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Thrust-Related Very Low Grade Metamorphism Within the Gurktal Nappe Complex (Eastern Alps)

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3 Text-Figures and 1 Table

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Eastern Alps
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Late Paleozoic
Very low grade metamorphism
Alpine tectonics

Inhalt

Störungsbezogene niedrigstgradige Metamorphose innerhalb der Gurktaler Decke (Ostalpen)

Zusammenfassung

Die alpidische (Oberkreide) niedrigstgradig metamorphe Überprägung der post-variszischen Decksedimente der Gurktaler Decke wurde durch Illitkristallinitäts- und Inkohlungsuntersuchungen erfasst. Die Daten weisen auf eine thermische Überprägung durch die progressive sedimentäre Versenkung sowie auf lokale scherungsbedingte Effekte entlang von Störungszonen hin. Am internen Störungskontakt zwischen Stolzalpendecke und Pfannock-Einheit kann ein Hiatus in der Inkohlung erkannt werden, der sich in der Illitkristallinität jedoch nicht widerspiegelt. In der tektono-metamorphen Geschichte der Gurktaler Decke können daher vier Stadien unterschieden werden:

1) Überschiebung der Murauer Decke über das Ostalpine Kristallin.
2) Überschiebung der Stolzalpendecke über die Murauer Decke mit nachfolgender Faltung der Stolzalpendecke. Dabei wird die Inkohlung innerhalb der post-variszischen Decksedimente syn- bis post-tektonisch geprägt.
3) Die weitere Überschiebung bewirkt die Imbrikation der Pfannock-Einheit zwischen Murauer Decke und Stolzalpendecke.
4) Die oberkretazische duktile Abschiebungstektonik bewirkt die Reequilibrierung der Illitkristallinität zu einem kontinuierlichen Metamorphosegradienten. Dabei bleibt die organische Maturität unbeeinflusst.

Abstract

The pattern of Alpine (Late Cretaceous) very low grade metamorphism within the post-Variscan cover of the Gurktal Nappe Complex (GNC) has been investigated by combining illite crystallinity and coalification data. Very low grade metamorphism in the GNC is related to burial heating and to shear-induced effects along fault planes. The internal fault plane between Stolzalpe Nappe and Pfannock Unit is characterized by a break in coalification, whereas no break is recorded by illite crystallinity data. In the tectono-metamorphic history of the GNC four stages are discriminated:

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1) Overthrusting of the Murau Nappe upon the Austroalpine basement.
2) Thrusting and subsequent folding of the Stolzalpe Nappe upon the Murau Nappe, accompanied by syn- to post-thrusting coalification within late Carboniferous cover sequences of the Stolzalpe Nappe.
3) Progressive thrusting resulted in the imbrication of the Pfannock Unit between Murau Nappe and Stolzalpe Nappe.
4) Late Cretaceous ductile low angle normal faulting reequilibrates illite crystallinity to a continuous metamorphic gradient due to shear-related mechanism. The organic maturation remained unaffected during this event.

1. Introduction

Nature and extent of thrusting of the phyllitic Gurktal Nappe Complex (GNC) over medium grade metamorphic rocks of the Austroalpine cystalline basement forms a classic problem of Alpine tectonics (e.g. TOLLMANN, 1987 versus FRANK, 1987). According to VON GOSEN (1989) and KOROKNAI et al. (1999), thrusting occurred during early Late Cretaceous times, involving a basement slice (Pfannock Unit of TOLLMANN [1975] and VON GOSEN et al. [1985]) in-between the two internal nappes of the GNC. During this event the metamorphic overprint reached very low grade to low grade conditions.

