MITT.ÖSTERR.MINER.GES. 146 (2001)

ALPINE CHLORITOID AND GARNET FROM THE HOCHGRÖSSEN MASSIF (SPEIK COMPLEX, EASTERN ALPS)

by

S.W. Faryad[1,2] & G. Hoinkes[2]

[1]Department of Geology and Mineralogy
Technical University, Letná 9, 04200 Košice, Slovakia
[2]Institute of Mineralogy and Petrology
University of Graz, Universitätsplatz 2, A-8010 Graz

Abstract
The Permian-Triassic cover sequences that overlay northern parts of the Austroalpine basement units, east of Tauern Window, contain chloritoid (X_{Mg} = 0.17 - 0.25), chlorite and white mica (Si = 3.2 a.p.f.u.), which indicate P-T conditions of 510 - 530°C at 0.7 - 0.9 GPa for the Eo-Alpine metamorphism. Similar P-T conditions are estimated for Eo-Alpine mineral assemblages from the underlaying basement rocks of the Seckau Complex. Feldspathic gneisses contain grossularite-rich and pyrope-poor garnet ($Grs_{36}Alm_{46-36}Sps_{14-24}Py_{1-3}$), which is known from many medium- to high-pressure metagranites and orthogneisses in the Alps and the Western Carpathians. It is associated with albite, phengite (Si = 3.5 a.f.u.), biotite and epidote. The calculated P-T conditions of 550°C and 0.9 - 1.0 GPa fit well with a geotherm of 12 - 14°C/km, which was deduced for the southwards increasing Eo-Alpine metamorphism within the Austroalpine units in the Eastern Alps.

KEY WORDS: chloritoid, garnet, Alpine metamorphism, Middle Austroalpine units, Eastern Alps

Introduction
Eo-Alpine metamorphism is widespread in the Austroalpine basement rocks and their autho-chtonous Permo-Mesozoic cover (HOINKES et al., 1999). In contrast to the polymetamorphic Austroalpine basement, which show Caledonian, Variscan, Permian and Cretaceous metamorphic imprints, metamorphic minerals in the Permo-Mesozoic metasediments are solely the product of Eo-Alpine metamorphism. The P-T conditions derived from these rocks give important clues to the polymetamorphic history of the nearby basement rocks. In the case of the Hochgrößen Massif, Ar/Ar dating of amphiboles from eclogites of the Speik Complex show an early Variscan age (FARYAD et al., 2001). The metamorphic mineral assemblages in the adjacent Permian Rannach Formation indicate an Eo-Alpine overprint, which also must have been active in the basement too. In this paper we present petrological data from the Permian Rannach Formation and the adjacent basement gneisses of the Seckau Complex, which enables the reconstruction of the Eo-Alpine P-T conditions in this part of the Eastern Alps.

Geological setting

The Hochgrößen Massif is part of a heterogeneous unit, tectonically sandwiched between the north-dipping Paleozoic Greywacke Zone in the north (hangingwall) and the south-dipping Wölz micaschists, equivalent to the Micaschist-Marble Complex in this area, in the south (Fig. 1). This unit contains fragments of the Speik and Core Complexes with transgressing Permo-Mesozoic sediments. To the N and NE of the Hochgrößen summit, an allochthonous body of strongly foliated serpentinite structurally overlies a paragneiss sequence with minor intercallations of amphibolites which form parts of the Core Complex, termed the "Engelberg Gneiss" in this area and which are attributed to the Seckau crystalline basement (METZ, 1964). Retrogressed eclogites and amphibolites form a concordant lens within the serpentinite body close to its eastern margin ("upper eclogite unit"). Metasediments (conglomerate, quartzite, phyllite) attributed to the Permian-Mesozoic Rannach Series are present in the hangingwall, either discordantly overlying the Engelberg gneiss, or tectonically intercalated within the serpentinite body (EL AGEED, 1979; METZ, 1980).

