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ECLOGITE AND GARNET AMPHIBOLITE PEBBLES FROM MIOCENE CONGLOMERATES (PANNONIAN BASIN, HUNGARY): IMPLICATIONS FOR THE VARISCAN METAMORPHIC EVOLUTION OF THE TISZA MEGAUNIT

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Abstract: Eclogite and garnetiferous amphibolite pebbles were found in Miocene conglomerates directly overlying the Variscan crystalline basement of the Tisza Megaunit in the Pannonian Basin of Hungary. Peak metamorphic conditions were in the medium temperature part of the eclogite facies (600–650 °C, 13–15 kbar) with garnet, omphacitic pyroxene, quartz and rutile as primary assemblage. Breakdown from peak P-T conditions resulted in symplectitic intergrowth of clinopyroxene, plagioclase and quartz. Continuous retrogression involving garnet caused formation of the matrix assemblage of clinopyroxene, plagioclase, amphibole, ilmenite and quartz. Amphibole-plagioclase porphyroblasts formed during the last stage of retrogression. Amphibole-bearing symplectites record P-T conditions of 500–570 °C and 8–12 kbar in garnetiferous amphibolite, but no pyroxene was detected there. K-Ar geochronological data on amphibole show 348±13 Ma cooling ages which is nearly 100 Ma younger than previously suggested. Final uplift to surface conditions occurred in Miocene times causing the first appearance of exotic metabasite pebbles in clastic sedimentary rocks.

Key words: Variscan Orogeny, Pannonian Basin, Tisza Megaunit, thermobarometry, garnetiferous amphibolite, eclogite.

Introduction

Eclogites and other high-pressure metabasic rocks are important for establishing the pressure-temperature (P-T) conditions during subduction and/or collision. Within the European Variscan Orogenic Belt, eclogites — although volumetrically minor — are widely distributed (for review see O'Brien et al. 1990) testifying to high-pressure (HP) event(s) during the polymetamorphic evolution of the orogen.

As HP metamorphic rocks are quite rare in the Pannonian Basin (and especially in the Tisza Megaunit, e.g. Ravasz-Baranyai 1969), pebbles found in Miocene conglomerates represent important markers for the pre-Alpine and Alpine geodynamic history of the area. Description of various rock types, not exposed in the Mecsek Mts (SW Hungary) and adjacent areas had revealed the significance of exotic pebbles in Neogene clastic sediments (Szakmány & Józsa 1994). Therefore, the careful petrographic investigation of these conglomerates can provide a tool for the better understanding of events which affected the geological evolution of the Tisza Megaunit.

The main goal of this study is to present petrological and geochronological data on eclogite and garnetiferous amphibolite samples, newly discovered from Miocene sediments in the SW part of the Tisza Megaunit. Furthermore, the pressure-temperature conditions of metamorphic evolution of these exotic rocks and their significance for the pre-Alpine evolution of the Tisza Megaunit are discussed.

Geological setting

The Tisza Megaunit (Fig. 1) originated from the northern, European margin of Tethys by mostly Meso-Alpine horizontal displacements of microplates (Géczy 1973; Kovács 1982; Kázmér & Kovács 1985). It forms the basement of S Hungary, and is bounded by the Mid Hungarian (or Zagreb-Zemplín) Line to the north, whereas it can be followed over the state boundary to Northern Croatia and Serbia (Yugoslavia), and to Western Transylvania (Romania) in the southern and eastern directions, respectively.

Szederkényi (1984) divided the pre-Alpine (mostly Variscan) basement complexes of the Tisza Megaunit into two major parts: the Parautochthon Unit and the South Hungarian Nappe (or Békés-Codru Unit). The prevailing rocks of both units are paragneisses and micaschists with minor amphibolites and — in some areas — marble intercalations. Voluminous syncollisional, S-type Variscan granitoids are also found in various parts of the Tisza Megaunit (Buda & Nagy 1995). In SW Hungary, the Parautochthon Unit is composed of the Babócsa, Baksa and Mórágy Complexes (Fig. 2). The first two are built up predominantly by metapelites, while the latter is dominated by granitoids.

In general, the first metamorphic event recorded in the Parautochthon Unit is characterized by Barrow-type amphibolite facies regional metamorphism. This event was overprinted by a low-pressure Variscan event closely related to granitoid magmatism ranging from sub-greenschist facies up to the am-

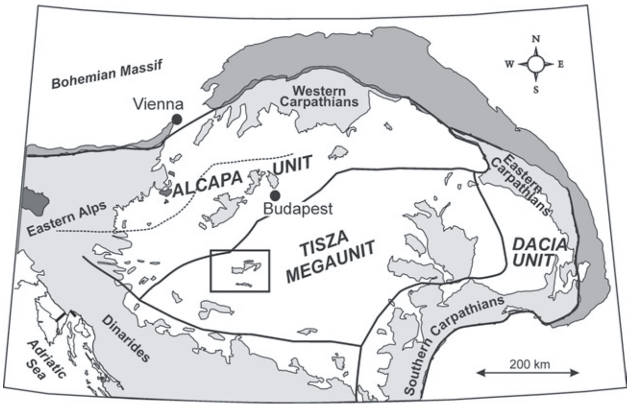

Fig. 1. Main tectonostratigraphic units of the Pannonian Basin and neighbouring areas. Black square shows the enlarged area in Fig. 2.

phibolite facies. Árkai (1984) and Árkai et al. (1985) calculated peak conditions of metamorphism of 500–600 °C and 5–9 kbar for gneisses, micaschists and intercalated amphibolites, which were thought to be pre-Variscan (Lelkes-Felvári & Sassi 1981). Árkai et al. (1985) elaborated alternative pre-Variscan–Variscan polycyclic and Variscan polyphase models. At present no isotopic ages older than Variscan are available for the metamorphic basement of the Tisza Megaunit (Lelkes-Felvári et al. 1996). This can be due to the intense Variscan metamorphism. Horváth & Árkai (2002) reported Alpine (Cretaceous) amphibolite facies metamorphism with peak conditions of 650 °C and 9 kbar from metapelites from the Békés-Codru Unit.

Non-metamorphic Late Paleozoic overstep sequences were deposited on different parts of the Parautochthon Unit (Kovács et al. 2000). The oldest formation overlying all the basement complexes in the southwestern part of the Tisza Megaunit is the fluviatile, Upper Carboniferous Téseny Sandstone, belonging to an active continental margin/volcanic arc provenance (Varga et al. 2000), and missing in other areas. Subsequent Lower Permian and Mesozoic formations occur in the entire area, but they do not form a continuous cover above the basement.

Lower-middle Miocene (Eggenburgian-Carpathian (?lower Badenian)) fluviatile formations occupy large areas in the Mecsek Mountains and its surroundings (Szakmány & Józsa 1994). The coarse-grained Szászvár Formation and the fine-grained Budafa Formation represent the lowest part of this sequence. In these sequences, conglomerate beds appear in huge amounts and this kind of sedimentation reaches a considerable thickness (in some boreholes several hundred meters). Hámor (1970) assumed that the two formations differ in age, but Máthé et al. (1997) considered them to be heteropic. The rock type, the size of clasts, as well as the amount and proportion of