In this study, metamorphic data (coalification of organic matter and illite crystallinity) of post-Variscan sediments, covering the Early Paleozoic basement of the GNC, are used to unravel the relationship between Alpine nappe stacking and thermal overprint. This gives some implications about the position of the Pfannock Unit in respect to the nappe assembly of the GNC. Although there are several papers dealing with the effects of shearing on the crystal growth of white mica (e.g. MERRIMAN et al., 1995; ÁRKAI et al., 1997) and on the graphitization of organic matter (WILKS et al., 1993a,b; SUCHY et al., 1997), the nature of the relationship between organic maturation and illite crystallinity during progressive shearing remains unclear. A metamorphic section across a major nappe boundary of the Eastern Alps is used in this paper to demonstrate that organic and inorganic metamorphic parameters respond differently to shear-related processes.

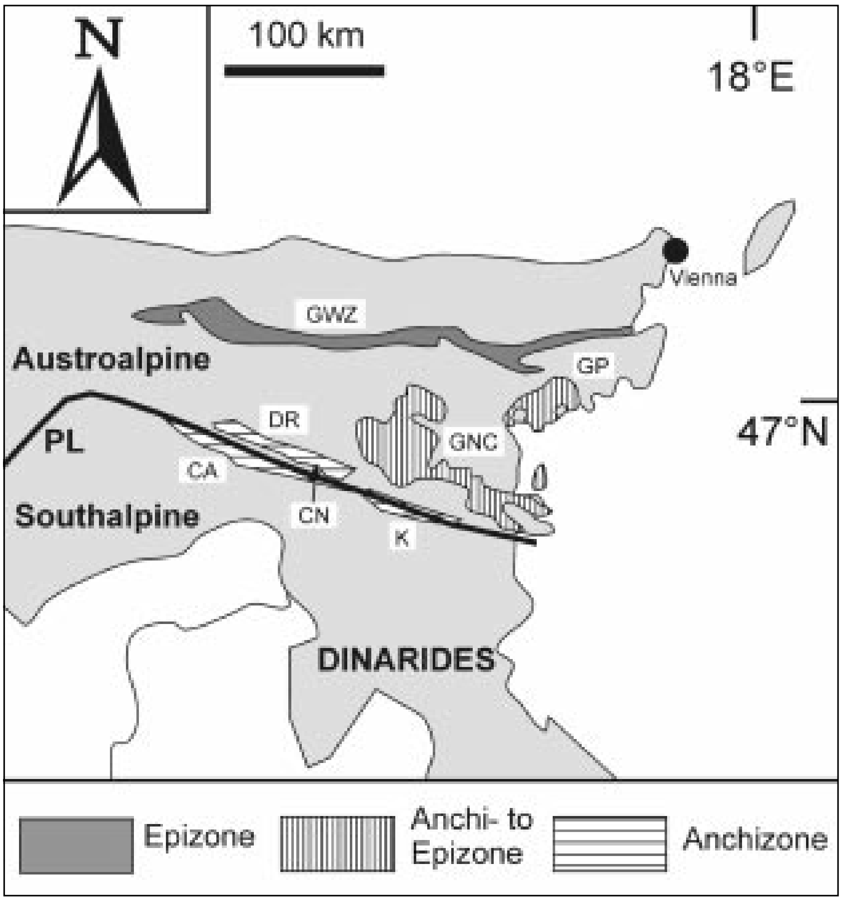
2. Geological Setting

In the Alpine realm, Early Paleozoic (Variscan) as well as Mesozoic (Alpine) convergence between continental plates resulted in closure of oceanic domains and terminated with continent-continent collision during the Carboniferous and Cretaceous (e.g. NEUBAUER, 1988, 1994). During both collisional events the paleogeographic external zones were effected by very low to low grade metamorphism. These zones are now implicated in the Alpine edifice as parts of the structurally uppermost unit of the Eastern Alps (Upper Austroalpine Nappe Complex, sensu TOLLMANN [1995]) and in the Southern Alps (see Text-Fig. 1).

