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Organic metamorphism across the Gleinalm Shear Zone (Almgraben/Geistthal, Steiermark)

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With 4 Figures and 1 Table
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Summary: The presence of garnet in black shists of the Schönberg Formation indicates a higher metamorphic rank near to the northwestern margin of the Graz Paleozoic, represented by the Late Cretaceous Gleinalm Shear Zone. Raman spectroscopy of carbonaceous matter enclosed in black shists from both sides of this fault evidences a similar metamorphic overprint. In a larger distance, the rank of organic metamorphism decreases into the interior of the Graz Paleozoic, depicting a thermal aureole along the fault contact. This observation is explained by advective heat transfer during Late Cretaceous exhumation of the Gleinalm Crystalline along a large-scale continental transform, extending to the lower-crustal Plattengneiss Shear Zone.

Zusammenfassung: Organische Metamorphose an der Gleinalm Scherzone (Almgraben/Geistthal, Steiermark). – Am Nordwest-Rand des Grazer Paläozoikums, an der Gleinalm Scherzone, indiziert das lokale Vorkommen von Granat im Schwarzschiefer der Schönberg Formation einen lokal höheren Metamorphosegrad. Die Raman-Spektroskopie von organischen Bestandteilen der Schwarzschiefer von beiden Seiten dieser Störung belegt eine übereinstimmende metamorphe Prägung. Die Abnahme des Grades der organischen Metamorphose in das Innere des Grazer Paläozoikums zeichnet eine thermische Aureole entlang des Kontaktes nach. Diese Beobachtung wird durch den advektiven Wärmetransport während der spätkretazischen Exhumation des Gleinalm Kristallins in einer überregionalen Scherzone, die mit der Plattengneis Scherzone verbunden ist, erklärt.

1. Introduction

The Gleinalm Shear Zone (Neubauer et al. 1995) separates the Gleinalm Crystalline from the tectonically overlying Graz Paleozoic (Figure 1). Sinistral strike-slip shearing in this zone (Krohe 1987; Neubauer 1988; Neubauer et al. 1995) resulted from isothermal decompression (Krenn 2001; Rantitsch et al. 2005; Krenn et al. 2008) of the Gleinalm Crystalline below the Graz Paleozoic during the Late Cretaceous (Neubauer et al. 1995; Kurz & Fritz 2003; Tencer & Stüwe 2003). Advective heat flow and convecting fluids accompanied the exhumation of the metamorphic basement (Willingshofer et al. 1999; Bojar et al. 2001; Krenn 2001; Rantitsch et al. 2005; Krenn et al. 2008; Wölfler et al. 2010). By studying the metamorphic alteration of organic matter, Rantitsch et al. 2005 mapped an aureole of higher metamorphic rank at the tectonic contacts of the Graz Paleozoic to the Gleinalm Crystalline, explained by dissipating heat from the crystalline basement. The study of Rantitsch et al. 2005 focused however on the dip-slip margins of the Graz Paleozoic and did not present detailed data from the Gleinalm Shear Zone. Now, field mapping of metasediments in

