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5. Alpine Geology

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5. Alpine Geology

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Swiss Society of Mineralogy and Petrology (SSMP)

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5.1

Rb-Sr isochron ages from phengite inclusions in garnets from eclogite facies metasediments of the Zermatt-Saas Fee Zone (Western Alps)

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The ultramafic, mafic and metasedimentary units of the Zermatt-Saas Fee Zone (ZSZ) (Western Alps) were subducted to eclogite-facies conditions, reaching peak pressures and temperatures of 20-28 kbar and 500-600 °C. The rocks were partially retrogressed to greenschist-facies conditions during exhumation. Published Rb-Sr isochron ages obtained on matrix phengites in metasediments of the ZSZ are believed to date cooling to below the closure temperature of phengite of ca. 500 °C. Here we present Rb-Sr isochrons of phengite fully included in garnets to date garnet growth. We show that garnet acted as a shield for the completely included phengites, preventing Rb and Sr isotopic exchange with the matrix.

Garnets were separated from two metasedimentary samples from Triftji, using the Selfrag apparatus. Phengites included in garnet were manually recovered from abraded garnet separates. The Rb and Sr isotopic compositions of the phengite inclusion separates and of matrix minerals were analysed using the TIMS at the University of Wisconsin. Phengite inclusion ages for the samples are 44.25 ± 0.48 Ma and 43.19 ± 0.32 Ma. They are ~4 m.y. older than the corresponding matrix mica ages of 40.02 ± 0.13 Ma and 39.55 ± 0.25 Ma, respectively. To explain the 4 Ma difference in age for the phengites included in the garnet and the phengites in the matrix we suggest that: (a) phengites were included during prograde garnet growth; (b) inclusion of phengite in the garnet allowed for total isolation of the inclusions for isotopic exchange with the matrix, and hence the micas were protected against re-equilibration during the further prograde and subsequent retrograde path, even though the metamorphic peak exceeded the closure T of the Rb/Sr system in phengite- ; and (c) the 44 Ma inclusion age is a mixed age for the incorporation of phengite in garnet, weighted towards the later part of the garnet growth; hence towards the peak of the prograde metamorphism. The results are consistent with previous Sm-Nd and Lu-Hf geochronology on the ZSZ. They confirm that at least parts of the ZSZ underwent peak metamorphic HP conditions younger than 43 m.y. ago, followed by rapid exhumation to upper greenschist-facies conditions at 39.9 ± 0.5 Ma.

5.2

Constraining Alpine brittle deformation with hydrothermal monazite

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Two millimeter-sized hydrothermal monazites from an open fissure (cleft) that developed late during a dextral transpressional deformation event in the Baltschieder valley, Aar Massif, Switzerland, have been investigated using electron microprobe and ion probe. The monazites are characterised by high Th/U ratios typical of other hydrothermal monazites. Deformation events in the area have been subdivided into three phases: (D_1) main thrusting including formation of a new schistosity; (D_2) dextral transpression; and (D_3) local crenulation including development of a new schistosity. The two younger deformational structures are related to a subvertically-oriented intermediate stress axis, which is characteristic for strike slip deformation. The inferred stress environment is consistent with observed kinematics and the opening of such clefts. Therefore, the investigated monazite-bearing cleft formed at the end of D2 and/or D3, and during dextral movements along NNW dipping planes.

Interaction of cleft-filling hydrothermal fluid with wall-rock results in REE mineral formation and alteration of the wall-rock. The main newly-formed REE-minerals are Y-Si, Y-Nb-Ti-minerals and monazite. Despite these mineralogical changes, the bulk chemistry of the system remains constant and thus these mineralogical changes require redistribution of elements via a fluid over short distances (cm). Low-grade alteration enables local redistribution of REE, related to the stability of the accessory phases. This allows high precision isotope dating of cleft monazite. $^{232}Th/^{208}Pb$ ages are not affected by excess Pb (Janots et al., 2012) and yield growth domain ages between 8.03 ± 0.22 Ma and 6.25 ± 0.60 Ma.
The monazite crystallization is coeval or younger than 8 Ma zircon fission track data (Michalski and Soom 1990) and hence occurred below 280°C.

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5.3

Tracing Permian lower continental crust through rifting and orogeny

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In the Western Alps crustal fragments of the Austroalpine domain, once belonging to the northwest margin of Adria, are widely distributed. The IIDK in the Sesia Zone and the Valpelline in the Dent Blanche show numerous similarities to the Kinzigite Formation of the Ivrea Zone. The IIDK and Valpelline show a large variability in Alpine overprint, therefore correlation of these units to their origin in the Adriatic margin is often difficult. Marginally overprinted mineral assemblages indicate amphibolite to granulite facies metamorphic conditions. However sometimes only mineral relics, pseudomorphs and zircon crystals preserve the high-T history of the rocks. Zircons are known to be very robust to resetting under severe geological conditions and are thus used as archives.

To be able to compare and link the lower crustal fragments in the Western Alps to the Ivrea Zone, it is necessary to understand the variability of ages and textures in zircons related to metamorphic grade. Recent high precision geochronology in the Ivrea Zone (e.g., Ewing *et al.*, 2013, Peressini *et al.*, 2007) has resolved three relatively short-lived (metamorphic) events during Carboniferous/Permian time. Ewing *et al.* (2013) showed that the Ivrea Zone was affected first by a regional metamorphic event at ca. 316 Ma, a second contact metamorphic event around 276 Ma and a third event most likely related to fluid flow at ~258 Ma. Samples for the present study were collected in two valleys along two metamorphic field gradients within the Kinzigite Formation.

