High Pressure Metamorphism in the NW Bohemian Massif: Comparisons and contrasts between the Modanubian Zone, Münchberg Massif, ZEV, ZTT and Erzgebirge.

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Introduction

Relics of rocks formed during high pressure (HP) metamorphism such as eclogites, granulites and garnet peridotites, are volumetrically small but widely distributed throughout the crystalline core of the Variscan orogenic belt in Europe (e.g. O'Brien *et al.* 1990). Such HP rocks are well represented in the Bohemian Massif where they are found in each country - Poland, Czechoslovakia, Austria and Germany - over which the massif extends. In this short overview, only HP rocks from the northwest of the massif, within 100km of the deep drilling site, are considered i.e. from the Münchberg Massif (MM), Zone of Erbendorf -Vohenstrauss (ZEV) and Oberviechtach area of the Oberpfalz (Opf) in NE Bavaria and Mariánské Lázně Complex (MLC) and Erzgebirge (ERZ) in NW Bohemia (see Fig. 1). The key petrological features of the rocks along with pressure-temperature (P-T) estimates for different phases of the multi-stage metamorphic history of the units are presented. The significance of the different derived P-T-time paths is discussed along with implications for possible tectonic scenarios.

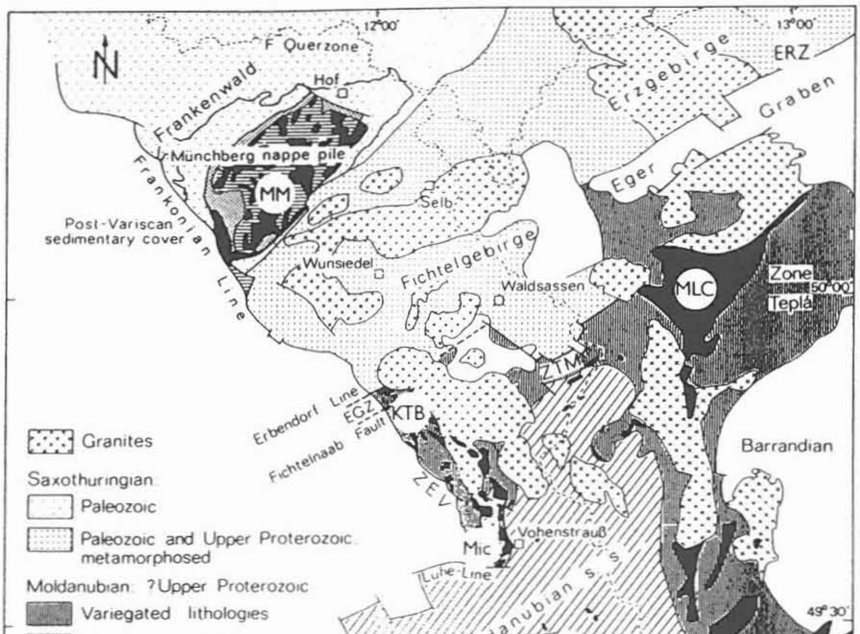


Figure 1. Simplified geology of the NW edge of the Bohemian Massif (based on the geological map of Bavaria 1:500000. Line drawing courtesy of K.-P. Kelber, Würzburg). Abbreviations for localities as in the text.

A. ECLOGITES

Erzgebirge

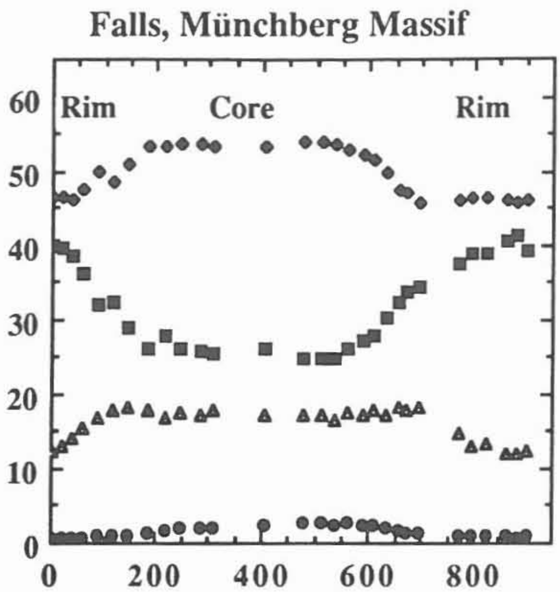
Samples were collected from the small hill Meluzína about 6km ENE of Jáchymov. The eclogite body sits in a series of quartzite, quartzose mica schist and two-mica ortho- and paragneisses (Klápová 1987) The continuation of this unit across the border into Germany, where it is known as the Keilberg Series, also contains numerous eclogites (e.g. Schmidt *et al.* 1990). Dominantly fine grained (<0.3mm), eclogites comprise strongly zoned garnet (Alm_{41-56} $Prp_{7.5-9}$ Grs_{22-35} $Sps_{0.5-9}$ in the same grain; Fig. 2), omphacite (X_{Jd}=0.38, X_{Mg}=0.81), quartz and rutile with additional phengite (X_{Mg}=0.8, Si=3.5 p.f.u.) clinozoisite and rare phlogopite. Omphacite generally shows very fine-grained breakdown rims of symplectitic plagioclase (An_{10}) and less jadeitic clinopyroxene (X_{Jd}<0.2, X_{Mg}=0.62) and phengite is often rimmed by a biotite-plagioclase intergrowth. An early fabric of aligned omphacite, clinozoisite and phengite wraps garnet and is overgrown by large (1-2mm) pale blue porphyroblasts of actinolite (in the winchite field when more sodic) which is sharply zoned to deep blue ferroan pargasite against garnet. Estimated P-T conditions for the eclogite facies stage are >15kbar, 600°C, with the symplectite stage HP granulite conditions at around 14kbar and 700°C.

