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P-T data of Ky-St-Grt gneisses hosting HP amphibolites and eclogites from the Austroalpine Polinik complex, Kreuzeck Mountains, Eastern Alps, Austria

Research article

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Abstract: This study focuses on metapelites of the Polinik complex in the Kreuzeck Mts. southeast of the Tauern Window, Eastern Alps, where kyanite – staurolite - garnet gneisses host eclogites and high pressure (HP) amphibolites of the Austroalpine basement. The stable mineral assemblage is garnet – staurolite – biotite – kyanite – quartz. Estimated metamorphic conditions from conventional geothermobarometry are 654±30 °C and 0.9±0.08 GPa, and Average P-T values calculated by THERMOCALC, are 665±15 °C at 0.77±0.09 GPa. Formation of the present mineral association in gneisses is related to the exhumation (D2) stage of hosted eclogites/HP amphibolites within a lateral strike-slip zone.

Keywords: Ky-St-Grt gneiss • geothermobarometry • PT Average • Austroalpine Polinik complex • gneiss • eclogite • lateral strike-slip

1. Introduction

The region of the Kreuzeck Mts. southeast of the Tauern Window in the Austrian Eastern Alps reveals a contrasting Cretaceous overprint of the Austroalpine (AA) basement complexes from (sub-) greenschist to high-pressure (HP) amphibolites/eclogite facies [1–3]. The HP amphibolites/eclogites and the host Ky-Grt paragneisses, orthogneisses and rare calc-silicate layers form tectonic lenses of the AA Polinik structural complex along a dextral strike-slip shear zone (Fig. 1). The first evidence of HP metamorphism in the Kreuzeck Mts. was mentioned by [1]. Putiš et al. [2] discovered the eclogitic metabasites in close association with eclogitic micaschists, mylonites, mylonitoclasites to ultracataclasites within the AA basement and defined the separated HP Polinik structural complex (Fig. 1).

Hoke [1] found a WNW-ESE tectonic zone between the area of the Strieden peak and the Teuchl Valley and called it the main mylonite zone (MMZ). Putiš et al. [2] recog-

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nized the continuation of the MMZ further to the east at least up to the eastern edge of the Kreuzeck Massive and performed a detailed meso- and microfabric analysis along this WNW-ESE striking and steeply SSW dipping dextral lateral strike slip zone, with associated mylonites, mylonitoclasites and ultracataclasites. Mylonitoclasite is a transitional member here between mylonites and cataclasites, where plastic (dislocation creep) and cataclastic flow run contemporaneously in separated layers of the same rock. While quartz or calcite rich aggregates are still plastically deforming phases in mylonitic layers, feldspars or dolomite rich aggregates/layers behave cataclastically in the same rock. This mechanism seems to be characteristic of the exhumation temperature interval between 500 – 300 °C at relatively higher exhumation rates and differential stresses [2] in quartz-feldspar, or calcite-dolomite rocks in the studied shear zone, dividing the Ragga and Strieden structural complexes, with the exhumed HP rocks of the Polinik complex (Fig. 1).

The AA unit of the studied Kreuzeck Mts. is incorporated into Cretaceous collision nappe structure, truncated by steeply south dipping Tertiary dextral (top-to-WNW) strike slip fault zones [4–6].

The AA complexes represent an orogenic wedge [7] of continental crust that formed during the Early Cretaceous collision [8, 9] following the closure of the Meliata-Hallstatt ocean in the Late Jurassic. This event caused an extreme shortening of the AA unit with internal structural complexes metamorphosed to eclogite to greenschist facies cropping out in the Kreuzeck Mts. at the distance of a few kilometers.

The HP amphibolites, eclogites and eclogitic micaschists of the AA Polinik structural complex form tectonic lenses within the Ky-Grt paragneisses, orthogneisses and amphibolites, sporadically containing thin layers of marbles and calc-silicate rocks. These rocks often show ductile deformation and dynamic recrystallization of plagioclase and quartz, while the mafic minerals such as amphibole and pyroxene were subjected only to reaction via recrystallization during the exhumation [2].

The aim of the paper is to characterize the metamorphic P-T conditions of Ky-St-Grt paragneisses that are hosting rocks of HP amphibolites/eclogites in the Polinik structural complex. Metamorphism of Ky-St-Grt paragneisses was referred to the exhumation (D2 stage) of the HP amphibolites and eclogites. The estimated temperature of metamorphism, D1-stage, represented by peak metamorphic assemblage of HP amphibolites (garnet, barroisite, clinozoisite, rutile) to eclogites (garnet, omphacite, zoisite, rutile) was ca. 530 °C at minimum pressure of 1.1 GPa [2] according to conventional geothermobarometry. Pseudosection calculation from an eclogite yields pressure of ca. 1.6 GPa and temperature around 650 °C, represented by garnet, omphacite, zoisite, phengite, rutile field [3].