The GNC (Text-Fig. 2) as a part of the Upper Austroalpine Nappe Complex is structurally divided into the lower, low grade metamorphic Murau Nappe and into the higher, very low to low grade metamorphic Stolzalpe Nappe, involving a phyllitic Ordovician to Early Carboniferous basement and Late Carboniferous to Neogene cover sequences (SCHRAMM et al., 1982; NEUBAUER & PISTOTNIK, 1984; VON GOSEN et al., 1985, 1987; VON GOSEN, 1989; NEUBAUER & FRIEDL, 1997). Phyllonitic rocks at the western margin of the GNC (Phyllonitic zone) are interpreted as strongly deformed parts of the Murau Nappe (NEUBAUER & PISTOTNIK, 1984).

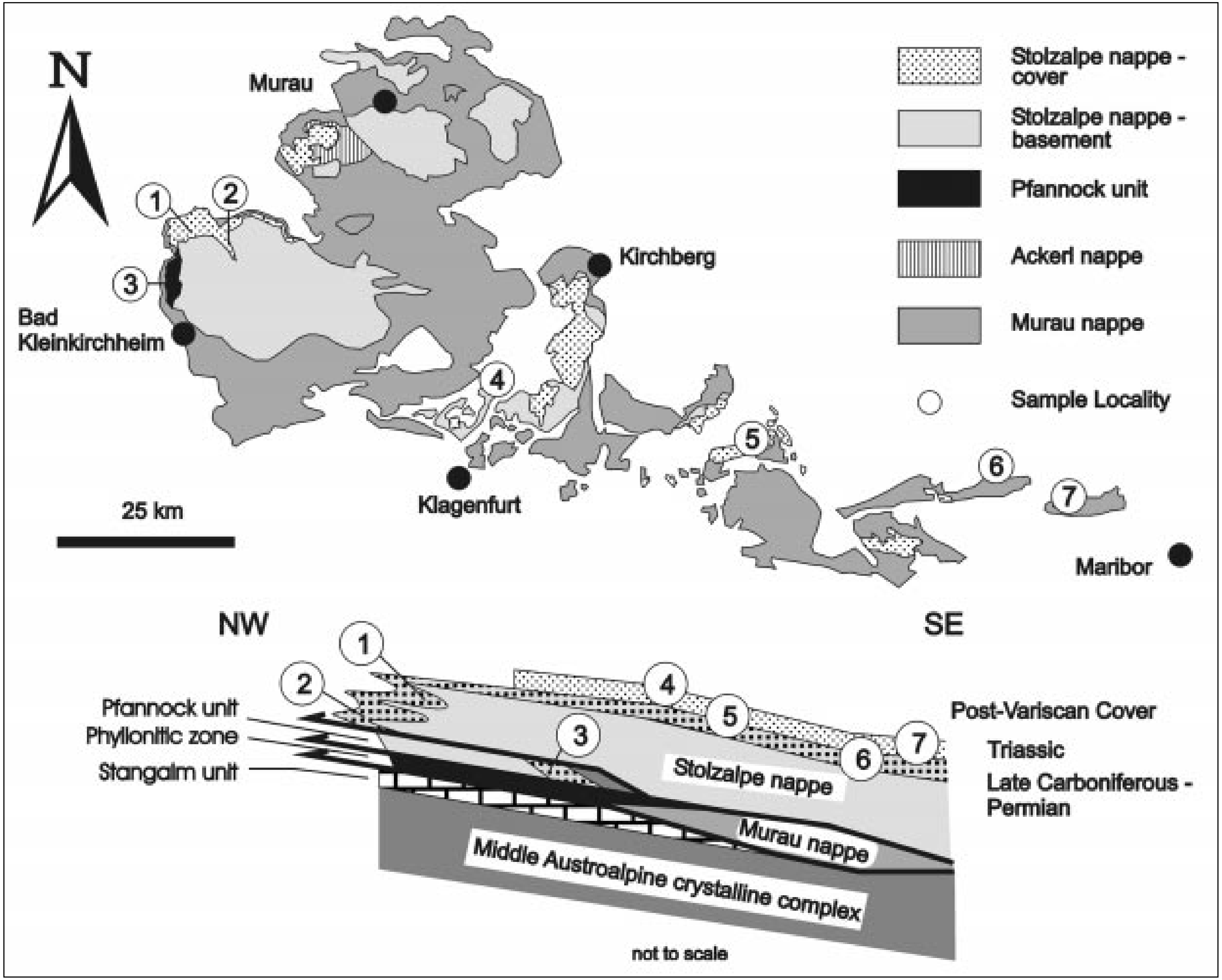
The footwall rocks of the GNC are medium grade metamorphic rocks of the Middle Austroalpine unit of the Eastern Alps. At the western margin of the GNC this basement is transgressively overlain by a Permian to Mesozoic cover sequence (Stangalm Unit, see Text-Fig. 2; PISTOTNIK, 1976).