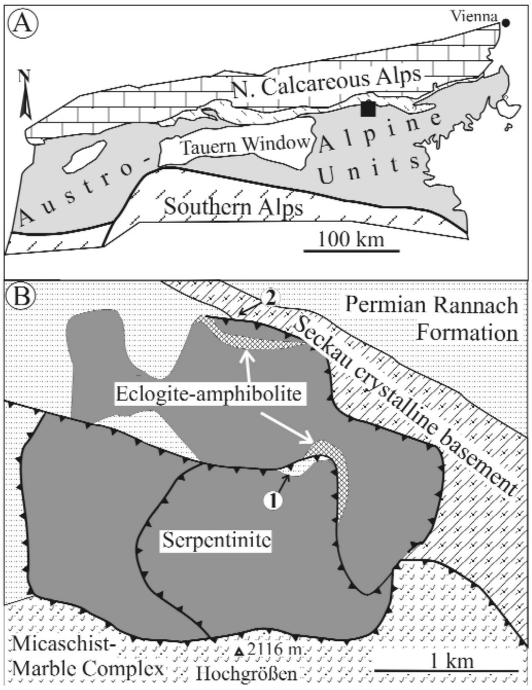

Fig. 1
Position of the Hochgrößen Massif (black box) in the frame of Eastern Alps (A) and detailed geological map of the Hochgrößen massif (B) (El Ageed, 1979). The serpentinites and eclogite-amphibolites belong to the Speik Complex. Numbers in circles indicate the sample locations: 1- Permian quartzite and 2- orthogneiss and amphibolite of the Seckau Complex.

Petrography and mineral compositions

The quartzite samples were collected from the Rannach Formation which are exposed near to the top of the Hochgrößen Massif adjacent to amphibolized eclogite (Fig. 1B). They are in tectonic contact with serpentinites and amphibolized eclogites. The samples collected from the Seckau Complex are feldspar gneisses and amphibolites near the contact with the serpentinites. All minerals were analysed with a scanning electron microscope JEOL 6310 with wavelength- and energy-dispersive spectrometers at the Institute of Mineralogy and Petrology at the University of Graz. Analytical standards include pyrope (Mg, Al), adular (K), rutile (Ti), tephroite (Mn), jadeite (Na, Si) and andradite (Fe, Ca). Operating conditions were 15 kV and beam currents of 10 and 15 nA. Representative mineral analyses are given in Tables 1-3.

The Rannach Formation quartzite

The rocks reveal a strong foliation, which is defined by white mica and elongated quartz grains. Additional to white mica, the rocks contain chlorite and chloritoid. All phases are in textural equilibrium, although some chloritoids are partly replaced by chlorite. Muscovite has a relatively low celadonite content of 3.1 a.p.f.u., but high paragonite contents of 17 - 22 mol % (Tab. 1). Some large muscovite crystals show compositional zoning with slightly increasing phengite contents towards the rims (Si = 3.2 a.p.f.u.). Chloritoid has an X_{Mg} = 0.17 - 0.25 which decreases from the core to the rim (Tab. 2). Some chloritoid crystals have more then one parallel lamellae, which are relatively rich in Fe^{2+} contents (Fig. 2). The Fe^{3+} (< 0.02 a.p.f.u.) and Mn (< 0.05 a.p.f.u.) contents are low. Individual crystals of chlorite that are in textural equilibrium with chloritoid and mica have X_{Mg} = 0.5 (Tab. 2).

	Quartzite		Gneiss		amphibolite
Mineral	Ms	Ms	Ms	Bt	Bt
Sample	Lm73-c	Lm73-r	Lm68	Lm68	Lm89
SiO_2	47.46	48.56	49.34	36.43	37.17
TiO_2	0.09	0.00	0.60	2.11	1.60
Al_2O_3	36.34	32.46	30.44	16.97	16.71
Fe_2O_3	0.00	1.71	1.97	0.00	0.00
FeO	0.66	0.77	1.77	20.66	19.12
MnO	0.07	0.00	0.07	0.26	0.15
MgO	0.32	1.48	2.40	8.43	11.91
CaO	0.05	0.57	0.01	0.04	0.06
Na_2O	1.35	0.42	0.15	0.09	0.05
K_2O	9.26	10.11	9.39	9.34	9.83
Total	95.60	96.08	96.15	94.33	96.6
Si	3.114	3.203	3.252	2.895	2.874
Al^{IV}	0.886	0.797	0.748	1.105	1.125
Al^{VI}	1.924	1.727	1.617	0.484	0.359
Ti	0.005	0.000	0.030	0.126	0.091
Fe^{3+}	0.000	0.085	0.098	0.000	0.000
Fe^{2+}	0.036	0.043	0.098	1.373	1.205
Mn	0.004	0.000	0.004	0.018	0.009
Mg	0.031	0.146	0.236	0.998	1.337
Ca	0.004	0.040	0.001	0.003	0.005
Na	0.172	0.054	0.019	0.014	0.007
K	0.775	0.851	0.790	0.947	0.945
X_{Mg}				0.421	0.526

c and r refer to core and rim.
Mineral formulae and ferric/ferrous iron ratios were calculated on the basis of 11 oxygens and 6 cations + Na + K + Ca