(1) In **Val Strona di Omegna** (N-Italy) a regional field gradient is exposed, with *P–T* conditions ranging from 650°C at 3–6 kbar to >900°C at 10–12 kbar (Ewing et al., 2013; Luvizotto & Zack, 2009; Redler et al., 2012). Zircon crystals in the lowest grade samples (mid amphibolite facies) show no datable overgrowth rims. Detrital cores have variable textures (igneous and metamorphic clasts), with ages clustering into three groups: the oldest one is Grenvillian (950–1000 Ma), the second and dominant group clusters around the Cadomian orogeny (530–650 Ma), and a third group preserves Variscan ages (~350 Ma). Towards higher metamorphic grade (T~750°C), zircon crystals are rich in inclusions (mostly sillimanite, minor feldspar and quartz) and have detrital cores; these show the same age distribution as the lowest grade samples (Grenvillian, Cadomian, Variscian). The Carboniferous/Permian metamorphic overgrowth rims show three age groups (315 Ma, 290 Ma and 270 Ma). At highest grade (≥900°C) few very small detrital cores are present. Zircons crystals in leucosomes show less complex textures, and the rim morphologies indicate growth in the presence of the anatectic melt. In melanosome domains zircon rims are more heterogeneous and have textures typical of high-grade metamorphism, such as planar growth banding, radial sector zoning and fir-tree sector zoning. Zircon ages show a similar distribution as the other samples (304 Ma, 273 Ma, 261 Ma); however, absolute ages are shifted towards younger ages.

(2) In **Val Sesia** (N-Italy) the metamorphic field gradient is dominated by contact metamorphism. The metamorphic conditions range from 680–940°C and 4–7 kbar (Redler *et al.*, 2012). Zircons show detrital cores with complex resorption and overgrowth textures. The detrital cores have Cadomian ages of ~570 Ma and Caledonian ages of ~430 Ma. Zircon mantles have ages of ca. 310 Ma, and rims ages cluster around 290–280 Ma.

Zircon ages obtained from the IIDK and Valpelline units show similar patterns in their overall Carboniferous/Permian age distribution as in the Ivrea Zone. However absolute ages for the individual slices deviate from those the Ivrea Zone; preliminary data indicate the following pattern:

Ivrea	IIDK	Valpelline
315 / 290 / 260	302 / 285 / 271	287 / 274 / 264 Ma
304 / 273 / 261		

So far it remains ambiguous whether these differences are due to partial preservation or indicate real differences in the original crustal positions within the Adriatic margin; additional work is underway.

These observations are promising as a help in correlating slices of continental crust, exposed now as tectonic blocks scattered across the Western Alps. Indeed, their approximate crustal position prior the Alpine rifting, subduction and uplift may be related to the Ivrea Zone, where continuous metamorphic field gradients are established, especially when the *P–T*-data of the Carboniferous / Permian metamorphic imprint in each tectonic fragment is also incorporated in the analysis.

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5.4

Tracing the continuous P-T path in metamorphic rocks by combining thermobarometry with a micro-mapping approach

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Our understanding of geodynamic and processes in subduction zones critically relies on estimates of the pressure-temperature (P-T) conditions of crystallization of metamorphic mineral assemblages. In subduction-collision mountain belts, eclogitic rocks have witnessed burial to LT-HP conditions followed by rapid exhumation. In favorable cases a series of assemblages remains, preserved in the same sample, with metamorphic minerals that grew at different times and under a range of equilibrium conditions of P, T, pH and fO2. Such distinct assemblages provide the opportunity to calculate the preserved local equilibrium condition and to construct a detailed P-T path from a single thin section. Ideally, P-T estimates can be correlated with deformational microstructures observed at micrometer scale. The identification of relationships between microstructures, chemical variations and metamorphic conditions demands contiguous compositional data in at least two dimensions, i.e. compositional maps.

To explore links between microstructure and P-T equilibrium conditions X-ray images acquired using the electron microprobe are very useful. The X-ray data processing involves several steps such as (i) analytical standardization, (ii) classification, (iii) structural formulae and (iv) estimation of P-T conditions. These tasks are achieved using a MATLAB©-based graphical user interface program XMapTools (Lanari et al. in press, freely available at http://www.xmaptools.com). To estimate P-T conditions of crystallization at the micrometer scale, XMapTools include a set of ~50 empirical and semi-empirical thermobarometry functions and can easily be coupled with forward (i.e. Gibbs free energy minimization) and inverse (i.e. multi-equilibrium) modeling calculations.

In this contribution we present some select examples of application of XMapTools to rocks from NW Himalaya, from the Atbashi Range and from the Alps. In the Himalayas, an extensively retrogressed eclogite sample from the Stak massif, northern Pakistan was investigated (Lanari et al. 2013, in press). A continuous P-T path and P-T maps (Fig. 1) were calculated from the eclogite stage to amphibolite-facies retrogression. In the Atbashi Range (southern Tien-Shan, Kyrgyzstan) a large massif (10 x 100 km) of continental HP rocks was investigated to reconstruct the geodynamic evolution of the northern rim of the Tarim basin (Loury et al. 2012). In the Alps (Glacier-Rafray Klippe, Aosta valley), phengite in leucocratic dyke was analyzed to link P-T conditions to the timing of the HP metamorphism. These examples will illustrate how X-ray data can be used to decipher P-T paths. In such case, P-T estimates have been estimated using both inverse modeling multi-equilibrium and equilibrium phase diagrams computed for a specific rock composition using forward modeling software (Theriak-Domino).