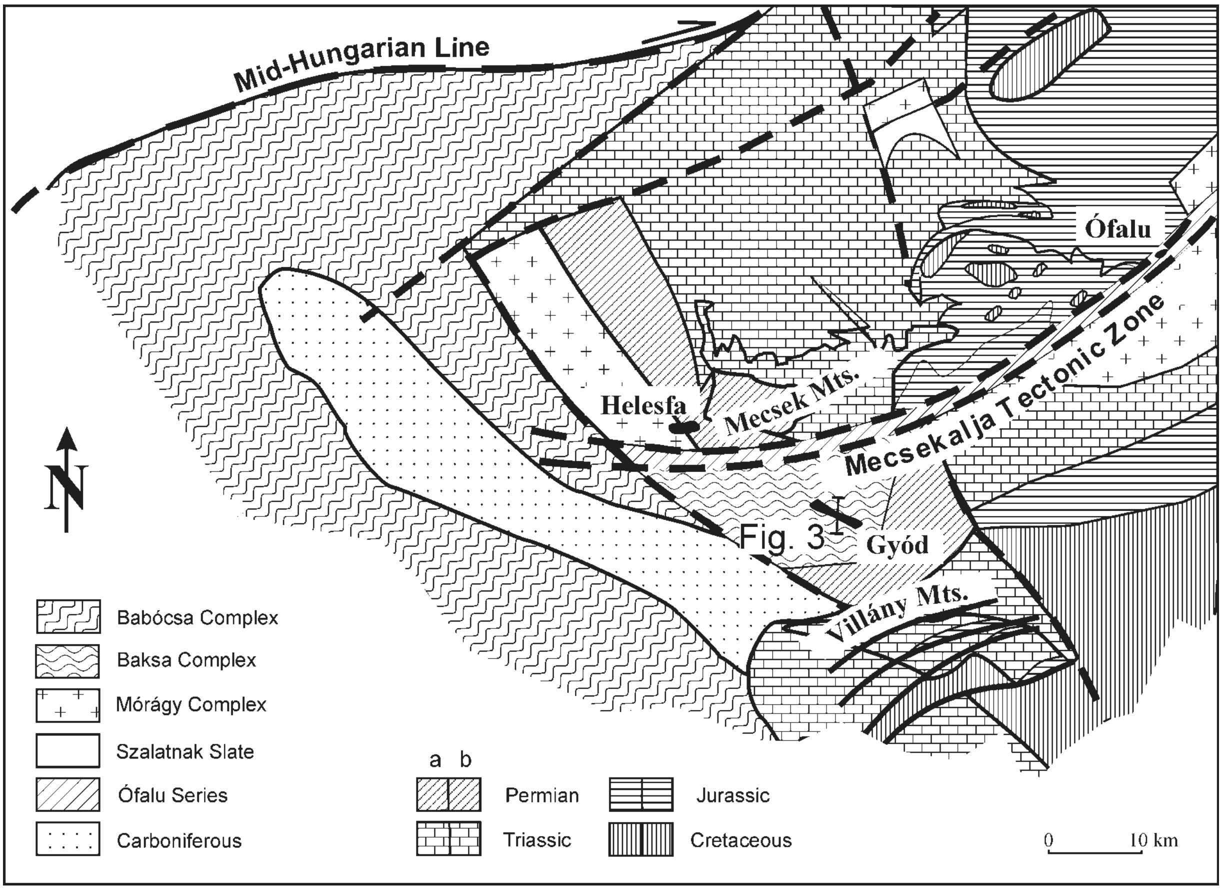

Fig. 2. Pre-Tertiary geological map of SW Hungary showing the main basement units, ultramafic bodies (Gyód, Helesfa and Ófalu) are indicated by black spots. **a** — covered, **b** — uncovered, almost all pre-Permian complexes are covered.

different clast types in these conglomerate beds, are strongly variable, depending on the accumulation area. Small amounts (generally <1 %) of garnetiferous amphibolite (retrograde eclogite?) pebbles occur only in the westernmost part of the area covered by the Miocene conglomerates. The size of the pebbles varies greatly, between 0.5 and 25 cm. The roundness of the clasts is poor, they generally show a subangular shape. The garnetiferous amphibolite pebble presented in this paper comes from a conglomerate outcrop of the Szászvár Formation near the Helesfa serpentinite body (Fig. 2).

The borehole Gyód-2 (Fig. 3), from which the investigated eclogite sample comes, is located in the central part of the Baksa Complex (Fig. 2) above the so-called Gyód magnetic anomaly 5–7 km in length and 300–500 m in width. The serpentinite body strikes WNW-ESE, similar to that of the medium-grade metapelitic country rocks (mainly micaschists, paragneisses and amphibolites). It has tectonic contact with the country rocks. According to Szederkényi (1976) the rocks of the Baksa Complex suffered prograde, Barrovian regional metamorphism changing from the chlorite zone (in the north) to the sillimanite zone (in the south). A clockwise P-T path with early kyanite-staurolite, and younger sillimanite was reported from the paragneiss-micaschist rocks of the borehole Baksa-2 located in the southern edge of the Baksa Complex (Árkai et al. 1999). Király (1996) obtained P-T estimates of 550–650 °C and 5–7 kbar for amphibolites from the borehole Gyód-3. The Mecsekalja Tectonic Zone borders the complex (Fig. 2) in the north, which was a regional shear zone during a late stage of the Variscan Orogeny (Ar-Ar ages on micas in the range of 270–300 Ma; Lelkes-Felvári et al. 2000). The zone was still active during the Alpine Orogeny, as it separates Variscan metamorphic rocks/granitoids and non-metamorphic Mesozoic sediments of the Mecsek Mts (Fig. 2). To the south, Permian sediments and rhyolites, and Mesozoic formations of the Villány Mts are exposed.

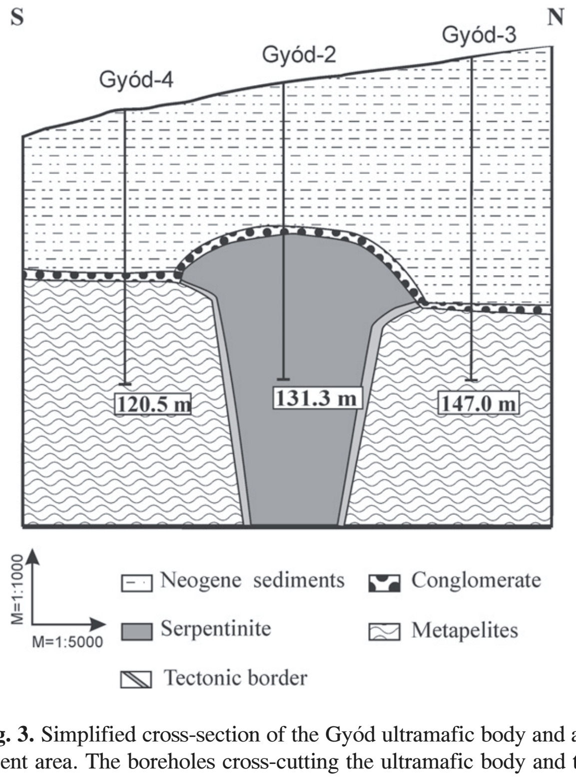

Fig. 3. Simplified cross-section of the Gyód ultramafic body and adjacent area. The boreholes cross-cutting the ultramafic body and the metapelitic country rocks are also indicated.

Below the Pleistocene–Lower Pannonian sediments and basal conglomerate layer (with the eclogite pebbles), a nearly vertical serpentinite body was drilled in the Gyód area. In a narrow central slab a relatively fresh harzburgite zone occurs. Balla (1981) described the serpentinite together with other serpentinite bodies near Helesfa and Ófalu (Fig. 2) as dismembered fragments of obducted oceanic lithosphere. Beside eclogite and garnetiferous amphibolite, serpentinite and quartz pebbles are found in the basal conglomerate layer. The pebbles are moderately rounded with a diameter ranging between 0.5 and 10 cm (max. 15 cm) and are cemented by yellowish white carbonate material with Limnocardium fossils.

Methods

Chemical analyses of minerals were carried out with a JEOL JXCA-733 electron microprobe equipped with 3 WDS in the Laboratory for Geochemical Research, Hungarian Academy of Sciences, Budapest. The measuring conditions were: 15 kV acceleration voltage; 40 nA sample current; electron beam with a diameter of 5 µm; 5 s counting time. Matrix effects were corrected by using the ZAF method. The following standards were used for quantitative analysis: orthoclase (K, Al, Si), synthetic glass (Fe, Mg, Ca), spessartine (Mn), rutile (Ti) and albite (Na).

K/Ar measurements were performed in the Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), Debrecen. The interlaboratory standards Asia 1/65, HD-B1, LP-6 and GL-0 as well as atmospheric Ar were used for control and calibration of analyses. Details of the instruments, the applied methods and results of calibration have been described by Balogh (1985) and Odin et al. (1982). K/Ar ages were calculated using the constants proposed by Steiger & Jäger (1977).

The mineral abbreviations used in this study follow Kretz (1983) and Bucher & Frey (1994).

Petrography and mineral chemistry

Mineral assemblages and representative compositions of minerals used in thermobarometric calculations are presented here and listed in Tables 1 to 5. Cation numbers are calculated for 12 oxygens for garnet, 6 for clinopyroxene, 8 for plagioclase and 23 for amphibole. Fe^{2+}/Fe^{3+} ratios were calculated by charge balance for garnet and clinopyroxene, the structural formulae of amphibole come from Robinson et al. (1982).

Eclogite

The eclogite pebble from the basal conglomerate overlying the Gyód serpentinized ultramafic body in the borehole Gyód-2 (Figs. 2 and 3) is rounded, non-foliated and 8 cm in length. A fine-grained greyish matrix and coarse-grained reddish brown

Table 1: Mineral assemblages of the eclogite sample. In the garnetiferous amphibolite only symplectite (without Ca-pyroxene) and matrix assemblages are recognized. See text for details.

	Eclogite	Symplectite	Matrix	Retrograde
Garnet	━━━	━━━	━━━	
Omphacite	━━━			
Rutile	━━━	– – –	– – –	
Quartz	━━━	━━━	━━━	━━━
Ca-pyroxene		━━━	━━━	
Plagioclase		━━━	━━━	━━━
Amphibole			━━━	━━━
Ilmenite		– – –	━━━	━━━
Epidote				━━━
Biotite				━━━
Chlorite				━━━

garnets can be seen in the hand specimen. The eclogite consists of garnet, clinopyroxene, amphibole, plagioclase, quartz, subordinate biotite, chlorite, carbonate, and accessory rutile and ilmenite.

