PETROLOGY OF A CORDIERITE-ANDALUSITE-BEARING GRANITE FROM THE SATTELSPITZE (MONTE SELLA), FRANZENSFESTE (SOUTH TYROL, ITALY)

by

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Abstract

The Permian intrusive complexes in the northern realm of the Southalpine domain, the Brixen/Bressanone granite, the Ifinger/Ivigna granodiorite and the Kreuzberg/Monte Croce granite, cover an area of about 250 km^2 and are aligned along the Periadriatic Lineament. The Brixen granite is the only plutonic complex that shows a wide compositional variation in lithologies, compared to the compositionally rather uniform Ifinger and Kreuzberg granodiorite/granite. The major part of the Brixen granite is granitic-granodioritic in composition with the mineral assemblage K-feldspar + plagioclase + biotite + quartz + accessories (zircon, apatite, ilmenite, ± monazite). The south-eastern border is characterized by the occurrence of tonalite, quartz-diorite and quartz-gabbro. At the north-western rim, several unusual types of plutonic bodies occur, namely a garnet-fayalite-bearing granite and a two mica- andalusite-cordierite-granite. Geological and geochemical investigations reveal that the two mica codierite-andalusite granite from the Sattelspitze (Monte Sella) represents a peraluminous pegmatitoid body of the latest stage of magmatic activity.

Introduction

In the Southalpine domain, the Permian intrusive complexes of the Brixen, Ifinger and Kreuzberg granite/granodiorite cover an area of ~ 250 km^2 (Fig. 1) and are thought to have been the result of the collapsing Variscan orogenic belt, which led to the formation of large extensional terrains (ACQUAFREDDA et al., 1997; BARGOSSI et al., 1981; BARGOSSI et al., 1998; DEL MORO & VISONA, 1982). Although these intrusive complexes were already mapped (DEL MORO & VISONA, 1982) and considerable literature concerning their magmatic evolution already exists (BONIN et al., 1993; SCHUSTER et al., 2001; DAL PIAZ & MARTIN, 1998) only geochronological data (BONIN et al., 1993; BORSI et al., 1972; ROTTURA et al., 1998; MAROCCHI et al., 2008) and almost no petrological data from the intrusions (BONIN et al., 1993; ACQUAFREDDA et al., 1997) are available so far. The aim of this research is to obtain a genetic frame for the different intrusions especially for the peraluminous, aluminosilicate-bearing samples.