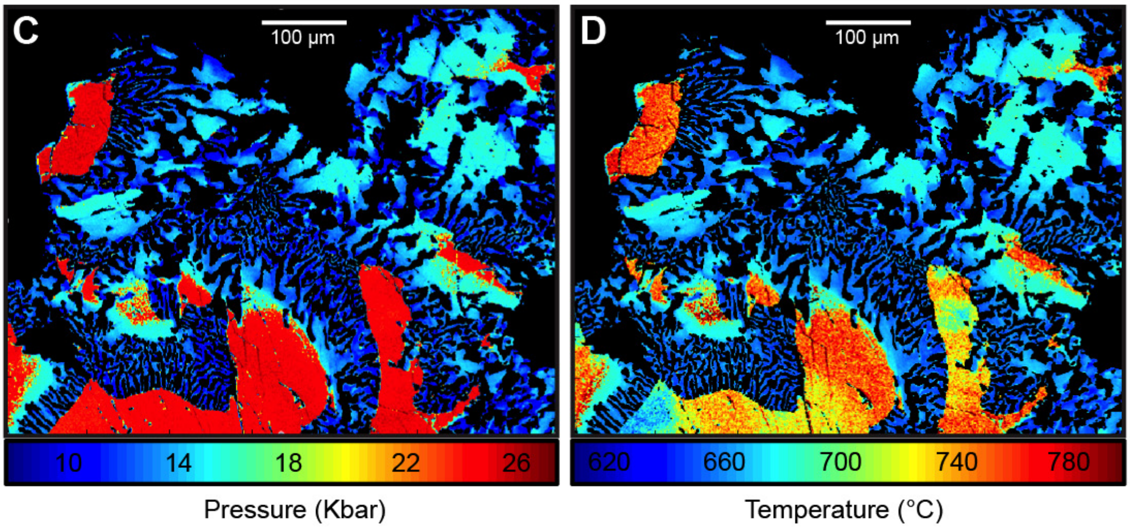

Figure 1. Pressure and Temperature maps of clinopyroxene modified from Lanari et al. (2013, in press). This eclogite sample comes from the Stak massif in Himalaya (N Pakistan). HP omphacite grains are destabilized into symplectite of clinopyroxene + amphibole + plagioclase.

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5.5

The volcano-sedimentary evolution of a Late-Variscan intermontane basin in the Swiss Alps (Glarus Verrucano) as revealed by zircon U-Pb age dating

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The Late Palaeozoic Glarus Verrucano basin formed in an intermontane graben in the aftermath of the Variscan orogeny. Its entirely continental fill, the Glarus Verrucano, mainly consists of immature alluvial fan and playa deposits with intercalated bimodal volcanics (basalts and rhyolites, see Figure 1). It can attain a maximum thickness of 1600 m. Despite its importance for local and regional geology, no modern sedimentologic or stratigraphic studies on the GVB exist.

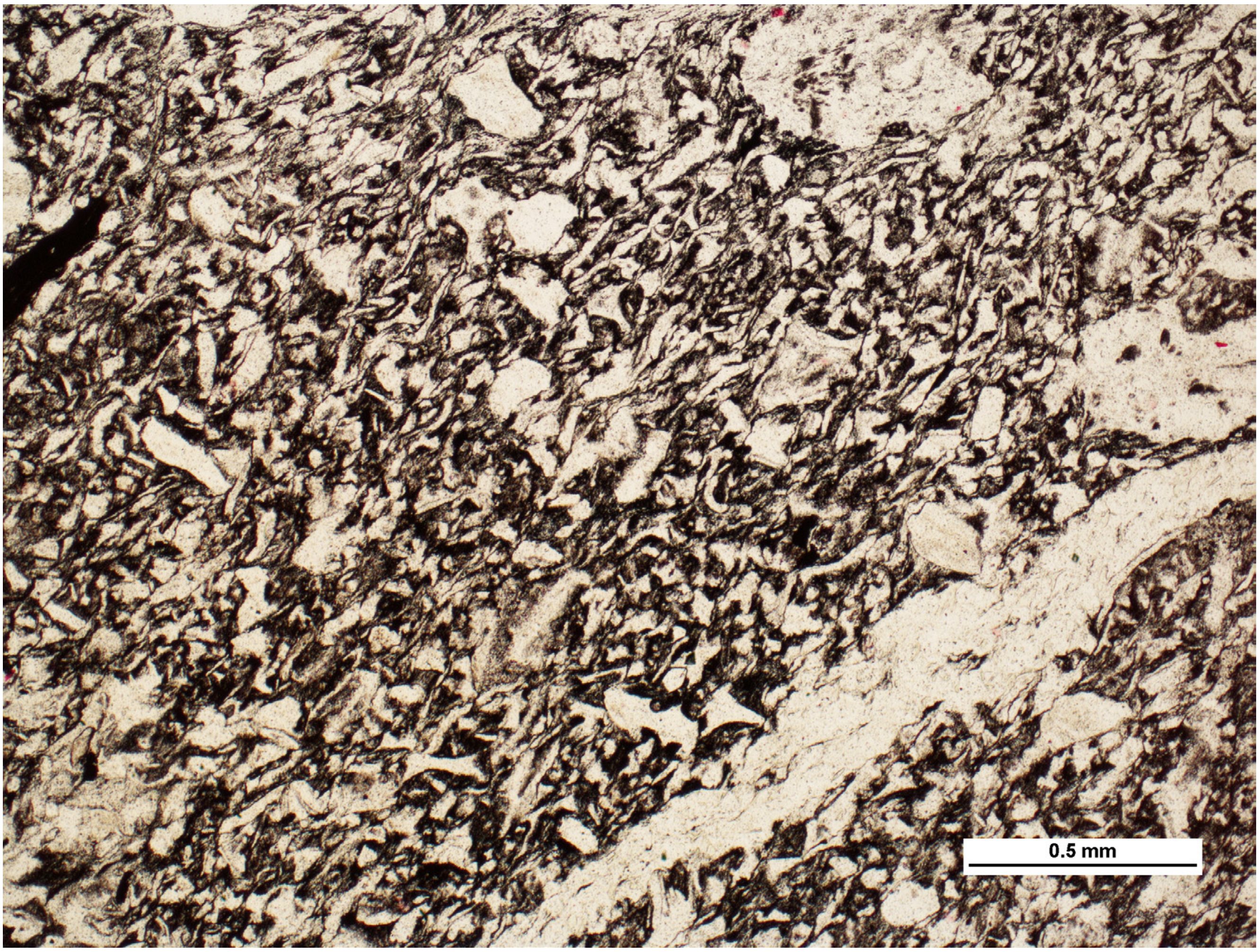

Figure 1.The youngest volcanic rocks in the Glarus Verrucano: ignimbritic rhyolites ("Schönbüel quartzites", Upper Chrauchtal, Canton Glarus). In thin sections the characteristic recrystallized glass shards can easily be recognized. Age: 268 Ma. From Letsch et al. 2013.