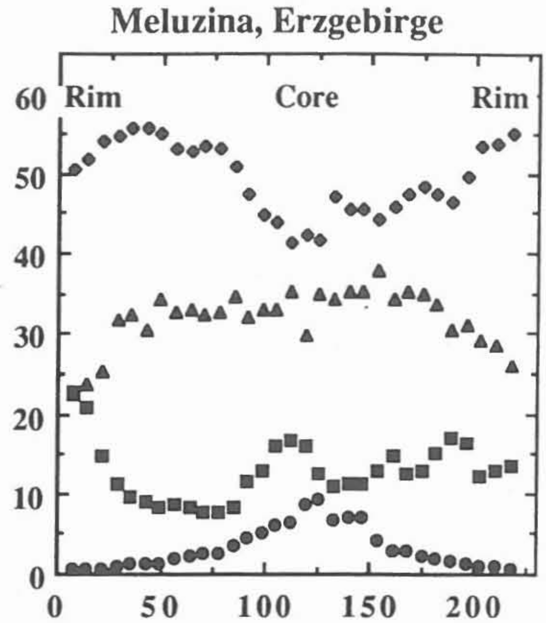
Münchberg Massif.

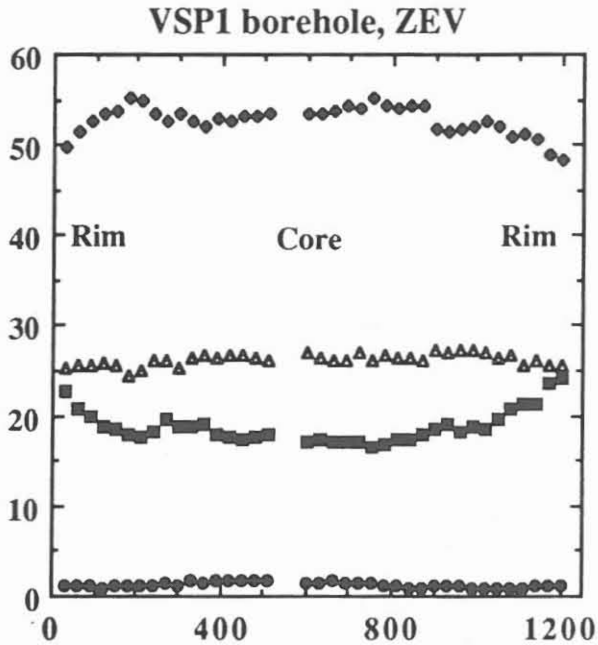
Eclogites of the Münchberg Massif were described in the early 1800's, even before the name 'eclogite' existed, and have long been the target of petrological investigations (for an historical overview, compilation of geochemical and mineralogical data and extensive reference list, see Okrusch *et al.* 1991). The Massif was long considered a protruding basement diapir but is now regarded as an allochthonous stratigraphically and metamorphically inverted nappe-pile, resting on a very low grade Saxothuringian Zone Palaeozoic sequence, preserved within the Vogtland Syncline (e.g Behr *et al.* 1980) Eclogites occur within an upper-most unit of hornblendic gneisses, amphibolites and carbonate-rocks in ortho- and para-gneisses resting above a lower series, sometimes showing a 'granulite tendency', comprising monotonous metaclastics, metamorphosed acid and basic intrusions and some serpentinite intercalations.

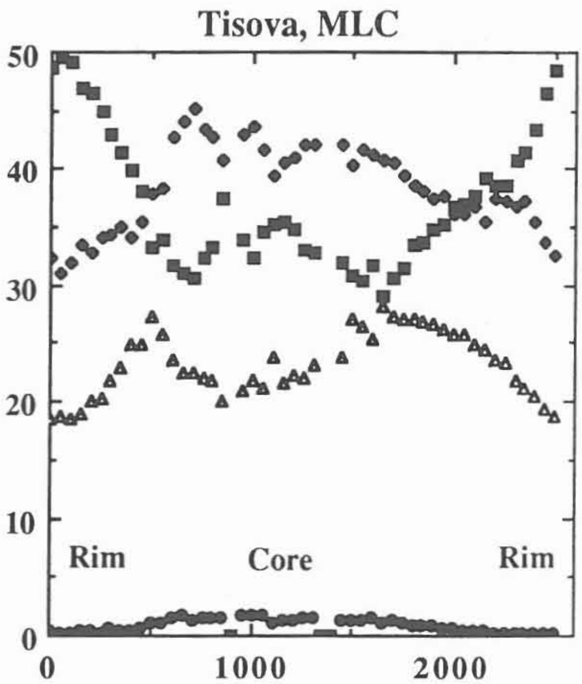
Two macroscopically different eclogite groups have been distinguished: a dark coloured, kyanite-free type, of oceanic MORB composition and a light, kyanite-bearing variety, mostly corresponding to a plagioclase-rich cumulate source. All eclogites contain garnet, omphacite, quartz and rutile with varying proportions of kyanite, phengite, zoisite and amphibole. Important petrological features are:

- prograde growth zoning and/or two stage growth in garnet (Fig. 2);
- inclusion patterns and honeycomb texture of garnet aggregates implying a derivation by static coronitic overgrowth of former gabbros;
- dusty, darker green chromian omphacite and deep blue chromian kyanite in local Cr-rich domains (probably sites of igneous spinels);
- two evolutions of hornblende, kyanite, zoisite and phengite;
- veins containing any of the eclogite facies minerals thus indicating the presence of fluids during HP conditions;
- breakdown of omphacite to a symplectite of less jadeitic clinopyroxene + sodic plagioclase ± amphibole, later replaced by diablastic amphibole + plagioclase aggregates;
- garnet breakdown to aluminous amphibole + plagioclase;
- phengite breakdown to biotite + plagioclase;
- kyanite rimmed by paragonite;
- rutile replaced by titanite;
- fluid inclusions indicating the presence of a fluid phase during the amphibolite facies recrystallisation;









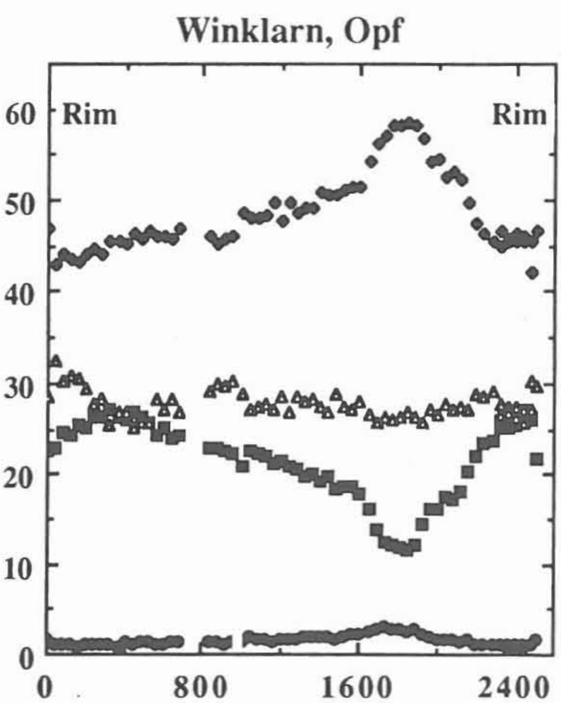


Figure 2. Garnet zoning profiles from selected eclogites. vertical scale is mol% component, horizontal scale is scan distance in microns.

