Pre- and early Variscan evolution of the ZEV units

Ulrich Harms, KTB-Projektgruppe, NLfB, Stilleweg 2, 30655 Hannover

Introduction

The Zone of Erbendorf-Vohenstrauß (ZEV) is in its lithological structure and the medium- to high-pressure tectonometamorphic overprint comparable to other similar units in the NW Bohemian massif: The Münchberger Gneismasse (*sensu stricto*), the Zone of Tepla-Domazlice and the Marianske Lazne Complex, all of which were considered to be outlayers of the Bohemicum (Abb. 1). Therefore the ZEV is not an exceptional unit in the area, but represents an important rock association, whose structure and evolution reflects the orogenic processes in the western Bohemian massif. The unexpected depth range and the steep layering of the foliation as well as its position along the border Saxothuringicum/Moldanubicum, confirms the importance of this unit. The "supracrustal" series of the ZEV have been shown by the drilling and seismic and gravimetric investigations to be of great lateral and depth extend. Therefore, the ZEV and the similar units form a major part of the western Bohemian massif.

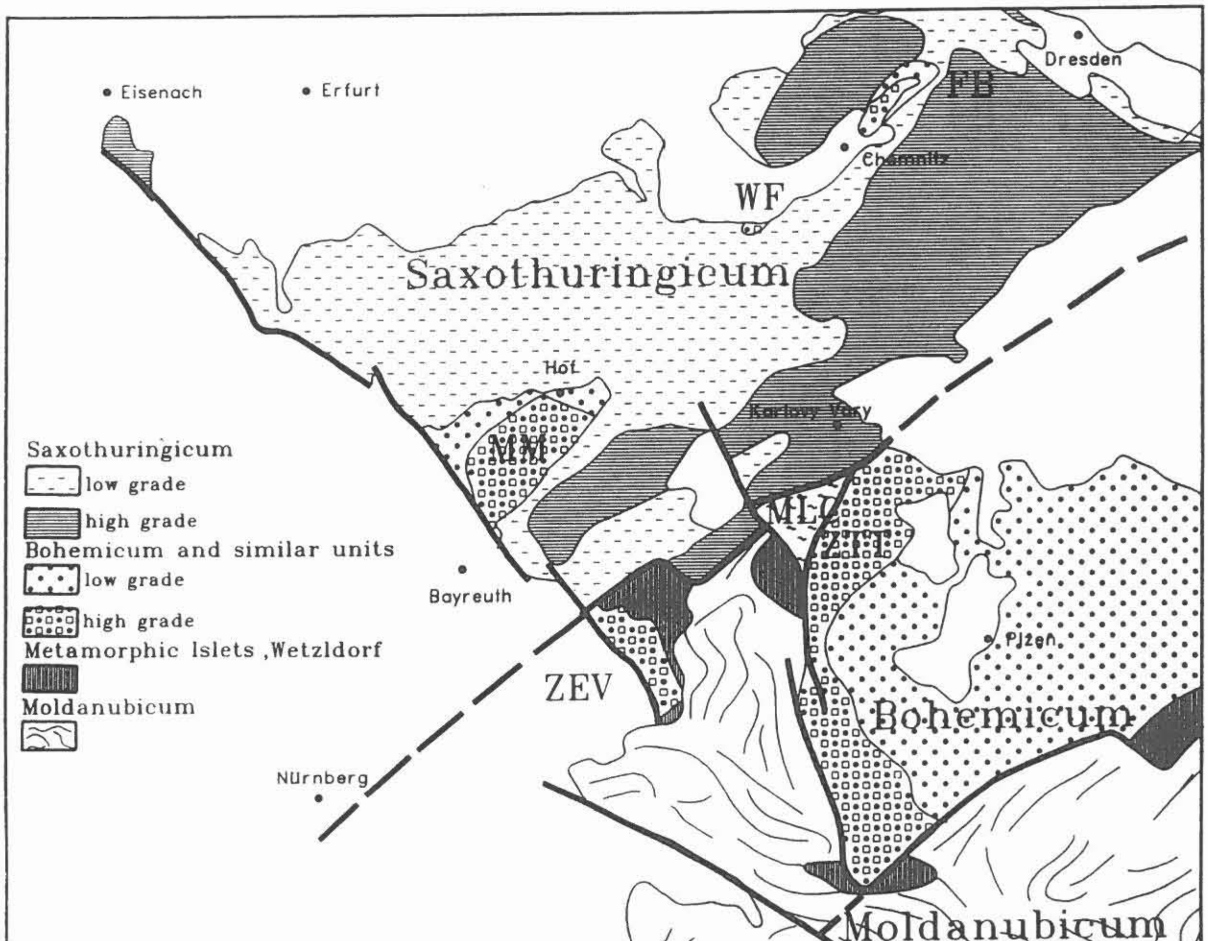

Fig.. 1: Geological sketch map of the western part of the Bohemian massif. MM = Münchberger Gneismasse, FB = Frankenberg, WF = Wildenfels, ZTT = Zone of Tepla-Domazlice, MLC = Marianske Lazne Complex.

Lithological units of the ZEV

The drilled sequence of metabasic and metasedimentary rocks within the northern ZEV can be subdivided in 3 associations on the basis of the detailed petrographic, structural and geochemical investigations (Kontny et al., 1994; Hoffmann & de Wall, 1994; Harms et al., 1993) and the tectonic correlation (Hirschmann et al., 1994) (Fig. 2):

