallization process is observed from above downwards it can be shown that *below the consolidation front an accumulation of lighter lithophile components must have taken place* (Dahm, 1984). The reason must be looked for in the well-known phase response in the solidification of multicomponent-systems, where the solid phase is always richer in the components with the higher melting point or the higher density and the residual melt below the crystallization front correspondingly is depleted in these components. Thus the residual melt gets more and more "acid". Since a total concentration balance by diffusion in the melt — basing on a theoretical equilibrium crystallization — is not realistic and also the gravitation promotes a movement of lighter components in the mantle melt upwards, a concentration peak of lithophile ("acid") portions of material below the consolidation front occurs. Thus, an extreme density inversion is existing, where density contrasts of $\geqq 0.5\ g/cm^3$ occur. Below an ultrabasic mantle crystallization product with a mean intermediate melt is existing (Dahm, 1984).

Finally, on the question of a sial formation in the upper mantle it should be said that such a process was possible not only at the beginning of crustal development, but it takes place up to now in all probability. The melts enriched with lighter lithophile components cause an extreme density instability. They are locally concentrated mostly in zones of weakness situated in the marginal region to the oceanic crust — thin the lithosphere and arch it up before they reach the crust. There they can underlie further fractioning.

Indication of the model conception

The model of the mantle diapirism in Central Europe and the relation of the Variscan-postkinematic granites to this diapir is essentially confirmed by several geologic, petrologic and geophysical observations in this area.

a) The palaeogeographic situation and the spatial expression of Variscan tectogenetic-deformative processes and geophysical anomalies suggest the existence of a Variscan diapirism in Central Europe:

— At the beginning of Variscan epoch (Upper Devonian) the central region of the present Bohemian massif arched up, whereas the surrounding areas underwent a geosynclinal subsidence (Schönenberg — Neugebauer, 1981, and other authors).

— The Variscan tectonic activities and the sedimentation troughs migrated in starlike-polar manner from the inner zone into the outer regions (Paech, 1977 for Central Europe; Schönenberg, 1977 for the East Alps). The Fig. 4 illustrates the starlike radiation of these processes.

— The metamorphosis and folding intensity decrease from "inside to outward", whereas the Variscan main zones have a typical arcuate shape.

— Many different geophysical fields in Central Europe have still recently an anomalous behaviour. Positive anomalies of conductivity (magnetotellurics), of the heat flow and of the propagation time of P-waves (Grässle — Oesberg, 1980) should be stressed, since they point to inhomogeneities in the upper mantle. A positive anomaly of the geoid in Central Europe (Fig. 5) has after Rugenstein (oral communication) its cause in a mantle diapir which rises up relatively high as a gravimetrically and seismologically significant disturbing body from a depth of 100—150 km.

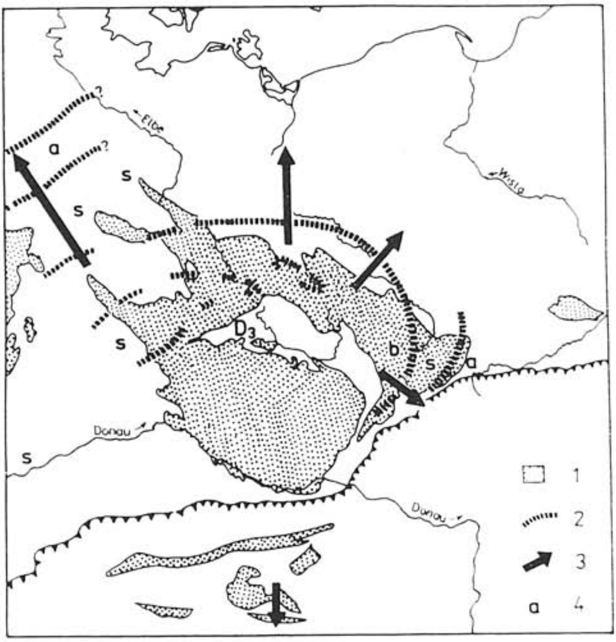

Fig. 4. Polarity and age of Variscan tectogenesis in Central Europe (after Paech, 1977) under inclusion of the Variscan belt of the East Alps (after Schönenberg, 1977).