Table 1

Selected microprobe analyses of muscovite (Ms) and biotite (Bt) from the Permo-Triassic Rannach Formation quartzites, feldspar gneisses and amphibolites.

	chloritoid			chlorite	
Sample	Lm73	Lm73	Lm-76	lm73	Lm76
SiO_2	25.28	25.54	24.39	25.71	24.01
TiO_2	0.08	0.00	0.05	0.00	0.08
Al_2O_3	40.88	41.32	41.27	23.29	23.85
FeO	22.39	22.66	23.41	21.14	25.57
MnO	0.16	0.00	0.60	0.09	0.04
MgO	4.19	4.00	2.76	17.14	14.20
CaO	0.01	0.00	0.00	0.06	0.02
Na_2O	0.04	0.01	0.04	0.02	0.06
K_2O	0.00	0.00	0.03	0.01	0.03
Total	93.03	93.53	92.55	87.46	87.86
Si	2.048	2.056	2.004	5.325	5.057
Ti	0.005	0.000	0.003	0.000	0.013
Al	3.904	3.921	3.997	5.684	5.923
Fe^{2+}	1.517	1.526	1.608	3.662	4.504
Mn	0.011	0.000	0.042	0.016	0.008
Mg	0.506	0.480	0.338	5.291	4.459
Ca	0.001	0.000	0.000	0.013	0.005
Na	0.006	0.002	0.006	0.006	0.024
K	0.000	0.000	0.003	0.003	0.007
X_{Mg}	0.250	0.239	0.174	0.591	0.497

Calculation of mineral formulae: Chloritoid: 12 oxygens and 2 cations, Chlorite: 28 oxygens.

Table 2

Microprobe analyses of chloritoid and chlorite from quartzites of the Rannach formation.

Basement rocks of the Seckau Complex

Based on the mineral assemblages of the gneissic rocks, albite, quartz, muscovite, biotite and accessory epidote, chlorite, K-feldspar and garnet, we assume it represents an orthogneiss. It is mylonitized and large albite crystals (up to 3 mm in size) show fractures and recrystallization to a fine-grained matrix. Back-scatter electron images indicate that some albite sub grains have relatively An-rich rims (An = 0.7 mol %). The K-feldspar forms individual grains (up to 1 mm), but also occurs as inclusion together with biotite and muscovite in albite. Muscovite and biotite are concentrated along shear zones. The muscovite is phengitic with Si contents of 3.25 a.p.f.u. and Fe_{tot}+Mg contents of 0.42 a.p.f.u. and shows a low paragonite content (Na/(Na+K+Ca) = 0.02)) (Tab. 1). The biotites have a constant X_{Mg} value of 0.43. Garnet forms inclusions in albite porphyroblasts and occurs in contact with quartz (Fig. 3). Garnet is zoned with cores rich in Mn and poor in Fe ($Grs_{36}Alm_{36}Sps_{24}Py_1$) compared to the rims ($Grs_{36}Alm_{46}$ $Sps_{14}Py_3$) (Tab. 3, Fig. 4). Epidote has pistazite contents of 54 mol.%. Chlorite replaces biotite and garnet.