- chlorite, albite, epidote and actinolite (± white mica) in late veins or overgrowing older, higher grade assemblages;
- late stage pumpellyite lenses within phengite.

(Franz *et al.* (1986), Klemd (1989), O'Brien (1989b) and Okrusch *et al.* (1991) give further details).

Geothermobarometric studies have been predominantly applied to samples from the locality Weissenstein. Franz *et al.* (1986) obtained 13-17kbar, 620±50 °C for the phengite-quartz eclogite stage and 8.5-12kbar, ≈620 °C for the symplectite stage. Klemd (1989), favouring the existence of an H_2O-rich fluid phase, estimated minimum conditions of >20kbar at 600-650 °C for the eclogite stage and 6.5kbar at 600 °C (from fluid inclusion studies) for the amphibolite facies overprint. However, when samples from other Münchberg Massif localities were investigated (O'Brien 1989b), a much wider range of temperatures (550-730 °C) were calculated.

The most important recent discovery is the presence of a second omphacite generation, in symplectite form, in the kyanite-bearing eclogites. As this coexists with plagioclase and quartz an actual pressure can be calculated by albite-jadeite-quartz geobarometry for this early breakdown stage of around 14kbar. This contrasts with the situation in the plagioclase-free eclogite facies assemblage where only minimum pressures, also in the range 12-15kbar, are calculated by the same method. However, the experimentally determined 'plagioclase-out' conditions for quartz tholeiite and high-alumina basalt (broadly eqivalent to the dark and light eclogites respectively) show that the more aluminous compositions retain plagioclase to higher pressures (e.g. Ringwood & Green 1966). This could mean that the early symplectite stage in the light eclogites corresponds to a recrystallisation in the dark eclogites still in plagioclase-free conditions. The appreciation of such a HP breakdown is fundamental to our understanding of the P-T evolution of the Münchberg Massif and gives greater credence to the higher pressures presented by Klemd (1989) and the possibility of the former existence of coesite in these rocks (Chesnokov & Popov 1965).

Mariánské Lázně Complex

The Mariánské Lázne Complex of NW Bohemia comprises a strongly deformed series of mostly tholeiitic mafic rocks - amphibolites, metagabbros and eclogites - with serpentinites, quartzofeldspathic gneisses and some thin marbles and calc-silicate rocks (Kastl & Tonika 1984). From the variety of metamorphic histories found and the presence of numerous shear zones the complex has been interpreted as a stack of tectonic units (Jelínek *et al.* 1989). Eclogites, variably retrograded, were studied from the localities Tisová and Louka. These show a complex multistage metamorphic evolution. Important textural and mineralogical features of selected samples are:

- large (5mm) euhedral garnets (Alm_{31-49} Prp_{25-50} Grs_{18-29} $Sps_{0.2-1.9}$ in the same grain: Fig. 2) with a distinctly older homogeneous core zone rich in inclusions (mostly rutile, quartz and amphibole) and an inclusion-poor rim where Mg rises sharply and Fe and Ca fall;
- garnet rimmed initially by pargasite with plagioclase and sometimes spinel and later entirely replaced by hornblende, epidote and chlorite;
- omphacite (X_{Jd}=0.38), often with inclusions of zoisite, partially or totally replaced by a symplectite of less jadeitic clinopyroxene (X_{Jd}<0.2) and plagioclase (An_{20});
- growth in areas of fine-grained symplectite of small aggregates of new clinopyroxene;
- replacement of symplectite pyroxene leading eventually to a more calcic plagioclase intergrown with brown (later green) hornblende;
- growth of coronas or aggregates of orthopyroxene and clinopyroxene, surrounded by plagioclase, where fractures through garnet pass alongside quartz inclusions;

- diablastic aggregates of biotite and plagioclase after phengite;
- very fine-grained decay of zoisite/clinozoisite;
- partial or total breakdown of kyanite to sapphirine+spinel+corundum in plagioclase sometimes with later staurolite (X_{Mg}=0.4);
- rutile rimmed by ilmenite and later titanite;
- late veins with albite, actinolite, epidote, titanite and chlorite.

These features show that the rock passed from an early amphibolite stage (garnet core composition and inclusions) to eclogite facies conditions (garnet overgrowth, omphacite but no plagioclase: P>14kbar, T≃680 °C) and then passed through the HP granulite (symplectite clinopyroxene, reappearance of plagioclase: ≃12kbar, ≃750 °C), MP granulite (aggregates/coronas of orthopyroxene and new clinopyroxene: ≃10kbar, ≃680°C), amphibolite (amphibole+plagioclase growth at expense of garnet and pyroxene) and greenschist facies fields (vein assemblage).