1) b-units = tholeiitic amphibolites and metagabbros with rare occurrences of ultrabasic rocks,

2) g-units = metagreywackes and metasiltstones with minor concordant intercalations of alkali-amphibolite-layers,

3) v-units = alternating layers of metagreywackes to metapelites, alkali-amphibolites and alkaline hornblende-gneisses, subordinate are calc-silicate-layers and marbles;

magmatic dykes like lamprophyres, diorites and pegmatoid veins crosscut the metamorphic units in minor amount and small thicknesses.

Correlation and importance of the v-units

The units v1 and v2 occur in the Hauptbohrung and the Vorbohrung in nearly the same depth and have a similar composition and succesion. Nevertheless, a considerable smaller thickness was obtained in the Hauptbohrung in v1, because some parts are tectonically truncated (Fig. 2). Below 7260 m the sequence of v1 was met again in nearly identical manner, therefore a repetition by tectonic offset along the main fault of the Franconian line (seismic reflector SE1) has to be assumed. v2 (VB und HB) and v1 are clearly different from the b-units, but the differences inbetween the both v-series are small. e.g. v2 has prevailing hornblende-gneisses with alkali-rich trachybasaltic to dacitic composition.

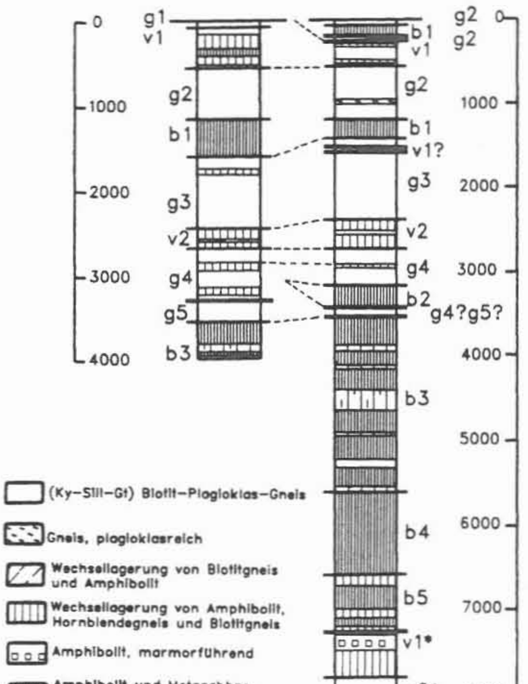

Fig. 2: Lithological units in the drilling sections and their correlation (according to Hirschmann et al., 1994).

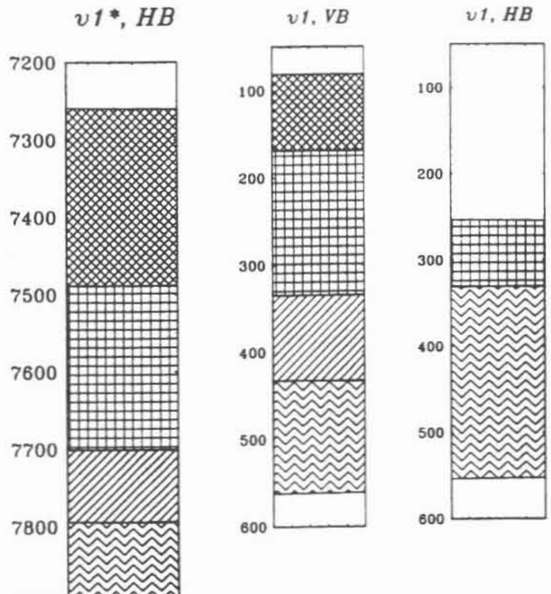

Fig.. 3: Subdivision of the units v1 and v1*, respectively, in the Vor- and der Hauptbohrung *v1 (VB) can be subdivided in 4 subunits:*