Rock	gneiss		amphibolite	gneiss	amphibolite	
Mineral	Gr	Gr	Amph	Ep	Ep	Ep
Sample	lm68-c	lm68-r	lm89	lm68	lm89	lm89
SiO_2	37.44	37.37	43.19	37.75	39.44	39.43
TiO_2	0.07	0.18	0.60	0.17	0.21	0.21
Al_2O_3	21.18	21.09	12.67	25.84	27.85	28.19
Fe_2O_3	0.73	0.00	2.20	9.07	7.60	7.91
FeO	15.54	20.68	14.62	0.00	0.00	0.00
MnO	10.57	6.17	0.42	0.32	0.17	0.18
MgO	0.59	0.80	9.00	0.08	0.14	0.31
CaO	13.68	12.72	11.05	22.97	24.1	24.18
Na_2O	0.00	0.02	1.48	0.03	0.00	0.02
K_2O	0.00	0.02	0.45	0.09	0.01	0.00
Total	99.82	99.04	95.68	96.32	99.52	100.43
Si	2.980	2.997	6.547	3.009	3.020	2.996
Al^{IV}	0.020	0.003	1.453	0.000	0.000	0.004
Al^{VI}	1.968	1.990	0.811	2.427	2.514	2.520
Ti	0.004	0.011	0.068	0.010	0.012	0.012
Fe^{3+}	0.044	0.000	0.251	0.544	0.438	0.452
Fe^{2+}	1.034	1.387	1.853	0.000	0.000	0.000
Mn	0.713	0.419	0.053	0.020	0.010	0.010
Mg	0.070	0.096	2.034	0.009	0.016	0.035
Ca	1.167	1.093	1.795	1.961	1.977	1.969
Na	0.001	0.003	0.435	0.004	0.000	0.002
K	0.000	0.002	0.087	0.009	0.001	0.000
Grs	0.367	0.358	Zo	0.437	0.526	0.532
Alm	0.347	0.462	Ep	0.544	0.438	0.452
Pyr	0.023	0.032				
Sps	0.239	0.140				
Adr	0.022	0.000				
X_{Mg}	0.063	0.064	0.523			

Calculation of mineral formulae: Amphibole: 23 oxygens and averaged Fe^{3+} from 13 and 15 cations, Epidote: 12 oxygens and 1 OH-group, Garnet: 12 oxygens and using the equation $Al^{VI} + Cr + Ti + Fe^{3+} = 2$ for garnet.

Table 3

Selected microprobe analyses of garnet (Gr), amphibole (Amph) and epidote (Ep) from the gneisses and amphibolites of the Seckau Complex.

The metabasites associated with orthogneisses are very fine-grained foliated rocks, which contain the assemblage amphibole, biotite, albite and small amounts of epidote, quartz and K-feldspar. Amphibole composition varies between tschermakite and magnesiohornblende with Si = 6.45 - 6.55, Al^{VI} = 0.8 and Na^{M4} = 0.14 a.p.f.u. Both, amphibole and biotite have X_{Mg} = 0.52 and they seem to be in equilibrium with epidote (Ps = 0.44 - 0.45 mol %) and albite.

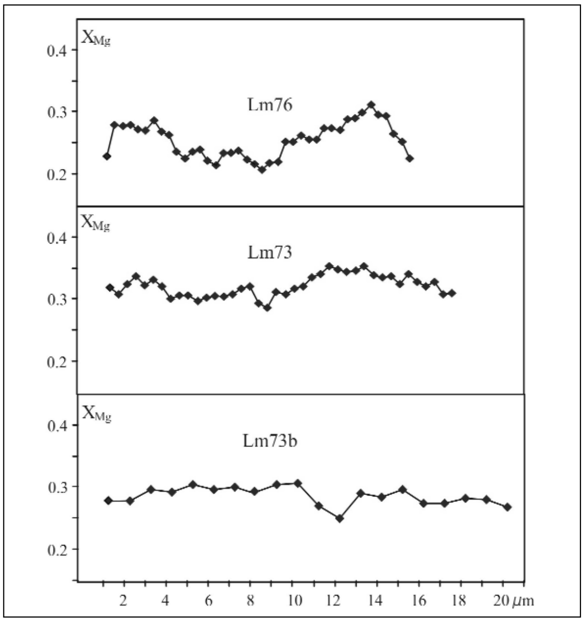

Fig. 2
Compositional profiles of chloritoids from the quartzites in the Rannach Formation

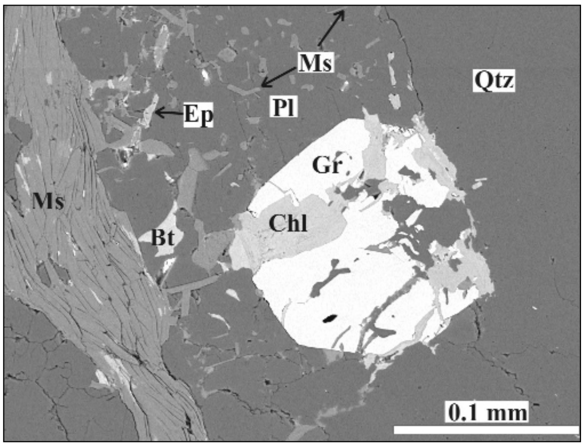

Fig. 3
Fractured idiomorphic garnet in the feldspar gneisses of the Seckau Complex. Bt-biotite, Chl-chlorite, Ep-epidote, Gr-garnet, Ms-muscovite, Pl-plagioclase-albite, Qtz-quartz.