Zone of Erbendorf-Vohenstrauss

Presently interpreted as a nappe unit straddling the Moldanubian Zone - Saxothuringian Zone boundary (Weber & Vollbrecht in K.T.B. 1986), the ZEV consists predominantly of metasediments and a variety of amphibolites with minor metagabbros, ultramafics and acid orthogneisses. The KTB pilot hole, which is located in the northern part of this unit (Fig.1) yielded a number of samples with relict HP assemblages but the only satisfactory retrograded eclogite came from a small vertical seismic profiling borehole (VSP1), about 150m to the NE (Röhr, O'Brien, Okrusch & Patzak in prep.). The rock contains;
- zoned garnet (Alm_{48-54} Prp_{16-24} Grs_{24-27} $Sps_{0.8-1.8}$:Fig. 2);
- coronas around garnet of plagioclase (inner) and amphibole (outer);
- a most relictic clinopyroxene (X_{Jd}=0.22) always with lamellar exsolved plagioclase laths testifying to an initially higher jadeite content;
- well developed vermicular symplectites of jadeite-poor diopside + plagioclase (An_{25}) around the relict pyroxene;
- replacement of the symplectite by pargasitic to tschermakitic amphibole and plagioclase (An_{40});
- rutile replaced by ilmenite and in complex intergrowths with titanite;
- late veins containing epidote, actinolite, chlorite, pumpellyite, calcite and K-feldspar.

Preliminary geothermobarometric calculations indicate 13kbar, ≃715°C for the symplectite-bearing HP granulite stage implying even higher pressure for the earlier eclogite facies stage.

Eclogites, some with orthopyroxene, have been described from Kaimling, near Michldorf (Mic in Fig.1), in the southern part of the ZEV (Busch 1970; Voll 1960). However, bulk rock and mineral chemistry suggests that the rocks are in fact garnet pyroxenites.

Oberpfalz

In the Oberpfälzerwald, especially in the area around Oberviechtach, small bodies of retrograded HP rocks, associated with serpentinised peridotite, are found within typical Moldanubian Zone cordierite -sillimanite or biotite -plagioclase gneisses. An important exposure is the quarry SE of Winklarn where eclogites, garnet pyroxenites, garnet websterites and also HP metasedimentary rocks occur together. Typical metabasites, with N-type MORB geochemical features, originally contained garnet+omphacite+rutile±quartz±kyanite±clinozoisite but the assemblage is never retained intact. Important petrological features are:
- growth-zoned and homogenised garnets both with retrograde rims;
- inclusions of omphacite (up to X_{Jd}=0.35) in garnet;
- early lamellar exsolution of sodic plagioclase from groundmass omphacite leaving a less jadeitic clinopyroxene;
- replacement of former omphacite/Na augite by vermicular symplectites of diopside + plagioclase itself later replaced by diablastic amphibole +plagioclase;

- coronas of orthopyroxene and/or clinopyroxene + plagioclase around quartz grains adjacent to garnet;
- early kelyphitic orthopyroxene-spinel-plagioclase coronas around garnet usually almost totally replaced by radiating amphibole +plagioclase;
- rutile replaced by ilmenite and later titanite;
- kyanite replaced by aggregates of hercynite in anorthite;
- clinozoisite replaced by anorthite dusted with tiny opaques;
- crosscutting veins with albite, epidote, actinolite and chlorite.

The textures and mineral compositions (see O'Brien 1989,1989b) indicate a multi-stage metamorphic history probably starting in the amphibolite facies (low Mg garnet cores + inclusions of amphibole) and continuing through the eclogite (710°C, >15kbar), HP granulite (800°C, 12kbar), MP granulite (>800°C, 8-10kbar), amphibolite and greenschist facies.

Ironically, the freshest-looking 'eclogite' from Winklarn is in fact a garnet clinopyroxenite. In this rock garnet is essentially homogeneous - Alm_{38} Prp_{45} Grs_{13} Adr_4 - whilst clinopyroxene is diopside with only minor Na and Al: subsiduary phases are pale yellow Mg-hornblende, rutile and apatite. An associated rock is a coarse-grained garnet websterite comprising garnet (Alm_{30} Prp_{53} Grs_{16}), orthopyroxene (En_{78}, Al_2O_3=0.15 -1.0 wt%), diopside (X_{Mg}=0.9, Al_2O_3 < 1 wt%), olivine (Fo_{73}), spinel and rutile. Garnet in the websterite is invariably surrounded by a very fine-grained kelyphite composed of an early orthopyroxene (X_{Mg}=0.65, Al_2O_3= 2-3 wt%) and spinel intergrowth partially replaced by later magnesio-hornblende and, even later, anorthite. Geobarometry using the primary orthopyroxene yields the surprisingly high pressure of 28kbar. Elsewhere in the Bohemian Massif, such high pressures are deduced for garnet peridotites (Medaris & Carswell 1990) and coesite-bearing eclogite (Schmädicke pers. comm.). The minimum pressures derived for Oberpfalz eclogites by garnet-omphacite-quartz geothermobarometry could therefore be significantly lower than those actually experienced.

In summary, there are some vitally important features of the eclogites in this region that should be recognised:

1) Garnets show growth zoning or textures which, in conjunction with inclusion suites, indicate a lower pressure crustal history before the HP eclogite facies metamorphism.

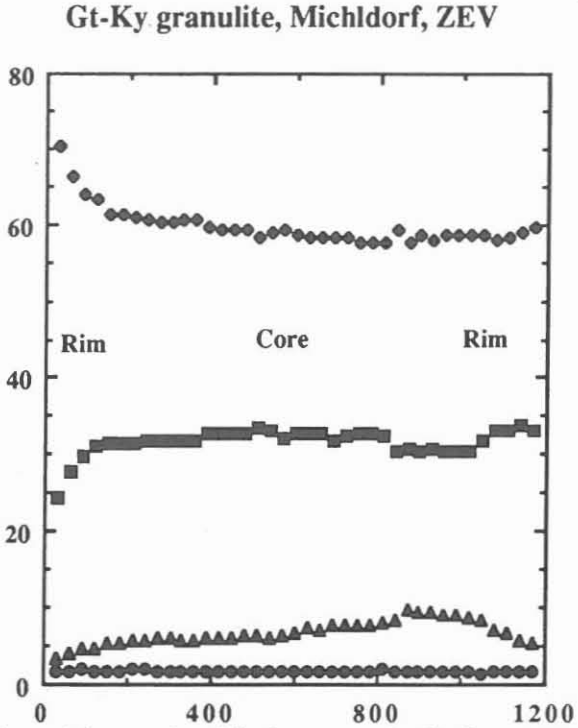
2) Re-equilibration during uplift is always multi-stage with at least one breakdown episode above 10kbar.

