AUSTRIAN JOURNAL OF EARTH SCIENCES | VOLUME 103/2 | 132 - 137 | VIENNA | 2010

THE EVOLUTION OF THE MAGNETIC TEXTURES ACROSS THE SOUTHERN CONTACT AUREOLE OF THE BRIXEN GRANODIORITE (SOUTH-TYROL, ITALY)

Werner F. THÖNY[1)*)], Stefan WYHLIDAL[1)], Wolfgang THÖNY[2)], Peter TROPPER[1)] & Robert SCHOLGER[2)]

1) University of Innsbruck, Faculty of Geo- and Atmospheric Sciences, Institute of Mineralogy and Petrology,

1) Innrain 52, A-6020 Innsbruck, Austria;

2) University of Leoben, Chair of Geophysics, Peter-Tunner-Strasse 25, 8700 Leoben, Austria;

*) Corresponding author, werner.thoeny@uibk.ac.at

KEYWORDS

susceptibility
anisotropy
magnetic
aureole
contact
texture

ABSTRACT

The southern rim of the Brixen granodiorite complex near Franzensfeste/Fortezza provides an excellent opportunity to study the influence of contact metamorphism on the magnetic fabric of the Variscan metamorphic Brixen quartzphyllite. A well defined profile was sampled in order to establish the petrological, mineralogical and textural influence of the thermal overprint. Four distinct zones could be specified in terms of their mineralogical composition in a vicinity of less than 200 meters from the contact with the intrusion. Within this area an increase of temperature from 520°C far (~ 200m) from the contact up to 600°C near (~ 10m) the contact was established. Anisotropy of magnetic susceptibility (AMS) data show that the magnetic texture changes only very little across most part of the contact aureole. Only in the innermost hornfelses (~ 600°C), the clearly oblate fabric of the Brixen Quartzphyllite changes into a well defined slightly dipped prolate fabric similar to the fabric of the granite.

Der südliche Rand des Brixner Granodiorits in der Nähe von Franzensfeste eröffnet die exzellente Möglichkeit den Einfluss der permischen Kontaktmetamorphose auf das magnetische Gefüge des variszisch metamorphen Quarzphyllits zu studieren. Ein sorgfältig ausgewähltes Profil wurde beprobt, um die petrologische, mineralogische und texturelle Einfluss der thermischen Überprägung zu erhalten. Vier verschiedene Zonen konnten aufgrund ihrer mineralogischen Zusammensetzung in einem Bereich von weniger als 200 Meter vom Kontakt unterschieden werden. Innerhalb dieses Bereichs konnte ein Temperaturanstieg von 520°C (weit entfernt vom Kontakt, 200m) auf 600°C (nah am Kontakt, 10m) nachgewiesen werden. Die Anisotropie der magnetischen Suszeptibilität (AMS) Daten zeigen, dass sich die magnetische Textur innerhalb der Kontaktaureole größtenteils nur äußerst gering ändert. Nur in den innersten Hornfelsen (600°C) zeigt sich eine Veränderung vom deutlich oblaten Gefüge des Brixner Quarzphyllits in ein gut definiertes, leicht gekipptes prolates Gefüge, ähnlich dem Gefüge des Granits.

1. INTRODUCTION

In the Southalpine domain the Permian intrusive complexes of the Brixen, Ifinger and Kreuzberg granodiorite cover an area of ~ 250 km² and are thought to have been the result of the collapsing Variscan orogenic belt, which led to the formation of large extentional terrains (Bargossi et al., 1981, 1998; Del Moro and Visona, 1982; Acquafredda et al., 1997;. The Brixen granodiorite covers an area of about 180 km² and shows a wide range of different intrusion types, from gabbroic intrusion in the southern part to high-silicic intrusions at the northern margin of the intrusion (Fig.1). The area of interest is at the gravel road from Franzensfeste/Fortezza (South-Tyrol, Italy) to Riol (Fig.2). Within the range of 900 – 1050 meters above sea level the inner part of the contact aureole is crosscut by the gravel road in a low angle. Therefore an almost vertical profile across the aureole, in relation to the petrological zones, occurs in the outcrops. The Permian granodiorites intruded into the Brixen Quartzphyllite which transformed in a hornfels during the thermal overprint.