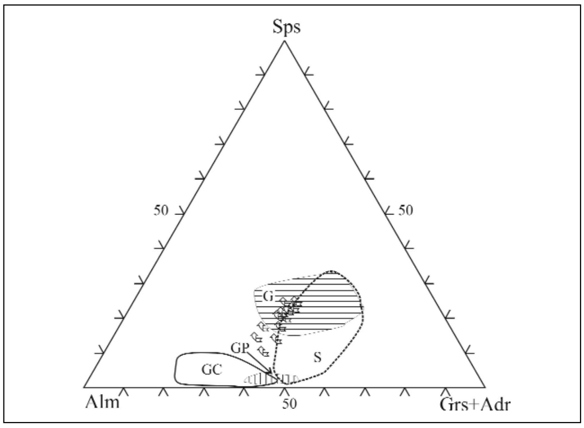

Fig 4
Garnet composition from the feldspar gneisses (stars), occurring beneath serpentinites in the Hochgrößen Massif. For comparison garnets from some metagranites and orthogneisses from the literature are also shown: S-Sopron (TÖRÖK, 1998), GP- Gran Paradiso (LEGOFF & BALLEVRE, 1990), G-Gemericum (FARYAD & DIANISIKA, 1989, 1999), GC-Grobgneiss Complex (unpublished data of the authors).

P-T conditions

Consistent with experimental investigations and natural occurrences of chloritoid-bearing rocks (SPEAR & CHENY, 1989; THEYE & SEIDEL, 1991; FARYAD, 1995; GOFFE & BOUSQUET, 1997) the lack of garnet in chloritoid-bearing quartzite suggests that metamorphic temperatures were not higher than ca 550°C. The composition of the chloritoid rim is apparently in equilibrium with chlorite and the $K_D^{Ctd/Chl}$ values $[(Fe^{2+}/Mg)^{Ctd}/(Fe_{tot}/Mg)^{Chl}]$ for chloritoid rims ranges between 1.67 - 1.86. This value is similar to that reported for other chloritoid-chlorite pairs from low- to medium-grade rocks (GOFFE & BOUSQUET, 1997; CHOPIN & MONIE, 1984; THEYE et al., 1992, AZANON & GOFFE, 1997). Following FRANCESCHELLI & MEMMI (1999), the zoning character in chloritoid is strongly controlled by chloritoid-forming reactions. In the stability field of pyrophyllite, X_{Mg} increases towards rim in chloritoid with increasing temperatures for any variations in pressure. This is caused by a strong negative slope of the chloritoid-forming reaction

Pyrophyllite + Chlorite ⇔ Chloritoid + Quartz + H_2O (1)

The zoning profile in chloritoid from samples Lm-73 and Lm-76, where X_{Mg} first increases and then decreases towards the rim may therefore be explained by assuming that the rocks crossed the pyrophyllite/kyanite phase boundary during the late stage of chloritoid growth and the Fe-Mg exchange between chloritoid and chlorite took place in the kyanite field. According to VIDAL et al. (1999) the equilibrium constant of this exchange reaction varies linearly with 1/T from 300°C to ca. 600°C. The empirical calibration $\ln_{KD}$(ctd/chl) = 1977.7/T(K)-0.971 (VIDAL et al., 1999), applied to the chloritoid-bearing quartzite at the Hochgrößen Massif ($K_D^{Ctd-Chl}$ = 1.63 - 1.85) resulted in temperatures of 504 - 511°C. Similar temperatures at 0.9 GPa were also estimated for kyanite-bearing metapsammites from the Alpi Apuane/Italy (FRANCESCHELLI & MEMMI, 1999) which contain chloritoid and chlorite of similar composition ($K_D^{Ctd-Chl}$ = 1.6 - 1.8). The lack of kyanite in our samples is probably the result of the bulk-rock composition of the quartzite. Calculation of the reaction

Mg-Chlorite + Muscovite + Quartz ⇔ Mg-Chloritoid + Celadonite + H_2O (2)

using the program THERMOCALC v. 2.5 (HOLLAND, 1996, written comm.) for coexisting chloritoid, muscovite and chlorite yields 500 - 510°C at 0.85 GPa (Fig. 5).