Explanations: 1 — area with outcropping basement or Variscan molasse; 2 — boundary between areas with similar deformation age; 3 — polarity of Variscan tectogenesis; 4 — age of main folding in areas of similar deformation age; a — Asturian, s — Sudetian, b — Bretonian, D_3 — Upper Devonian.

b) Following aspects are suggesting the transition of sialic (intermediate) magmas from the uparched mantle region into the crust, especially into the Erzgebirge anticline:

— The upper mantle of the East Erzgebirge Mts. and of the neighbouring Elbe valley zone is anomalous. Accumulations of lithophile incompatible components (alkali, rock, CO_2, H_2O, SiO_2 ...) occur (Seifert et al., 1985; Kramer—Seifert, 1984).

— For the Erzgebirge Mts., especially for the east and central part, an acid — intermediate crust, attaining the Moho, must be supposed. Above all, the extreme minimum of gravity (< —40 mgal), the very low seismic wave velocity

($V_p = 6.0$—$6.2\ km\ s^{-1}$) throughout the crust and the very high heat flux ($\sim 75\ mW\ m^{-2}$) (cf. K a u t z l e b e n, 1983) suggest it.
— The petrology of xenolithes in young magmatites does not point to the existence of granulites or other katazonal metamorphites in the Erzgebirge lower crust. Syenitic-dioritic schliers and inclusions, however, could be found (K r a m e r — S e i f e r t, 1984).

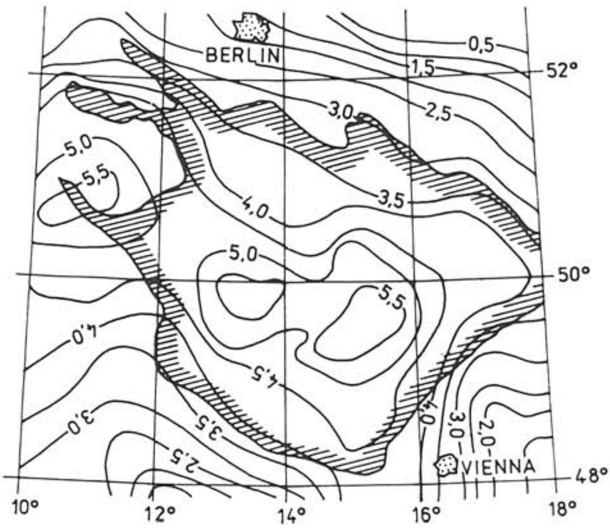

Fig. 5. Undulations of the geoid in the range of the Bohemian massif.
Note: Geoid — equipotential surface of gravity; values in m related to the astro-geodetic geoid of W o l f (1957).

— The safely complete acid-intermediate crustal composition, of the east and central part of the Erzgebirge Mts. cannot be explained by an intracrustal melting, since from gneisses and graywackes at most only 50—70 % melt can be obtained (W i n k l e r, 1976). R u g e n s t e i n could show that a gravity model of the East and Central Erzgebirge Mts. corresponds with the measured values only in the case if the emplacement of granitoids from a subcrustal or margin region is supposed.

c) The transition of the sialic mantle melts into the crust of the Erzgebirge anticline took place obviously preferably in the east part. Besides the anomalous mantle in the East Erzgebirge which has already been mentioned the following data point to such a hypothesis:
— Reflection-seismic deep sounding indicates that probably in the region of the East Erzgebirge Mts. and Elbe valley zone an unambiguous Moho discontinuity is not expressed, but that there is a "diffuse" mantle-crust transition (cf. B ö l s c h e — K r e s s e r, 1980).
— In the West Erzgebirge Mts. a complete acid crust is not to be expected since here in the lower crust already increased P-wave velocities occur (K a u t z l e b e n, 1983).

— The metamorphism and age zonality of the Erzgebirge Mts. (increase from W to E) can be explained convincingly if an intense rise and following erosion is supposed for the east part.
— The extensive expanding in the upper crust of the east part of the Erzgebirge anticline indicated by the occurrence of an intensive postkinematic-subsequent magmatism (Bankwitz et al., 1979; Wetzel, 1982) points at such an intense uplifting of the East Erzgebirge Mts.

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