Garnet forms an- or subhedral porphyroblasts (4–10 mm in size) with cores full of inclusions such as quartz, plagioclase, amphibole, opaque minerals and tiny *omphacite* grains with a jadeite content of 34–36 % (Fig. 4a,b). The rim is free of inclusions. The garnets are surrounded by a *symplectite* composed of clinopyroxene, plagioclase, rare quartz and ilmenite (Fig. 4b). *Clinopyroxene* forms coarse-grained, vermicular grains intergrown with plagioclase indicating breakdown of an earlier formed phase (Na-richer omphacitic clinopyroxene). Cpx is diopside with low Al and Na content (jadeite is less than 5 %), whereas $Mg/(Mg+Fe^{2+})$ is 0.74. *Plagioclase* occurring in symplectite is An_{18-19}. The grain size of the symplectite-forming minerals is ca. 50–100 μm. Fine-grained *amphibole*-bearing clinopyroxene-plagioclase-quartz assemblage is dominant in the matrix of the sample. It has a smaller grain size (<50 μm) than the symplectite and contains rare garnets as well. Clinopyroxene is augite with higher $Mg/(Mg+Fe^{2+})$ ratio, and slightly higher Al content than Cpx of the symplectite. Plagioclase shows slightly lower An content than Pl in symplectite (16 %). Amphibole is rich in TiO_2 (more than 1 wt. %) and falls into the magnesio-hornblende field in the nomenclature of Leake et al. (1997). Ilmenite flakes may occur together with this mineral assemblage.

Garnet cores show low Sps content (less than 1 %), high Grs (21–25 %) with Prp and Alm contents of 18–21 %, and 54–56 %, respectively. In the triangular diagram of Coleman et al. (1965) the garnet core compositions plot into the field of C type eclogite, but quite close to type B (Fig. 5). Two compositionally different garnet rims can be seen, which are in contact with the symplectite and the matrix, respectively (Fig. 6a). The highest Alm and lowest Prp contents were measured where symplectite is found near the garnet rims. Grs and Sps do not show any changes from the core compositions. Garnet rims not in contact with the symplectite have Sps content over 1 % with Grs down to 20–23 %, whereas Alm contents are similar to those in the core. Prp is somewhat higher than in the core regions. Small garnets (max. 1 mm) in the matrix domain have compositions similar to garnet rims in contact with the matrix assemblages.

Large prismatic hypidioblasts of amphibole sometimes form kelyphitic rims on garnet or overgrow the symplectite

Table 2: Representative chemical composition of garnets used in thermobarometric calculations. FeO* = Fe total.

Rock type	Eclogite							Amphibolite	
Stage	eclogite		contact with sympl		contact with matrix		in matrix	core	rim
SiO_2	38.73	38.23	38.15	37.82	38.87	38.68	39.08	38.47	38.68
TiO_2	0.04	0.09	0.15	0.27	0.02	0.04	0.08	0.01	0.08
Al_2O_3	21.38	22.27	21.88	21.81	22.53	22.05	22.33	21.48	21.68
FeO*	25.60	25.62	25.90	26.99	25.19	25.24	24.57	26.39	28.07
MnO	0.37	0.30	0.43	0.48	0.58	0.47	0.48	1.23	1.33
MgO	5.50	4.66	4.93	4.39	6.15	5.66	5.42	4.07	4.71
CaO	8.35	9.11	8.56	7.76	7.43	8.25	8.84	8.71	6.34
Na_2O	0.01	0.03	0.04	0.00	0.02	0.02	0.02	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.98	100.31	100.04	99.52	100.79	100.41	100.82	100.36	100.89
				cation numbers on the basis of 12 oxygens					
Si	3.014	2.972	2.977	2.977	2.984	2.991	3.001	3.009	3.010
Ti	0.002	0.005	0.009	0.016	0.001	0.002	0.005	0.001	0.005
Al	1.961	2.040	2.012	2.023	20.390	2.009	2.021	1.980	1.988
Fe^{2+}	1.629	1.665	1.688	1.777	1.617	1.632	1.578	1.706	1.819
Fe^{3+}	0.037	0.000	0.002	0.000	0.000	0.000	0.000	0.020	0.007
Mn	0.024	0.020	0.028	0.032	0.038	0.031	0.031	0.081	0.088
Mg	0.638	0.540	0.573	0.515	0.704	0.652	0.620	0.474	0.546
Ca	0.696	0.759	0.716	0.654	0.611	0.683	0.727	0.730	0.529
Na	0.002	0.004	0.006	0.000	0.003	0.003	0.003	0.000	0.000
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	8.003	8.005	8.011	7.995	7.996	8.003	7.985	8.000	7.991
Prp	21.35	18.10	19.20	17.29	23.70	21.75	20.98	15.86	18.32
Alm	54.53	55.82	55.95	59.66	54.46	54.43	53.37	57.03	61.02
Sps	0.81	0.66	0.95	1.07	1.27	1.02	1.05	2.72	2.94
Grs	21.46	25.43	23.70	21.97	20.58	22.79	24.60	23.41	17.36

Table 3: Representative chemical composition of pyroxenes used in thermobarometric calculations. FeO* = Fe total, mg# = Mg/(Mg+Fe^{2+}).

Stage	eclogite	sympl	matrix
SiO_2	54.17	52.64	52.87
TiO_2	0.14	0.09	0.10
Al_2O_3	10.30	1.63	2.74
FeO*	5.74	9.12	6.37
MnO	0.02	0.07	0.07
MgO	9.31	12.96	14.09
CaO	14.66	21.83	22.34
Na_2O	5.21	0.93	1.22
K_2O	0.00	0.00	0.00
Total	99.55	99.27	99.80
	cation numbers on the basis of 6 oxygens		
Si	1.954	1.971	1.943
Al^{IV}	0.046	0.029	0.057
T site	2.000	2.000	2.000
Al^{VI}	0.391	0.043	0.062
Fe^{3+}	0.008	0.033	0.052
Ti	0.004	0.003	0.003
Mg	0.500	0.723	0.772
Fe^{2+}	0.096	0.199	0.112
M1 site	1.000	1.000	1.000
Fe^{2+}	0.069	0.055	0.032
Mn	0.001	0.002	0.002
Ca	0.567	0.876	0.880
Na	0.364	0.067	0.087
M2 site	1.000	1.000	1.000
Total	4.004	4.016	4.026
mg#	0.75	0.74	0.80
Jd	35.63	3.49	3.46

Table 4: Representative chemical composition of amphiboles used in thermobarometric calculations. FeO* = Fe total, mg# = Mg/(Mg+Fe^{2+}).

Rock type	Eclogite		Amphibolite	
Stage	matrix	late	in garnet	matrix
SiO_2	45.28	45.35	49.59	42.83
TiO_2	1.24	0.60	0.27	0.76
Al_2O_3	11.32	12.94	6.36	13.49
FeO*	11.35	9.87	15.27	17.51
MnO	0.05	0.09	0.35	0.39
MgO	13.85	14.73	13.40	10.11
CaO	11.19	11.64	10.99	9.81
Na_2O	2.24	2.19	1.27	2.74
K_2O	0.37	0.39	0.17	0.52
Total	96.89	97.80	97.67	98.16
	cation numbers on the basis of 23 oxygens			
Si	6.560	6.455	7.137	6.232
Al^{IV}	1.440	1.545	0.863	1.768
T site	8.000	8.000	8.000	8.000
Al^{VI}	0.493	0.626	0.216	0.545
Ti	0.135	0.064	0.029	0.083
Fe^{3+}	0.504	0.565	0.813	1.127
Mg	2.991	3.125	2.874	2.193
Fe^{2+}	0.871	0.610	1.025	1.004
Mn	0.006	0.010	0.043	0.048
C site	5.000	5.000	5.000	5.000
Ca	1.737	1.776	1.695	1.529
Na	0.263	0.224	0.305	0.471
B site	2.000	2.000	2.000	2.000
Na	0.366	0.380	0.049	0.302
K	0.038	0.071	0.031	0.096
A site	0.434	0.451	0.080	0.398
Total	15.606	15.642	15.351	15.785
mg#	0.77	0.84	0.74	0.69

and matrix assemblage clearly postdating them (Fig. 4a). The average size is 200 μm and some of them are strongly corroded by retrograde chlorite. This amphibole generation is tschermakite with lower FeO, TiO_2 and higher MgO content than amphibole in the matrix, and occurs together with Ca-richer plagioclase (with An content of 18 %). Anhedral quartz with coronas of amphibole and clinopyroxene (see above) may reach 250–300 μm in the matrix, but smaller grains occur in the symplectites. Amphibole-clinopyroxene corona developed around quartz grains near garnets. Similar textures were found in garnet-clinopyroxene amphibolites (retrogressed eclogites) in the Tatra Mts, Western Carpathians (Janák et al. 1996). Mineral compositions in the corona are similar to the matrix. Quartz can also be found around altered amphibole and rare biotite. Subordinate biotite is very rare and breaks down to chlorite and fine-grained white mica. Rutile forms xenoblastic grains 30–60 μm in length, both in the garnets and in the symplectites, where it occurs together with ilmenite. It can be found exclusively as an inclusion in garnet or in the symplectite zone, but never in the matrix which contains only ilmenite.

Garnetiferous amphibolite

The pebbles are fine-grained, and have a predominant green colour with small red garnets. Nematoblastic garnet-bearing amphibolites consist mainly of amphibole and plagioclase,

Table 5: Representative chemical composition of plagioclases used in thermobarometric calculations. FeO* = Fe total.