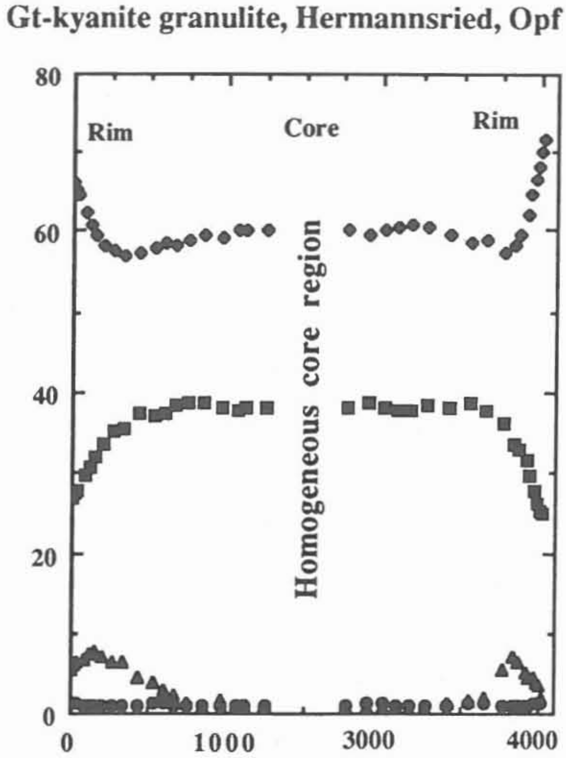
3) There is a distinct difference in eclogite-stage temperatures across the studied domain: lower temperatures generally being found in the Münchberg Massif and Erzgebirge (western part) than in the other areas studied. The same temperature difference applies to the breakdown stages as orthopyroxene (from garnet-quartz reaction) and spinel±sapphirine ±corundum (after kyanite) only occur in the higher temperature retrograded eclogites.

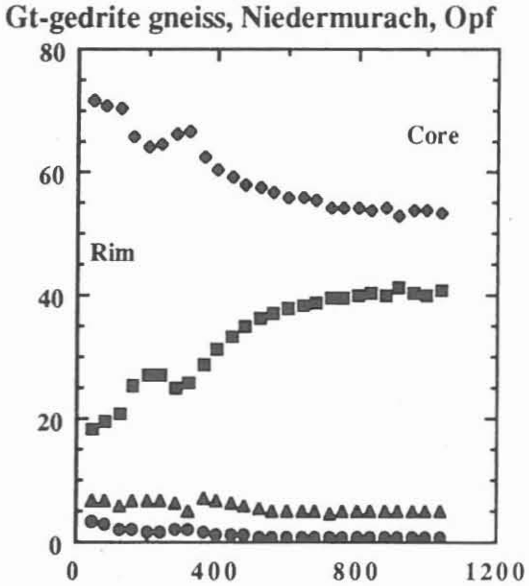
Rather than being discouraged by the complex nature of these rocks one should in fact be encouraged because they have so much of the Variscan history encoded within them: it just takes a little more effort and ingenuity to decipher that history. In addition, a careful study of variably retrograded samples will allow constraints on cooling-rate and uplift-rate to be determined hence proving or disproving tectonometamorphic models.

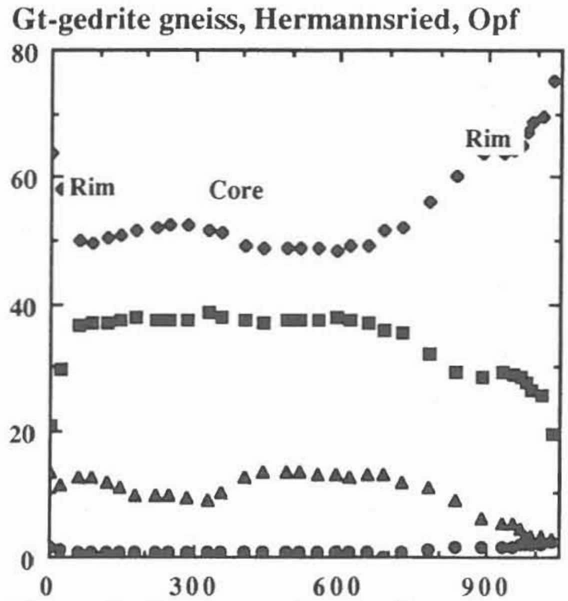
B. CORONITIC METAGABBROS

Basic rocks, within which the original igneous texture has been statically overgrown by a later metamorphic assemblage, are documented from high grade metamorphic terrains over the whole world (see Mongkoltip & Ashworth 1983; Joesten 1986 for overviews). In the area studied, such rocks are known from the Münchberg Massif (Matthes & Seidel, 1977), Mariánské Lázně Complex (Kastl & Tonika 1984) and the ZEV









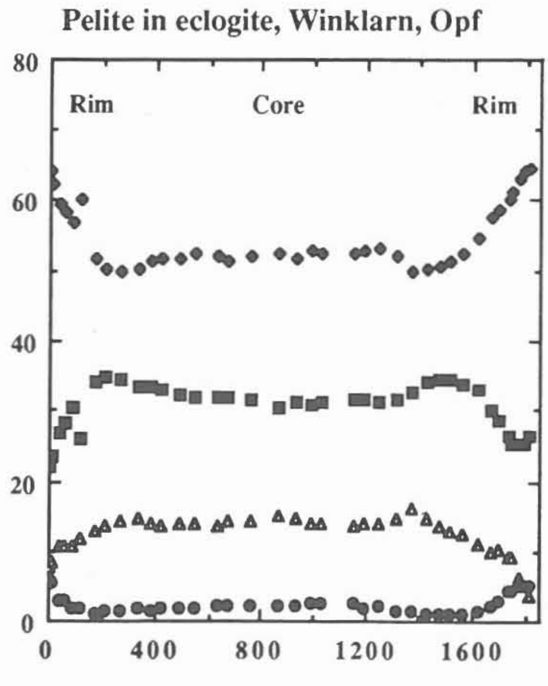
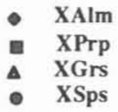


Figure 3. Garnet zoning profiles from selected non-mafic rocks. Vertical scale is mol% component horizontal scale is scan distance in microns.