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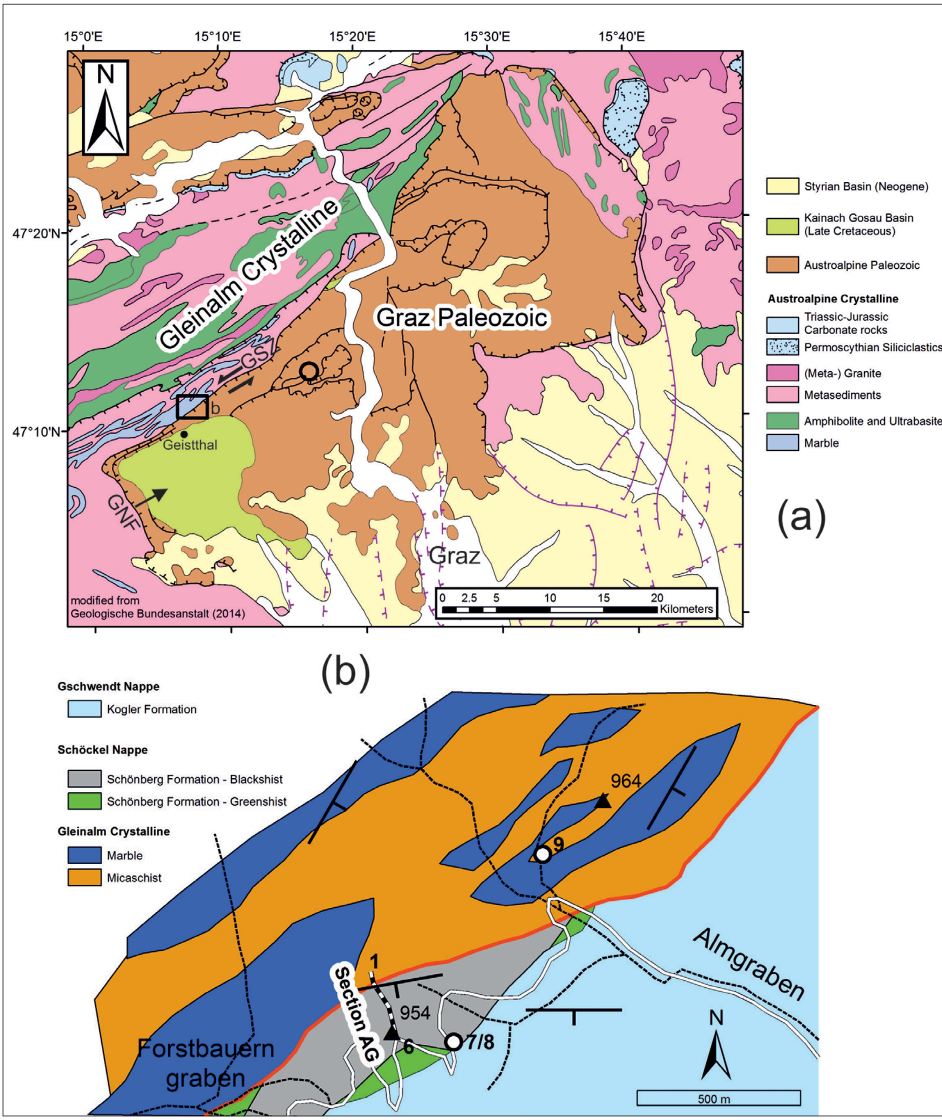

Fig. 1: Location of the study area within the Eastern Alps. As indicated in 1a (derived from data of the Geological Survey of Austria), Late Cretaceous shearing (NEUBAUER et al. 1995) was accommodated by sinistral shearing of the thrust contact between the Graz Paleozoic and the Gleinalm Crystalline (GSZ= Gleinalm Shear Zone) and by normal faulting along the Graden Normal Fault (GNF, RANTITSCH & MALI 2006). The circle in (a) indicates the location of the samples from RANTITSCH et al. 2005 used in this study. (b) Geological map with the studied Almgraben section (AG) of the study area.

Abb. 1: Lage des Arbeitsgebietes. Abbildung 1a (zusammengestellt aus Daten der Geologischen Bundesanstalt, Wien) zeigt die spätkretazische sinistrale Schertektonik (NEUBAUER et al. 1995) entlang der Überschiebung des Grazer Paläozoikums auf das Gleinalm Kristallin (GSZ= Gleinalm Scherzone) und an der Graden Abschiebung (GNF, RANTITSCH & MALI 2006). In Abbildung 1a ist die hier verwendete Probenlokation aus RANTITSCH et al. 2005 durch einen Kreis dargestellt. Abbildung 1b zeigt eine geologische Karte der Umgebung des bearbeiteten Almgraben Profils (AG).

the Almgraben near to Geistthal (Rantitsch et al. 2013) enabled the study of the metamorphic overprint in a nearly complete section across the Gleinalm Shear Zone (Figure 1b). To complete the present metamorphic map along an important Late Cretaceous detachment of the Eastern Alps and to map the metamorphic aureole, the Almgraben section was examined by Raman spectroscopy of carbonaceous matter (RSCM, Beyssac et al. 2002), extending the metamorphic map of Rantitsch et al. 2005.