Anisotropy of magnetic susceptibility reflects the statistical alignment of platy or elongate magnetic (usually ferromagnetic) grains. AMS is defined in terms of the magnetic susceptibility ellipsoid, which has principal axes along the directions of maximum (K_1), intermediate (K_2) and minimum (K_3) susceptibility. If $K_1 = K_2 = K_3$, the ellipsoid is spherical and the specimen has an isotropic magnetic susceptibility. If $K_1 \approx K_2 > K_3$, the ellipsoid is oblate (disc-shaped). If $K_1 > K_2 \approx K_3$, the ellipsoid is prolate (cigar-shaped). Oblate susceptibility ellipsoids are commonly observed in sedimentary rocks and in rocks with a significant foliation, with K_3 oriented perpendicular to the bedding and foliation, respectively. Prolate ellipsoids can be observed in volcanic lava flows and current-deposited sediments, where K_1 is aligned parallel to the palaeoflow direction. Significant AMS can also be produced during straining of rocks, and has been used to infer the orientation of the strain ellipsoid (e.g., Kligfield et al., 1983). Anisotropy of remanent magnetization is also of interest in palaeomagnetic studies. A full treatment of anisotropies of susceptibility and remanent magnetization is given in Tarling and Hrouda (1993).

Anisotropy of magnetic susceptibility is a usefully tool for determining the conditions of emplacement of granitoids by interpretation of the internal structure (e.g. Stacey, 1960; Hrouda and Lanza, 1989) and the relationship between rock fabrics and magnetic fabrics (e.g. Hrouda, 1982; Bouchez, 1997). Most rocks contain small percentage of ferromagnetic minerals that

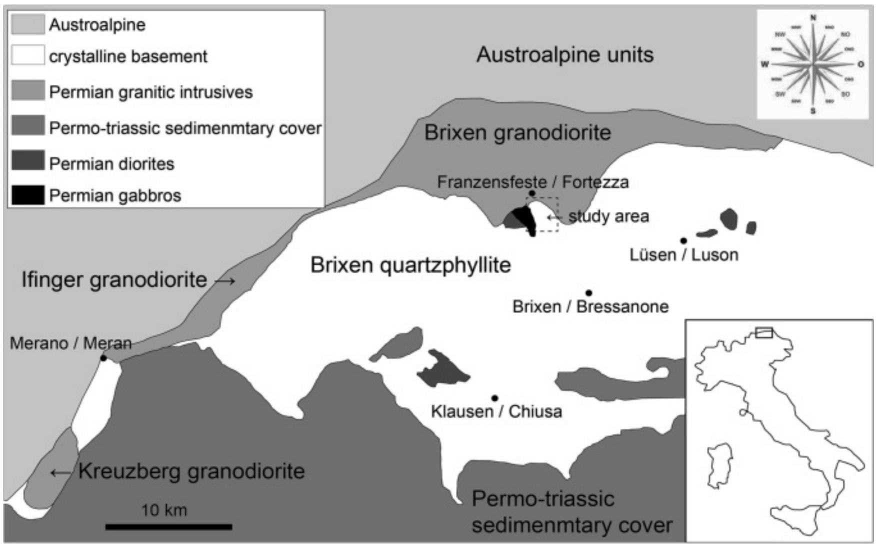

Figure 1: Schematic map of the northern realm of the Southern Alps roughly showing the position of the Permian contact aureole of the Brixen granodiorite.

become deformed and/or reorientated, and are strained as a part of the whole rock. For granitoids, iron bearing silicates, especially biotite and amphibole, carry paramagnetic properties. Therefore the magnetic fabric can be directly related to the crystallographic preferred orientation (CPO) of the paramagnetic carriers (Hrouda, 1982). In iron bearing rocks ore minerals like magnetite and hematite obliterate paramagnetic properties. Therefore magnetic fabrics are related to primary shape anisotropies or inhomogeneous grain distribution (Rochette et al., 1992). The magnitudes of the principal magnetic susceptibilities and their orientations within the rock, the magnetic susceptibility anisotropy, constitute the rock magnetic fabric. The study of magnetic fabrics was initiated by Graham (1954) and since then it has been established that magnetic susceptibility anisotropy ellipsoids in all rocks reflect the strain ellipsoids (e.g. King, 1966; Hrouda, 1973). The axial ratios of the susceptibility ellipsoids are related exponentially to the strain ratios of the strain ellipsoids (Wood et al., 1976) indicating the possibility of obtaining complete strain ellipsoids data from the magnetic fabric.