Abbreviations of minerals [10]: Ann – annite, An – anorthite, Alm – almandine Als – aluminosilicate, Bt – biotite, Chl – chlorite, Cld – chloritoid, Grt – garnet, Grs – grossular, Ky – kyanite, Ms – muscovite, Pl – plagioclase, Qtz – quartz, Prp – pyrope, Rt – rutile, Sil – sillimanite, Sps – spessartine, St – staurolite, Tur – tourmaline, Wmca – white mica.

2. Geological setting

The Alpine structure of the Eastern Alps was formed during two main orogenies, a Cretaceous orogeny followed by a Tertiary one [11]. They reflect the closure of an embayment of the Neotethys Ocean (Meliata Ocean), The latter is due to the closure of the Alpine Tethys oceans between Apulia and Europe. The result of the orogenic movement is a complex nappes stack, which is built up from north to south and from bottom to the top by the following units [12]: The proximal parts of the Jurassic to Cretaceous European margin built up the northern Alpine foreland and the Helvetic nappes comprises the Piemont-Ligurian and Valais ocean (Alpine Tethys) and the Brianconnais Terrain. Apulia consists of the northern Austroalpine nappes and the Southern Alpine unit [13]. The Cretaceous (Eo-Alpine) metamorphism affects mainly the Austroalpine nappes, while the Tertiary metamorphism primarily evidend in the Pennic domain, and some units of the Lower Austroalpine nappes show signs of both events [14, 15].

The AA nappes [16] are composed of crustal material with a complex Phanerozoic history. They can be subdivided into a Lower and an Upper Austroalpine unit. The former shows a remarkable reworking related to the opening and closure of the Piemont - Ligurian and Valais ocean, whereas the internal structure of the latter is due to the closure of the Tethys embayment. Coming from the north the Upper Austroalpine unit is built up by Mesozoic sedimentary sequences of the Northern Calcareous Alps, Paleozoic metasediments and metavolcanics of the Graywacke zone and the crystalline basement units with remnants of Paleozoic and Mesozoic metasediments.

The strongly reactivated higher-grade metamorphic Variscan basement structural complexes ("Altkristallin") with the occurrences of Alpine amphibolites to eclogites were also mapped westwards of the Kreuzeck Mountains – in the Schober Mountains - and mentioned in published short reports [17–20] for the Austrian Geological Survey