2. Geological Setting

The examined NNW-SSE oriented section (Figure 1b) dissects the Gleinalm Shear Zone in the Almgraben Valley, NE to Geistthal (Steiermark). The metamorphic basement of the Gleinalm Crystalline is represented here by SE-dipping micaschists with interbedded amphibolite and marble layers, locally accompanied by thin black schist beds. In the section, a banded (calcite) marble layer shows a tight NW-vergent recumbent fold, indicating late Early Cretaceous (Eoalpine) thrusting, preceding Late Cretaceous exhumation (Krohe 1987; Kurz & Fritz 2003). Neubauer et al. 1995 reported Eoalpine (87.6 Ma) epidote-amphibolite facies peak metamorphic conditions. Tencer & Stüwe 2003 estimated 575°C ±51°C and ca. 10.4 ± 1.2 kbar for micaschists in a locality near to the examined section (sample 3 in Tencer & Stüwe 2003, see also Raič et al. 2012). After peak metamorphism, the Gleinalm Crystalline was exhumed in a dome-like structure ("Gleinalm Dome" sensu Neubauer et al. 1995), retrogressing the mineral assemblages to greenschist-facies metamorphic conditions along the dome margins (Neubauer et al. 1995). The absence of metamorphic pebbles in the Late Cretaceous Gosau Basin (Ebner & Rantitsch 2000), overlying the Graz Paleozoic (Figure 1a), indicates that the Gleinalm Crystalline was not exhumed to the surface during the Late Santonian/Early Campanian (ca. 80 Ma). Age dating proofs that the central part of the dome was cooled to 225°C at ca. 61 Ma (Neubauer et al. 1995) and to 200°C at ca. 50 Ma (Hejl 1997).

The map pattern suggests a nearly vertical dip of the Gleinalm Shear Zone. No kinematic indicators have been observed in the examined section. However, Neubauer et al. 1995 described a general sub-horizontal stretching lineation with an overall sinistral sense of shear. On the southern side of the fault, the SE-dipping Lower Devonian Schönberg Formation (Flügel 2000) of the Schöckl Nappe represents the Graz Paleozoic (Ebner 1998). It comprises black schists, green schists and phyllites with locally interbedded limestone beds. Only at the fault contact, strongly deformed black schists contain macroscopically observable garnets and indicate therefore a local higher degree of metamorphism. Further to the south, limestones of the Middle Devonian Kogler Formation (Ebner 1998) overly tectonically (Ebner 1998) the Schönberg Formation. RSCM data (Rantitsch et al. 2005) assign the studied section to the metamorphic aureole at the margins of the Graz Paleozoic with temperatures at ca. 500°C.

3. Samples and Methods

The section was sampled by nine black schist samples at the crest of the Almgraben Valley (Figure 1b). Six samples (AG 1-6) come from a road cut (15° 7.29' E, 47° 11.44' N in the WGS84 coordinate system), crossing the Gleinalm Shear Zone. Two samples (AG 7, 8) come from outcrops of the Graz Paleozoic in a larger distance to samples AG 1-6, and one sample (AG 9) represents a black schist layer of the Gleinalm Crystalline near to the section (Figure 1b). The samples of the Schönberg Formation (AG 1-6) cover tightly a distance of ca. 30 meters to the fault. They are completed by two samples in a fault distance of ca. 470 meters. To include samples of the Schönberg Formation in a greater distance, two samples (GP 20, GP 21) of Rantitsch et al. 2005 complete the used data set (Figure 1a).

Carbonaceous matter was separated chemically from the rock matrix (see Rantitsch et al. 2004 and Lünsdorf et al. 2012 for the details). The first order Raman spectrum of the carbonaceous matter (Wopenka & Pasteris 1993; Beyssac et al. 2002) of the Almgraben samples was recorded as described by Lünsdorf et al. 2012. Preparation and analysis of the samples GP 20 and GP 21 are described in Rantitsch et al. 2005. The Raman spectra were analyzed numerically as described by Rantitsch et al. 2014 and Lünsdorf & Lünsdorf 2014. An empirical equation, estimates peak metamorphic temperatures from the R2 parameter, resulting from the numerical analysis of the Raman spectrum (Beyssac et al. 2002). In this contribution, the modified equation of Rantitsch et al. 2004 is used.