- *1) 81 - 168 m alkaline marble-amphibolites*
- *2) 169 - 334 m alternating layers with metatrachytes*
- *3) 335 - 432 m alkali-rich amphibolites*
- *4) 433 - 561 m gneissses, subordinate amphibolites*

v1(HB) comprises two of these characteristic subunits

- *2) 254 - 330 m alternating layers with metatrachytes*
- *4) 331 - 552 m gneissses, subordinate amphibolites*

v1 (HB) corresponds to v1 (VB)*

- *1) 7260 - 7488 m alkaline marble-amphibolites*
- *2) 7489 - 7700 m alternating layers with metatrachytes*
- *3) 7701 - 7794 m alkali-rich amphibolites*
- *4) 7795 - ~7900 m gneissses, subordinate amphibolites*

The v-units have a volcano-sedimentary character and intercalations of pelitic and carbonaceous metasediments in contrast to the b- and g-units. These differences are e.g. expressed in S-isotope values, which are clearly negative (~-10‰ $\delta^{34}S$) in gneisses and metabasic rocks of the v-units, whereas in g- und b-units overwhelmingly higher values occur (Berner & Puchelt; 1994). The reason can be primary pre-metamorphic sulfate-reduction due to bacteria or volcano-exhalative depletion in heavy Sulfur. The $\delta^{34}S$ determinations show furtheron the possibility of a stratigraphic correlation, because the b-units show typical magmatic S-isotope values (~0‰ $\delta^{34}S$) and the g-units have $\delta^{34}S$ in the range of -7 - 0‰.

The alternating units are a connecting element between g- and b-units, because of the concordant occurence of small to medium sized layers (cm to m) of interfingered paragneisses and metabasic rocks, which implies a syngenetic deposition and extrusion of the precursor rocks. Furtheron, geochemical investigations of whole rock compositions give indications of a genetic relationship between tholeitic (b) and alkaline (v) metabasic rocks (Hoffmann & de Wall, 1994); also radiometric age determinations on magmatic zircons from the v1*-unit (Söllner, 1994) show identical ages with those from the b-unit (Hölzl et al., 1993; von Quadt, 1993). Hence a contemporaneous extrusion or intrusion of all different metabasic rocks has to be envisaged, which determines the sedimentation of the gneiss precursors as well.

Formation and milieu of the ZEV-rocks

Paragneisses

The gneisses in the v- and g-units are characterized by a relatively homogeneous geochemical composition with variabilities from Si-rich and Al-poor to Si-poor and Si-rich varieties (comp. Fig. 4). These subtypes correspond also to petrographically and structurally discernable types, all of which can be deduced to clay mineral rich and arenaceous precursors, respectively (Harms et al., 1993; Müller & Mingram, 1993). The clay- and sand-rich subtypes constitute a minute layering in the range of cm to m, which resembles turbiditic flysch deposits.

The chemical composition lookes like that of modern greywackes and siltstones from basins at convergend plate boundaries (Müller & Mingram, 1993). Therefore the gneisses from the ZEV may be interpreted as former greywacke sediments from an island arc or continental margin.