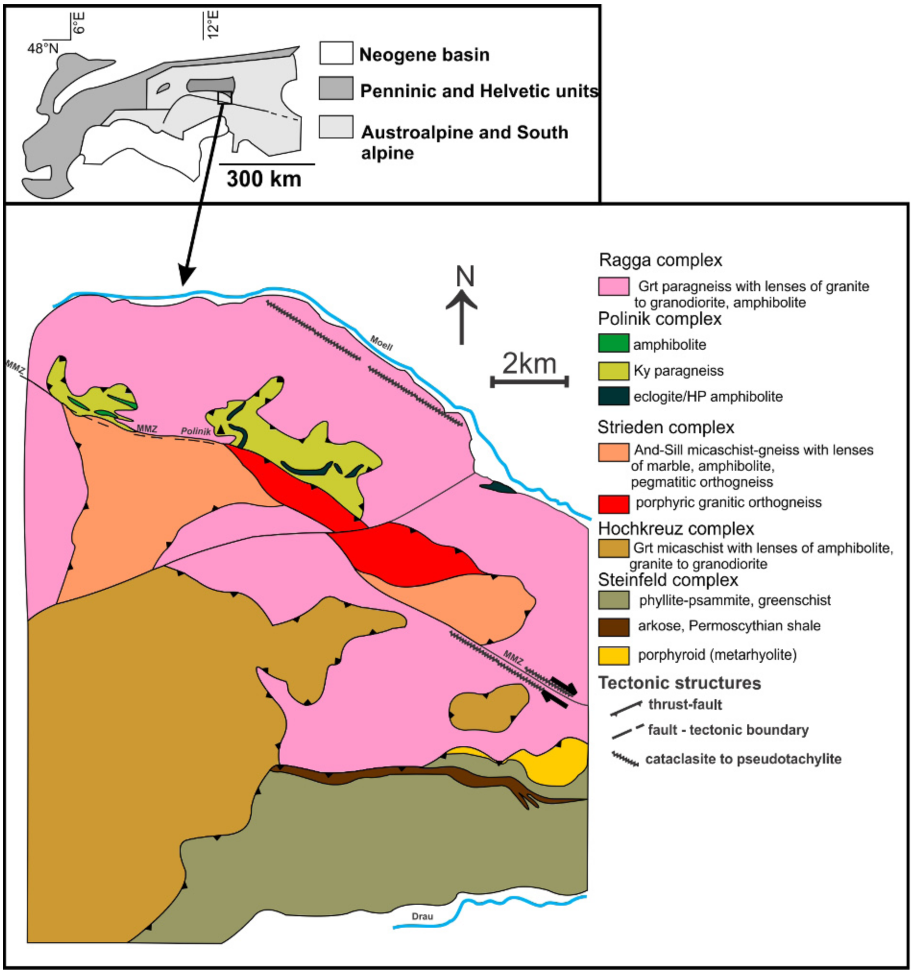

Figure 1. Simplified geological map of the central part of the Kreuzeck Mts. (after Putiš et al., 1995-1997 and Putiš, 1998)

in Vienna.

The Polinik structural complex is located in the Kreuzeck Mts. south of the Tauern Window as a part of the AA basement structural complexes (Fig. 1). Hoke [1] published examples on mesostructures and their relationship to metamorphic and mylonitic events from the northwestern part of the Kreuzeck Mts. According to mapping work [17, 21, 22] there are at least 5 stacked AA structural complexes in the Kreuzeck Mts. (Fig. 1).

They are (from north and tectonic bottom):

1. The Ragga structural complex, built of paragneisses, amphibolites, migmatites and orthogneisses;
2. The Polinik structural complex with eclogites, eclogitic high-Na augite amphibolites and barroisite-bearing amphibolites, orthogneisses and Ky-St-Grt paragneisses to eclogitic micaschists;
3. The Strieden structural complex with Sil-And paragneisses and St-Grt micaschist gneisses, associated with Grt amphibolites, Cal-Dol-Tr marbles, small pegmatitic and large orthogneiss bodies;
4. The Hochkreuz structural complex with micaschists, graphitic quartzites and large amphibolitic, gabbro-amphibolitic to layered amphibolitic bodies;
5. The Steinfeld structural complex with metapelites, metagreywackes, greenschists, porphyroids and Cld schists.

The Polinik structural complex shows the strongest Alpine overprint [2] and is restricted along the MMZ around the Polinik Mt. peak [1]. Recently, tourmaline-bearing eclogites were found in this region [3], which probably indicate