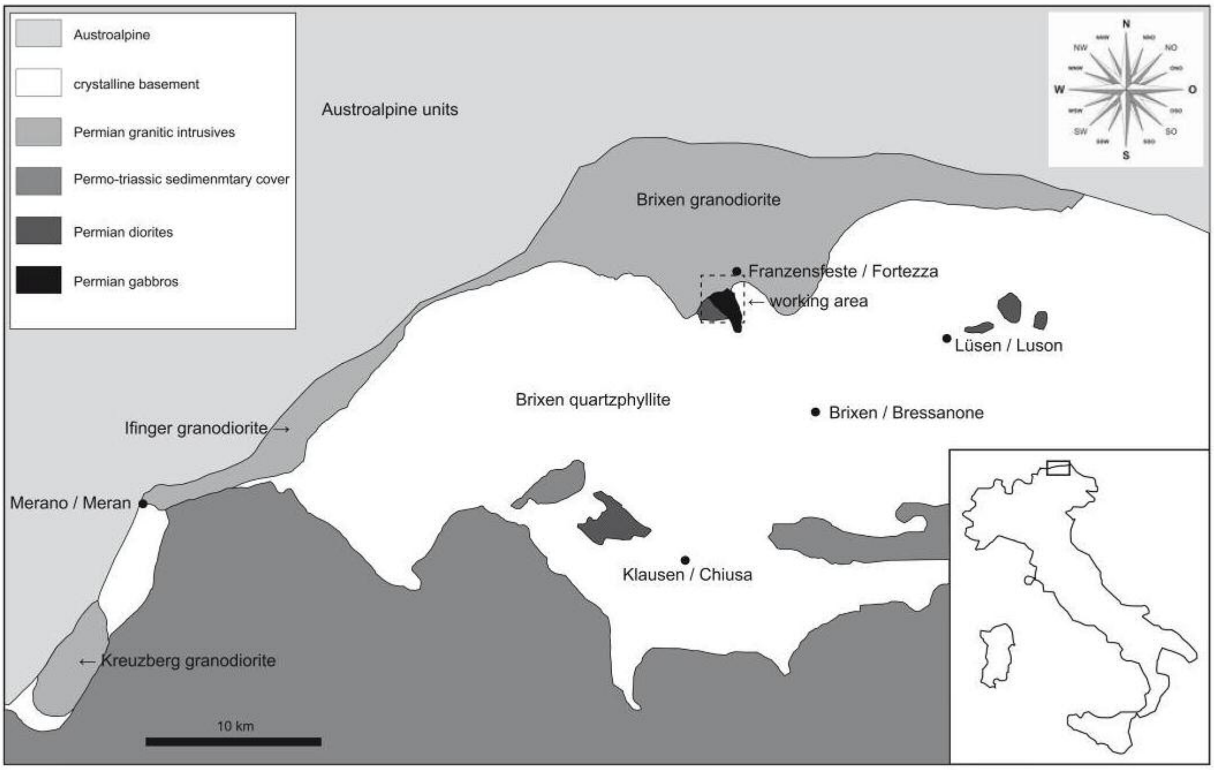

Fig. 1:
Schematic geological sketch of the northern Southalpine area showing the major tectonic units and lithologies.

Geological relations

The Brixen granite complex is a composite intrusion and intruded into the Variscan metamorphic basement of the Brixen quartzphyllites during the Permian extensional phase after the collapse of the Variscan orogeny. This complex shows a wide spread of different intrusion types which can roughly be referred to a dyadic magmatic evolution (BARGOSSI et al., 1998). The south-eastern part is composed of frequently occurring gabbroic-dioritic rocks which represent the first part of the magmatic development followed by granitic-granodioritic intrusions (Fig. 2) and occasionally peraluminous pegmatitoid bodies occur, which represent the last magmatic activity.

Pegmatitoid bodies (e.g. garnet-fayalite granite, two-mica-cordierite-andalusite granite, Fig. 3, Fig. 4), which clearly crosscut the granite were found at the north-western rim of the intrusive body.

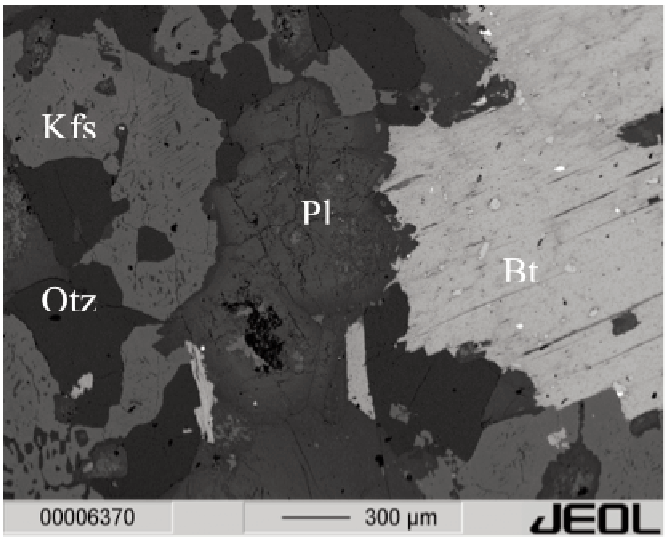

Fig. 2:
Back scattered electron (BSE) image of the Brixen granite (sample Gr A) showing the mineral assemblage K-feldspar (Kfs) + plagioclase (Pl) + biotite (Bt) + quartz (Qtz).