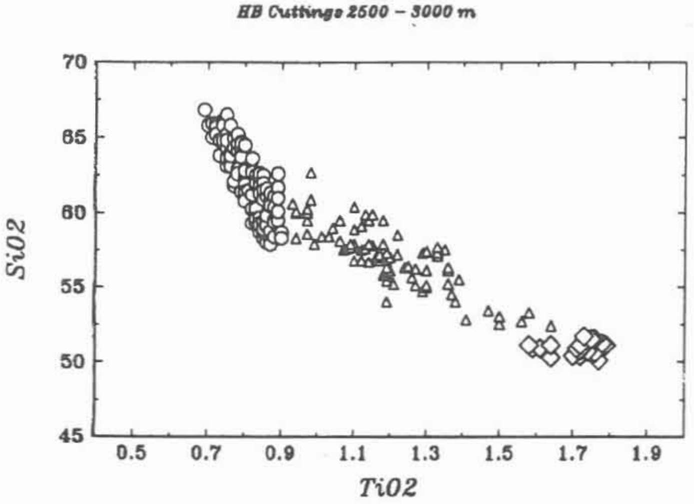

Fig. 4: Composition of paragneisses (circles), hornblende-gneisses (triangles) and amphibolites (diamonds) from unit v2. The hornblendegneisses have compositions between gneisses and amphibolites.

Metabasites

Amphibolites and metagabbros from the b- and v-units can be discriminated due to their occurrence, host rocks and their composition. The amphibolites and hornblende-gneisses of the v-units tend to alkaline compositions rich in Niobium; the subordinately occurring metabasics of the g-units are similar to them. On the contrary the metagabbros and amphibolites of the b-units have merely tholeiitic compositions (Fig. 5).

The amphibolites and metagabbros of the b-units are similar to enriched mid-ocean ridge baslats (E-MORB) (Abb. 6). Especially b4 (5690-6580) shows transitions from less differenciated to strongly fractionated, cumulated and layered compositions. Comparable canges from dykes, lava flows and isotropic gabbros towards differentiated depleted gabbros and ultramafics are well known from ocean floors and ophiolites (Harms & Godizart, 1993). The tectonic milieu of the b-units can be characterized as magmatic ocean floor in small oceanic basins and aulacogens (Red Sea, Gulf of California) or oceanic plateaus with off axis magmatism (Cocos plate seamounts). In the southern ZEV occur normal mid-ocean ridge basalts (N-MORB), which represent typical ocean floor (Schüssler et al., 1989).

The amphibolites from the v-units comprise alkaline tholeiitic to alkali-basaltic compositions, as recently occurring in intraplate- or rift-milieus (Fig. 6) (oceanic islands, continental rifts, "hot spot" volcanism). The hornblende-gneisses are of trachybasaltic to trachyandesitic compositions. The intermediate members are not magmatic differentiates of the precursors of the metabasic rocks, but represent sedimentary mixtures of greywackes (=gneiss precursors) with tuffitic material (derived from amphibolite precursors) (compare Fig. 4). The close primary interlayering of volcanic and turbiditic rocks evidences an tectonically active marine milieu.

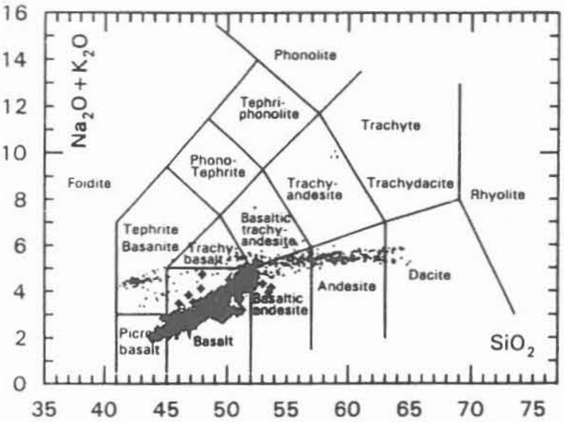

Fig. 5: Classification diagram total alkalies (Na_2O + K_2O) versus SiO_2 for metabasic rocks. b4-metabasics are shown as thick crosses and v1, v2 and v1* (HB) as cirles.

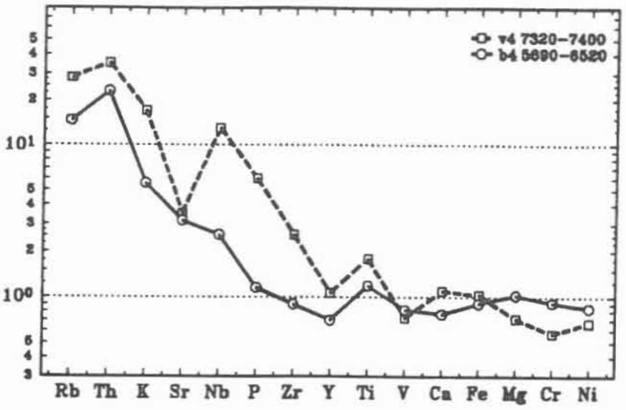

Fig. 6: Comparison of mean values of b- and v-metavolcanics in an multi-element-diagram, normalised to MORB. The elevated Nb- to Ti-values of the v-amphibolites show an alkali- or intraplate character.