4. Results and Discussion

The Raman spectra of carbonaceous matter from the Almgraben section differ significantly from spectra collected in the same stratigraphic horizon of the interior parts of the Graz Paleozoic (Figure 2). This is most obvious by comparing the intensity ratio of the D1 (defect) band to the G (graphite) band between the sampled localities (Figure 3). The R2 ratio (D1/(G+D1+D2) peak area ratio) correlates inversely with peak metamorphic temperatures (Beyssac et al. 2002). The low R2 ratio observed in the Almgraben section near to the Gleinalm Shear Zone indicates therefore relatively higher peak metamorphic temperatures than in the interior parts of the Graz Paleozoic (Table 1).

Within the Gleinalm Crystalline, a RSCM temperature of ca. 580 ± 40°C is calculated. This estimate is in accordance with the estimate of Tencer & Stüwe 2003, reflecting Eoalpine metamorphic conditions. The same temperature is observed at the other side of the shear zone (Figure 3), decreasing with increasing distance to the fault trace. In a distance of ca. 500m, the temperature decreases to ca. 520°C. In a larger distance (Figure 1a), the RSCM temperature is estimated with ca. 350°C ± 60°C (Table 1), reflecting Eoalpine tectonic burial of the sampled hori-

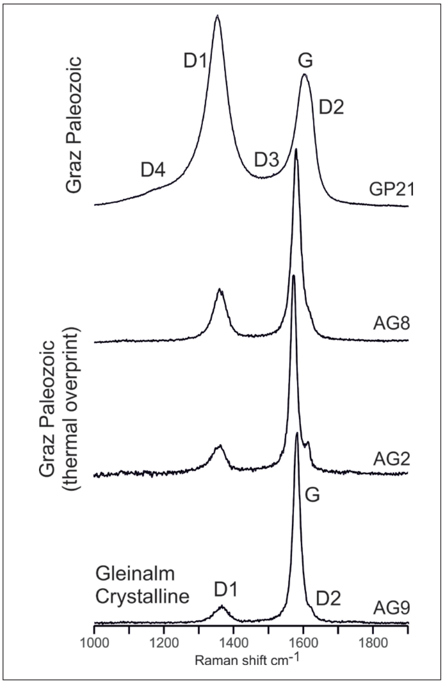

Fig. 2: Representative Raman spectra of carbonaceous matter enclosed in black schists of the Almgraben section (see Fig. 1).
Abb. 2: Repräsentative Raman-Spektren der organischen Substanz aus dem Schwarzschiefer des Almgraben Profils (Abb. 1)