The low field anisotropic susceptibility of a rock sample can be interpreted as an oriented strain ellipsoid with three mutually perpendicular axes $K_{max} \geq K_{int} \geq K_{min}$, which are defined by their orientation and intensities. The bulk susceptibility is given by the parameter $K = 1/3\ (K_{max} + K_{int} + K_{min})$; the total anisotropy by the parameter $P = K_{max} / K_{min}$; the linear anisotropy by the parameter $L = K_{max} / K_{int}$ (lineation L) and the planar anisotropy by $F = K_{int} / K_{min}$ (foliation F). The ratio $L / F = E$, is the ellipticity of the susceptibility ellipsoid, thus if $E > 1$ the ellipsoid is prolate and the lineation is more developed than the foliation and conversely if $E < 1$ the ellipsoid is oblate and the foliation is more developed than the lineation.

2. PETROGRAPHY OF THE HORNFELSES OF THE CONTACT AUREOLE

The Brixen Quartzphyllite contains the mineral assemblage garnet + muscovite + biotite + chlorite + albite + quartz (zone 0) (Fig. 3a). The first zone (200 meters from the contact, zone 1) is characterized by the formation of newly grown biotite (Fig. 3b). These biotites grow across the Variscan foliation (ø 148/36). The following zone (zone 2, 150 m from the contact) is petrologically characterized by the formation of cordierite and the disappearance of garnet (Fig. 3c). The breakdown of garnet at these temperatures leads to the formation of phosphates, especially monazite and xenotime. In the third zone (zone 3, 60 m from the contact) andalusite

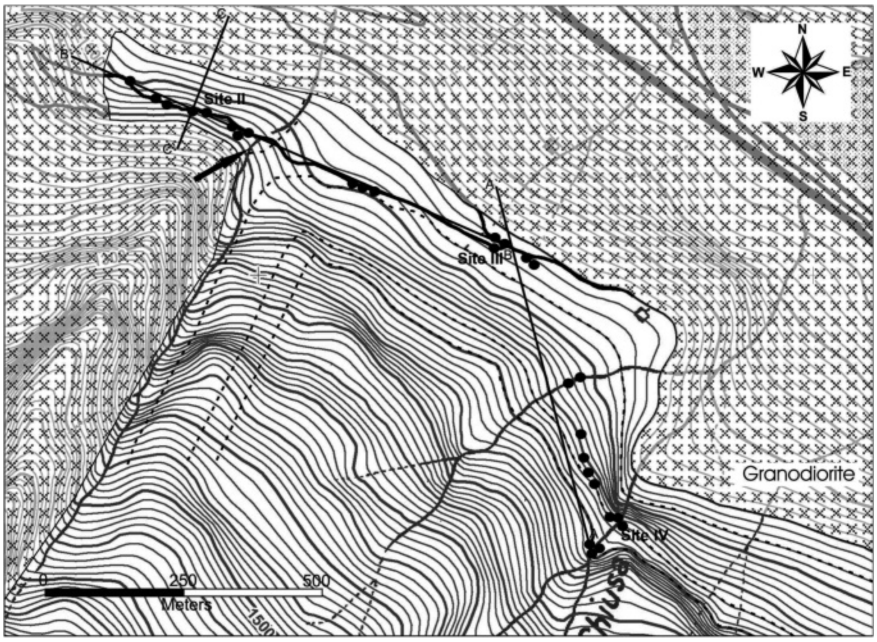

Figure 2: Sketch of the contact aureole showing the sample locations as well as the locations where the drilling (site II – IV) was performed. The other two sites (I, V) are not shown on the sketch. Site I (drilling of the granodiorite) is placed in the central part of the intrusion. Site V is located in an area far from the contact (500m) where no influence of the Permian contactmetamorphic thermal overprint could be obtained. The domains signified with (crosses (x) represents the granodioritic body. The dashed lines in the figure show the assumed positions of the boundaries of the petrologically different zones. The black dots represent the sampling points for the petrological investigations. The drilling points are indicated as site II – IV.

appears which forms almost idiomorphic grains. The innermost zone (zone 4, <10 m from the contact) is characterized by the formation of spinel and very rarely by the appearance of corundum (Fig. 3d). This assemblage can only be observed within the last few meters to the contact and represents the part of the aureole which shows the highest thermal overprint. The drilling was done at four sites within the hornfels and one site within the granodiorite, all of them, where possible, in close vicinity to sampling places for the petrological investigations. The petrography of the granodiorite is linked with geochronological investigations on these samples and is described in detail in Thöny (2008).