Rock type	Eclogite			Amphibolite	
Stage	sympl	matrix	late	sympl	matrix
SiO_2	63.48	63.81	63.19	63.92	65.78
TiO_2	0.00	0.08	0.02	0.01	0.00
Al_2O_3	24.03	22.67	23.56	22.70	21.44
FeO*	0.17	0.16	0.08	0.20	0.27
MnO	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.03	0.01
CaO	3.73	3.44	3.84	3.55	2.60
Na_2O	9.12	9.48	9.19	9.49	10.07
K_2O	0.07	0.02	0.13	0.12	0.10
Total	100.60	99.80	100.01	100.02	100.27
	cation numbers on the basis of 8 oxygens				
Si	2.783	2.821	2.789	2.821	2.886
Ti	0.000	0.003	0.001	0.000	0.000
Al	1.242	1.181	1.226	1.181	1.109
Fe^{3+}	0.060	0.006	0.003	0.007	0.010
Mn	0.000	0.000	0.000	0.000	0.000
Mg	0.000	0.000	0.000	0.002	0.001
Ca	0.175	0.163	0.182	0.168	0.122
Na	0.775	0.813	0.786	0.812	0.857
K	0.004	0.009	0.007	0.007	0.005
Total	4.985	4.996	4.994	4.997	4.990
An	18.36	16.55	18.62	17.01	12.41
Ab	81.23	82.54	80.63	82.31	87.03
Or	0.41	0.91	0.75	0.68	0.56

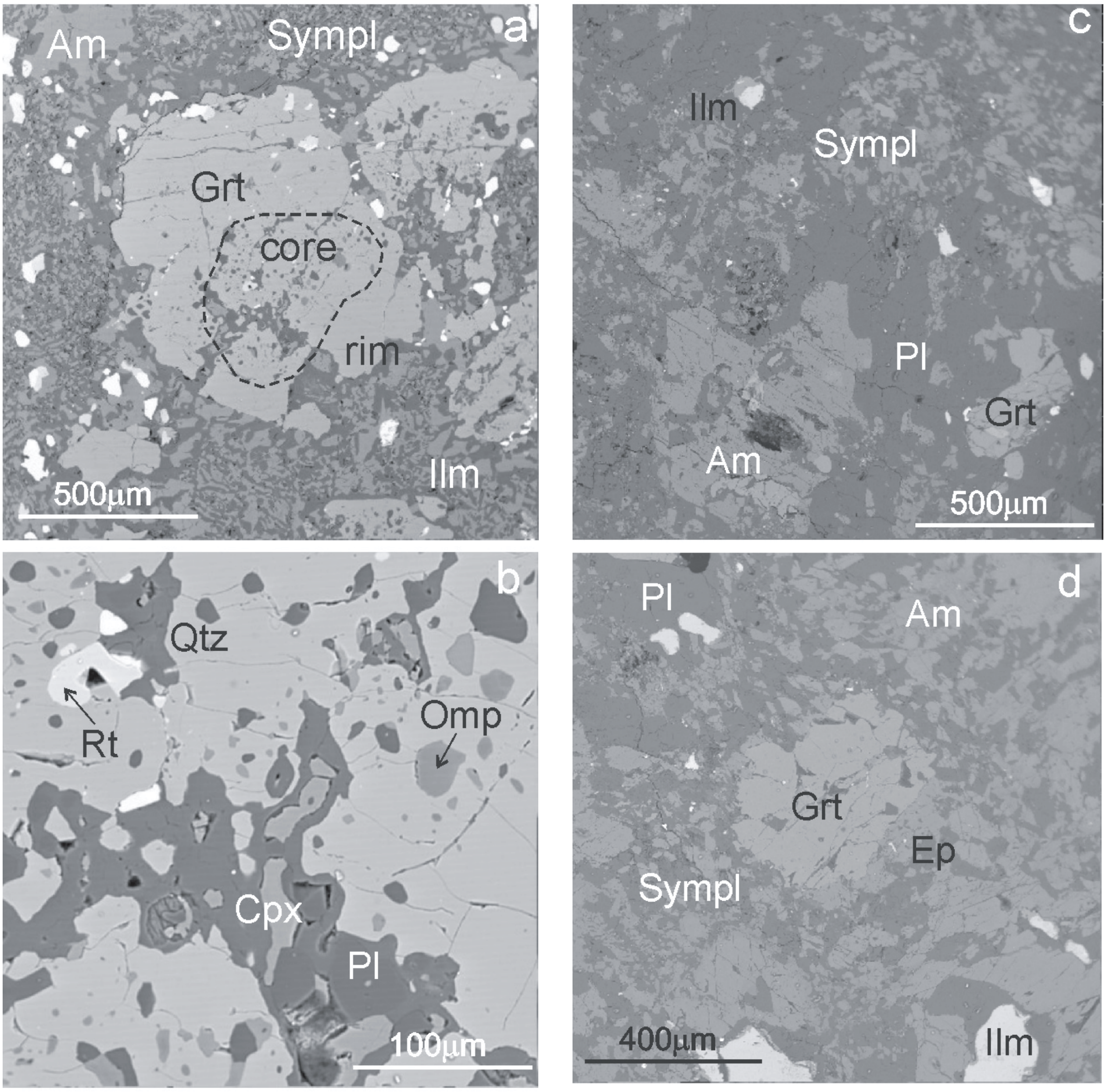

Fig. 4. Microtextures in the investigated eclogite (a, b) and garnetiferous amphibolite sample (c, d). (**a**) BSE image of the eclogite sample. Note garnet with inclusion-rich core and inclusion-free rim (broken line shows core-rim boundary). Large amphibole (Am) and plagioclase postdate the earlier-formed symplectite. Ilmenite can be found exclusively in the matrix. (**b**) Enlarged view of centre of Fig. 4a. Eclogitic assemblage of omphacite, quartz and rutile in garnet core replaced by Ca-clinopyroxene and plagioclase. (**c**) BSE image of garnetiferous amphibolite sample. Relict, corroded garnet and symplectitic intergrowth of amphibole and plagioclase replaced by late amphibole (Am) and plagioclase (Pl). Ilmenite (Ilm) occurs both in the symplectite and the matrix. (**d**) BSE image of garnetiferous amphibolite sample. Garnet (Grt) altered to epidote (Ep) on the rims occurs together with symplectitic intergrowth of amphibole and plagioclase (Sympl). Matrix is composed of amphibole (Am), plagioclase (Pl) and ilmenite (Ilm).

some garnet, quartz and opaque minerals; accessories are apatite, zircon, rutile and biotite.

Garnets (up to 1–2 mm) are rounded and corroded grains looking fresh in the internal parts, but altered to epidote (and very rarely biotite) on the rims (Fig. 4c,d). Due to late brittle tectonic effects some grains are disintegrated, and plagioclase has crystallized among the remnants. Microprobe analyses of garnets show distinct core and rim compositions (Figs. 5 and 6b). Garnet cores have Grs content over 20 %, with Alm ranging between 54 and 57 % and Prp at ca. 15 %. Rim compositions are represented by higher Alm (around 60 %), whereas Grs is less than 20 % (11 to 18 %). Prp is also higher on the rims. Sps does not show any great variation, and is generally around 2–3 %.

Two generations of *amphibole* can be recognized in the studied samples. The first has a small grain size (30–40 μm), occurring as green/yellowish blasts, and generally forming symplectites (Fig. 4c,d) with fine-grained *plagioclase* (+/– epi-

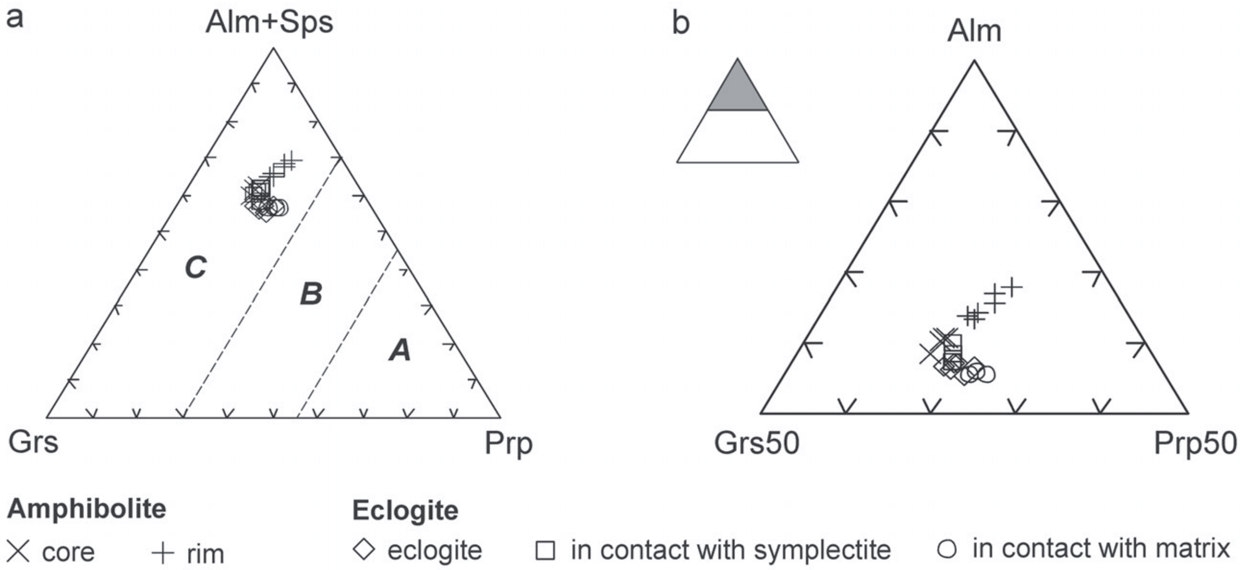

Fig. 5. Chemical composition of garnets: (**a**) (Alm+Sps)–Grs–Prp triangle of Coleman et al. (1965), and (**b**) Alm–Grs–Prp triangle.