Geotectonic position

The precursors of the metamorphic rocks from the ZEV were all formed in a marin basin, which must not conclusively be a single basin containing all precursors. The former greywackes must have been deposited in a deep sink close to the source, which can be a continental margin or island arc, whereas the extrusion of the v-unit metabasics need either a initial rift at a nascent ocean or an aulacogen or alternatively an enriched mantel source in an oceanic environment like a plateau, off-axis volcanism or oceanic island. The majority of b-unit amphibolites where generated most probably in an oceanic spreading axis; the vast occurrence of N-MORBs in the southern ZEV confirms the formation of a ocean basin. In general, the rock association of the ZEV could have been formed genetically and spatially related in a marginal oceanic basin, the present intercalation may be a result of syn-sedimentary deposition and ex- or intrusion and of early accretion during a subductional process.

Metamorphic evolution

Thermobarometric investigations on gneisses from the drillholes (Reinhardt, 1993) and their surroundings (Schulte, 1994) show a prograde evolution along the kyanite-sillimanite-transition in the P-T field up to 650 - 700° C at approximately 8 kbars. Maximum pressures in excess of 10 kbars can be excluded. After this high-grade amphibolite event an isothermal uplift - probably interrupted by a minor pressure increase - occurred (Fig. 7), until the rocks were retrograded in lower amphibolite- and greenschist facies conditions in a common path with the metabasic rocks (Godizart and Zulauf, 1993). The resulting metamorphic path is typical for collisional orogenes.

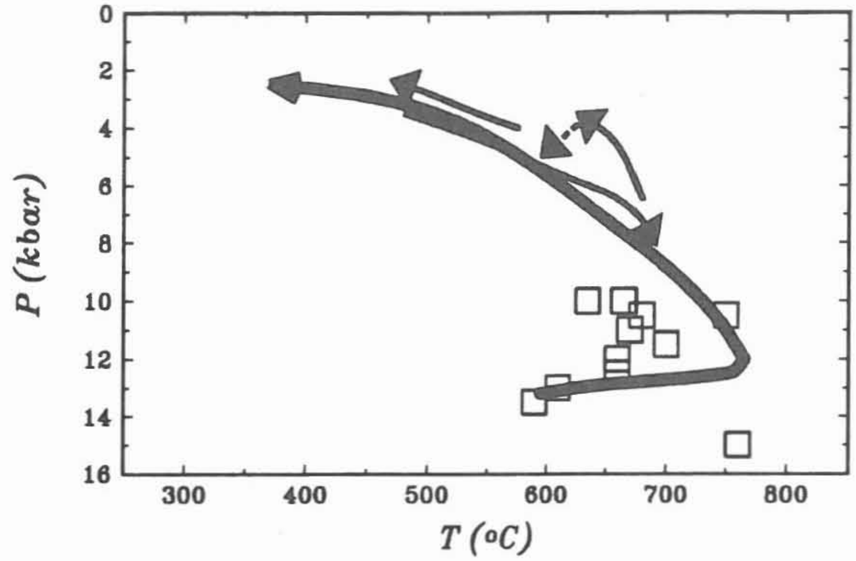

Fig. 7: Metamorphic evolution of ZEV rocks. Quadrangles are P-T data of metabasic rocks according to O'Brien et al. (1992), thick line is the P-T path of metabasic rocks from the drillhole after Godizart & Zulauf (1993), thin arrows show the P-T evolution of the gneisses (Reinhardt, 1994). Errors are not depicted!

amphibiolites from the v-units. Anyhow, O'Brien et al. (1992) found for a single sample from the v2-series pressures of ~10kbar and all metabasic samples from the different b- and v-units show decompression reactions which point to a high pressure imprint prior to the common amphibolite facies metamorphosis.

A multiphase complex metamorphosis must be assumed for the ZEV rocks, whose metabasic rocks were overprinted in an early high-pressure event which is lacking in the metasediments. These gneisses were subducted to medium-pressure ranges only, while the dense basic units were brought to greater, different depths in a subductional process; the v-units could have reached an "intermediate" position. During the amphibolite facies event all parts of the ZEV were brought to a similar P-T range and achieved the majority of their present relation, irrespective of possible later brittle tectonic displacement.