For the present project we sampled volcanic rocks (rhyolitic tuffs) for high-precision zircon U-Pb dating (CA-TIMS) and clastic sediments for detrital zircon U-Pb dating (LA-ICP-MS). In the Glarus Verrucano we distinguish two volcanic episodes (Figure 2). A first phase (Mären Formation) was of bimodal character with basaltic lava flows and rhyolitic flows (mainly ignimbrites). The lowest rhyolitic tuff (Sample DL V5) yielded a zircon U-Pb age (CA-TIMS) of 285 Ma. A second phase ("Schönbüel quartzites", Schönbüel formation, Figure 1) was exclusively of rhyolitic (ignimbritic) character. One ignimbrite layer (sample DL V7) yielded an U-Pb age (CA-TIMS) of 268 Ma. Thus, the lifespan of the Glarus Verrucano basin can be estimated as at least 17 Ma.

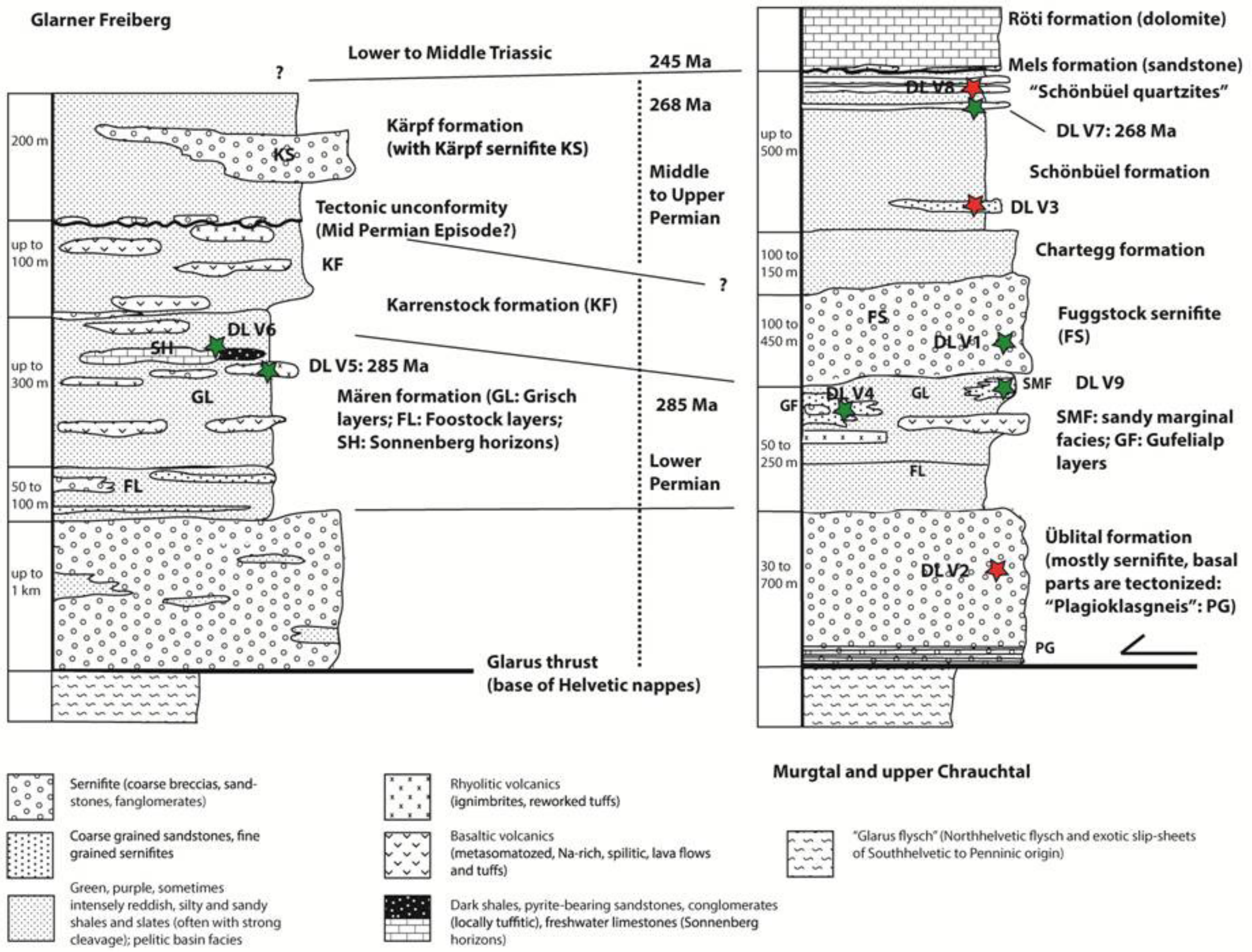

Figure 2. Schematic stratigraphic sections through the Verrucano in the Freiberg (left) and Murgtal/upper Chrauchtal area (right). Asterisks indicate sampling sites (green/red: sample yielded enough/not enough zircons for analysis). Stratigraphy mainly after unpublished PhD theses summarized by Trümpy and Dössegger (1972). From Letsch et al. 2013.

The detrital zircon ages from four samples (DL V1, V4, V6, V9) yielded mostly unimodal to slightly bimodal age distribution patterns with dominantly late Variscan ages (296 to 298 Ma) and subordinate older ages (with a maximum at 458 Ma, Ordovician). Synsedimentary zircons were present in each sample. Thus, the Glarus Verrucano records fast erosion and exhumation of the surrounding source areas, which were mainly composed of rather young intrusive rocks. Synsedimentary volcanism culminated in the Early Permian but continued into the early Late Permian.

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5.6

New tectonic limits in the Central Alps : the case of the “Simano nappe”

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The “Simano nappe” is a classical tectonic element of the Lower Penninic nappes in the Central Alps. It consists in a large, mainly gneissic body, situated geographically between the Maggia-Sambuco and the Adula nappes. Our researches reveal that it is a composite body made of at least two tectonic units of completely different origin, separated by a major Alpine thrust.

1.- The lower unit, the *Verzasca* nappe, lost most of its sedimentary cover, probably by early syn-tectonic erosion. Remnants of its Mesozoic cover are preserved as boudinaged lenses which discontinuously materialize the axial trace of a deep isoclinal recumbent syncline. Its Triassic is similar to rocks of same age in the Teggiolo zone, on the other side of the Maggia synform.