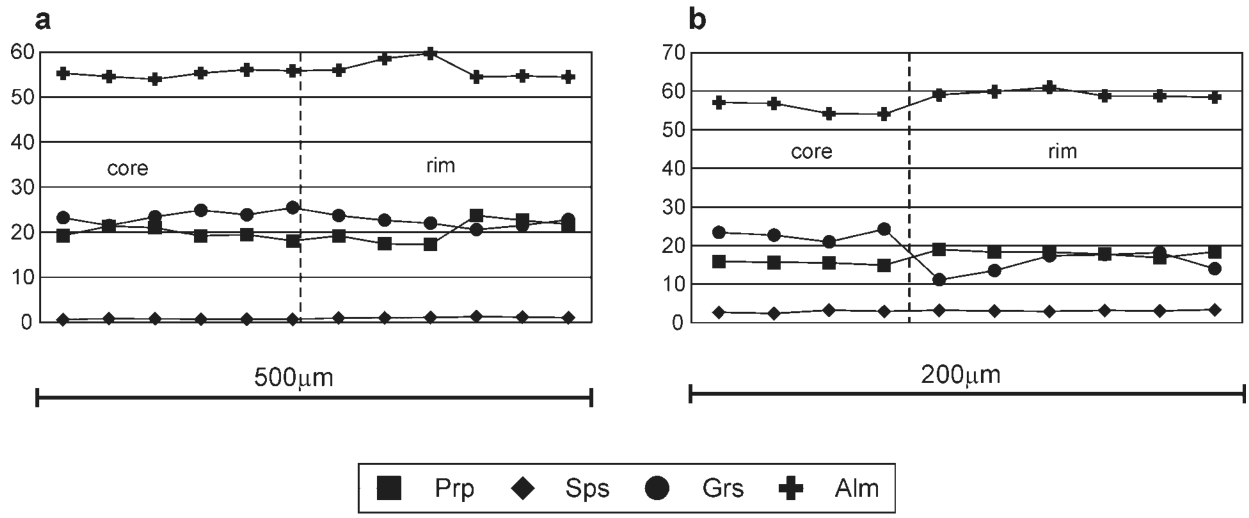

Fig. 6. Compositional zoning profile of garnet in eclogite (**a**), and in garnetiferous amphibolite (**b**). Note the distinct core-rim compositions in amphibolite garnet.

dote) after a previous phase (presumably omphacitic clinopyroxene). Amphibole and plagioclase can also be found as inclusions in garnet core regions. Amphibole compositions plot in the magnesio-hornblende field (Leake et al. 1997), with SiO_2 around 49 wt. % and Al_2O_3 over 13 wt. %, whereas Na_2O is lower than 1.5 wt. %. Plagioclase is An_{14-17}.

Coarse-grained (1–1.5 mm), dark green–yellowish green hypidioblasts of amphibole and plagioclase with polysynthetic twins (Fig. 4c) form the matrix assemblage. In very rare cases amphibole is replaced by biotite. It is richer in Al_2O_3, Na_2O and TiO_2, and poorer in SiO_2 and MgO relative to the symplectite-forming amphibole. This is tschermakite according to the nomenclature of Leake et al. (1997). Plagioclase is richer in Na (An_{10-12}) compared to symplectitic plagioclase. All large matrix amphibole and plagioclase grains show wavy extinction, and the larger plagioclase grains are disintegrated into smaller parts similarly to garnets.

The coarse-grained opaque minerals (mostly ilmenite) are corroded, in some cases leucoxenized. The other opaque phases are very fine-grained euhedral magnetite crystals. Among the accessories there is a large amount of apatite. Rutile is rare, occurring as inclusions in amphibole or in plagioclase. Rare zircon appears as very fine-grained euhedral crystals.

Thermobarometry

Before performing any P-T calculations, it is worth trying to determine whether the observed mineral compositions truely reflect various stages of metamorphism or they show compositional readjustments to retrograde processes. The compositional changes observed in clinopyroxenes (omphacitic Cpx in the core of garnet, Na-poor cpx in the symplectites) clearly demonstrate the change from eclogite facies to lower-P (most probably amphibolite facies) conditions. This is supported by the presence of rutile exclusively in garnet cores, and ilmenite occurring in the matrix and symplecite assemblages. Amphibole can be found in the matrix with clinopyroxene and plagioclase, and with plagioclase as kelyphitic rims replacing garnet or postdating the matrix. Kelyphitic amphiboles have lower Ti content indicating lower-T conditions (Ernst & Liu 1998). The close compositional range of most of the plagioclases in different textural domains seems to cause some ambiguity in the geothermobarometrical calculations. One of the reasons is that plagioclases reequilibrated after the formation of the matrix assemblage. However, reequilibration of plagioclase is not very probable, because cation diffusion in plagioclase is known to be quite slow (Grove et al. 1984). In the case of pressure increase the An component of the plagioclase decreases with increasing Grs in coexisting garnet. We observed decreasing An content in plagioclases of symplectite and matrix, respectively, but Grs did not show any increase. The matrix has amphibole of magnesio-hornblende composition with significant Ca content presumably coming from clinopyroxene and/or garnet. Plagioclases overgrowing the matrix with amphibole have An content higher than in the matrix reflecting the change from cpx-bearing assemblages to amphibole-plagioclase assemblage.

The computer program THERMOBAROMETRY of Kohn & Spear (1995) with various calibrations (see below) was used for pressure-temperature (P-T) determinations. P-T calculations were also performed with the TWEEQU program (version 2.02) of Berman (1991) using the thermodynamic dataset of Berman (1988), and activity models for garnet (Berman 1990), clinopyroxene (Berman et al. 1995), amphibole (Mäder & Berman 1992) and plagioclase (Fuhrman & Lindsley 1988).

Eclogite

Temperatures for the eclogite stage were estimated using several calibrations of the garnet-clinopyroxene Fe-Mg exchange thermometer. Using the core compositions of garnet together with omphacite inclusions the temperature of the eclogite stage was between 670–700 °C with the Ellis & Green (1979) calibration which seems to be a slight overestimate. The calibration of Krogh (1988) and Krogh-Ravna (2000) gave 600–650 °C, 50–60 °C less than the Ellis & Green (1979) method. The pressure is 13–15 kbar (minimum P) using the jadeite content of omphacitic clinopyroxene for the eclogite (Holland 1980 and 1983). The TWEEQU method gave slightly higher T (650–740 °C) than the Grt-Cpx exchange thermometers. These data indicate that the eclogite equilibrated at the medium temperature (MT) field of Carswell (1990). Pressure-temperature data for the large matrix amphibole-plagioclase pairs were ca. 470 °C and 8–10 kbar (Plyusnina 1982).

Garnetiferous amphibolite

Garnet-hornblende Fe-Mg exchange thermometry from Graham & Powell (1984) and garnet-plagioclase-hornblende-

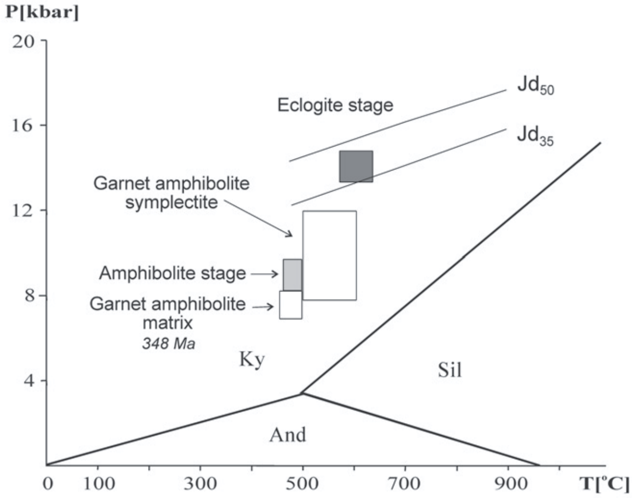

Fig. 7. Pressure-temperature conditions for the eclogite and garnetiferous amphibolite samples, constrained by thermobarometric data. Hornblende K-Ar age data from amphibolite are also shown. Aluminosilicate triple point according to Holdaway (1971), stability of omphacite (Jd_{35} and Jd_{50}) according to Holland (1983).

quartz barometry from Kohn & Spear (1990) were performed for garnet rim and adjacent hornblende and plagioclase in the symplectites. These estimates are 500–570 °C and 8–12 kbar. The same P-T range was obtained with inclusions of hornblende and plagioclase in garnet. For the retrograde stage we obtained ca. 500 °C and 8 kbar with the method of Plyusnina (1982).