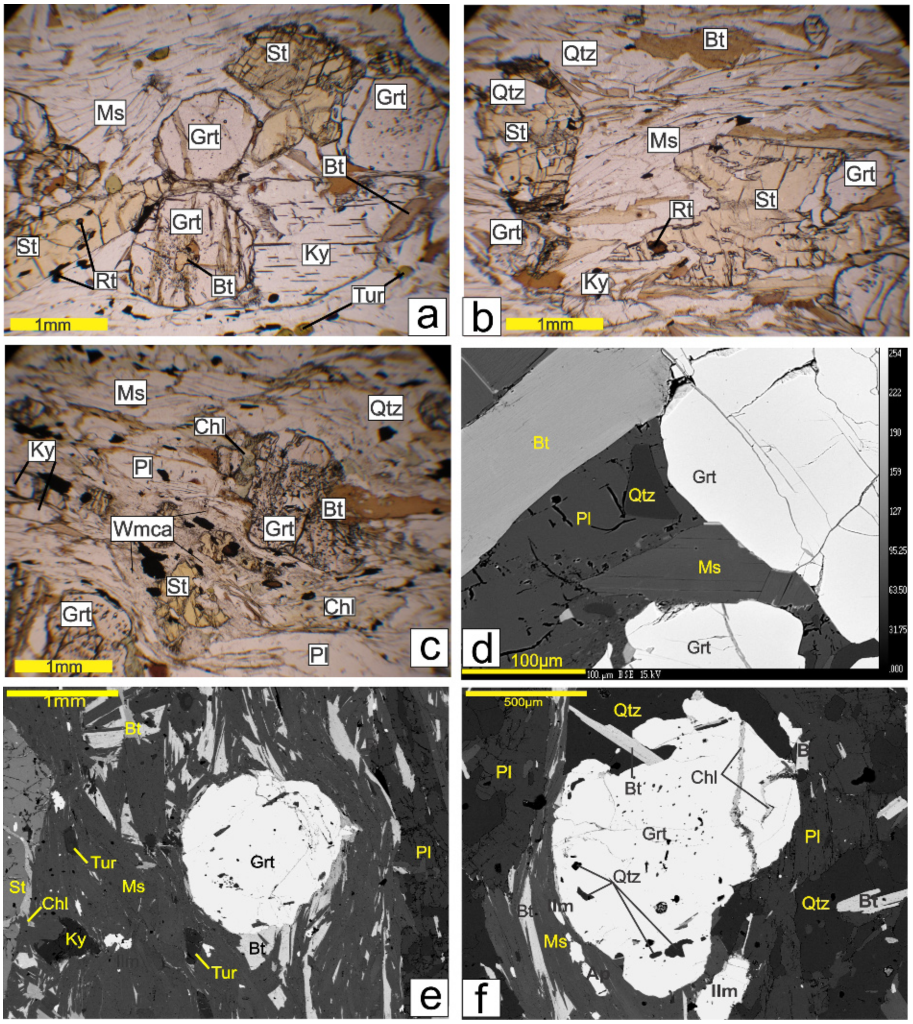

Figure 2. Microstructures and BSE images of Ky-St-Grt gneisses. a-b) Stable mineral assemblage Grt-St-Ms-Ky-Pl-Qtz (Sample Pomo41). c) Staurolite is replaced by white mica and chlorite, garnet is replaced by chlorite (Sample Pomo16). d - f) BSE images of mutual contact between Grt, Bt, Pl, Ms, used for geotermobarometry (Sample Pomo41).

external boron-rich fluid infiltration during eclogite metamorphism.

3. Material and Methods

Three samples of gneisses were collected from the area of the Polinik Mörnig (N 46°54,109', E 13°10,034') and Keselsee (N 46°53,065', E 13°12,126') in the Polinik structural complex.

Chemical composition of minerals and BSE images were obtained by using a JEOL 6310 SEM equipped with a LINK ISIS energy dispersive system and a MICROSPEC wavelength dispersive system at the Department of Mineralogy und Petrology, University of Graz (Austria), where analytical conditions were 15 keV accelerating voltage and 6 nA beam current on PCD with following standards used: Si *Kα*, Al *Kα* and K *Kα*: orthoclase, Fe *Kα*, Mg *Kα*: garnet, Mn *Kα*: rhodonite, Na *Kα*: jadeite, Ti *Kα*: sphene, Zn *Kα*: willemite, Ni *Kα*: Ni. and by a CAMECA SX-100 electron–microprobe at Dionız Štúr State Institute of Geology in Bratislava (Slovakia), where analytical conditions were 15 keV accelerating voltage and 20 nA beam current, beam size was 2 – 10 µm. The following standards were used: Si *Kα*, Ca *Kα*: wollastonite, Al *Kα*: corundum, K *Kα*: orthoclase, Fe *Kα*: fayalite, Mg *Kα*: forsterite, Mn *Kα*: rhodonite, Na *Kα*: albite, Ti *Kα*: rutile, Zn *Kα*: willemite, Ni *Kα*: Ni.

For bulk-rock chemical analysis a Bruker Pioneer S4

XRF-system was used at the Department of Earth Sciences, Karl–Franzens–University, Graz, Austria. Samples were prepared as fused pellets (containing 1 [g] powdered sample + 7 [g] Fluxana FX-X100 powder). Major and trace elements were measured and standardized by approximately 40 international standard materials. XRF analysis have the following uncertainties: major elements (1-100%: 1-2% relative), minor elements (0.1-1%: 2-5% relative), trace elements (100 - 1000 ppm: ∼5% relative; <100 ppm: 5-10% relative).

Common geothermometers based on Fe-Mg exchange reactions between coexisting Grt and Bt [23] combined with the GASP geobarometer [24] were used to estimate *P-T* conditions of metamorphism and using the average *P-T* mode in THERMOCALC (version 3.31 and dataset 5.5) [25] with internally-consistent thermodynamic dataset of [26], following the approach given in [27]. Activities for mineral end-members were calculated using the AX software written by Tim Holland [28].

4. Petrography and mineral chemistry

Ky-St-Grt paragneisses consist of the main mineral assemblage Grt, St, Bt, Ms, Pl, Ky, Qtz, ±Tur (Fig. 2a-b). Garnet forms euhedral to subhedral porhyroblast (up to 0.3 cm) and it is mostly enriched in quartz (50 – 100 μm) inclusions. Some of the porhyroblasts contain inclusions of biotite (100 – 200 μm) and white mica (100 – 150 μm).