Radiometric age determinations

Precambrian ages are known from U-Pb data on zircons from the v- und g-units (Söllner, 1993; Teufel, 1988). Early- to Neoproterozoic magmatic und metamorphic events in the source area of the metasedimentary precursors are indicated, which are known from the neighboring Moldanubian gneisses in the same age range, and must stem from a similar or identical, mainly continental source.

Late Cambrian to early Ordovician ages were determined in all units. The magmatic crystallisation of the b-metabasics occurred at around that time because U-Pb data from zircons (von Quadt, 1993; Hölzl et al., 1993) show ages between ~495 and ~477 Ma. Recent investigations by Grauert et al. (1994) on abraded (482 Ma) and not abraded zircons (477 Ma) from b3 show little but clear differences, which may be explained through a metamorphic overprint a short time span after the formation. Also the v1* metavolcanics have shown preliminary U-Pb zircon ages of the magmatic crystallisation of ~488 Ma (Söllner, 1994). Hence, an early Ordovician contemporaneous formation and sedimentation of all precursors of the ZEV can be assumed, since the v-metabasics date the sedimentation due to their close interfingering.

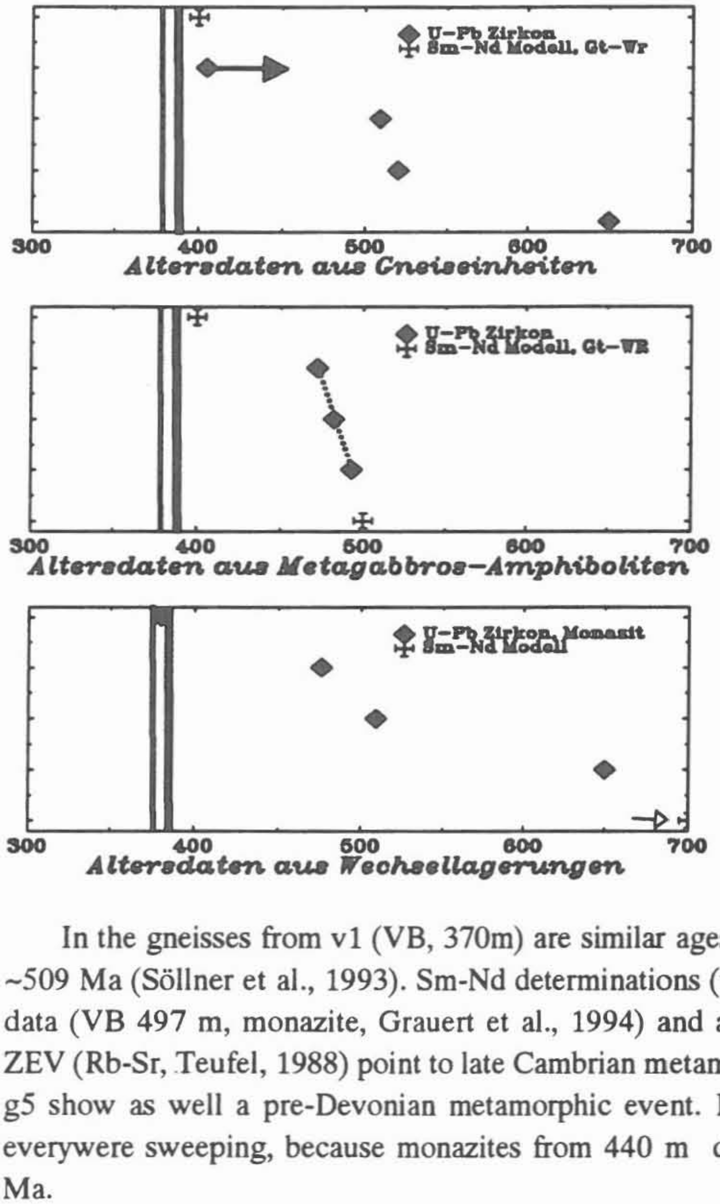

Fig. 8: Important age data from the different rock units of the ZEV, see text for references. Upper part - g-units, middle part - b-units, lower part - v-units.