2.- The upper unit, the *Campo Tencia* nappe, has a very different constitution. The Triassic of its sedimentary cover (called the Campo Lungo zone) is similar to the Triassic of several units that belong to the middle part of the Lower Penninic nappes (e.g. Monte Leone, Adula, Valser Schuppen, etc). Recent researches provide hints that this Triassic is a reduced, littoral equivalent of the Briançonnais Triassic platform.

The differences in the petrographic composition of the gneissic basements of these two parts (orthogneisses abundant in Verzasca, scarce in Campo Tencia, etc) had been noticed long ago by previous authors who already considered the possibility of a subdivision of the “Simano nappe” into two or more “Lappen” (a distinction generally abandoned on modern tectonic maps). However our proposition is different as it is also based on significant differences of their Mesozoic cover series: these reveal different geological evolutions and different paleogeographical positions before their coupling during an early stage of Alpine tectonics. The presence in the “Simano” gneissic body of a few remnants of the Triassic cover of the Verzasca nappe confirms this interpretation. Consequently the origin of the Campo Tencia nappe is internal with respect to the Verzasca nappe.

We will discuss several consequences of these new observations.

5.7

Retrograde evolution of paleo- to recent fluids and their impact on mineral precipitation in the Gotthard base tunnel between Amsteg and Sedrun, Switzerland

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The present study is focused on eight selected Alpine fissures situated in different crystalline units of the Aar massif along the Gotthard railway base tunnel. Preliminary results of the fluid evolution from paleo- to the recent fluids are presented and preliminarily interpreted.

Due to compressional tectonics, the investigated Alpine fissures opened at PT-conditions of 350 - 410 °C and 3.5 - 4 kbar (Mullis et al., 2001; Mullis, 2011). Episodic tectonic activity affected these fissure systems. According to such tectonic events, already formed fissure minerals like quartz were systematically sheared, broken and reheald, trapping fluids during retrograde conditions.

Salinity of the trapped fluids evolved from 10 wt % in the earliest fluid inclusion population to ≤ 2 wt % NaCl equivalents in the latest detected fluid inclusion population. Comparing fluid compositions of paleofluids with recent fluids (Bergwässer; Bucher, 2011; Seelig & Bucher, 2010), bulk salinities decrease to values between 0.27 to 0.035 wt %.

Due to the episodic tectonic events, several paleofluid populations and at least 3 mineral assemblages formed. One mineral assemblage within the Central Aar granite (Alpine fissure 42 W) is characterized by precipitation of anhydrite, baryte and pyrite, showing $\delta^{34}S$ of anhydrite of 25.6 ‰.

Preliminary interpretation:

1. The decrease in salinity within paleofluids during retrograde conditions along a geotraverse through the Central Alps is well known (Mullis et al., 1994). Dilution of salt-enriched metamorphic fluids is interpreted predominantly by infiltration of meteoric water due to enhanced tectonic activity.
2. Sulfur infiltration during retrograde conditions is interpreted to originate from overlying Triassic evaporites (above the crystalline rocks of the Aar massif), due to strong tectonic events.
3. The decrease in salinity from the youngest paleofluids (within fluid inclusions of fissure minerals) to recent waters (Bergwässer) of up to 100 times is controlled by meteoric waters, the neotectonic fault networks, the actual orography of the Alpine body, and in consequence, the deep lying discharge systems along the concerned valleys.

To improve the presented preliminary results, more stable isotope and ICP-MS investigations are planned.

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5.8

Provenance analysis of the Voirons Flysch (Gurnigel nappe, Haute-Savoie, France): highlighting two major sources

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Our provenance analysis has identified two major sources for the Voirons Flysch. The first one supplied most of the members of this flysch and is similar to that of the Gurnigel Flyschs. It is characterized by a high content in quartz and sedimentary clasts. The second one is specific to the Vouan Conglomerates and is localized in basement rocks. Next steps will be to provide a sedimentary model and the paleogeographic location of the Voirons Flysch basin.

In the Chablais Prealps, the Gurnigel nappe is represented by the Voirons Flysch which is exposed in the Voirons and Vouan massifs and in some minor reliefs. This flysch is subdivided into three units: (1) the Voirons Sandstones (VS) basically constituted by a thick-bedded sandstone series, punctuated with some conglomeratic layers; (2) the Vouan Conglomerates (VC) formed of m-thick beds of matrix-supported conglomerates with subordinate sandstones; and (3) the Saxel Marls (SM) represented by a series of m-thick marl layers separated by thinly bedded sandstones. Finally to the NE, the Allinges Sandstones (AS) is considered as the lateral equivalent of VC or the VS, according to previous works. This succession is interpreted as a sequence from intermediate (VS) to proximal (VC and AS) turbidites, topped by distal turbiditic/contouritic facies (SM).

Biostratigraphic investigations (Ospina-Ostios et al., 2013) have rejuvenated this flysch from the Middle Eocene to the Late Eocene - Early Oligocene, which is in discrepancy with most palaegeographic models where the Gurnigel nappe is subducted earlier (up to the Middle Eocene) while the North Penninic flyschs go up to the Oligocene. Additionally few sedimentological studies have been made and provenance interpretation of this flysch is mainly based upon the other Gurnigel Flyschs studies.

More than 250 thin sections have been elaborated from the three members of the Voirons Flysch. Each thin section has been stained in order to differentiate alkaline feldspars, plagioclases and quartz. Counting of 300 points per section was made following the Gazzi-Dickinson method. Quartz and feldspars enclosed in lithoclasts have been counted in a dedicated class. Other constituents have also been taken into account as extra-counting.

All samples have been classified as quartzo-feldpathic sandstones with variable composition. They are depleted in lithoclasts. Most of them plot into the Continental Block field in Qm-F-Lt ternary diagrams (Dickinson and Suczek, 1979) and are organized into two clusters. The first one regroups the VS, SM and AS in the Transitional continental to Mixed area, while the second group is located in the Basement uplift field. This separation between the former group and the VC is confirmed by the relative content in lithoclasts (mainly sedimentary in the former and metmorphic to volcanic in VC). Additionally heavy-mineral analysis reveals a rich content in garnet for the VC, whereas the other members are characterized by a more important ZTR content.