The obtained P-T conditions for the various assemblages are shown in Fig. 7. The P-T results indicate that the late (retrograde) stage of metamorphism in the investigated eclogite and garnetiferous amphibolite samples occurred at similar P-T conditions.

Geochronology

The garnetiferous amphibolite sample was analysed by the K-Ar method to establish the age bracket of metamorphism (or cooling). We used separated amphibole fractions after checking that the majority of the amphibole porphyroblasts belong to one mineral assemblage (matrix phase). The samples gave 348±13 Ma age data. Since the closure temperature of the hornblende K-Ar system is between 450–550 °C (e.g. McDougall & Harrison 1988), and the calculated temperatures for the garnetiferous amphibolite is close to this bracket, we conclude that the analysed sample was formed at around 348±13 Ma. Unfortunately, we were unable to derive any age data from the eclogite sample (and it would be highly problematic or impossible).

Discussion

Paleotectonic implications

The investigated exotic pebbles of metabasites clearly belong to the crystalline basement of the Baksa Complex of the

Tisza Megaunit according to their tectonic position and petrographic features. Eclogite was first described by Ravasz-Baranyai (1969) from the area, but without detailed petrological and mineral chemical data, thus geothermobarometric information is still lacking. The mineral assemblage is kyanite, phengite and margarite in additional to garnet, amphibole, quartz and rare omphacitic pyroxene, so they seem to be different from the rock type presented here, although kyanite-bearing and kyanite-free eclogites are common together in eclogite areas (e.g. Miller & Thöni 1997). M. Tóth (1995) reported garnet-bearing amphibolites (highly retrogressed eclogites) from the eastern part of the Tisza Megaunit, but the P-T results he obtained are on the lower-T limit of the eclogite facies (600–650 °C, 10–12 kbar), and the eventual shape of the P-T path is controversial. He stated that peak P-T conditions were followed by retrogression into the greenschist facies, and then an amphibolite facies overprint occurred at near isobaric conditions.

The Variscan evolution of the basement complexes of the Tisza Megaunit is still an open question. Kovács et al. (2000) outlined the following scenario: 1. HP-LT metamorphism (eclogite relicts of Ravasz-Baranyai 1969 and M. Tóth 1995). This event is inferred to occur at about 400–440 Ma (Rb-Sr method, Svingor & Kovách 1981). The biggest problem of these age data is that these results were obtained on amphibolite xenoliths showing features of a late higher-T recrystallization caused by Variscan granitoids (Király 1996). 2. MP-MT Barrow-type metamorphism which is characteristic of the entire area of the Tisza Megaunit (for details see "Geological setting"). 3. LP-HT metamorphism closely related to granitoid magmatism. The latter two events took place between 350 and 270 Ma. The greatest concern with the published geochronological results is that most of them are biotite and white mica K-Ar or biotite Rb-Sr ages, so they represent only cooling ages. Furthermore, the P-T conditions of the rocks from which the dated minerals had been separated are not unambigous. While most authors generally accept the Variscan age of the MP-MT Barrow-type metamorphism, there is controversy about the age of the earlier HP metamorphism. Our new K-Ar data of 348±13 Ma obtained on amphibole fractions from the garnetiferous amphibolite better supports the Variscan age of the HP event.

P-T path

Petrographic investigations and mineral chemical data show a continuous change from eclogite facies assemblage (garnet, omphacitic cpx, rutile and quartz) through the lower-P assemblage of clinopyroxene-bearing symplectite to the cpx-amphibole-bearing matrix (HP amphibolite facies). The locally occurring mineral assemblage of late amphibole and plagioclase point to amphibolite facies conditions.

Peak conditions of eclogite formation are 600–650 °C and 13–15 kbar based on garnet-clinopyroxene exchange thermometry and jadeite content of omphacite (minimum P). No information is available for the early, prograde part of the P-T path. The breakdown of the eclogite facies assemblage occurred in several steps. Omphacitic clinopyroxene broke down to Na-poor clinopyroxene and Ca-rich plagioclase to produce the symplectite (reaction 1a):

omphacite + quartz = clinopyroxene + plagioclase

The different $Mg/(Mg+Fe^{2+})$ ratios for clinopyroxenes in the symplectite and in the matrix suggest that garnet participated in the reaction responsible for the formation of the matrix assemblage (Franceschelli et al. 1998). It is probable to assume that garnet was also involved in reaction (1):

garnet (core) + omphacite + quartz = garnet (rim) + clinopyroxene + plagioclase + amphibole (reaction 1b)

Late amphibole-plagioclase pairs formed at ca. 470 °C and 8–10 kbar via the following reaction (2):

garnet (rim) + clinopyroxene + H_2O *= amphibole + plagioclase*

or via reaction (3):

garnet (rim) + H_2O *= plagioclase + amphibole + quartz*

Rutile partly transformed to ilmenite at the same time with reactions (2 and 3), because it is only present in garnet cores and in the symplectites.

In the garnetiferous amphibolite sample only a symplectite stage and a retrograde (matrix) stage can be recognized. P-T calculations resulted in 500–570 °C and 8–12 kbar for the symplectites, and ca. 500 °C and 8 kbar for the retrograde stage. Despite the fact that no eclogite facies relicts can be recognized in the amphibolite, the presence of symplectites and the similar P-T conditions obtained for the retrograde stages in both samples indicate that the investigated rocks formed in a similar tectono-metamorphic setting.

Comparison with other Variscan eclogite terranes

The nearest crystalline basement outcrops to the investigated area are in the Eastern Alps and in the Dinarides. At present, the P-T conditions and age relations of pre-Alpine and Alpine metamorphism in the Dinaridic area are not well established. Neubauer et al. (1999) presented the distribution of pre-Alpine metamorphism in the Eastern Alps. Pre-Alpine eclogites outcrop in the Penninic basement of the Tauern Window with conditions of 620±100 °C, >12 kbar (Droop 1983) and 400–500 °C, 8–12 kbar (Zimmermann & Franz 1989). The age of eclogite facies metamorphism is 415±18 Ma (U-Pb on zircon) or 421±16 Ma (Sm-Nd method) according to von Quadt et al. (1997). In the Ötztal area of the Middle Austroalpine nappe complex ca. 730 °C and 27 kbar were estimated by Miller & Thöni (1995) for the Variscan eclogite formation (359±18 Ma and 373±20 Ma, Sm-Nd method on garnet and whole-rock; Miller & Thöni 1995). From the Speik Complex (Hochgrössen, Middle Austroalpine unit) Faryad et al. (2002) obtained an average temperature of 700 °C and a minimum pressure of 15 kbar. Ar-Ar radiometric data of amphibole in textural equilibrium with omphacite gave 397.3±7.8 Ma. In the Ulten Complex (Austroalpine basement) along the Periadriatic fault Hauzenberger et al. (1996) and Höller & Hoinkes (1996) found a two-stage evolution recorded in eclogites. They found ca. 700±50 °C and

>15 kbar for the peak metamorphic conditions in the eclogite facies. Subsequent decompression took place at ca. 600±50 °C and 6–7 kbar. Gebauer & Grünenfelder (1978) reported U-Pb zircon ages of 326–332 Ma for the Ulten Complex rocks. Von Räumer (1998) concluded that although the tectonic and metamorphic history of the basement units of the Alps can be compared to that of the Variscan crust in the Alpine foreland, most of these basement rocks do not represent the direct southern continuation of Variscan structural elements evident in the Massif Central or the Bohemian Massif.

Most Hungarian authors agree that the Variscan medium-grade metamorphics of the Tisza Megaunit show great similarities to the European Variscides, especially to the Moldanubian Zone of the Bohemian Massif (for recent review, refer to Kovács et al. 2000). For this reason, we turned our attention to the eclogites of the Bohemian Massif and tried to find similar petrographic features and P-T evolution. Medaris et al. (1995) reviewed the eclogites of the Bohemian Massif and divided them into various groups based on geochemical data, tectonic setting and P-T conditions. Comparing their data to our results supports the idea that the eclogite occurring in the SW part of the Tisza Megaunit shows great similarities to eclogites of the Monotonous Series of the Moldanubain Zone (minimum T-P conditions are 615–705 °C and 13–15 kbar there). Unfortunately, the exact age of eclogite formation is still undetermined there, but is most likely older than 380 Ma (Matte 1986; Franke 1989). Recently, Medaris et al. (1998) found prograde eclogite in the Gföhl Nappe, which is the uppermost allochthonous unit in the Moldanubian Zone. This result implies that eclogite facies metamorphism was probably Early Carboniferous in age, rather than Late Devonian as stated by Petrakakis (1997). In additional to eclogites, HP granulites are also important features of the Moldanubian Zone and the European Variscides (e.g. Carswell & O'Brien 1993; O'Brien & Carswell 1993; O'Brien et al. 1997; Cooke 2000), but so far this rock type has not been found in the Tisza Megaunit. Since we have no age of eclogite in the Tisza Megaunit, our comparisons are not justified and there are several other possibilities.