3. Analytical methods

Oriented drilling cores were taken with a length of 10 – 15 cm. At the Paleomagnetic laboratory of the University of Leoben the cores were cut into pieces of ~ 2 cm length and afterwards partitioned into units for the different analytical methods. The cut pieces were designated with the letters a, b, c. Letter c always represents the part of the core which is in closest vicinity to the surface and therefore shows the highest alteration rate. If necessary, when obviously highly altered, these samples were excluded. AMS measurements were performed on an AGICO KLY-2 kappabridge.

Polished rock chips were placed in the x-ray beam of a texture goniometer (wavelength CuKα = 1.5418, beam current = 40 kV and 30 mA) used in reflection mode. Eight lattice planes (<100>, <110>, <102>, <200>, <201>, <112>, <211>, <113>) have been directly measured at α-angles between 0° (centre) and 80° (periphery), corrected for defocusing effects and completed (a = 0° – 90°) by Fourier analyses. Lattice planes <001>, <101> and <011> were calculated using the orientation density function (ODF) based on the harmonic method of Roe (1965) and Bunge (1969). Only the most valuable c-axes <001> orientation distributions are shown as pole figures.

4. Results of the magnetic investigations

Along a thermometrically (outer aureole: 520°C for Ti in bio-

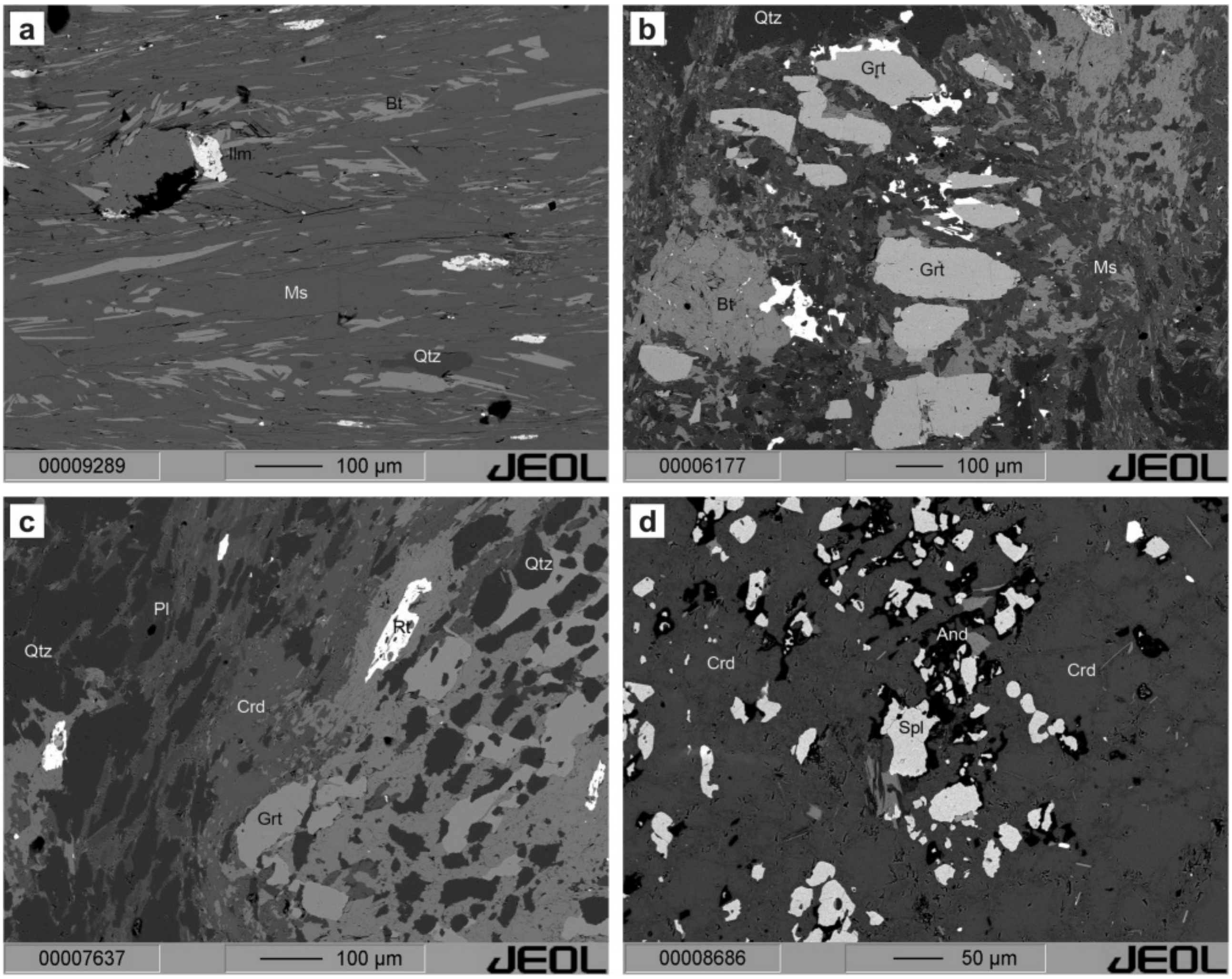

Figure 3: a) Back scattered electron (BSE) image of the Brixen quartzphyllite (zone 0) showing the Variscan assemblage chlorite (Chl) + biotite (Bt) + quartz (Qtz) + ilmenite (Ilm). b) BSE image of zone 1 showing the assemblage garnet (Grt) + biotite 1, 2 (Bt) + rutile (Rt) + muscovite (Ms) + chlorite (Chl) + quartz (Qtz). c) BSE image of zone 2 showing cordierite (Crd) + rutile (Rt) + plagioclase (Pl) + garnet (Grt) + biotite (Bt) + quartz (Qtz). d) BSE image of zone 4. The assemblage is aluminiumsilicate (AlSi) + spinel (Sp) + cordierite (Crd). e) BSE image of the Brixen granodiorite near the contact. The mineral assemblage is K-feldspar (Kfs) + plagioclase (Pl) + biotite (Bt) + quartz (Qtz). (Length of the scale bar: 300 µm).