Sample			**AG9**	**AG1**	**AG2**	**AG3**	**AG5**	**AG6**	**AG7**	**AG8**	**GP20**	**GP21**
Tectonic Unit			Gleinalm Crystalline	Graz Paleozoic								
Distance to the fault trace (m)			-100	2	12	17	24	27	470	470	3000	3000
N			9	10	8	10	9	9	10	10	10	10
D1	Position	mean	1363.4	1357.2	1358.8	1359.0	1357.6	1359.1	1359.8	1361.3	1350.1	1350.1
		sdv	2.1	2.5	2.4	1.8	3.5	1.6	2.5	2.1	1.8	1.9
	FWHM	mean	16.7	20.7	19.5	18.7	20.4	19.9	21.0	20.7	36.1	36.1
		sdv	2.1	1.3	2.2	0.8	2.2	0.8	1.1	1.2	0.4	0.4
D3	Position	mean									1513.6	1514.3
		sdv									9.7	10.0
	FWHM	mean									47.8	48.1
		sdv									1.3	1.0
G	Position	mean	1580.1	1574.3	1575.1	1576.1	1575.0	1576.1	1577.6	1580.3	1593.4	1593.4
		sdv	2.3	3.2	2.2	2.7	3.7	1.7	3.8	3.3	3.6	3.7
	FWHM	mean	10.3	10.9	10.6	11.5	11.6	11.4	12.6	13.8	25.4	25.2
		sdv	2.0	0.4	0.9	0.4	0.4	0.4	0.7	0.4	1.1	1.2
D2	Position	mean	1620.8	1613.4	1615.0	1616.0	1613.9	1615.9	1616.3	1618.5	1618.4	1618.3
		sdv	3.4	5.9	2.7	3.2	5.7	2.0	4.0	3.9	2.0	2.1
	FWHM	mean	3.3	5.0	4.5	4.7	4.9	5.3	6.4	5.6	11.3	11.3
		sdv	1.4	1.7	1.3	1.0	1.4	1.0	1.0	0.9	0.5	0.3
R2		md	0.145	0.182	0.145	0.194	0.220	0.227	0.265	0.288	0.645	0.645
		sdv	0.049	0.048	0.055	0.030	0.024	0.021	0.060	0.018	0.011	0.010
RSCM Temperature (°C)		max	614	598	614	594	584	581	566	556	412	412
		mean	582	564	582	559	547	544	527	516	353	353
		min	549	529	549	524	511	507	488	476	294	294

Tab. 1: Mean values and standard deviation (sdv) of the parameters (position, full width at half maximum, FWHM) obtained from the decomposition of N Raman spectra per sample. From the R2 parameter the RSCM temperatures are estimated from Beyssac et al. 2002, modified by Rantitsch et al. 2004.

Tab. 1: Mittelwert und Standardabweichung (sdv) der aus N Spektren berechneten Raman-Parameter (Position, Halbwertsbreite FWHM). Die RSCM Temperaturen wurden nach Beyssac et al. 2002, modifiziert nach Rantitsch et al. 2004, berechnet.

zon (Rantitsch et al. 2005). Thus, even a possible influence of shearing on the degree of graphitization (Barzoi 2015) is taken into account, high RSCM temperatures in a distance of ca. 500m evidence the presence of a broad zone of a higher metamorphic rank along the Gleinalm Shear Zone.

The convex shape of the temperature profile (Figure 3) resembles typical contact metamorphic temperature and organic maturation profiles formed by conductive heat transfer out of igneous intrusions (e.g. Wang 2012). However, in the study area, there is much evidence for Late Cretaceous advective heating of the Graz Paleozoic above the

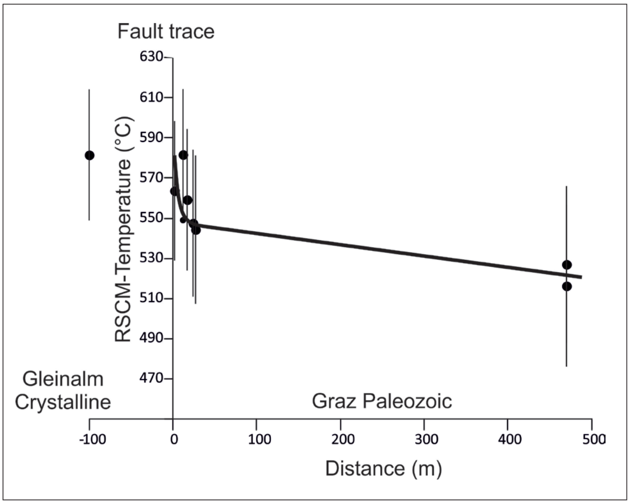

Fig. 3: RSCM temperatures of Beyssac et al. 2002, modified by Rantitsch et al. 2004 calculated from the Raman spectra of the Almgraben section.
Abb. 3: RSCM Temperaturen nach Beyssac et al. 2002, modifiziert von Rantitsch et al. 2004, berechnet aus den Raman Spektren des Almgraben Profils.

exhuming Gleinalm Crystalline basement (Willingshofer et al. 1999; Bojar et al. 2001; Krenn 2001; Rantitsch et al. 2005; Krenn et al. 2008; Wölfler et al. 2010).