Almandine-grossularite-rich garnet, similar to those from the feldspar gneiss, is known from metagranite and orthogneisses in the Alps (ACKERMAN, et al.,1972; MASSONNE & CHOPIN, 1989, LE GOFFE & BALLEVRE, 1990; BINO & COMPAGNONI, 1992; TÖRÖK, 1997) and the Western Carpathians (VRANA, 1980; FARYAD & DIANIŠKA, 1989) (Fig. 4). It is interpreted as product of medium to high-pressure metamorphism, where plagioclase destabilizes and grossularite-rich garnet forms. In all cases, medium- to high-pressure conditions were estimated for the garnet formation. Garnet-biotite thermometry based on the methods of KLEEMAN & REINHARD (1994) and PERCHUK & LAVRENTEVA (1983) gave temperatures of 533 - 561°C and 491 - 534°C, respectively. Because plagioclase is pure albite, it was not possible to apply the GASP reaction between garnet, plagioclase, kyanite and quartz for pressure estimation. The Si content of phengite (3.25 a.p.f.u) in these rocks indicates minimum pressures of 0.8 GPa at 550°C (MASSONNE & SCHREYER, 1987). Higher pressure (1.0 GPa at 550°C) can be obtained by equilibrium reaction

Clinozoisite + Biotite + Quartz ⇔ Garnet + Muscovite + H_2O (3)

Because of the low Mg content in garnet, this reaction was calculated using the TWQ v. 2.02 program (BERMAN, 1996 written comm.) for the system KFASH. A temperature of 610°C at 1.0 GPa was derived from amphibole-plagioclase thermometry (HOLLAND & BLUNDY, 1994). However, these temperature estimates should be regarded with caution since this thermometer should only be applied to amphiboles coexisting with plagioclase of An >10 mol %.

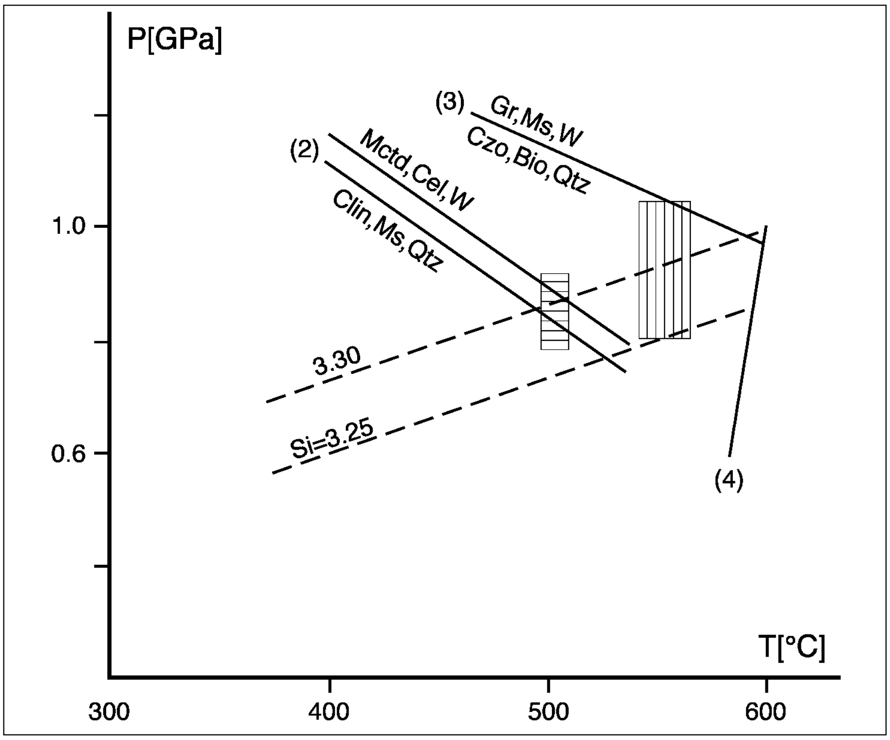

Fig. 5
Mineral equilibria for the Eo-Alpine mineral assemblages in the Permo-Triassic Formation and basement gneisses from the Hochgrößen Massif. The box with horizontal lines indicates temperature range, obtained with the calibration of VIDAL et al. (1999) for chloritoid and chlorite in the Permian quartzite. The box with vertical lines indicates the temperature range calculated with garnet-biotite thermometry for feldspar gneisses of the Seckau Complex. The Si-isopleths of phengites are according to MASSONNE & SCHREYER (1987). Line 4 shows the temperature, obtained from amphibole-plagioclase thermometry (HOLLAND & BLUNDY, 1994) for amphibolites in the Seckau Complex.