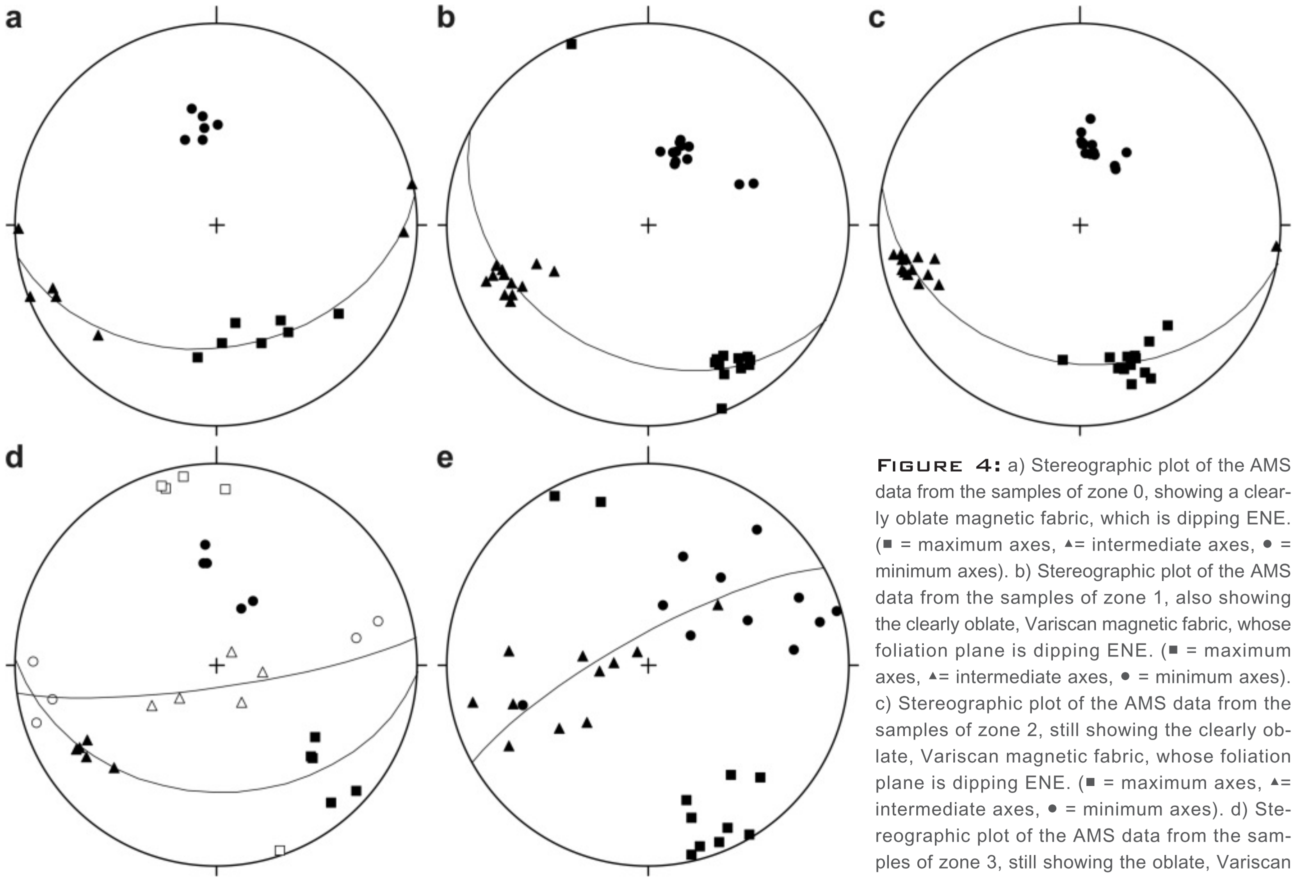

Figure 4: a) Stereographic plot of the AMS data from the samples of zone 0, showing a clearly oblate magnetic fabric, which is dipping ENE. (■ = maximum axes, ▲= intermediate axes, ● = minimum axes). b) Stereographic plot of the AMS data from the samples of zone 1, also showing the clearly oblate, Variscan magnetic fabric, whose foliation plane is dipping ENE. (■ = maximum axes, ▲= intermediate axes, ● = minimum axes). c) Stereographic plot of the AMS data from the samples of zone 2, still showing the clearly oblate, Variscan magnetic fabric, whose foliation plane is dipping ENE. (■ = maximum axes, ▲= intermediate axes, ● = minimum axes). d) Stereographic plot of the AMS data from the samples of zone 3, still showing the oblate, Variscan magnetic fabric but already including a younger, namely Permian, overprint which occurs as prolate magnetic fabric. (■ = maximum axes, ▲ = intermediate axes, ● = minimum axes). e) Stereographic plot of the AMS data from the Brixen granodiorite, showing the clearly prolate, Permian magnetic fabric and the foliation plane, which is dipping SSE. (■ = maximum axes, ▲ = intermediate axes, ● = minimum axes).

tite, 485-520°C feldspar thermometry; inner aureole: 660°C for Ti in biotite, 620°C feldspar thermometry) well-defined profile from the thermally unmetamorphosed basement into the granodiorite, five drilling sites were selected. The paleomagnetic investigations using the method of AMS (anisotropy of magnetic suscebtibility) focused on the detection of a pre-Permian