In the gneisses from v1 (VB, 370m) are similar ages assumed for a metamorphic event at ~509 Ma (Söllner et al., 1993). Sm-Nd determinations (wr-gt, Kreuzer et al., 1990) and U-Pb data (VB 497 m, monazite, Grauert et al., 1994) and ages from gneisses from the southern ZEV (Rb-Sr, Teufel, 1988) point to late Cambrian metamorphism in the gneisses. Zircons from g5 show as well a pre-Devonian metamorphic event. But this early event seems to be not everywere sweeping, because monazites from 440 m depths (VB) have U-Pb ages of ~380 Ma.

This, probably second, metamorphic event in the gneisses is evident from a great number of age determinationsn in the range of 380 and ~410 Ma (Sm-Nd wr-gt, von Quadt, 1990; U-Pb monazite, Grauert et al., 1994; K-Ar and Ar-Ar hornblendes, Kreuzer et al., 1990, Henjes-Kunst et al., 1994). On the ground of these relatively homogeneous data from different depths of the drillhole and from surface localities, a common metamorphosis of all units in the lower Devonian must be assumed. Cooling and elevation of the units occurred rapidly after the amphibolite facies metamorphism, because the K-Ar isotopic system in white micas was closed at 371 Ma (T ~ 350 °C); micas from the western Staurolith zone of the ZEV have ages of 380 Ma, which confirms a differential thermal evolution of the gneisses during the Devonian (Henjes-Kunst et al., 1994).

Temporal and geotectonic evolution of the ZEV

The following scenario is an attempt to synthesize the different data to a uniform geological history of the rock units of the Zone of Erbendorf-Vohenstrauss:

At about ~500 Ma started the formation of magmatic ocean floor (b-units), which was accompanied contemporaneously or slighty later with the extrusion of alkali-tuff(ite)s and volcanics and the alternating deposition of thick clastic greywacke sequences (g- and v-units). The spatial relationship of the different units seems to be quite close. After the deposition at least some parts of the basin infill were subducted very rapidly; while metabasic units reached deep burial, the less dense gneissic units escaped from very deep subduction. The multiphase metamorphic evolution points to stacking and imbrication in a continental orogenic wedge, causing the complex metamorphic loops (O´Brien et al., 1992). It is not precisely known when the units were joined together (see thick and thin path of metabasics in Fig. 9), but the units were commonly metamorphosed in the high-grade amphibolite stage at least during the lower to middle Devonian (400-380 Ma). Early cooling and decompression followed rapidly between 380 and 370 Ma. This processes must have been continued, because the Variscan deformation and metamorphism in the middle Carboniferous affected the ZEV only along the eastern edges and in alterations, while the surrounding Moldanubicum and Saxothuringicum were metamorphosed in a HT-LP event. This evidences a structurally high position in the crust for the ZEV at that time. The later tectonic events which brought the ZEV in its present deep position against the surrounding tectono-metamorphic terranes is still debated.

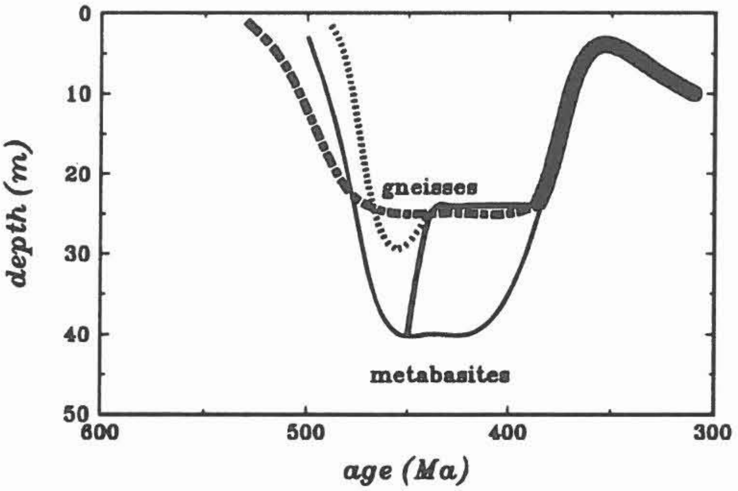

Fig. 9: Schematic time-depth-diagram of the ZEV evolution. Gneisses and alternating layers follow the dashed paths, metabasics from the b-units the full lines. The bold line shows the common Variscan history of the ZEV units. See text for detailed explanations.