(Keyssner *et al.* 1988; Röhr, O'Brien, Okrusch & Patzak in prep; Voll, 1960). Typical mineralogical features are:
- igneous Ca-plagioclase breakdown to secondary more sodic plagioclase clouded by inclusions of zoisite ± small crystals of kyanite;
- garnet growth over the plagioclase breakdown domain at margins to mafic phases;
- inclusions in the garnet of quartz, zoisite, kyanite and plagioclase;
- large ilmenites, exsolving rutile, surrounded by a garnet corona;
- metamorphic ortho- and clinopyroxenes replacing original igneous pyroxenes;
- considerable amphibole replacement of pyroxenes and primary amphibole.

Later events include titanite replacing ilmenite and rutile, and prehnite, pumpellyite and albite in small veins or growing in biotite (or chlorite after biotite) domains. Former olivine-bearing metagabbros from Kaimling, in the southern ZEV, show aggregates of orthopyroxene (pseudomorphing original olivine) surrounded by amphibole rich in vermicular spinel inclusions, and complex vermicular clinopyroxene-amphibole intergrowths replacing the igneous clinopyroxenes.

The textures indicate a polyphase history starting from the igneous protolith and partially recrystallising under sequential granulite (in some cases eclogite) facies, amphibolite facies and later low grade (prehnite-pumpellyite/greenschist) conditions. Taking the actual compositions of inclusion plagioclase and host garnet, geobarometers based on the assemblage grossular (in garnet)- anorthite (in plagioclase)- Al_2SiO_5- quartz (GASP) yield P>10kbar (for T>600^{o}C) for the areas studied (Fig. 4). The samples analysed were from Steinhügel, near Weissenstein, in the Münchberg Massif (Alm_{53} Prp_{21} Grs_{24} Sps_2, X_{An}=0.25), near Výškovice, in the Mariánské Lázně Complex (Alm_{41} Prp_{31} Grs_{26} Sps_2, X_{An}=0.3), and from the ZEV (KTB VB; Alm_{42} Prp_{31} Grs_{26} Sps_1, X_{An}=0.35). These pressures are corroborated by garnet -pyroxene -plagioclase -quartz geobarometry.

C. NON-MAFIC ROCKS

Relics of HP assemblages in non-mafic rocks of this region are rare due to their greater potential for retrogression compared to the essentially dry basic bodies. However, in the Oberviechtach area, pelites now containing low pressure parageneses with cordierite and sillimanite have been identified in which kyanite relics, kelyphitic orthopyroxene, orthoamphibole (gedrite or anthophyllite) and garnet compositional zoning (Fig. 3) attest to an earlier higher pressure metamorphism (O'Brien 1989b). Typical of the garnets are homogeneous cores and diffusion-zoned rims where Fe and Mn increase at the expense of Mg and Ca. Calculated pressures for the kyanite granulite stage are above 10kbar whilst cordierite assemblages indicate less than 5kbar. In the southern part of the ZEV, at Michldorf (Mic in Fig. 1), acid granulites containing zoned garnet (Fig. 3), kyanite, K-feldspar, plagioclase, quartz, biotite, rutile and graphite yield P-T conditions of 9-11kbar, ≃700-800^{o}C for the most relictic stage (Kleeman unpub.). From the Münchberg Massif, pressures above 10kbar were deduced for a garnet- phengite-quartz-zoisite (plagioclase only as a secondary phase) schist from Oberkotzau (O'Brien unpub.) and HP phases or their breakdown products have been identified from samples intimately associated with eclogites at Weissenstein (Klemd *et al.* 1989). The recognition of a former HP history in the country rocks of the eclogites is vitally important as it shows that slices of continental crust can be subducted to mantle depths and that the eclogites need not be 'foreign bodies'.

Discussion.

Mathematical modelling of the theoretical thermal evolution of the crust during tectonometamorphic events has led to an increased awareness of the relationship between P-T-t paths and the tectonic regime during