Compared to the other Gurnigel Flyschs (Winkler, 1984; Winkler et al., 1985), VS, SM and AS members present similarities and seem to have same provenance than the former: Continental block to clastic wedge provenance according to Garzanti et al. (2007). However, there is some difference as, for example, the lack of tourmaline. The VC is, in contrast, not related to the Gurnigel provenance. Its source is more influenced by basement, with high content in feldspars and relative richness in metamorphic rocks. These characteristics imply an Axial Belt provenance (Garzanti et al., 2007) with some inputs from a Magmatic Arc.

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P 5.1

Structure and kinematics of the northern Adula nappe (Central Alps, Switzerland) and its emplacement in the Lower Penninic nappe stack.

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The Adula nappe belongs to the Lower Penninic domain of the Central Alps. It consists mostly of pre-Triassic basement rocks containing also numerous eclogites. The Adula nappe has the peculiarity to comprise several cover occurrences within the basement. The nature of the deformation experienced by the nappe reveals a complex history with several deformation phases.

The purpose of our study is a better understanding of the Alpine kinematics of the northern Adula nappe with a special focus on the early deformation phases responsible for the nappe emplacement. This study is mainly based on a detailed geologic mapping of several representative key-areas in the Northern Adula nappe. It has been also extended to a multi-scale structural analysis of the nappe at a broader scale.

We recognized that the nappe emplacement is associated with two phases of deformation. The early Ursprung ductile deformation phase is characterized by folds that are compatible with a top-to-the-south shearing. The Zapport phase, partially contemporaneous with the Ursprung phase, produces the main structural features of the nappe by ductile north directed shear and forms two generations of isoclinal nappe-scale folds. These folds are revealed by a detailed mapping in areas preserved by later deformation. The Zapport phase folds are complex synclines cored by the sedimentary cover at the front of the nappe.

In the Eastern transect of the Central Alps, the Adula nappe and the nappes derived from paleogeographic domains located south of the Adula domain (hyper-extended margin) are mostly emplaced by detachment and basal accretion in the Alpine accretionnary prism. In contrast, the Adula nappe and the other nappes located northward in the paleogeography are derived from a coherent European slab and form fold-nappes. The specific paleogeographic position of the Adula domain at the leading edge of a coherent European slab explains why this unit was subducted to depth sufficient to form eclogites. This leads the Adula nappe to act as a major shear zone during the nappe emplacement.

Two later deformation phases postdate mainly the nappe emplacement. The Leis and the Carassino deformation phases are principally characterized by NW-vergent folds. These deformations affect the nappe front formed during the previous nappe emplacement phases.

P 5.2

Fluid-infiltration driven formation of reaction rims between carbonates and silica-rich sediments during contact metamorphism of the Buchenstein formation in the Southern Adamello contact aureole, Italy.

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Contact aureoles provide a unique natural laboratory to study rates and mechanisms of mineral reactions. Metamorphic reactions in contact aureoles are often driven by fluid-infiltration leading to large element fluxes and metasomatism between adjacent lithologies with different bulk composition. Intrusion of southern Adamello batholith into mainly dolomitic and calcareous sequences of lower to middle Triassic sediments produced a variety of metamorphic reactions and metasomatic textures. In this study, we present a detailed petrographic and geochemical characterization of the evolving reaction rims in the Buchenstein formation. The latter consists of well bedded pure limestones with nodular chert layers and some volcanoclastic, shale and sandstone intercalations. We collected a total of 12 samples with different grade of metasomatic overprint. Most samples locations are on the southern slope of Monte Frerone, ~ 50 m below the peak near the contact with the intrusion. Samples with lower grade metamorphism are collected about 400 m below the peak and one almost non-metamorphic sample was collected in Valle del Gaver south of the Monte Blumone.

Four zones with different mineral assemblages can be distinguished in the investigated samples. Progressing from marl to hornfels layer the zones are as follows: (1) calcite + clinopyroxene, (2) wollastonite, (3) quartz + plagioclase + clinopyroxene, and (4) plagioclase + quartz + biotite. Layer (1) is mostly homogeneous and dominated by coarse-grained (up to 800 µm in diameter) calcite with some fine-grained (50 µm) rounded clinopyroxene. Layer (2) consists almost entirely of wollastonite with a few xenomorphic clinopyroxene crystals. Here, two different textures of wollastonite can be recognized: a) grey elongate radiating aggregates and b) short prismatic grains of brightly yellow color showing lamellar twinning. The grain size of both wo-occurrences is strongly variable ranging from 20 to 750 µm in diameter. A continuous increase in size of the clinopyroxenes is observed in layer (3) towards the silica-rich hornfels layer. On the opposite side, i.e. at the contact to the wollastonite-rich layer, the typical grain size does not exceed 20 µm and clinopyroxene forms small roundly grains, which overgrow plagioclase in a quartz dominated matrix. Clinopyroxene is already up to 300 µm and forms xenomorphic poikilitic grains near the hornfels contact. In this zone, plagioclase is the dominating phase in the matrix. Plagioclase crystals are strongly xenomorphic with many inclusions of quartz. In contrast, idiomorphic twinned plagioclase (up to 200 µm) can be observed beneath fine-grained clinopyroxene in the zone near the contact to the wollastonite layer. A few up to one millimeter broad veins dominated by coarse-grained clinopyroxene and some plagioclase occur in layer (3). Layer (4) is a hornfels with a mostly homogeneous fine-grained plaqioclase-quartz-matrix. Here, biotite occurs as small (up to 20 µm) flaky grains, but are also rarely found as aggregates as large as 200 µm in diameter. A preferred orientation of biotite parallel to the overall layer structure can be observed. Some idiomorphic titanite crystals are found, mostly in contact with clinopyroxene within the transition zone between layers (3) and (4). The whole sequence described above is about 5 cm in length and repeats itself on hand specimen scale, whereas the exact width of different layers can vary between samples.

Element X-ray maps measured by electron microprobe show a general decrease of Al and Si from the hornfels towards the calcite-dominated layer. Reverse, observed Ca-concentration decreases from carbonate to the hornfels layer. Taken together, these gradients represent the major element fluxes of Ca, Al, and Si during fluid-infiltration at elevated temperatures.