Acknowledgement

The data and results presented here are partly based on discussions during the workshops on "Early history of the ZEV", (Gießen, November, 1993) and "Importance of the v-units" (Windischeschenbach, March, 1994). I am indebted to all contributing colleagues for distilling this preliminary evolutionary scheme of the ZEV.

References

Berner Z & Puchelt (1994) Das Schwefel-Isotopenprofil der KTB am Scheidepunkt: Lithologie- oder Teufenabhängig. This volume.

Godizart G & Zulauf G (1993) Ductile normal faults in the KTB Hauptbohrung - Evidence of late Variscan extensional collapse. KTB report, 93-2, 103-105.

Grauert B, Abdullah N, Lork A, O'Brien PJ (1994) Relikte ordovizischer Metamorphite in KTB-Bohrkernen und Gesteinen des KTB-Umfeldes. This volume.

Harms U, Godizart G (1993) Formation of metabasic rocks: Geochemical interpretation of core and cuttings data. KTB report, 93-2, 79-82.

Harms U, Hirschmann G, Lich S, Pechnig R, de Wall H (1993): Gneisses of the KTB Vorbohrung and Hauptbohrung: I. Lithological units subdivision and correlation. KTB report, 93-2, 67-74.

Henjes-Kunst F, Höhndorf A, Kreuzer H, Seidel E (1994) K-Ar & 40Ar-39Ar mineral dating on core samples from KTB-VB and HB. This volume.

Hirschmann G, Lich S, De Wall H. (1994) KTB Oberpfalz - einige Ergebnisse der geowissenschaftlichen Bearbeitung. Zbl Geol Paläont, 7/8, 861-873.

Hölzl S, Hofmann B, Köhler H (1993) U-Pb and Sm-Nd dating on a metabasite from the KTB main bore hole. KTB report, 93-2, 391-392.

Hoffmann A, de Wall H (1994) Alkaline Series of the KTB - The key for a genetic interpretation of the ZEV metavolcanics. This volume

Kontny A, et KTB Feldlabor (1994) The lithological profile of the KTB Hauptbohrung (7200 - 8729.7 m). Results from the KTB field laboratory. This volume.

Kreuzer H, Müller P, Carl C, Ebadi A, Höhndorf A, Patzak M (1990) Mineral dating on core samples from 500 to 2000 m depth of the KTB drill hole. KTB report, 90-4, 546.

Miller H, Söllner F, Loske W (1990) U-Pb-Datierungen and Zirkonen aus Gneisen der KTB-Vorbohrung. KTB report, 90-4, 544.

Müller H, Mingram B (1993). Gneisses of the KTB Vorbohrung and Hauptbohrung: II. Source rocks and petrogenesis. KTB report, 93-2, 75-78.

O'Brien PJ, Röhr C, Okrusch M, Patzak M (1992) Eclogite facies relics and a multistage breakdown in metabasites of the KTB pilot hole, NE Bavaria: implications for the Variscan tectonometamorphic evolution of the NW Bohemian Massif. Contrib Mineral Petrol, 112, 261-278.

von Quadt A (1990) U-Pb zircon and Sm-Nd analyses on metabasites from the KTB pilot bore hole. KTB report, 90-4, 545.

von Quadt A (1993) Metagabbro from the KTB pilot hole: a multi-element approach. KTB report, 93-2, 393-394.

Reinhardt J (1994) Beitrag zum Protokoll des Workshops "Frühe Geschichte der ZEV", Gießen, 17.-18. 11. 1993.

Schüssler U, Richter P, Okrusch M (1989) Metabasites from the KTB Oberpfalz target area, Bavaria - Geochemical characteristics and examples of mobile behavior of "immobile" elements. Tectonophysics, 157, 135-148.

Schulte B (1993) Late cordierite in the Zone of Erbendorf-Vohenstrauss (ZEV): evidence of isothermal uplift of parts of the western ZEV. KTB report, 93-2, 115-120.

Söllner F (1994) U-Pb systematics on zircons from chlorite gneiss of metavolcanic layer v4 (7260-7800m) from the KTB Hauptbohrung. This volume

Teufel S (1988) Vergleichende U-Pb- und Rb-Sr-Altersbestimmungen an Gesteinen des Übergangsbereiches Saxothuringikum/Moldanubikum, NE-Bayern. Göttinger Arbeiten Geologie Paläontologie, 35, 87pp.