The Ordovician to Early Carboniferous sediments of the Stolzalpe Nappe were consolidated during the Variscan orogenesis in the Visean to Westfalian (NEUBAUER & SASSI, 1993) and subsequently overlain by Late Carboniferous to Neo-



Text-Fig. 1.
Location of the Gurktal Nappe Complex (GNC) within the Eastern Alps.
For comparison, the pattern of Alpine very low to low grade metamorphism in late Paleozoic strata of the Eastern and Southern Alps (RANTITSCH, 1997) is also shown.
GWZ = Graywacke Zone; GP = Graz Paleozoic; CA = Carnic Alps; CN = Carboniferous of Nötsch; DR = Drau Range; K = Karawanken Range; PL = Periadriatic Lineament.

Text-Fig. 2.
The structural units of the Gurktal Nappe Complex (redrawn from NEUBAUER, 1987) with all sample locations.
A schematic section across the Gurktal Nappe Complex shows the structural units during Cretaceous thrusting (redrawn from VON GOSEN, 1989).



gene cover sequences (see VON GOSEN, 1989; SCHÖNLAUB, 1993 and KRAINER, 1993 for full references). Alpine tectonics in the early Late Cretaceous resulted in overthrusting of the GNC upon the Austroalpine basement and subsequent large-scale folding of the Stolzalpe Nappe (NEUBAUER, 1987; VON GOSEN, 1989). During folding Late Carboniferous cover sediments came into an inverted position at the overturned limb of a recumbent fold (see Text-Fig. 2). A break in metamorphic P-T conditions between Middle Austroalpine basement units and the Murau nappe is considered to result from Late Cretaceous low angle normal faulting that juxtaposed these units along a ductile shear zone with top to the ESE displacement by reactivating older thrust surfaces (KOROKNAI et al., 1999).

At the western margin of the GNC, a slice of orthogneiss covered by Late Carboniferous to Anisian sediments (Pfannock Unit) is imbricated between Murau and Stolzalpe Nappe (Text-Fig. 2). Because of locally preserved stratigraphic contacts of Late Carboniferous sediments both to Pfannock orthogneiss and to phyllites of the Stolzalpe Nappe (PISTOTNIK, 1996) the position of the Pfannock Unit in respect to Alpine tectonics remains uncertain.

The metamorphic overprint of Variscan and post-Variscan sediments within the GNC was studied before by illite crystallinity measurements (SCHRAMM et al., 1982; VON GOSEN et al., 1987) and by the determination of Conodont Colour Altertion Indices (NEUBAUER & FRIEDL, 1997). In the Pfannock Unit and in the Stolzalpe Nappe an Alpine (Cretaceous) very low grade metamorphic overprint without break in-between was demonstrated by SCHRAMM et al. (1982) using exclusively illite crystallinity data.