Figure 4.
Corona gabbro pressures from GASP

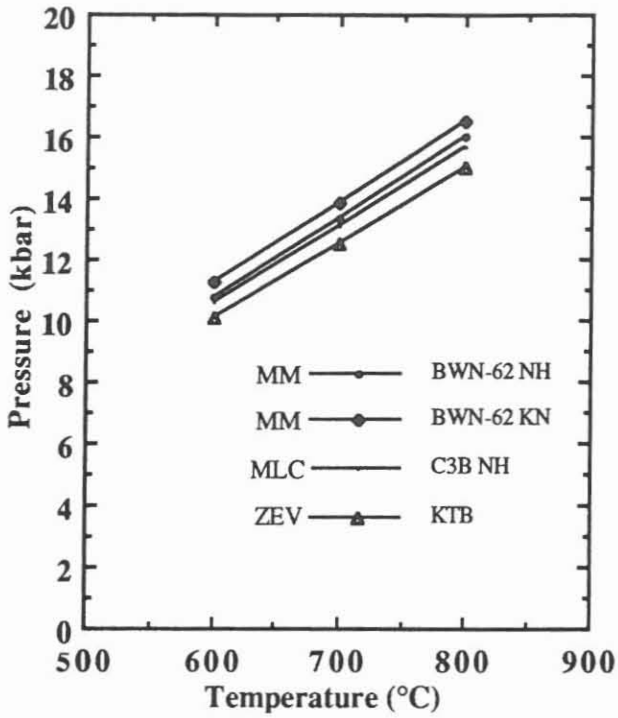


Figure 5
P-T data, retrograded eclogites, NW Bohemian Massif

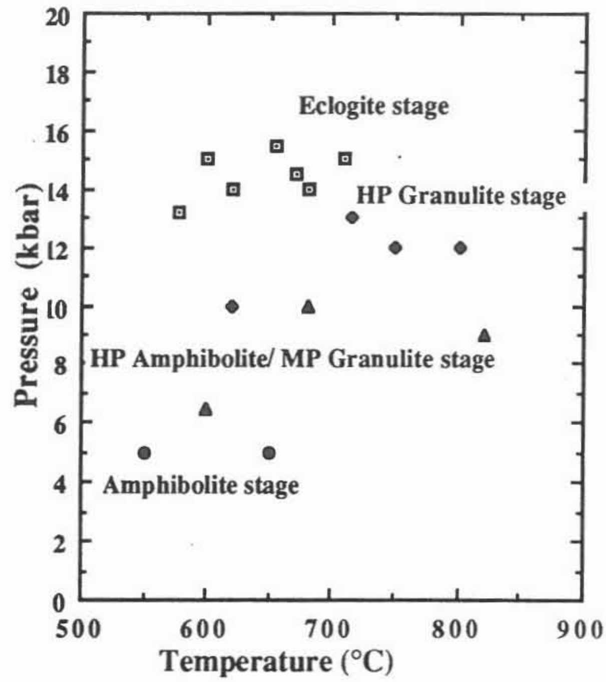
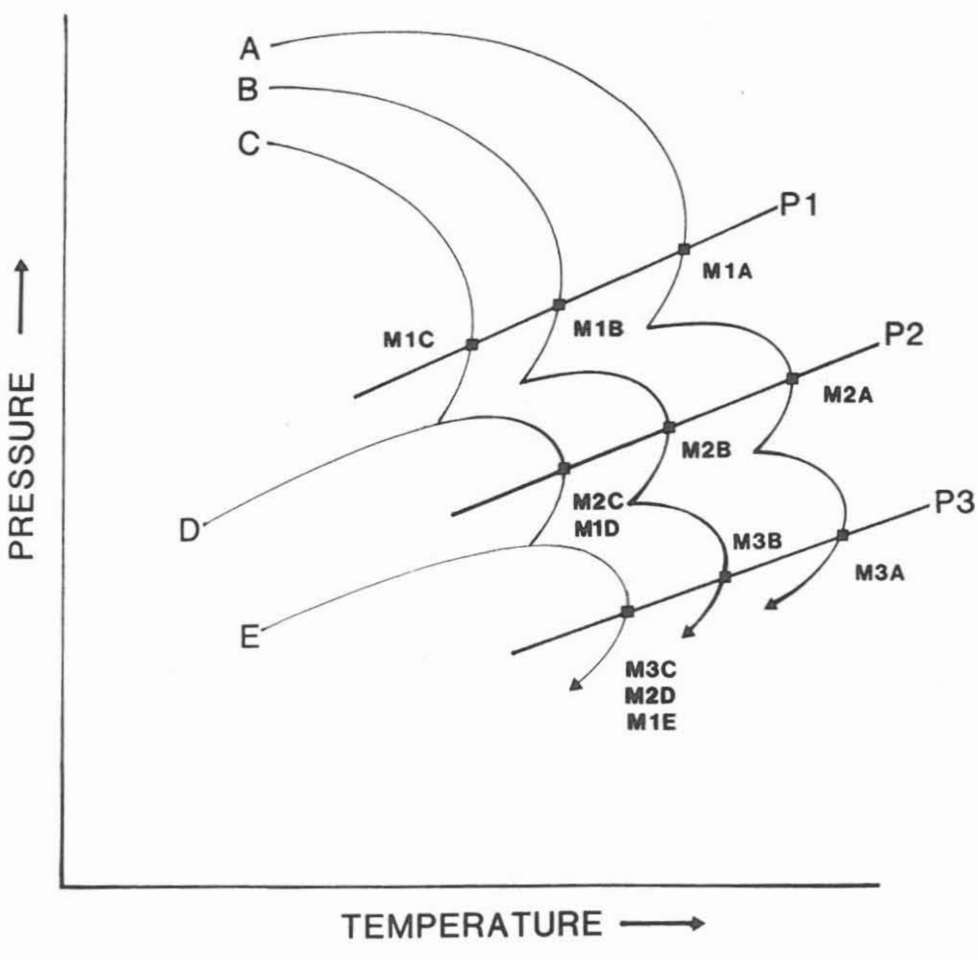


Figure 6. Schematic P-T paths. (See discussion for explanation)



metamorphism (e.g. Thompson & England 1984). At a first glance, the data from the NW Bohemian Massif seem to show a series of clockwise loops similar to those predicted for the lower levels of crust thickened by thrusting and then thinned by erosion. The theoretical models predict that in such simple one stage thrusting/erosion events, peak temperatures, and thus the most likely metamorphic conditions recorded, occur at pressures below the peak pressures endured. Peak T conditions recorded in rocks buried originally to different depths plot in P-T space as a 'pseudo geotherm' or *piezothermic array* (Richardson & England 1979). A simple uninterrupted thermal history appears unlikely in the case of the polymetamorphic Variscan HP rocks. Taking the highest P rocks, the eclogites, it can be seen that P-T conditions for corresponding breakdown stages, because of the regional temperature variation, produce a series of piezothermic arrays. This is shown schematically in figure 6. Rock units A, B and C, with differing initial depths of burial, record P-T conditions for a first metamorphism, M1, which define a piezothermic array, P1. However, later reactivation leads to a second metamorphism, M2 and a second piezothermic array, P2. For rock unit D, juxtaposed with unit C during this event, this is only the first metamorphism. Likewise, a further reactivation leads to M3 in units A, B and C, M2 in unit D and M1 in newly involved unit E: all points together define P3.

It seems reasonable to propose that each partial reaction has been prompted by further thermal perturbations caused by renewed tectonism e.g. thrusting (or, in the later stages, magmatism). Alternatively, reactions may be retarded by the lack of a fluid phase with transformation only taking place when dehydration reactions are triggered in neighbouring or underlying units or effective fluid pathways are opened: again possibly tectonically induced. Thus, within the orogen as a whole, periods of active tectonism are interspersed with quiet erosional episodes. Such a multi-stage thrusting model can also explain the apparent discrepancy between the metamorphic grade of adjacent rocks. During each rejuvenation stage, deeper-level rocks can be interfolded, in ductile shear zones, with rocks having shallower crustal histories. However, the newly combined rock units will have a common P-T path subsequent to their juxtaposition. For example, some coronitic metagabbros show *maximum* P-T conditions of the HP granulite facies whilst associated eclogites have a HP granulite *breakdown* stage but both share a later amphibolite facies overprint. One must bear in mind, however, that some rocks may have endured metamorphic conditions outside the stability field of their constituent minerals but, due to kinetic factors, have not reacted. Likewise, some rocks may have totally recrystallised to lower pressure assemblages during uplift whilst others, even in the same outcrop, may have been shielded from deformation and/or fluid influx and thus preserve varying degrees of an earlier history.