fabric in the visibly textureless hornfelses as well as the possible change of that fabric (AMS). The first drilling area (site V, 6 data-points) is within the contactmetamorphic thermally unmetamorphosed quartzphyllite and shows an oblate fabric and the highest degree of anisotropy of 13.5 % (Fig. 4a). Within all sites, characterized by an oblate magnetic fabric K_{min} + K_{int} are located within the foliation plane that is striking ENE (WSW), dipping to SSE. With decreasing distance to the intrusion the degree of anisotropy decreases to 11.6 % within the outer contact aureole (Fig. 4b, Fig. 4c). Samples taken 10 m away from the intrusion show a decrease in anisotropy and still an oblate fabric (5 data-points) with K_{min} axes of 4/53 and additionally an average Kint axes of 234/26 and a maximum axes of 131/24 with a degree of anisotropy of 6.5 % (Fig. 4d). The hornfels samples closest to the contact (1 meter distance, 5 data-points) are characterized by a prolate magnetic fabric, very similar to the fabric of the granodiorite, with flat K_{max} axes of 348/7 and a small degree of anisotropy of 4.2 %. A great circle is defined by the K_{int} (243/65) and the Kmin axes (81/23) (Fig. 4d). This change within the magnetic fabric is remarkable since no change within the mineralogical composition could be discerned. The granodiorite shows a typical prolate magnetic fabric. The average orientation of the Kmax axes (■) is 156/10. The Kint (▲, 249/10) and the Kmin (●, 35/70) axes define a WSW – ENE oriented girdle distribution (Fig. 4e).