Sample	Loc	Age	IC	Rmax	Ro	s	Rmin	s	N
KS1	1	lC	0.42	4.39		0.36	3.38	0.44	49
KS2	1	lC	0.57	4.69		0.45	3.30	0.64	48
KS3	1	lC	0.44	4.49		0.32	3.08	0.41	25
KS4	1	lC	0.53	4.41		0.41	2.91	0.63	110
KS5	1	lC	0.38	4.20		0.29	3.14	0.43	70
KS6	1	lC	0.44	4.32		0.32	3.01	0.54	15
KS7	1	lC	0.4	4.58		0.44	3.10	0.53	15
KS8	1	lC	0.44	4.77		0.34	3.48	0.39	24
KS9	1	lC	0.43	4.50		0.22	3.63	0.35	27
KS10	1	lC	0.43	4.66		0.31	3.64	0.43	10
KS11	1	lC	0.4	4.85		0.29	3.83	0.42	21
KS12	1	lC	0.34	4.97		0.38	2.96	0.39	31
T1	2	lC	0.28	5.73		0.46	3.26	0.45	60
T2	2	lC	0.25	7.83		0.40	1.27	0.24	9
T3	2	lC	0.38	5.96		0.43	3.07	0.54	35
T4	2	lC	0.34	6.01		0.40	3.31	0.71	62
T4-1	2	lC		5.89		0.25	2.89	0.18	40
T5	2	lC	0.24						
T6	2	lC	0.25						
BH 1	3	lC	0.38	1.55		0.27			29
BH 2	3	lC	0.43	4.57		0.31	3.46	0.37	15
BH 3	3	lC	0.37	4.19		0.31	2.74	0.52	33
BH 4	3	lC	0.35	3.24		0.29	2.66	0.38	29
BH 5	3	lC	0.44	4.42		0.30	3.64	0.33	24
MK1	4	Carn			1.34	0.23			51
MK2	4	Carn			1.20	0.25			37
MK3	4	Carn			1.15	0.24			29
SP2	5	Carn	1.21		1.05	0.17			34
SP3	5	Carn			1.16	0.21			33
R 1	6	ePz	0.34						
R 3	6	ePz	0.16						
R 5	6	ePz	0.41						
R 8	6	ePz	0.33						
R 12	6	ePz	0.25						
R 15	6	ePz	0.35						
R 6	6	lC	0.36						
R 7	6	lC	0.25	GP					
R 9	6	lC	0.27						
R 10	6	lC	0.29	GP					
R 14	6	lC	0.32	GP					
R15	6	Per	0.35						
R 16	6	lC	0.36	GP					
R 17	6	lC	0.31	GP					
REM 6	7	Carn	0.99		0.83	0.17			8

Table 1.
Analytical data.
Loc = Locality of Text-Fig. 2; Age = stratigraphic age; ePz = Early Paleozoic; lC = Late Carboniferous; Per = Permian; Carn = Carnian; IC = Illite crystallinity in °Δ2Θ; R_{max} = maximum vitrinite reflectance; R_{min} = minimum vitrinite reflectance; s = standard deviation; N = number of vitrinite reflectance measurements; GP = graphitic organic matter).

3. Samples and Methods

To evaluate the prevailing Alpine thermal overprint we focus on post-Variscan sediments (see also RANTITSCH, 1997). Nevertheless, in the Remschnigg section (locality 6 in Text-Fig. 2) we determined the metamorphic overprint also in shales of the Early Paleozoic basement.

Samples of dark coloured shales and siltstones from Late Carboniferous (Stephanian) fluvial overbank sediments of the Stangnock Formation (KRAINER, 1989, 1993) come from the localities "Königstuhl" (locality 1; KRAINER [1989]), "Turrach" (locality 2), "Brunnacher Höhe" (locality 3; LIEGLER [1970]; SCHLÖSER et al. [1990]) and from the Remschnigg Range (locality 6). Permian red beds (Werchzirm Formation), overlying Late Carboniferous shales were sampled in the Remschnigg Range (Locality 6). Samples of Carnian shales of the Raibl Group come from the locality "Launsdorf" (locality 4; DULLO & LEIN [1980]), from the locality "St. Paul" (locality 5; THIEDIG et al. [1975]) and from the locality "Heiligengeist" at the Remschnigg Range (locality 7; VON BENESCH [1914]).