Biotite occurs as matrix minerals and inclusion in Grt. As a matrix mineral it is in mutual contact with Grt, Ms and Pl (Fig. 2d). Kyanite occurs in the matrix as prismatic subhedral grains (Fig. 2a). Ky-Sil transformation that would indicate a shift from the kyanite into the sillimanite field is not observable. Plagioclase varies in grains size (100 – 500 μm) and occurs within the matrix only (Fig. 2d-f). The whole matrix is overgrown by muscovite. Retrograde chlorite replaces Grt and Bt. Kyanite is partly replaced by margarite and staurolite by white mica and chlorite respectively (Fig. 2c). Tourmaline, titanite, apatite, monazite occur as accessory mineral phases in the matrix.

Representative microprobe analyses are given in Table 1 - 2.

Garnet porhyroblast ($Alm_{71-77}Prp_{15-20}Grs_{5-2}Sps_{7-1}$) reveals a growth zoning (Fig. 3) with a higher Mn concentration (5 – 7 mol %) in the core ($Alm_{71}Prp_{18}Sps_{7}Grs_{2}$). The outer rim composition ($Alm_{72}Prp_{20}Grs_{5}Sps_{2}$) is poorer in Sps and richer in Prp component then the core composition. The rim shows an increase in Mn of up to 4 mol% and increase in Alm component of up to 77 mol% ($Alm_{77}Prp_{15}Sps_{4}Grs_{2}$). Ca, Mg, Mn and Fe maps of garnet (Fig. 3) show zoning patterns that are consistent with prograde Grt growth. There is a slight increase in manganese in the rim of Grt which indicates slight resorption (Fig. 3d).

All chemical analyses of biotite are normalised on the basis of 22 O assuming all Fe as Fe^{2+}. Composition of the Bt inclusions with X_{Mg} = 0.55 – 0.46 is very similar to matrix Bt with X_{Mg}=0.51 – 0.55. Ti in biotite is in the range of 0.17 – 0.21 *a.p.f.u.* (atom per formula unit).

Staurolite occurs in the matrix as porhyroblast (up to 0.1 – 0.3 cm) with inclusions of Qtz, Bt, and Rt. Staurolite contains up to 0.64 wt% of ZnO and the X_{Mg} of 0.22 – 0.14 exhibits a slight decrease towards the rim.

White mica is present as inclusions within Grt and as a porhyroblast overgrowing the foliation. Inclusions show slight chemical variation where X_{Mg} is in range from 0.5 – 0.3 and muscovite content is ∼0.6, paragonite content is ∼0.3 with celadonite ∼0.07 and Fe-celadonite ∼0.03 content. Chemical composition of matrix white mica is muscovitic ∼0.6, paragonitic ∼0.2 with celadonite ∼0.12 and Fe-celadonite ∼0.08 content in the rim.

Plagioclase composition ranges from X_{An} 0.12 – 0.13.

Quartz forms veins and occurs mostly in mutual contact with plagioclase and some occurrence is around garnet.

5. Chemical whole rock composition

The studied rocks consist of SiO_2 in the range of 50.4 – 51.13 wt%. Al_2O_3 is in the limits of 25.21 – 26.68 wt% which is compatible with the abundant occurrence of Ky and St in the rocks. The content of Fe_2O_3 varies from 10.41 to 11.39 wt%. The amount of MnO is less then 1% (0.14 – 0.32 wt%), CaO is from 0.3 to 1.4 wt% and K_2O is in the range of 4.4 – 4.7 wt%. Figure 4 displays the plotted fields for common bulk compositions for pelitic schists and metagranites. The high Al pelite field represents bulk composition of studied rocks.

6. Geothermobarometry

The *P-T* conditions of metamorphism of Ky-St-Grt paragneisses were calculated for the stable mineral assemblage Grt-Bt-St-Ms-Pl-Qtz. The intersection of Grt-Bt geothermometer and GASP geobarometer show temperature of 654±30 °C at 0.9±0.08 GPa. Temperature