Discussion and conclusions

Textural relations and mineral compositions in the Permo-Triassic quartzites and the basement feldspar gneisses at the Hochgrößen Massif indicate that chloritoid and garnet were formed during Eo-Alpine metamorphism. Maximum temperatures of 510 - 530°C in the kyanite stability field were calculated for the Permian-Triassic quartzite and ca. 550°C at 0.9 - 1.0 GPa for feldspar gneisses of the Seckau Complex.

The estimated P-T conditions of the Permo-Triassic sedimentary cover and the basement orthogneisses from the Hochgrößen Massif fit well with the Eo-Alpine geotherm (13°C/km), inferred from the Middle Austroalpine Complexes, which overthrust the Speik Complex (FARYAD & HOINKES, 2001). The Wölz and Kor- and Saualpe Complexes situated south of the Hochgrößen Massif yielded P-T conditions of 1.2 - 1.3 GPa at 650°C and 1.5 - 1.8 GPa at 700°C, which reflects the increase of metamorphic conditions towards the south.

The Rannach Formation and the Seckau Complex adjacent to the northern part of the Wölz Complex reveal a pressure dominated metamorphic history during the Cretaceous, which may be explained by Eo-Alpine crustal thickening within the Austroalpine realm due to compressive tectonics caused by the closure and subduction of the Hallstatt-Meliatta ocean in the course of the northward drift of the African Plate towards Europe.

Acknowlegments

This work was supported by FWF – projects P13058 GEO and LM00417 GEO and VEGA 1/8071/01. K. Ettinger F. Koller and P. Tropper are thanked for reading and review of the manuscript.

References

ACKERMAND, D., KARL, F. & RASSE, P. (1972): Granat mit Zusammensetzung zwischen Almandin und Grossular aus den westlichen Hohen Tauern, Österreich. - Contrib. Mineral. Petrol., 37, 29-38.

AZANON, J. M. & GOFFE, B. (1997): High-pressure, low-temperature metamorphic evolution of the central Alpujarrides, Betic Cordillera (south-east Spain). - Eur. J. Mineral., 9, 1035-1051.

BINI, G. G. & COMPAGNONI, R. (1992): Very high-pressure metamorphism of the Brossasco coronite metagranite southern Dora Maira Massif, Western Alps. - Schweiz. Mineral. Petrogr. Mitt., 72, 347-363.

CHOPIN, C. & MONIE, P. (1984): A unique magnesiochloritoid-bearing high-pressure assemblage from the Monte Rosa western Alps: petrologic and Ar-Ar radiometric study. - Contrib. Mineral. Petrol., 87, 388-398.

EL AGEED AI. (1979): The Hochgrößen ultramafic-mafic association, its associated mineralisation and petrogenetic significance. - Unpubl. Thesis, University of Cologne, 248 pp

FARYAD, S. W. (1995): Petrology and phase relations of low-grade high-pressure metasediments from the Meliata unit, Western Carpathians, Slovakia. - Eur. J. Mineral., 7, 71-87.

FARYAD, S. W. & DIANIŠKA, I. (1989): Garnet from granitoids of the Spisško-gemerské rudohorie Mts. - Geol. Zbor. Geol. Carpath. 40, 6, 715-734.

FARYAD, S. W. & DIANIŠKA, I. (1999): Alpine overprint in the early Paleozoic of the Gemericum. - Mineral. Slov., 31, 485-490.

FARYAD, S. W., HOINKES, G. (2001): Metamorphism along a South-North Cross-section in the Middle Austroalpine units east of the Tauern Windows (Easter Alps, Austria). - Geolines, 13, 54-55.

FARYAD, S. W., HOINKES, G., MELCHER, F., PUHL, J., MEISEL, T. & FRANK, W. (2001): Relics of eclogite facies metamorphism in the Austroalpine basement, Hochgrößen (Speik Complex), Austria. - Mineralogy and Petrology (in press).