The inorganic degree of low temperature metamorphism was evaluated by means of illite crystallinity (IC; cf. FREY, 1987). In this paper the anchizone is defined using the limiting values of KÜBLER (1984; $0.42 > IC > 0.25$). The analytical techniques are in accordance with the recommendations of KISCH (1991) and were described in SACHSENHOFER et al. (1998). The rank of organic maturation was determined by the measurement of vitrinite reflectance (R_{max}, R_{min} in Paleozoic samples, Ro in Carnian samples) under oil immersion at a wavelength of 546 nm, following standard coal petrological methods (STACH et al., 1983).

4. Results

4.1. Coalification of Organic Matter

Coalification of Late Carboniferous samples ranges from semi-anthracite (2.0 %<R_{max}<2.8 %) up to meta-anthracite (R_{max} >6.0 %, R_{min} >2.0 %).

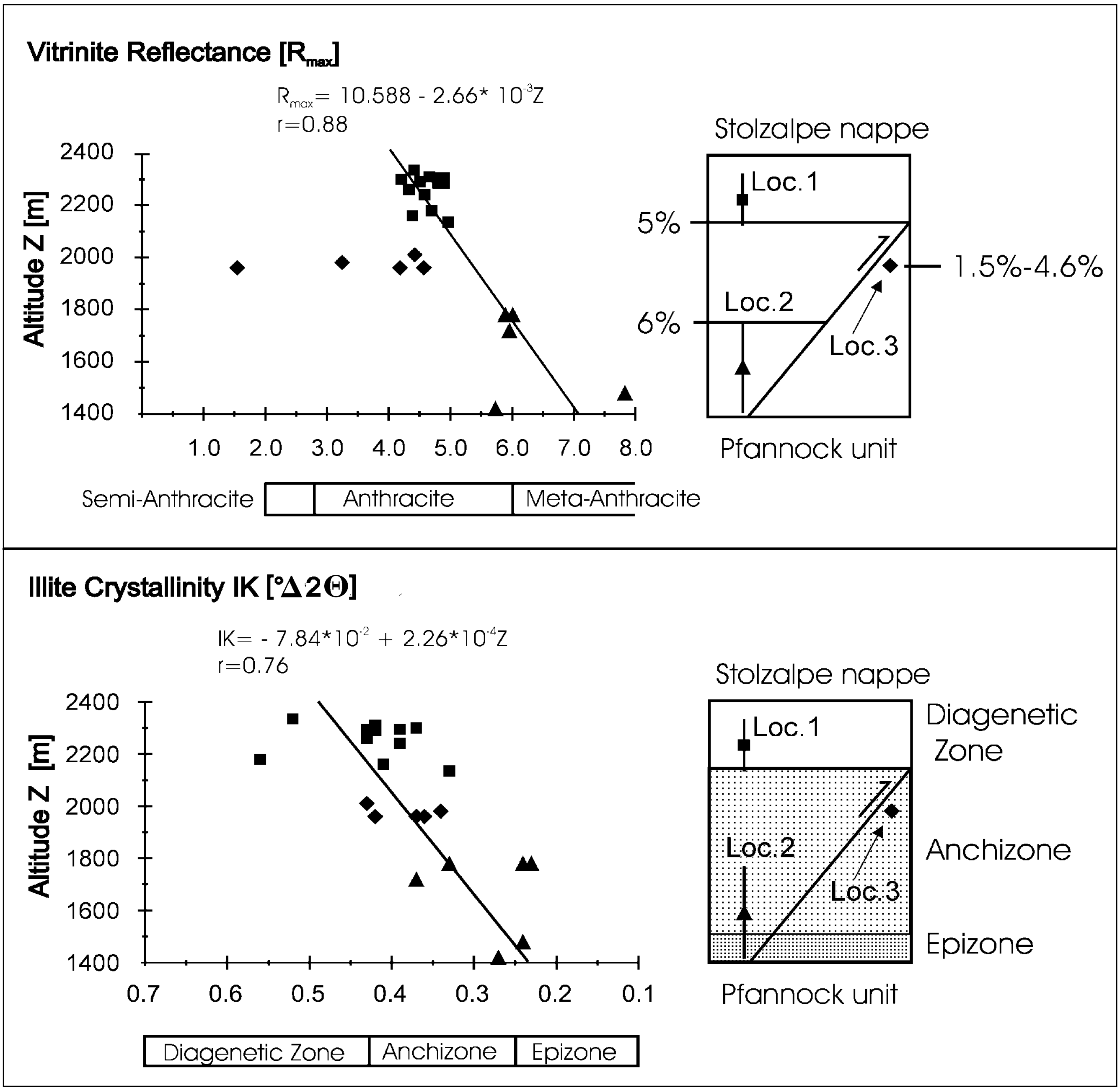
Most of the samples show a coalification rank in the anthracitic-stage of organic maturation ($2.8<R_{max}<6.0$ %; see Tab. 1). In the Remschnigg area (locality 6), organic matter in Carboniferous shales is completely transformed to semigraphite ($R_{max}>6.0$ %, $R_{min}<2.0$ %). Coalification of Carnian Raibl shales ranges from the high-volatile bituminous stage to the medium-volatile bituminous stage (0.83 to 1.34 % Ro), showing a slight increase towards the west.