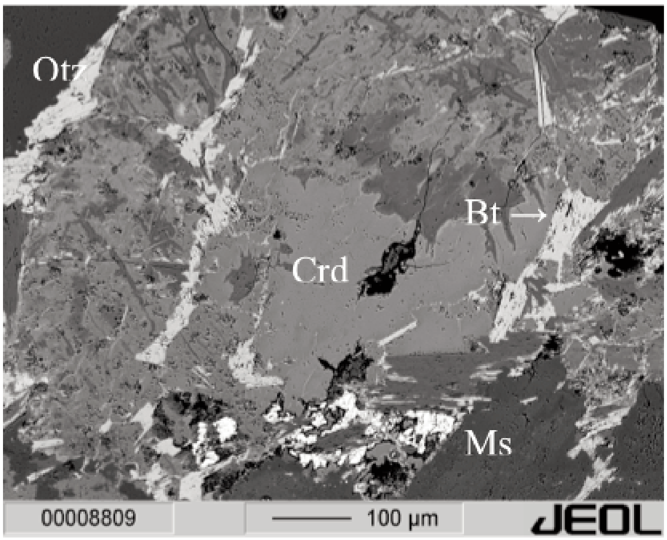

Fig. 3:
BSE image of the two mica-andalusite-cordierite granite showing the assemblage biotite (Bt) + cordierite (Crd) + muscovite (Ms) + quartz (Qtz).

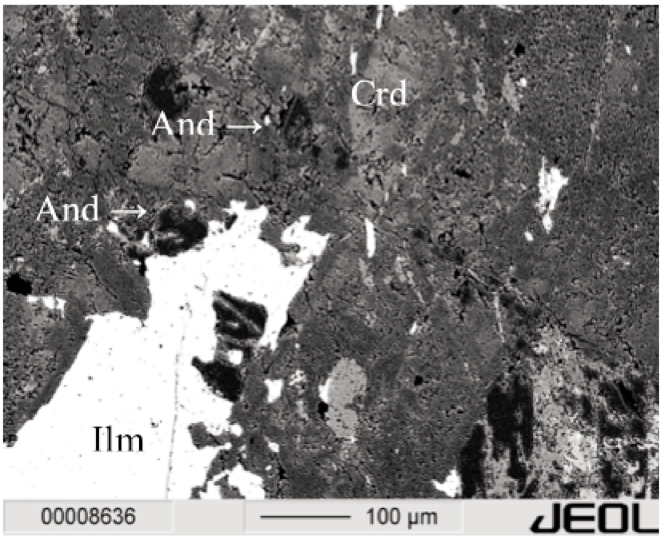

Fig. 4:
BSE image of the two mica-andalusite-cordierite granite showing andalusite (And) adjacent to cordierite (Crd) and ilmenite (Ilm). Andalusite shows the typical rhombohedral habitus.

Analytical techniques

Electron microprobe analysis (EMPA) of all minerals was performed using the JEOL 8100 SUPERPROBE at the Institute of Mineralogy and Petrography at the University of Innsbruck. Operating conditions were 15 kV acceleration Voltage and 20 nA beam current. A scanning mode with a raster size of at least 10 x 7 μm was used for the analysis of feldspars and micas to prevent loss of alkalis. Mineral formulae were calculated using the software NORM II (ULMER 1993, written comm.).

Micro-Raman spectroscopy: confocal micro-Raman spectra were obtained with a HORIBA JOBIN YVON LabRam-HR 800 micro-Raman spectrometer. Samples were excited at room temperature with the 633 nm emission line of a 17 mW He-Ne-laser through an OLYMPUS 100X objective. The laser spot on the surface had a diameter of approximately 1 μm and a power of about 5 mW. Light was dispersed by a holographic grating with 1800 grooves/mm. Spectral resolution of about 1.8 cm^{-1} was experimentally determined by measuring the Rayleigh line. The dispersed light was collected by a 1024 x 256 open electrode CCD detector. Confocal pinhole was set to 1000 μm. Several spectra of single crystals of aluminium silicates in thin sections were recorded without polarizers for the exciting laser and the scattered Raman light.