5. DISCUSSION

The elaborated data show that the magnetic textures of the quartzphyllite and hornfelses respectively are not affected, except within <10 m to the contact, by the Permian contactmetamorphic overprint. This fact can be reduced to either that sampling points are too far away from the intrusion, which is in our case negligible, or a too low tempered magmatic body. Latter would be a good explanation due to the knowledge that silica-rich magmas usually reach maximum temperature of about 700°C. Though an increase of the anisotropy factor E (= L/F), cause by a decrease of the foliation (F), can be observed with decreasing distance to the contact (Fig. 5). The distinct decrease of the foliation factor is declining from the point in the contact aureole where absolutely textureless hornfelses the first time appear (~ 520°C). This is a clear hint for the thermal overprint which was, as mentioned above, obviously not high enough to eliminate the Variscan oblate fabric.

Site	Lat.	Long.	Zone		D (max)	I (max)	D (int)	I (int)	D (min)	I (min)		L	F	P	E
I	46°46´38.19“	11°37´56.37“	Granodiorite	mean vector (sig. 95%)	156	10	249	10	35	70	Mean values	1.01	1.014	1.024	0.996
				Apert. conf. cone	17.2°		22.4°		21.3°		Std. deviation	0.004	0.008	0.008	0.010
II	46°46´54.66“	11°36´24.84“	Zone 4	mean vector (sig. 95%)	131	24	234	26	4	53	Mean values	1.022	1.032	1.054	0.991
				Apert. conf. cone	10.4°		20.6°		21.2°		Std. deviation	0.005	0.024	0.021	0.026
III	46°46´47.82“	11°36´44.28“	Zone 2	mean vector (sig. 95%)	123	15	220	30	14	57	Mean values	1.017	1.036	1.054	0.982
				Apert. conf. cone	7.8°		7.7°		5.3°		Std. deviation	0.014	0.007	0.019	0.012
IV	46°46´32.07“	11°36´54.54“	Zone 1	mean vector (sig. 95%)	150	17	248	27	31	57	Mean values	1.032	1.078	1.113	0.957
				Apert. conf. cone	5.6°		5.2°		6.6°		Std. deviation	0.007	0.012	0.019	0.007
V	46°45´6.12“	11°36´49.5“	Zone 0	mean vector (sig. 95%)	158	40	253	6	351	50	Mean values	1.008	1.125	1.134	0.897
				Apert. conf. cone	14.0°		13.8°		4.9°		Std. deviation	0.004	0.02	0.024	0.014

Table 1: Magnetic data and orientation data and position of the AMS drilling holes (sites I-V)

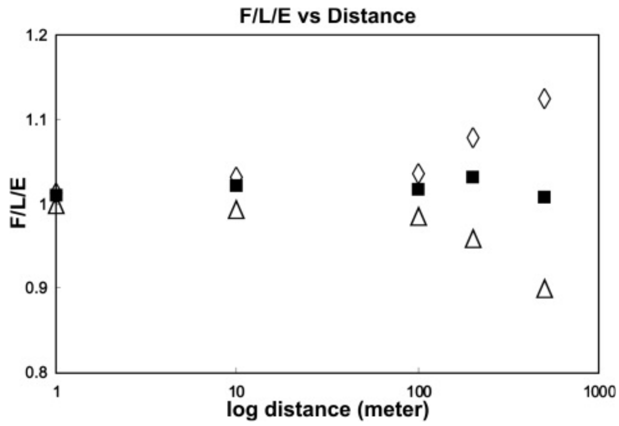

Figure 5: Diagram showing the behaviour of the anisotropy factors (F, L, E) vs. distance to the contact. ◊ represent the foliation (F), ■ represent the lineation (L) and Δ represent the E factor which is defined by L / F. The clearly oblate texture of the quatzphyllites, defined by a distinct foliation, changes into a prolate texture similar to the texture of the granodiorite.

6. Conclusions

Investigations on the magnetic susceptibility of metamorphic rocks may unveil information about the evaluated samples which are not perceptible. The above discussed case allows a prospectus on other low to medium tempered contact aureoles. Textural information can obviously remain in case that a) the temperature of the intrusion is to low to develop a large contact aureole or b) the temperature of the country rock is to low, the burial depth respectively, to get a far reaching heat flow within the surrounding area. In these categories a lot of aureoles could be investigated to receive macroscopic hidden textural information of these rocks.

Acknowledgments

The Financial support through the FWF-project P-17878-N10 to P. T. is gratefully acknowledged. Several students are thanked for their support carrying the drilling machine, water, cans and a lot of other stuff to the drilling sites.