4.2. Clay Mineralogy

Based on detailed x-ray investigations, illite-muscovite, chlorite and quartz are the dominant mineral phases. Albite, K-feldspar and pyrite occur in minor quantities. In the Carnian shales discrete smectite is a major constituent of the mineral assemblage. As also stated by SCHRAMM et al. (1982) and VON GOSEN et al. (1987), anchizonal illite crystallinity values are found in Late Carboniferous sediments (see Tab. 1). In the Remschnigg area (locality 6), Permian red beds, Carboniferous shales as well as the underlying early Paleozoic shales display uniform anchizonal illite crystallinities (see Tab. 1). Therefore, the postulated absence of a metamorphic break between basement and cover of the Stolzalpe nappe (SCHRAMM et al., 1982; VON GOSEN et al., 1987) is confirmed by our data set. The presence of a dominant smectitic phase in the Carnian Raibl shales indicates diagenetic conditions in Carnian and post-Carnian sediments.

5. Discussion

At the northwestern margin of the GNC it seems possible to fit a statistically significant ($\alpha = 0.01$) correlation line ($r = 0.88$) between vitrinite reflectance and altitude of the



Text-Fig. 3.
Correlation of illite crystallinity and coalification data with the altitude of the sample location at the NW margin of the Gurktal Nappe Complex (the localities are shown in Text-Fig. 2) with a sketch of the nappe structure.

sample location for samples from the Stolzalpe Nappe (Text-Fig. 3). Accepting this line, it is obvious that the strongly scattered vitrinite reflectances in the Pfannock Unit (locality 3, Text-Fig. 2) are unrelated with the sample group of the Stolzalpe Nappe. Applying the same model for illite crystallinity, a statistically significant (α = 0.01) correlation (r = 0.76) between illite crystallinity and altitude of the sample location is outlined for all samples of the Stangnock Formation (Text-Fig. 3). Accordingly, there is no break in illite crystallinity between Pfannock Unit and Stolzalpe Nappe cover.

Interpreting the variation of the metamorphic data at the western end of the GNC exclusively as a function of sedimentary and tectonic burial (i.e. neglecting any regional variation of the metamorphic pattern) it is obvious that vitrinite reflectance within the post-Variscan cover of the Stolzalpe Nappe is decreasing from top to bottom. From the correlation line between coalification and altitude of the sample location a continuous coalification gradient seems to be reliable (Text-Fig. 3). Consequently, coalification in this structural unit is explained in terms of burial heating. Coalification in the Pfannock Unit, however, did not reach the high rank of organic maturation of the structurally overlying Stolzalpe Nappe (Text-Fig. 3)! Therefore, a pretectonic coalification inside the Pfannock Unit in respect to overthrusting by the Stolzalpe Nappe has to be assumed (metamorphic event 1).