If such a scenario is correct, calculated P-T-t paths may only be valid for each rock sample or outcrop. Structural elements such as folds, cleavages and foliations must then be carefully related to mineral evolutions in order to prove a shared tectonometamorphic history for separated localities. For geochronological investigations, the metamorphic stages within chosen samples must be carefully characterised but the problem of possible isotopic disequilibrium or zonation even on the scale of a single mineral may still remain. In conclusion it can be stated that the Variscan evolution of the deep borehole location and surroundings is extremely complex and only a coordinated interdisciplinary approach can hope to unravel the story bound within these enigmatic rocks.

References.

Behr, H-J., Engel, W., Franke, W., Giese, P. & Weber, K. (1984) The Variscan belt in Central Europe: main structures, geodynamic implications, open questions. Tectonophysics, 109, pp15-40.

Busch, K. (1970). Die Eklogit der Oberpfalz und ihr metamorpher Abbau. N. Jahrb. Mineral. Abh., 113, pp138-178.

Chesnokov, B.V. & Popov, V.A. (1965). Increase in volume of quartz grains in South Urals eclogite. Doklady Acad. Sci. USSR, Earth Sci., 162, pp176-178.

Franz, G., Thomas, S. & Smith, D.C. (1986). High pressure phengite decomposition in the Weissenstein eclogite, Münchberger Gneiss Massif, Germany. Contrib. Mineral. Petrol., 92, pp71-85.

Jelínek, E., Mísař, Z., Souček, J. & Tonika, J. (1989). Guide book, Third International Eclogite Conference. Post-conference Field Trip.

Joesten, R. (1986). The role of magmatic reaction, diffusion and annealing in the evolution of coronitic microstructure in troctolitic gabbro from Risör, Norway. Mineral. Mag., 50, pp441-467.

Kastl, E. & Tonika, J. (1984). The Mariánské Lázně metaophiolite complex (West Bohemia). Krystalinikum, 17, pp59-76.

Keyssner, S., Massalsky, T., Müller, H., Röhr, C., Graup, G. & Hacker, W. (1988). Tiefbohrung KTB-Oberpfalz VB, Ergebnisse der geowissenschaftlichen Bohrungsbearbeitung im KTB-Feldlabor (Windischeschenbach), Teufenbereich von 992 bis 1530m. KTB Report, 88-6, B1-B88.

Klápová, H. 1987. Eclogites of the Krušné hory Mts (in Czech.) Ph.D. Thesis, MS Faculty of Science, Charles University, Prague.

Klemd, R. (1989). P-T conditions and fluid inclusion characteristics of retrograded eclogites, Müchberger Gneiss Massif, Germany. Contrib. Mineral. Petrol., 102, pp221-229.

Klemd, R., Matthes, S. & Okrusch, M. (1989). Hochdruckrelikte im metapelitischen Nebengestein des Weissenstein Eklogits (Münchberger Gneiskomplex). Ber. Deutsche Mineralog. Ges., 1, p96.

K.T.B. (1986). Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland, KTB, Ergebnisse der Vorerkundungsarbeiten Lokation Oberpfalz. K. Weber & A. Vollbrecht (eds), 2nd KTB-Kolloquium (Seeheim, Odenwald, 19-21 September, 1986) 186pp.

Matthes, S. & Seidel, E. (1977). Bestehen genetische Beziehungen zwischen Eklogit und Meta-Gabbro innerhalb des Münchberger Gneisgebietes? Neues Jahrb. Mineral. Abh., 129, pp269-291.

Medaris, L.G. Jr. & Carswell, D.A. (1990).The petrogenesis of Mg-Cr garnet peridotites in European metamorphic belts. In: Carswell, D.A. (ed) Eclogite Facies Rocks, Blackie, Glasgow, pp260-290.

Mongkoltip, P. & Ashworth, J.R. (1983). Quantitative estimation of an open-system symplectite-forming reaction: restricted diffusion of Al and Si in coronas around olivine. J. Petrol., 24, pp635-661.

O'Brien, P.J. (1989). The petrology of retrograded eclogites of the

Oberpfalz Forest, NE Bavaria, West Germany. Tectonophysics, 157, pp195-212.

O'Brien, P.J. (1989b). The petrology of eclogites and related rocks from the Bavarian margin of the Bohemian Massif, West Germany. Unpubl. Ph.D. Thesis, University of Sheffied, U.K.

O'Brien, P.J., Carswell, D.A. & Gebauer, D. (1990). Eclogite formation and distribution in the European Variscides. IN: Carswell, D.A. (ed) Eclogite Facies Rocks, Blackie, Glasgow, pp204-224.

Okrusch, M., Matthes, S., Klemd, R., O'Brien, P.J. & Schmidt, K. (1991). Eclogites of the Northwestern Margin of the Bohemian Massif: A Review. (Eur. J. Mineral. in press).

Richardson, S.W. & England, P.C. (1979). Metamorphic consequences of crustal eclogite production in overthrust orogenic zones. Earth Planet. Sci. Lett., 42, pp183-90.

Ringwood, A.E. & Green, D.H. (1966). An experimental investigation of the gabbro-eclogite transformation and some geophysical implications. Tectonophysics, 3, pp383-427.

Schmidt, W., Schmädicke, E. & Werner, C.-D. (1990). Eklogite des Erzgebirges. DMG-Tagung 1990, Nachexkursion. Beihefte zum European Journal of Mineralogy vol. 2, pp125-169.

Thompson, A.B. & England, P.C. (1984). Pressure-Temperature-Time paths of regional metamorphism II. Their inference and interpretation using mineral assemblages in metamorphic rocks. J. Petrol., 25, pp929-955.

Voll, G. (1960). Stoff, Bau und Alter der Grenzzone Moldanubikum/ Saxothuringikum in Bayern unter besonderer Berücksichtigung gabbroider, amphibolitischer und kalksilikatischer Gesteine. Geol. Jahrb. Bh., 42, pp1-138.