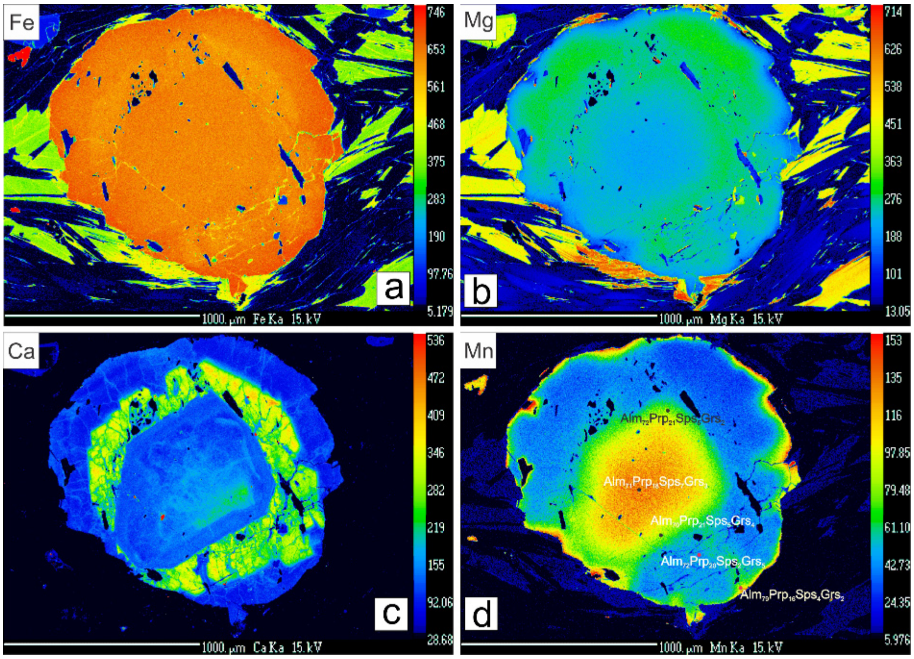

Figure 3. X-ray maps of Fe, Mg, Ca and Mn distribution in Grt in Ky-St-Grt gneiss, sample Pomo41.

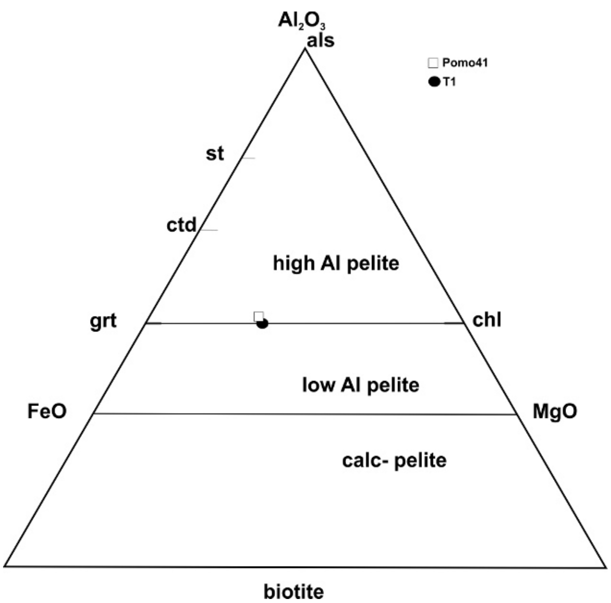

Figure 4. AFM projection showing position of bulk composition of Ky-St-Grt gneisses. Projection is done from muscovite using composition corrected for Al_2O_3.

665±15 °C at 0.77±0.09 GPa has been calculated by P-T average mode in THERMOCALC 3.31 (Table. 3). Results are in good accordance with THERMOCALC calculations as can be expected from mineral assemblage and chemistry.

7. Discussion and conclusions

The change of tectonic regime from compressional thrusting to strike slip is evident from the mapped geological structure of the Kreuzeck Mts., as well as microstructures and related textural patterns of Qtz and Cal [2]. This is related to the closure of the Pennine ocean and the following continental collision between Apulia or Adria indenter (with the AA structural complexes) and the European plate [11, 12].

Pre-Late-Cretaceous collisional compression and nappe thrusting of the AA structural complexes within the studied area can be inferred mainly from regional subhorizontal boundaries of the 5 crustal sheets or nappes (= structural complexes), thrust one over another with a clear north-directed vergency [2, 29].

The HP Polinik and the MP Strieden structural complexes, which were tectonically emplaced onto the Ragga structural complex, represent the AA basement fragments with the recorded features of Cretaceous-Tertiary reactivation, because these complexes are located along the ductile-brittle strike-slip shear zone or MMZ [1, 2].

Hoke [1] proposed exhumation of HP rocks along the MMZ

Table 1. Representative microprobe analyses of garnet, biotite and white mica.