P 5.3

Fluid investigation on prograde, T-max and retrograde inclusions in quartz from the southern part of the NEAT Gotthard base tunnel, Central Alps: preliminary results.

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The present study is focused on fluid inclusions in quartz, which are formed during increasing, maximum and decreasing temperature conditions.

The main topics to investigate are:
1. the evolution of fluid composition during prograde, T-max and retrograde conditions
2. the evolution of fluid composition and pressure at 400 °C from Biasca to the North of the Piora valley
3. the fluid evolution from the metasedimentary rocks of the Piora valley toward the crystalline units situated North and South of them
4. the difference between surface and NEAT base tunnel fluids.

Quartz samples were collected especially from Alpine fissures within the NEAT Gotthard base tunnel between the southern Gotthard massif and Biasca, situated in the Penninic Leventina nappe. In addition samples were also collected in quartz segregates (QS) and in Alpine fissures of the Piora valley.
All fluid inclusions are investigated by microthermometry. Prograde fluid inclusions are systematically found in the QS. They are stretched or decrepitated and contain the highest amount of CO_2. Tessin habit quartz (THQ) that were formed close to the T-max contain CO_2-enriched fluids in ± idiomorphic inclusions. Late retrograde H_2O-enriched fluid inclusions are common in both, QS and THQ.

Results:
1. The evolution from prograde (in QS) over ≤ T-max (in early THQ) to younger retrograde (in THQ) fluid inclusions display a characteristic decrease in CO_2-content, from ≥ 65 to ≤ 5 % CO_2 at pressures from ~3 to ≤ 2 kbar.
2. Prograde fluids show a decrease of CO_2 from the Piora valley toward the Lucomagno nappe in the South and the Gotthard massif in the North.
3. T-max fluids in the base tunnel show an increase of CO_2 and fluid pressure from South (Leventina nappe) to North (Piora valley).

Discussion and preliminary conclusions:
1. The source of CO_2 are metasedimentary rocks of the Piora valley and metasediments situated under the Leventina nappe. This is supported by fluid inclusions containing the highest CO_2-content located on prograde overprinted QS. Thus CO_2 was predominantly produced by decarbonatisation of metasedimentary rocks (Mullis et al. 1994).
2. Decrease of CO_2 within the given locality is probably controlled by meteoric water contribution and carbonate precipitation during retrograde conditions, what has to be proved by stable isotope investigations.
3. Fluid migration decreases from the Piora valley toward the crystalline Gotthard massif and the Lucomagno nappe.

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P 5.4

Lu-Hf ages form the Zermatt-Saas Fee ophiolite

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The Alpine chain is a classic continent-continent collisonal orogen that formed by the collision of Apulia/Africa with the Europe, after the closure of the Liguro-Piemont oceanic trough. Today, the remnants are exposed in the Western Alps as eclogite facies rocks of the Zermatt-Saas Fee (ZSF) unit. The eclogites have been the focus of many geochronological studies aiming at constraining the Alpine high-pressure event. Garnets are particularly useful, because they clearly belong to the HP paragenesis. There is a large spread in garnet-isochron ages throughout the ZSF unit, depending on the location and/or decay system. This spread can either have a petrologic and/or a geologic origin. For example, it was shown that due to differences in prograde Lu (enriched in early grown garnet cores) and Sm (enriched in late-grown garnet rims) zoning, Lu-Hf ages can be skewed towards the onset of garnet growth, whereas Sm-Nd most closely dates peak metamorphism (Skora et al. 2009). Conversely, it is well possibly that the ZSF unit was subducted diachronously. This study aims to shed light on garnet age differences found in the ZSF unit.

We have combined trace-element zoning in garnets with new Lu-Hf garnet geochron ages in order to extract information on its prograde growth. In total, 4 new Lu-Hf ages from Pfulwe (49.9 ± 3.3; 51.9 ± 2.7; 46.9 ± 3.6; and 47.0 ± 2.3 Ma) and one from Chamois, Valtournenche (52.7 ± 2.7) are very similar to the Lu-Hf age from Lago di Cignana, Valtournenche (48.8 ± 2.1, Lapen et al. 2003). The similarity of Lu-Hf ages and Lu zoning suggest that all these localities have shared a similar prograde tectonic history. In fact, we have suggested that the Lago di Cignana garnets have grown over 20 m.y., peaking at around 40 Ma (Skora et al. 2009). Two Saas-Fee and one Val d'Ayas samples, however, produced much younger Lu-Hf ages (40.7 ± 2.3; 38.1 ± 4.5; and 39.2 ± 2.2, respectively), which are close to exhumation ages of the Zermatt-Saas Fee zone. Neither differences in whole rock geochemistry, nor differences in rare earth element zoning can be held responsible for this discrepancy. This suggests a much later prograde history for these samples, and growth times that were much shorter (<10 m.y.) when compared to the other locations.

Combined, the new Lu-Hf ages suggest that the ZSF was subducted diachronously. Areas that have oldest Lu/Hf ages (~50 Ma) are structurally located highest in the obducted ZSFO. Their inferred prograde garnet growth interval results in initial subduction ages which are close to what is permitted by other geological constraints. We conclude, that these areas must have originated at the southernmost realm of the Liguro-Piemont ocean, being subducted first. On the other hand, samples dated from the Saas Fee area yield young Lu/Hf ages (~40 Ma age). Here the eclogite are structurally just above the Monte Rosa unit (Brainnconais/Europe), at the structural base of the ZSF. Hence their paleoposition was likely the northernmost realm of the Liguro-Piemont ocean, subducting last. We interpret the first group to have had significantly longer prograde garnet growth times compared to the second group, which is well reconciled with the fact that, initially, the ZSFO was subducted oblique, turning into a near-perpendicular subduction zone towards the end.