Conclusions

1. The investigated HP metabasite samples (eclogite and garnetiferous amphibolite) occur in Miocene conglomerates resting on top of the Variscan crystalline basement of the SW part of the Tisza Megaunit, Hungary. Geochronological data show cooling ages for amphiboles at around 348±13 Ma suggesting a Variscan retrogression of the rocks which contradics the earlier results (400–440 Ma; Svingor & Kovách 1981).

2. Peak metamorphic conditions were in the MT part of the eclogite facies (600–650 °C, 13–15 kbar) with garnet, omphacitic pyroxene, quartz and rutile as primary assemblage. During the breakdown from peak P-T conditions symplectitic intergrowth of clinopyroxene, plagioclase and quartz formed. Continuous retrogression involving garnet caused formation of the matrix assemblage. Amphibole-plagioclase porphyroblasts represent the last stage of retrogression. Amphibole-bearing symplectites record similar P-T conditions in garnetiferous amphibolite, but no pyroxene was detected there.

3. The investigated metabasites and serpentinites were emplaced in the medium-grade metasedimentary country rocks (recording no signs of HP metamorphism) after the main metamorphic event (270–320 Ma). Final uplift to surface conditions occurred in Miocene times and caused the first appearance of HP metabasite pebbles in clastic sedimentary rocks.

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References

Árkai P. 1984: Polymetamorphism of the crystalline basement of the Somogy-Dráva Basin (Southwestern Transdanubia, Hungary). *Acta Mineral. Petrogr. Szeged* 26, 129–153.

Árkai P., Nagy G. & Dobosi G. 1985: Polymetamorphic evolution of the South Hungarian crystalline basement, Pannonian Basin: geothermometric and geobarometric data. *Acta Geol. Hung.* 28, 165–190.

Árkai P., Horváth P. & Nagy G. 1999: A clockwise P-T path from the Variscan basement of the Tisza Unit, Pannonian Basin, Hungary. *Geol. Croatica* 52, 109–117.

Balla Z. 1981: Plate tectonics interpretations of the South Transdanubian ultramafics. *Acta Mineral. Petrogr. Szeged* 25, 3–24.

Balogh K. 1985: K/Ar dating of Neogene volcanic activity in Hungary: Experimental technique, experiences and methods of chronologic studies. *Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI) Rep.*, D/1, 277–288.

Berman R.G. 1988: Internally-consistent thermodynamic data for minerals in the system Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-TiO_2-H_2O-CO_2. *J. Petrology* 29, 445–522.

Berman R.G. 1990: Mixing properties of Ca-Mg-Fe-Mn garnets. *Amer. Mineralogist* 75, 328–344.

Berman R.G. 1991: Thermobarometry using multi-equilibrium calculations. A new technique, with petrologic applications. *Canad. Mineralogist* 29, 835–855.

Berman R.G., Aranovich L.Y. & Pattison D.R.M. 1995: Reanalysis of the garnet-clinopyroxene Fe-Mg exchange thermometer. II. Thermodynamic analysis. *Contr. Mineral. Petrology* 30–42.

Bucher K. & Frey M. 1994: Petrogenesis of metamorphic rocks. *Springer*, Berlin–Heidelberg–New York, 1–318.

Buda Gy. & Nagy G. 1995: Some REE-bearing accessory minerals in two types of Variscan granitoids, Hungary. *Geol. Carpathica* 46, 67–78.

Brügel A., Dunkl I., Frisch W., Kuhlemann J. & Balogh K. 2000: The record of Periadriatic volcanism in the Eastern Alpine Molasse zone and its palaeogeographic implications. *Terra Nova* 12, 42–47.

Carswell D.A. 1990: Eclogites and eclogite facies: definitions and classifications. In: Carswell D.A. (Ed.): Eclogite facies rocks. *Blackie*, Glasgow, 1–13.

Carswell D.A. & O'Brien P.J. 1993: Thermobarometry and geotectonic significance of high-pressure granulites. Examples from the Moldanubian Massif, Lower Austria. *J. Petrology* 34, 427–459.

Coleman R.G., Lee D.E., Beatty L.B. & Brannock W.W. 1965: Eclogites and eclogites: Their differences and similarities. *Geol. Soc. Amer. Bull.* 76, 483–508.

Cooke R.A. 2000: High-pressure/temperature metamorphism in the St. Leonhard Granulite Massif, Austria: evidence from intermediate pyroxene-bearing granulites. *Int. J. Earth Sci.* 89, 631–651.

Droop G. 1983: Pre-Alpine eclogites in the Penninic basement complex of the Eastern Alps. *J. Metamorph. Geology* 1, 3–12.

Ellis D.J. & Green D.H. 1979: An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria. *Contr. Mineral. Petrology* 71, 13–22.

Ernst W.G. & Liu J. 1998: Experimental phase-equilibrium study of Al- and Ti-contents of calcic amphibole in MORB — A semiquantitative thermobarometer. *Amer. Mineralogist* 83, 952–969.

Faryad S.W., Melcher F., Hoinkes G., Puhl J., Meisel T. & Frank W. 2002: Relics of eclogite facies metamorphism in the Austroalpine basement, Hochgrößen (Speik complex), Austria. *Miner. Petrology* 74, 49–73.

Franceschelli M., Eltrudis A., Memmi I., Palmeri R. & Carcangiu G. 1998: Multi-stage metamorphic re-equilibration in eclogitic rocks from the Hercynian basement of NE Sardinia (Italy). *Miner. Petrology* 62, 167–193.

Franke W. 1989: Tectonostratigraphic units in the Variscan belt of central Europe. *Geol. Soc. Amer. Spec. Paper* 230, 67–90.

Fuhrman M.L. & Lindsley D.H. 1988: Ternary-feldspar modeling and thermometry. *Amer. Mineralogist* 73, 201–216.

Gebauer D. & Grünenfelder M. 1978: U–Pb zircon dating of Alpine-type garnet peridotites, example Val d'Ultimo (eastern Alps, northern Italy). *U.S. Geol. Surv. Prof. Pap. Open-File Rep.* 78–101, 135–137.

Géczy B. 1973: The origin of the Jurassic faunal provinces and the Mediterranean plate tectonics. *Ann. Univ. Sci. Budapest R. Eötvös. Nom. Sect. Geol.* 16, 99–114.

Graham C.M. & Powell R. 1984: A garnet-hornblende geothermometer: calibration, testing and application to the Pelona Schists, Southern California. *J. Metamorph. Geology* 2, 13–34.

Grove T.L., Baker M.B. & Kinzler R.J. 1984: Coupled CaAl–NaSi diffusion in plagioclase feldspar: Experiments and applications to cooling rate speedometry. *Geochim. Cosmochim. Acta* 48, 2113–2121.

Hámor G. 1970: The Miocene of the Eastern Mecsek Mts. *Ann. Hung. Geol. Inst.* 53, 1–483 (in Hungarian).

Hauzenberger C.A., Höller W. & Hoinkes G. 1996: Transition of eclogite to amphibolite-facies metamorphism in the Austroalpine Ulten Zone. *Miner. Petrology* 58, 111–130.

Holdaway M.J. 1971: Stability of andalusite and the aluminium silicate phase diagram. *Amer. J. Sci.* 271, 97–131.

Holland T.J.B. 1980: The reaction albite = jadeite + quartz determined experimentally in the range 600–1200 °C. *Amer. Mineralogist* 65, 129–134.

Holland T.J.B. 1983: The experimental determination of activities in disordered and short-range ordered jadeitic pyroxenes. *Contr. Mineral. Petrology* 82, 214–220.

Horváth P. & Árkai P. 2002: Pressure-temperature path of metapelites from the Algyő-Ferencszállás area, SE Hungary: thermobarometric constraints from coexisting mineral assemblages and garnet zoning. *Acta Geol. Hung.* 45, 1–27.

Höller W. & Hoinkes G. 1996: Fluid evolution during high-pressure partial melting in the Austroalpine Ulten Zone, Northern Italy. *Miner. Petrology* 58, 131–144.

Janák M., O'Brien P.J., Hurai V. & Reutel C. 1996: Metamorphic evolution and fluid composition of garnet-clinopyroxene amphibolites from the Tatra Mountains, Western Carpathians. *Lithos* 39, 57–79.

Kázmér M. & Kovács S. 1985: Permian–Paleogene paleogeography along the Eastern part of the Insubric–Periadriatic lineament system: evidence for the continental escape of the Bakony-Drauzug Unit. *Acta Geol. Hung.* 28, 71–84.

Király E. 1996: New results on the research of polymetamorphic basement of South-East Transdanubia. *Földtani Közlöny* 126, 1–23 (in Hungarian, with English abstract).

Kohn M.J. & Spear F.S. 1990: Two new geobarometers for garnet amphibolites, with applications to southeastern Vermont. *Amer. Mineralogist* 75, 89–96.

Kohn M.J. & Spear F.S. 1995: Thermobarometry. *Dept. of Geology, Renssealer Polytechnic Institute.*

Kovács S. 1982: Problems of the "Pannonian Median Massif" and the plate tectonic concept. Contributions based on the distribution of Late Paleozoic–Early Mesozoic isopic zones. *Geol. Rdsch.* 71, 617–640.