Garnet							Biotite				White mica		
Sample	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41
Position	core	rim	core	rim	core	rim	incl	incl	core	rim	matrix	matrix	matrix
SiO_2	37.78	37.80	37.56	37.35	37.76	37.33	36.49	35.93	35.84	34.91	47.85	47.35	46.71
TiO_2	0.01	0.02	0.00	0.00	0.00	0.00	1.43	1.78	1.47	1.32	0.72	0.62	0.63
Al_2O_3	20.71	21.00	20.58	20.69	20.72	20.46	18.52	18.57	18.19	18.51	36.18	37.05	36.72
FeO	31.84	34.29	32.45	34.81	34.17	35.39	16.49	19.62	19.12	19.81	0.64	0.75	0.59
MnO	2.96	1.73	2.67	3.07	0.79	1.84	0.13	0.16	0.00	0.00	0	0	0
MgO	4.59	3.86	4.61	2.97	5.21	4.01	11.01	9.41	10.10	9.64	0.57	1.1	0.87
CaO	1.22	0.60	1.26	1.04	0.51	0.63	0.10	0.09	0.00	0.00	0	0.03	0
Na_2O	bd	bd	bd	bd	bd	bd	0.15	0.15	0.25	0.13	2.12	2.14	2.16
K_2O	bd	bd	bd	bd	bd	bd	9.34	8.95	8.91	9.07	8.15	8	8.1
Total	99.12	99.30	99.13	99.93	99.16	99.66	93.65	94.66	93.88	93.39	96.23	97.04	95.78
Si	3.032	3.030	3.019	3.016	3.025	3.009	5.560	5.493	5.513	5.433	3.107	3.053	3.052
Al	1.960	1.989	1.952	1.970	1.958	1.947	3.326	3.346	3.298	3.395	0.035	0.030	0.031
Ti	0.000	0.001	0.000	0.000	0.000	0.000	0.163	0.205	0.170	0.155	2.769	2.815	2.828
Fe^{3+}	0.007	0.000	0.026	0.012	0.016	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{2+}	2.130	2.329	2.156	2.338	2.273	2.346	2.101	2.509	2.459	2.578	0.035	0.040	0.032
Mn	0.201	0.117	0.182	0.210	0.054	0.126	0.017	0.021	0.000	0.000	0.000	0.000	0.000
Mg	0.549	0.461	0.552	0.357	0.622	0.482	2.501	2.146	2.316	2.236	0.055	0.106	0.085
Ca	0.105	0.051	0.109	0.090	0.044	0.054	0.016	0.015	0.000	0.000	0.000	0.002	0.000
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.043	0.074	0.039	0.267	0.268	0.274
K	0.000	0.000	0.000	0.000	0.000	0.000	1.816	1.745	1.748	1.799	0.675	0.658	0.675
X_{alm}	0.71	0.79	0.72	0.78	0.76	0.78							
X_{prp}	0.04	0.02	0.04	0.03	0.01	0.02							
X_{sps}	0.07	0.04	0.06	0.07	0.02	0.04							
X_{grs}	0.04	0.02	0.04	0.03	0.01	0.02							
X_{Mg}	0.18	0.16	0.18	0.12	0.21	0.16	0.54	0.46	0.49	0.46			

due to Cretaceous northward syn-collisional thrusting of the AA unit. A low-angle normal fault might have been active during the first exhumation stage as a continuation of collision/subduction D1 stage. However, no N-S striking stretching lineations have been preserved due to D2 and D3 tectonometamorphic overprints within the lateral strike-slip zone.

Putiš et al. [2] have proved that the final medium- (D2) to low-temperature (D3) exhumation occurred in a lateral transpression zone evidenced by the subhorizontal orientation of stretching lineations and asymmetric textural patterns of quartz and calcite. The data in this paper are related to final exhumation and emplacement of the HP (the Polinik structural complex) and MP rocks (the Strieden structural complex) during the Late Cretaceous dextral lateral strike slip movements in the frontal part of this collision wedge with stacked basement structural complexes.

Grt-St-Ky paragneisses as host rocks of metabasites (HP amphibolites to eclogites) in the Polinik structural complex reflect the metamorphic conditions of the exhumation (D2) stage of the HP rocks. They were either completely adapted to D2 metamorphic conditions during the exhumation of HP rocks, or they are the host rocks for only the D2 exhumation stage of the enclosed HP rocks. They do not preserve any relics of metamorphic minerals from an inferred former D1 peak burial stage.

The rock textures and conventional geothermobarometric data suggest intermediate to high grade of metamorphism of Grt-Ky paragneisses in the upper amphibolite facies. Zonation of Grt growth indicates prograde metamorphic reactions in paragneisses. The HP metabasites were partly retrograde overprinted at similar conditions [1, 2]. A slight retrograde overprint is seen in the Mn increase in garnet rims, which can be interpreted as the result of local resorption (Fig. 3d).

Table 2. Representative microprobe analyses of staurolite and plagioclase.