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P 5.5

Drowning history of Jurassic carbonate platform, Northern Atlasic fringe (NE ALGERIAN)

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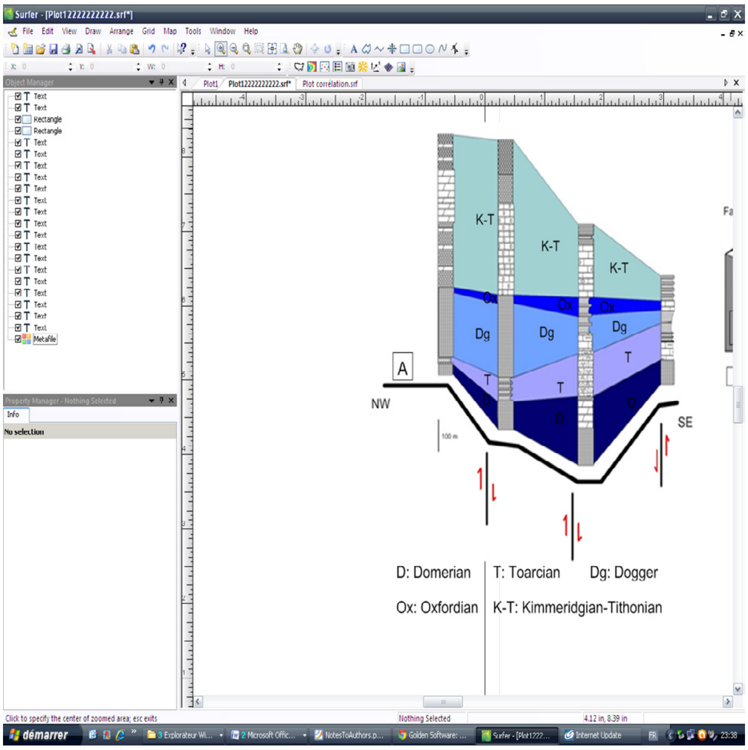
This study focuses on an area located at the convergence of the allochthonous and the Atlasic forelands of the Northren Algerian Alpine Belt. The objective of this work is to reconstruct the drowning history of the Jurassic carbonate platform, and discuss its relationship with the geodynamic evolution of the Southern Tethysian margin.
The identification and interpretation of drowning events in the platforms can help significantly to the reconstruction of the depositional, tectonics and eustatic history of these platforms.
The drowning of carbonate platforms was the subject of several stratigraphic and sedimentological researches in different places on the planet, at different periods of Phanerozoic times (Read, 1980, 1982, 1985, Kendall & Schlager, 1981, Schlager, 1981, 1989, Santantonio 1993).
The stratigraphic interpretation and correlation of the study area Jurassic series from a few cross-sections, have allowed the highlighting of the platform physiography during this geological period and individualizing three stratigraphic units. The synthesis of bio-sedimentological data reveals diversified facies, involving various deposits environments ranging from supratidal to deep pelagic peleoenvironments. These facies have evolved within subsidante carbonate ramp. Thereof has experienced drowning (Toarcian) and filling (Tithonian, Berriasian) phases, in relation with the eustatic sea level changes at the global scale and regional tectonics.



D : Domerian T : Toarcian Dg : Dogger Ox : Oxfordian K-T : Kimmeridgian-Tithonian
Figure 1.Correlation of the Jurassic series

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P 5.6

Diffusion-controlled garnet growth in silicious marbles of the Adamello contact aureole, N-Italy

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Metamorphic textures and spatial variations of chemical and isotopic composition are direct records of the temporal evolution, i.e. mineral reactions and mass transport of elements/isotopes in a rock and its mineral phases. More specifically, metamorphic mineral growth can be described by a combination of interface controlled and diffusion controlled processes. In this study, we present petrological and geochemical data combined with textural modeling to constrain the conditions and the reaction mechanism during contact metamorphic garnet growth in the southern Adamello Massif, Italy.

A petrological study was conducted on a contact metamorphic siliceous carbonates from the Adamello Massif, Italy. The sample contains garnet porhyroblasts ($Grs_{87}And_7Alm_3Pyr_1CaTi_2$), sitting in a fine-grained matrix of calcite+diopside+wolla stonite+anortite. The porphyroblasts are idiomorphic and poikiloblastic, ranging between 0.3-1 cm in diameter with small inclusions being uniquely diopside. In the hand specimen garnets are surrounded by concentric coronas of about 0.6-1.2 cm, indicating a diffusion-limited reaction mechanism to be responsible for the garnet formation.
In course of this study samples have been characterized regarding their mineralogical composition and textures using polarization microscopy, EMPA and cathodoluminescence microscopy. Additionally, the stable isotopic composition of carbon and oxygen of matrix calcite has been determined.

X-ray maps of garnets show distinct growth zoning, with Al decreasing from core to rim and Fe showing the inverse zoning pattern, whereas the distribution of Ca is homogenious. Stable isotopic compositions of carbonates from halos and matrix do not show any significant variation. However, measured values are in perfect agreement with previous results indicating the infiltration and equilibration of the carbonates with a light magmatic fluid phase. (Gerdes, et. al. 1999, Mueller, et. al. 2009).

Pseudosections have been calculated using the software package PerpleX (Connoly, 2005) based on the bulk rock composition of collected samples to constrain the garnet forming reaction history. Results indicate that garnet was produced by the breakdown of wollastonite, calcite and anorthite at water-rich conditions (XCO2= 0.3) and temperatures around 630°C. Limited transport of reacting species led to a depletion of wollastonite and anorthit surrounding the garnet porphyroblasts, representing the concentric halos seen in the hand specimen. The spatial relation of garnet and halo radius indicate a transport limited reaction mechanism.

The observed textures can successfully be reproduced using the SEG program (Foster, 1993), which has also been applied to decipher the relative phenomenological diffusion coefficients of Mg, Al, Ca and Si. Assuming no chemical potential gradient for Ca and a pore fluid being undersaturated in CO_2 (which can be justified by fluid infiltration during contact metamorphism), the wollastonite free zone is about the same size as the anorthite halo. Textures corresponding to the sample can be reproduced, assuming the wollastonite concentration being higher than the anorthite concentration and the transport of Al being about two orders of magnitude faster compared to Si. However, the modeled halo sizes strongly depend on the modal abundances and thus inverted concentrations for wollastonite and anorthite in the starting rock would result in inverted halo distributions.

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