Kovács S., Szederkényi T., Haas J., Buda Gy., Császár G. & Nagymarosy A. 2000: Tectonostratigraphic terranes in the pre-Neogene basement of the Hungarian part of the Pannonian area. *Acta Geol. Hung.* 43, 225–328.

Krogh E.J. 1988: The garnet-clinopyroxene Fe-Mg geothermometer–reinterpretation of existing experimental data. *Contr. Mineral. Petrology* 99, 44–48.

Krogh-Ravna E. 2000: The garnet-clinopyroxene Fe^{2+}-Mg geothermometer: an updated calibration. *J. Metamorph. Geology* 18, 211–219.

Kretz R. 1983: Symbols for rock-forming minerals. *Amer. Mineralogist* 68, 277–279.

Leake B.E., Woolley A.R., Arps C.E.S., Birch W.D., Gilbert M.C., Grice J.D., Hawthorne F.C., Kato A., Kisch H.J., Krivovichev V.G., Linthout K., Laird J., Mandarino J., Maresch W.V., Nickel E.H., Rock N.M.S., Schumacher J.C., Smith D.C., Stephenson N.C.N., Ungaretti L., Whitaker E.J.W. & Youzhi G. 1997: Nomenclature of Amphiboles: Report of the Subcommittee on Amphiboles of the International Mineralogical Association Commission on New Minerals and Mineral Names. *Mineral. Mag.* 61, 295–321.

Lelkes-Felvári Gy. & Sassi F.P. 1981: Outlines of the pre-Alpine metamorphism in Hungary. In: Karamata S. & Sassi F.P. (Eds.): IGCP Project No. 5. *Newsletter No. 3*, Padova-Beograd, 89–99.

Lelkes-Felvári Gy., Árkai P., Sassi F.P. & Balogh K. 1996: Main features of the regional metamorphic events in Hungary: a review. *Geol. Carpathica* 47, 257–270.

Lelkes-Felvári Gy., Árkai P., Frank W. & Nagy G. 2000: Late Variscan ultramylonite from the Mórágy Hills, SE Mecsek Mts., Hungary. *Acta Geol. Hung.* 43, 65–84.

M. Tóth T. 1994: Geochemical character of amphibolites from Tisza Unit on the basis of incompatible trace elements. *Acta Mineral. Petrogr. Szeged* 35, 27–39.

M. Tóth T. 1995: Retrograde eclogite in the crystalline basement of the Körös Unit, Hungary. *Acta Mineral. Petrogr. Szeged* 36, 117–129.

Máthé Z., Fórizs I., Tóth M. & Polgári M. 1997: Contributions to the clay mineralization and zeolitization of the Miocene tuffs in the Mecsek Mts., Hungary. *Geol. Carpathica Series Clays* 6, 47–55.

Mäder U.K. & Berman R.G. 1992: Amphibole thermobarometry, a thermodynamic approach. *Current Research, Part E, Pap. Geol. Surv. Canada* 92-1E, 393–400.

Matte P. 1986: Tectonics and plate tectonics model for the Variscan belt of Europe. *Tectonophysics* 107, 25–56.

McDougall I. & Harrison T.M. 1988: Geochronology and thermochronology by the $^{40}Ar/^{39}Ar$ method. *Oxford University Press*, New York, 1–212.

Medaris G., Jelínek E. & Mísař Z. 1995: Czech eclogites: Terrane settings and implications for Variscan tectonic evolution of the

Bohemian Massif. *Eur. J. Mineral.* 7, 7–28.
Medaris G., Fournelle J.H., Ghent E.D., Jelínek E. & Mísař Z. 1998: Prograde eclogite in the Gföhl Nappe, Czech Republic: new evidence on Variscan high-pressure metamorphism. *J. Metamorph. Geology* 16, 563–576.
Miller C. & Thöni M. 1995: Origin of eclogites from the Austroalpine Ötztal basement (Tirol, Austria): geochemistry and Sm-Nd vs Rb-Sr isotope systematics. *Chem. Geol.* 122, 199–225.
Miller C. & Thöni M. 1997: Eo-Alpine eclogitisation of Permian MORB-type gabbros in the Koralpe (Eastern Alps, Austria): new geochronological, geochemical and petrological data. *Chem. Geol.* 137, 283–310.
Neubauer F., Hoinkes G., Sassi F.P., Handler R., Höck V., Koller F. & Frank W. 1999: Pre-Alpine metamorphism in the Eastern Alps. *Schweiz. Mineral. Petrogr. Mitt.* 79, 41–62.
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 1–396.
O'Brien P.J. & Carswell D.A. 1993: Tectonometamorphic evolution of the Bohemian Massif: evidence from high-P metamorphic rocks. *Geol. Rdsch.* 84, 473–488.
O'Brien P.J., Kröner A., Jaeckel P., Hegner E., Zelazniewicz A. & Kryza R. 1997: Petrological and isotopic studies on Palaeozoic high-pressure granulites, Góry Sowie Mts., Polish Sudetes. *J. Petrology* 38, 433–456.
Odin G.S., Adams C.J., Armstrong L.R., Bagdasaryan G.P., Baksi K.A., Balogh K., Barnes I.L., Boelrijk N.A.I.M., Bonadonna F.P., Bonhomme M.G., Cassignol C., Chanin L., Gillot P.Y., Gledhill A., Govindaraju K., Haraka R., Harre W., Hebeda E.H., Hunziker J.C., Ingamells C.O., Kawashita K., Kiss E., Kreutzer H., Long L.E., McDougall I., McDowell F., Mehnert H., Montigny R., Pasteels P., Radicati F., Rex D.C., Rundle C.C., Savelli C., Sonet J., Welin E. & Zimmermann J.L. 1982: Interlaboratory standards for dating purposes. In: Odin G.S. (Ed.): Numerical dating in stratigraphy. *Wiley and Sons*, Chichester, New York, Brisbane, 123–149.
Petrakakis K. 1997: Evolution of Moldanubian rocks in Austria: review and synthesis. *J. Metamorph. Geology* 15, 203–222.
Philippot P. 1988: Déformation et éclogitisation progressives d'une croûte océanique subductée: Le Monviso, Alpes occidentales. Constraintes cinématiques durant la collision alpine. Documents et travaux. *Centre Géologique et Géophysique Université des Sciences et Techniques du Languedoc,* Montpellier, 19.
Plyusnina L.P. 1982: Geothermometry and geobarometry of plagioclase-hornblende-bearing assemblages. *Contr. Mineral. Petrology* 80, 140–146.
von Quadt A., Günther D., Friscenknecht R. & Franz G. 1997: The evolution of pre-Variscan eclogites of the Tauern Window (Eastern Alps): A Sm/Nd-, conventional and Laser ICP-MS zircon U-Pb study. *Schweiz. Mineral. Petrogr. Mitt.* 74, 265–279.
von Räumer J.F. 1998: The Paleozoic evolution in the Alps: from Gondwana to Pangea. *Geol. Rdsch.* 87, 407–435.
Ravasz-Baranyai L. 1969: Eclogite from the Mecsek Mountains, Hungary. *Acta Geol. Hung.* 13, 315–322.
Robinson P., Spear F.S., Schumacher J.C., Laird J., Klein C., Evans B.W. & Doolan B.L. 1982: Phase relations of metamorphic amphiboles: natural occurrence and theory. In: Veblen D.R. & Ribbe P.H. (Eds.): Amphiboles: Petrology and experimental phase relations. *Rewiews in Mineralogy* 9B. *Mineral. Soc. Amer.,* Washington, 1–227.
Steiger R.H. & Jäger E. 1977: Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth Planet. Sci. Lett.* 12, 359–362.
Svingor É. & Kovách Á. 1981: Rb-Sr isotopic studies on granodioritic rocks from the Mecsek Mountains, Hungary. *Acta Geol. Hung.* 24, 295–307.
Szakmány Gy. & Józsa S. 1994: Rare pebbles from the Miocene conglomerate of Mecsek Mts., Hungary. *Acta Mineral. Petrogr. Szeged* 35, 53–64.
Szederkényi T. 1976: Barrow-type metamorphism in the crystalline basement of Southeastern Transdanubia. *Acta Geol. Hung.* 13, 27–34.
Szederkényi T. 1984: Crystalline basement of the Great Hungarian Plain and its geological connections. *D.Sc. Thesis,* Budapest, 1–216 (in Hungarian).
Varga A., Szakmány Gy. & Józsa S. 2000: Geochemistry and provenance of Carboniferous sandstones: a case study in boreholes and redeposited Pebbles in Miocene conglomerate (Tisza Unit, S Hungary). (Goldschmidt 2000 An International Conference for Geochemistry, Oxford, U.K.) *J. Conference Abstr.* 5/2, 1045–1046.
Will T.M. & Schmädicke E. 2001: A first find of retrogressed eclogites in the Odenwald Crystalline Complex, Mid-German Crystalline Rise, Germany: evidence for a so far unrecognised high-pressure metamorphism in the Central Variscides. *Lithos* 59, 109–125.
Zimmermann R. & Franz G. 1989: Die Eklogite der Unteren Schieferhülle; Frosnitztal/Südvenediger (Tauern, Österreich). *Mitt. Österr. Geol. Gesell.* 81, 167–188.