The spectra were baseline-corrected by subtracting linear or squared polynomial functions and fitted to Voigt functions. Peak shifts were calibrated by regular adjusting the zero-order position of the grating and controlled by measuring the Rayleigh line of a (100) polished single crystal silicon-wafer. Accuracy of Raman peak shifts was better than 0.5 cm^{-1}. The detection range was 100-4000 cm^{-1}.

X-ray fluorescence analysis (XRF): Bulk rock XRF analyses were done at the Institute of Earth Science, Department of Mineralogy and Petrology in Graz using a Bruker Pioneer S4 X-Ray flourescence spectrometer. The samples were ground to a powder and prepared as fused pellets using $LiBO_4$ flux.

Petrography and mineral chemistry of the Brixen granite

The major part of the intrusion is represented by rocks with the assemblage of plagioclase + K-feldspar + biotite + apatite + zircon + quartz (Fig. 2). Areas of higher proportions of biotite and amphibole (DEL MORO & VISONA 1982) most likely occur in zones of higher water content within the melt. For our research two samples were investigated. Sample A (from the quarry Sachsenklemme) represents the central part of the granite and sample FF4 the rim in close vicinity to the quartzphyllite basement. Biotites from sample A and FF4 are very similar and show low amounts of Al and an enrichment in Ti. The average amounts of sample A are Ti = 0.436 apfu and Al = 2.705 apfu. Sample FF4 shows a composition of Ti = 0.435 apfu and Al = 2.593 apfu. K-feldspar from sample A shows X_K = 0.946, X_{Na} = 0.054, X_{Ca} = 0.000 which is different to sample FF4 showing X_K = 0.897, X_{Na} = 0.102, X_{Ca} = 0.001. Plagioclase grains from sample A show a zonation from anorthite-rich cores to albite-rich rims which could not be detected within sample FF4. Plagioclase cores from sample A show a composition of X_K = 0.016, X_{Na} = 0.461 and X_{Ca} = 0.523. The rim analyses are enriched in Na and yielded X_K = 0.023, X_{Na} = 0.625, X_{Ca} = 0.325. Compared to these data the plagioclase from sample FF4 shows a composition of X_K = 0.026, X_{Na} = 0.463, X_{Ca} = 0.511 which is similar to the core composition of sample A. This effect can be explained by faster cooling at the rim of the intrusion causing a chilled margin, while central parts had more time for cooling. In the north-western part the granite is cross cut by several pegmatitoid intrusions of highly variable sizes. A fayalite-granite (DEL MORO & VISONA, 1982) for example was located near Weißenbach, but only found as small lenses within the granite. Fayalite (Fe = 1.570 apfu, Mg = 0.016 apfu, Mn = 0.351 apfu, Si = 1.028 apfu, Σ = 2.965) occurs as small grains within quartz which then again is included in biotite. Fayalite was also analyzed using micro-Raman spectroscopy clearly showing the presence of a significant tephroite component. Within this sample garnet (X_{Fe} = 0.630, X_{Mg} = 0.010, X_{Mn} = 0.340, X_{Ca} = 0.020) occasionally occurs and is often associated with tourmaline.

Petrography and mineral chemistry of the cordierite-andalusite granite

The two-mica-cordierite-andalusite-bearing granite occurs at the Sattelspitze and contains the mineral assemblage quartz + K-feldspar + plagioclase + biotite + cordierite + muscovite + andalusite + ilmenite + apatite + zircon. Andalusite occurs as idiomorphic grains with an average diameter of about 50 microns, which are often surrounded by fine grained muscovite seams (Fig. 4). Cordierite shows beginning alteration to pinite (muscovite + chlorite) at the grain boundaries (Fig. 3).

Only the innermost parts of the cordierite grains do not show any alteration. Quartz and K-feldspar form large grains of up to hundred and more microns. Cordierite has a X_{Mg} of 0.3 and Na contents of 0.195 ± 0.035 apfu. K-feldspar shows an average composition of $X_K = 0.943$, $X_{Na} = 0.056$, $X_{Ca} = 0.001$ and plagioclase $X_K = 0.022$, $X_{Na} = 0.562$, $X_{Ca} = 0.416$. Biotites show Ti contents of 0.084 (± 0.028) apfu and Al contents of 4.068 (± 0.076) apfu. Muscovite from this sample shows Si contents of 3.035 (± 0.021) apfu and Al contents of 2.843 (± 0.033) apfu. Muscovite contains only a small phengitic component (Si - 3) of 0.035 apfu. Representative analyses of the minerals are shown in Table 1.