	Staurolite					Plagioclase		
Sample	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41	Pomo41
Position	core	rim	core	rim	rim	Pl	Pl	Pl
SiO_2	28.24	28.77	28.72	28.96	28.90	66.37	66.97	67.06
TiO_2	0.62	0.48	0.72	0.54	0.66	bd	bd	bd
Cr_2O_3	0.05	0.00	0.01	0.02	0.08	bd	bd	bd
Al_2O_3	53.72	54.79	54.57	54.90	54.71	21.29	21.56	21.35
FeO	12.99	11.85	12.62	12.20	12.39	bd	bd	bd
MnO	0.11	0.07	0.10	0.06	0.21	bd	bd	bd
MgO	1.92	1.11	1.55	1.13	1.33	bd	bd	bd
ZnO	0.64	0.60	0.51	0.50	0.45	bd	bd	bd
CaO	bd	bd	bd	bd	bd	2.49	2.56	2.41
Na_2O	bd	bd	bd	bd	bd	9.33	9.33	9.46
K_2O	bd	bd	bd	bd	bd	0.09	0.11	0
Total	98.26	97.67	98.81	98.31	98.73	99.69	100.53	100.46
Si	7.791	7.915	7.845	7.919	7.889	2.913	2.913	2.919
Ti	0.128	0.099	0.147	0.111	0.136	0.000	0.000	0.000
Cr	0.010	0.000	0.002	0.005	0.017	0.000	0.000	0.000
Al	17.471	17.764	17.570	17.694	17.605	1.101	1.105	1.095
Fe^{2+}	2.997	2.725	2.883	2.791	2.830	0.000	0.000	0.000
Mn	0.025	0.016	0.022	0.013	0.049	0.000	0.000	0.000
Mg	0.788	0.457	0.632	0.459	0.540	0.000	0.000	0.000
Zn	0.130	0.121	0.104	0.101	0.090	0.000	0.000	0.000
Ca	0.000	0.000	0.000	0.000	0.000	0.117	0.119	0.112
Na	0.000	0.000	0.000	0.000	0.000	0.794	0.787	0.798
K	0.000	0.000	0.000	0.000	0.000	0.005	0.006	0.000
X_{Mg}	0.21	0.14	0.18	0.14	0.16			
X_{An}						0.13	0.13	0.12

Table 3. Average P-T according to THERMOCALC v3.31, abbreviation of end members after [26]

Sample	T(°C)	P(Gpa)	X_{H_2O}	Fit	Cor	End members	Independent set of reactions
Pomo41	665±15	0.77±0.09	1	0.8	0.79	fst, an, ab, mu, pa, phl, ann, east, py, gr, alm, q, H_2O, ky	1) gr + q + 2ky = 3an 2) 6fst + 23gr + 48q = 69an + 8alm + 12H_2O 3) 3an + pa = ab + gr + H_2O + 3ky 4) 3east + 6q = 2mu + phl + py 5) mu + 2phl + 2ky = 3east + 5q 6) ann + q + 2ky = mu + alm

The observed mineral assemblage Grt, Bt, St, Ms, Pl, Qtz, Ky ± Tur indicates intermediate *P-T* Barrovian type of metamorphism. *P-T* condition were obtained by conventional geothermobarometry (654±30 °C at 0.9±0.08 GPa) and *P-T* Average mode from calculated equilibrium reactions by THERMOCALC 3.31 (665±15 °C at 0.77±0.09 GPa).

The reaction involved during metamorphism of Grt-Ky paragneisses resulting in the formation of Grt and Bt at the expense of Chl and Ms is:

$$1Ms + 3Chl + 3Qtz = 4Alm + 1Ann + 12H_2O \qquad (1)$$

This reaction limits the presence of Chl where Ms is in excess and is replaced by Grt and Bt at a temperature of about 520 °C [30]. Considering Mn contents in garnet cores, it can be assumed that Grt appears most likely at temperatures around 500 °C. Staurolite formation involves two main reactions:

$$Cld = St + Grt + Chl \quad (2)$$

$$Grt + Chl = St + Bi \quad (3)$$

The chloritoid consuming reaction 2 is not observed in our samples. No inclusions of Cld were identified in garnet, so it can be assumed that reaction 3 is the main discontinuous AFM reaction producing St, partly consuming Grt at temperatures slightly above 600 °C [30, 31]. Formation of Ky shortly thereafter, involves some St and all Chl being removed from the assemblage with the production of some Bt via reaction:

$$St + Chl = Ky + Bt \quad (4)$$

The resulting mineral assemblage is St-Ky-Bt-Grt-Ms-Pl-Qtz, representing middle to upper part of amphibolite facies (ca. 650 °C at 0.7-1.0 GPa), which is consistent with microtextural and geothermobarometric data.

The obtained petrological data do not provide any evidence of paragneisses as primary host rocks of HP metabasites during the D1 burial stage. Rather, alternation of these rocks as different lithological layers in many outcrops, indicate their common D1 stage of collision-subduction burial.

Rapid uplift and nearly isothermal decompression enabled sufficient time for the action of amphibolites facies conditions during the D2 exhumation stage of the HP rocks, including the host paragneisses.

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