FRANCESCHELLI, M. & MEMMI, I. (1999): Zoning of chloritoid from kyanite-facies metapsammites, Alpi Apuane, Italy. - Mineral. Mag., 63, 105-110.

GOFFE, B. & BOUSQUET, R. (1997) : Ferrocarpholite, Chloritoid and Lawsonite in Metapelites of the Versoyen and Petit St Bernard Units (Valais Zone, Western Alps) (French) - Schweiz. Min. Petrogr. Mitt., 77, 137-147.

HOINKES, G., KOLLER, F., RANTITSCH, G., DACHS, E., HÖCK, V., NEUBAUER, F. & SCHUSTER, R. (1999): Alpine metamorphism of the Eastern Alps. - Schweiz. Mineral. Petrogr. Mitt., 79, 155-181.

HOLLAND, T. J. B. & BLUNDY, J. D. (1994): Non-ideal interactions in calcic amphiboles and their bearing on amphibole-plagioclase thermometry. - Contrib. Mineral. Petrol., 116, 433-447.

KLEEMANN, J. & REINHARDT, J. (1994): Garnet-biotite thermometry revisited: The effect of Al(VI) and Ti in biotite. - Eur. J. Mineral. 6, 925-941.

LE GOFF, E. & BALLEVRE, M. (1990): Geothermobarometry in albite-garnet orthogneisses: a case study from the Gran Paradiso nappe (Western Alps). - Lithos, 25, 261-280.

MASSONNE, H. J. & CHOPIN, C. (1989): P-T history of the Gran Paradiso (western Alps) metagranites based on phengite geobarometry. - In: Evolution of Metamorphic Belts (eds. DALY, S., CLIFF, R. A. & YARDLEY, B. W. D.). Geol. Soc. London, Spec. Publication, 43, 545-549.

MASSONNE, H. J. & SCHREYER, W. (1987): Phengite geobarometry based on the limiting assemblage with K-feldspar, phlogopite, and quartz. - Contrib. Mineral. Petrol., 96, 212-224.

METZ, K. (1964): Die Nordgrenze des Bösensteinkristallins nach neuen Wegaufschlüssen zwischen Trieben und Rottenmann/Steirmark. - Verh. Geol. Bundesanst, 140-149, Wien.

METZ, K. (1980): Geologische Karte der Republik Österreich, Blatt 129 Donnersbach. - Geologische Bundesanstalt, Wien.

PERCHUK, L. L. & LAVRENTJEVA, I. V. (1983): Experimental investigation of exchange equilibria in the system cordierite-garnet-biotite. - In: SAXENA, S.K. (ed.): Kinetics and equilibrium mineral reactions. Adv. Phys. Geochem., 3, 199-239.

SPEAR, F. S. & CHENY, J. T. (1989). A petrogenetic grid for pelitic schists in the system SiO_2-Al_2O_3-FeO-MgO-K_2O-H_2O. - Contrib. Mineral. Petrol. 101, 149-164.

THEYE, T. & SEIDEL, E. (1991): Petrology of low-grade high-pressure metapelites from the external Hellenides (Crete, Peloponnese). A case study with attention to sodic minerals. - Eur. J. Mineral., 3, 343-366.

THEYE, T., SEIDEL, E. & VIDAL, O. (1992): Carpholite, sudoite, and chloritoid in low-grade high-pressure Metapelites from Crete and the Peloponnese, Greece. - Eur. J. Mineral., 4, 487-507.

TÖRÖK, K. (1998): Magmatic and high-pressure metamorphic development of orthogneisses in the Sopran area, Eastern Alps (W-Hungary). - N. Jb. Mineral. Abh., 173, 63-91.

VIDAL, O., GOFFE, B., BOUSQUET, R. & PARRA, T. (1999): Calibration and testing of an empirical chloritoid-chlorite Mg-Fe exchange thermometer and thermodynamic data for daphnite. - J. Metam. Geol., 17, 25-39.

VRÁNA, S. (1980): Newly formed Alpine garnets in metagranitoids of the Veporides in relation to the structure of the central zone of the West Carpathians. - Casopis pro Mineralogie, 25, 1, 41-54.

bei der Redaktion eingegangen: 25. Mai 2001

Manuskript angenommen: 26. Juni 2001