Exhumation of the Graz Paleozoic by northeast directed shearing was accommodated by normal faulting along the southwestern border (Graden Normal Fault; Rantitsch & Mali 2006) and by strike-slip faulting along the Gleinalm Shear Zone, forming the northwestern border (Neubauer et al. 1995; Figure 1a). Rantitsch et al. (2005) modeled the thermal effects of shearing along the Graden Normal Fault in one and two dimensions. In a two-dimensional model, the marginal parts of the Graz Paleozoic were thermally overprinted during a 5 Ma extension period with a vertical exhumation rate of 0.65 to 0.98 cm/year. To test this model, the observations at the Almgraben Section are used to constrain a similar 2D-model also for the Gleinalm Shear Zone.

Following Neubauer 1988 and Neubauer et al. 1995 we assume a steeply (80° to 90°) dipping fault and accept all other model parameter of Rantitsch et al. 2005. By applying the algorithm of Hoisch 2005, a reasonable fit of the model parameter with

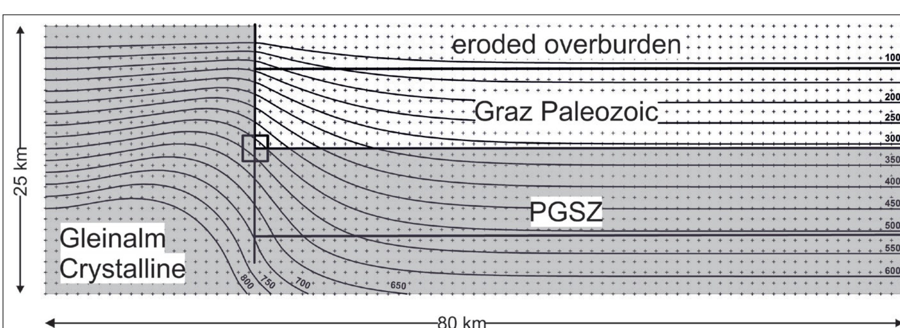

Fig. 4: Model results shown by the temperature (°C) array after 3 Ma strike-slip faulting and a vertical slip rate of 0.8 mm/a. The position of the Almgraben section is indicated by a square (PGSZ = Plattengneis Shear Zone).

Abb. 4: Modelltemperaturen (°C) nach 3 Ma Scherung und einer Scherrate von 0,8mm/a. Die Lage des Almgraben Profils ist durch ein Quadrat gekennzeichnet (PGSZ = Plattengneis Scherezone).

the estimated temperature constraints is achieved if a vertical slip rate of 0.8 to 1.0 cm/a during a 3 to 5 Ma period is assumed (Figure 4). Respecting a significant uncertainty of the geological boundary conditions, this is in good accordance with the estimates for the Graden Normal Fault. Consequently, assuming a maximum angle of shearing of 10°-20° along a nearly vertical fault, a fault-parallel slip of ca. 29-58 mm/a is estimated. Such a fault displacement is in the range for slip rates of continental transforms, representing crustal-scale fault zones, by reaching ductile decollements of the lower crust (Norris & Toy 2014). In the study area, this decollement is supposedly represented by the Plattengneiss Shear Zone of Kurz & Fritz (2003), accommodating large-scale exhumation of the Austroalpine Crystalline during the Late Cretaceous (Tencer & Stüwe 2003; Gasser et al. 2010).

5. Conclusions

Raman spectra of carbonaceous matter included in black shists of the Graz Paleozoic evidence a metamorphic field gradient, crossing the Gleinalm Shear Zone, which represents the boundary between the Gleinalm Crystalline and the Graz Paleozoic. Metamorphic temperatures from the RSCM thermometer (Beyssac et al. 2002, modified by Rantitsch et al. 2004) are in accordance with Eoalpine P-T data of Tencer & Stüwe 2003 from the Gleinalm Crystalline. Organic matter was metamorphosed during Late Cretaceous large-scale crustal shearing, exhuming the Gleinalm Crystalline into upper crustal levels. A rough thermal model suggests a high slip rate, typically for continental transform faults.

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