	Crd	Kfs	Pl	Bt	Ms
SiO_2	47.37	64.95	59.86	33.94	44.56
MgO	3.74	n.d.	0.01	4.30	0.50
K_2O	n.d.	15.85	0.33	9.57	10.70
CaO	0.00	n.d.	5.26	n.d.	n.d.
FeO	13.26	n.d.	0.03	23.45	1.45
Na_2O	0.73	0.76	7.99	0.18	0.70
Al_2O_3	31.75	18.46	25.00	21.80	36.48
Cr_2O_3	n.a.	n.d.	n.d.	0.009	0.02
TiO_2	0.03	n.d.	n.d.	0.96	0.06
MnO	1.27	0.03	0.01	0.63	0.03
Total	98.15	100.05	98.48	94.84	94.50
Si	5.034	2.996	2.697	5.306	6.007
Mg	0.593	n.d.	0.001	1.003	0.099
K	n.d.	0.933	0.019	1.909	1.840
Ca	n.d.	n.d.	0.254	n.d.	n.d.
Fe	1.179	n.d.	0.001	3.067	0.163
Na	0.151	0.068	0.698	0.055	0.183
Al	3.978	1.004	1.328	4.017	5.795
Cr	n.a.	n.d.	n.d.	0.001	0.002
Ti	0.002	n.d.	n.d.	0.113	0.006
Mn	0.115	0.001	n.d.	0.084	0.004
O	18.000	8.000	8.000	22.000	22.000
∑ cat.	11.050	5.002	4.998	15.555	14.099

Table 1:
Representative analyses of cordierite (based on 18 O), K-feldspar (based on 8 O), plagioclase (based on 8 O), biotite (based on 22 O) and muscovite (based on 22 O). Formulae were calculated using the program NORM Version 4.0 (ULMER, written comm.). n.d. = not detected, n.a. = not analyzed.

Thermobarometry of the cordierite-andalusite granite

Applying the Na-in-cordierite thermometer calibrated for granites (THOMPSON et al., 2002), yields T of about 550°C with an assumed $a_{H2O} = 0.5$. For this thermometer a lowering of a_{H2O} to 0.1 results only in slightly lower temperatures of 500–550°C. The occurrence of andalusite limits pressure to about 0.3 GPa at ca. 550°C.

Discussion

The rare cordierite-andalusite-bearing granite shows a peraluminous ($Al_2O_3 > Na_2O + K_2O + CaO$) character in terms of the bulk composition. The formation of these intrusions is thought to be related to the formation of melt in the crust caused by decompression during the extensional phase of the collapsing orogen (DEWEY, 1998; MALAVIEILLE, 1993; SCHUSTER et al., 2001; DAL PIAZ, 1993; DAL PIAZ & MARTIN, 1998). This decompression leads to a lowering of the melting temperature of the magma and further leads to the emplacement of viscous magma in rather shallow depths of the continental crust (DEWEY, 1998; MALAVIEILLE, 1993; SCHUSTER et al., 2001; DAL PIAZ, 1993). The cordierite-andalusite-bearing granite is geologically related to the granitic – granodioritic intrusions of the Brixen granite which represents the parent source of this late magmatic activity. In terms of its bulk composition, the cordierite-andalusite-bearing granite of the Sattelspitze shows an unusual composition which clearly distinguishes it from the surrounding parent granite/granodiorite (Table 2).