References

Acqufredda, P., Bargossi, G.M., Caggianelli, A. and Rottura, A., 1997. Emplacement dephts of Permian granitoids from central-eastern Southern Alps: estimates from hornblende-plagioclase thermobarometry. Mineralogica et Petrographica Acta, 40, 45-53.

Bargossi, G.M., Bondi, M., Landini, F. and Morten, L., 1981. Il plutone di Monte Croce (Alto Adige, Nord Italia). Rendiconti Societa Italiana di Mineralogia e Petrologia, 38 (1), 155-162.

Bargossi, G.M., Rottura, A., Vernia, L., Visona, D. and Tranne, C.A., 1998. Guida all´escursione sul distretto vulcanico atesino e sulle plutoniti di Bressanone-Chiusa e Cima d´Asta. Memorie della Societa Geologica Italiana, 53, 23-41.

Bouchez, J.L., 1997. Granite is never isotropic: an introduction to AMS studies of granitic rocks. In: J.L. Bouchez, D.H.W. Hutton and W.E. Stephens (eds.), Granite: From Segregation of Melt to Emplacement Fabrics. Kluwer Academic Publisher, Doordrecht, pp.95-112.

Bunge, H.J., 1969. Mathematische Methoden der Texturanalyse, Akademischer Verlag, Berlin, 1969.

Del Moro, A. and Visona, D., 1982. The epiplutonic Hercynian Complex of Bressanone (Brixen, Eastern Alps, Italy) Neues Jahrbuch für Mineralogie, Abhandlungen, 145, 1, 66-85.

Graham, J.W., 1954. Magnetic susceptibility anisotropy, an unexploited petrofabric element, Geological Society of America Bulletin, 65, 125-1258.

Hrouda, F., 1973. A determination of the symmetry of the ferromagnetic mineral fabric in rocks on the basis of magnetic susceptibility anisotropy measurements. Gerlands Beiträge zur Geophysik, 82, 390-396.

Hrouda, F., 1982. Magnetic anisotropy of rocks and remanences: developments in the characterization of tectonic, sedimentary and igneous fabric. Reviews of Geophysics, 29, 371-376.

Hrouda, F. and Lanza, R., 1989. Magnetic fabric in the Biella and Traversella stocks (Periadriatic Line); implications for the mode of emplacement. Physics of the earth and Planetary Interiors, 56, 3-4, 337-348.

King, R.F., 1966. The magnetic fabric of some Irish granites. Geological Journal, 5, 43-46.

Kligfield, R., Lowrie, W., Hirt, A.M. and Siddans, A.W.B., 1983. Effect of progressive deformation on remanent magnetization of Permian redbeds from the Alpes Maritimes (France). Tectonophysics, 97, 59-85.

Rochette, P., Jackson, M. and Aubourg, C., 1992. Rock magnetism and the interpretation of anisotropy of magnetic susceptibility. Reviews of Geophysics, 30, 209-226.

Roe, R.J., 1965. Description of crystallite orientation in polycrystalline materials: III, General solution to pole figures. Journal of Applied Physics, 36, 2024-2031.

Stacey, F.D., 1960. Stress induced Magnetic Anisotropy of Rocks. Nature, 188, 134-135.

Tarling, D.H. and Hrouda, F., 1993. The Magnetic Anisotropy Of Rocks. Chapman and Hall, London, 217 pp.

Thöny, W.F. 2008. Permian contact metamorphism in the South Alpine: U-Pb and U-Th-Pb geochronology of plutons and contact metamorphism. Unpublished PhD. Thesis, University of Innsbruck, 200 pp.

Wood, D.S., Oertel, G., Singh, J. and Bennett, H.F., 1976. Strain and anisotropy in rocks. Philosophical Transactions of the Royal Society of London, Ser. A 183, 27-42.

Received: 18 November 2009
Accepted: 6 October 2010

Werner F. THÖNY[1)*)], Stefan WYHLIDAL[1)], Wolfgang THÖNY[2)], Peter TROPPER[1)] & Robert SCHOLGER[2)]

[1)] University of Innsbruck, Faculty of Geo- and Atmospheric Sciences, Institute of Mineralogy and Petrology, Innrain 52, A-6020 Innsbruck, Austria;

[2)] University of Leoben, Chair of Geophysics, Peter-Tunner-Strasse 25, 8700 Leoben, Austria;

[*)] Corresponding author, werner.thoeny@uibk.ac.at