As seen by a continuous gradient in illite crystallinity across the whole nappe stack, the coalification break is not observed by illite crystallinity data (as also described by SCHRAMM et al. [1982] and VON GOSEN et al. [1987]). Therefore, illite recrystallization and organic maturation responded differently to the tectono-thermal stress. Because of the identical lithological composition of the samples it seems unlikely that a delay of organic maturation is restricted exclusively to the Pfannock Unit. Consequently, a second metamorphic event of illite recrystallization which does not affect the organic parameter (metamorphic event 2) results in the preservation of a break in the coalification trend.

A relationship between illite crystallinity and organic maturation is strongly influenced by shear-related mechanism like frictional heating (SUCHY et al., 1997), strain-induced crystal growth of mica (MERRIMAN et al. [1995]; ÁRKAI et al. [1997]), strain-induced graphitization of organic matter (WILKS et al., 1993a,b), reaction kinetics (TEICHMÜLLER et al. [1979]; KISCH [1987]) or local fluid circulation induced by shear heating (APRAHAMIAN & PAIRIS [1981]; KISCH [1987], and references cited herein; FERNÁNDEZ-CALLIANI & GALÁN [1992]; WARR & GREILING [1996]). Thus, it is supposed that ductile shearing between Stolzalpe Nappe and Pfannock Unit during regional uplift is the principal mechanism which triggered illite crystallinity and re-equilibrated the inorganic metamorphic section in the nappe pile.

Graphitization of organic matter in Carboniferous sediments of the Remschnigg Range indicates a significant higher degree of organic metamorphism compared to sediments at the western end of the GNC. The sediments investigated at this locality directly overly the ductile tectonic contact between Middle Austroalpine basement and GNC. Therefore, it is supposed that tectonically-induced graphitization of organic matter is the major cause of this observation. Such effects have been documented in several studies (SUCHY et al., 1997, cum.lit.). The associated anchizonal illite crystallinities indicate a delay of the inorganic parameter behind the organic parameter. In analogy to the Glarus thrust of the Swiss Helvetic Alps this delay may be an effect of strain-induced reduction in illite-muscovite crystallite size, which is not fully recovered by postshearing recrystallization (ÁRKAI et al., 1997).

6. Conclusions

The combination of organic and inorganic metamorphic data results in a better understanding of the processes of very low grade metamorphism acting during Cretaceous thrusting in the Gurktal Nappe Complex (GNC).

The relationship between illite crystallinity and organic maturation in Late Carboniferous cover sediments is strongly influenced by shear-related mechanism. At the western end of the GNC, a coalification hiatus between an internal fault plane is detected, which is not seen by means of illite crystallinity. At the eastern end of the GNC (in the Remschnigg area), a delay of illite recrystallization results in the association of graphitized organic matter with anchizonal illite crystallinities.

With the assumption stated above and refering to the tectonic model of VON GOSEN (1989) and KOROKNAI et al. (1999), the tectono-metamorphic history of the GNC is reconstructed in the following chronology:

1) Early Late Cretaceous overthrusting of the Murau Nappe upon the Austroalpine basement towards the NW.
2) Overthrusting of the Stolzalpe Nappe upon the Murau Nappe and subsequent folding, accompanied by a syn- to post-thrusting metamorphic event (metamorphic event 1). During this event the thermal peak of metamorphism was reached (NEUBAUER, 1987).
3) Progressive overthrusting of the Stolzalpe Nappe results in imbrication of the Pfannock Unit between Stolzalpe and Murau Nappe during regional uplift of the nappe. Strong tectonic fragmentation of the Pfannock Unit is responsible for a great scatter of coalification data within this unit.
4) Late Cretaceous low angle normal faulting along ductile shear zones (KOROKNAI et al., 1999) reequilibrates illite crystallinity to a new metamorphic gradient and did not affect the organic maturation (metamorphic event 2).

This study demonstrates that the different kinetics of organic and inorganic metamorphic parameters provide an important approach to model thrust tectonics in very low grade metamorphic rocks.

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