Sample	**MS4**	**MS5**		**MS4**	**MS5**		**MS4**	**MS5**
LOI	**1.23**	**1.05**	Ba	388	426	Pr	4	5
SiO2	**71.85**	**72.10**	Ce	28	38	Rb	248	256
Al2O3	**13.49**	**13.72**	Co	0	5	Sr	77	93
Fe2O3	**1.71**	**1.48**	Cr	0	1	Th	20	13
MnO	**0.05**	**0.05**	Cs	2	24	U	3	7
MgO	**0.25**	**0.21**	Cu	9	1	V	10	11
CaO	**0.78**	**0.36**	Ga	18	17	W	32	30
Na2O	**2.94**	**3.65**	Hf	6	3	Y	27	26
K2O	**5.08**	**5.22**	La	17	13	Zn	61	35
TiO2	**0.10**	**0.10**	Mo	0	3	Zr	95	60
P2O5	**0.10**	**0.10**	Nd	22	15	F	876	936
			Ni	14	12	Cl	0	1852
Total	**97.78**	**98.43**	Pb	64	48			

Table 2:
X-ray fluorescence analyses of the different intrusions from the area around Brixen. MS4 and MS5 are samples from the summit of the Sattelspitze (Monte Sella) which is the two mica-cordierite-andalusite granite. Amounts are given in weight percent (%) for the major oxides and in parts per million for the minor and trace elements (ppm).

Regarding the anatomy and classification of Al-rich pegmatites, the cordierite-andalusite-bearing granite type, detected in this area, should be labeled as miarolitic or eventually rare-element pegmatite (CERNY, 1982). The miarolitic pegmatites of the shallow level are found within granites or in the immediate vicinity (CERNY, 1982). Shallow depths and miarolitic pegmatites respectively are defined by CERNY (1982) to emplace in depths in the range of 1.5–3.5 km followed by the rare element pegmatites, occurring in a depth of 3.5–7.0 km. In the zone from 7–11 km mica-bearing pegmatites should form and >11 km depth, granulite-facies pegmatites occur (CERNY, 1982). Compared with the pressure conditions calculated for the Ifinger granodiorite the emplacement of these pegmatitoid bodies should be somewhere near the border of miarolitic to rare element pegmatites.

The bulk compositions of these rocks as shown in Table 2 are close to that of granites (CERNY, 1982) but they deviate from the average granitic composition mainly by low CaO and K_2O/Na_2O contents.

The genetic evolution of the two mica cordierite-andalusite granite is interpreted to form from a highly peraluminous residual melt. Andalusite is interpreted to be a primary phase within these rocks due to its appearance as idiomorphic grains, which most likely excludes them from forming during subsolidus processes (e.g. during breakdown of cordierite or another high Al-bearing phase). The formation of andalusite within these pegmatitoid rocks is also characteristic for low-pressure metamorphic terrains (CERNY & HAWTHORNE, 1982).

The magmatic bodies of this investigation intruded into the Variscan metamorphic basement during the Permian extensional phase after the collapse of the Variscan orogeny (SCHUSTER et al., 2001). The geodynamic model of the calc-alkaline magmatism is still a matter of debate and so far two tectono-magmatic models have been developed: i) magmatism originated in response to post orogenic lithospheric extension, without any relation to subduction (VOSHAGE et al., 1990; SINIGOI et al., 1994; BORIANI et al., 1995; ROTTURA et al., 1997, 1998; BARGOSSI et al., 1999; QUICK et al., 2003) and ii) magmatism originated in an Andean-type continental margin at the southern flank of the Variscan belt (VISONA, 1982; LORENZ & NICHOLLS, 1984; STILLE & BULETTI, 1987; DI BATTISTINI et al., 1988; FINGER & STEYRER, 1990). The Brixen granite complex is referred to have undergone a dyadic magmatic evolution, due to its large spread in chemical compositions (BARGOSSI et al., 1998). Late-stage pegmatitoid bodies such as the garnet-fayalite granite and the two-mica-cordierite-andalusite granite clearly crosscut the granodiorite and thus form the latest stage of the magmatic evolution of this complex. Geochronological investigations on the garnet-fayalite granite using Sm/Nd garnet and whole rock isochrones yielded 280 ± 2 Ma for this late stage of magmatism.

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