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Reply

Chloritoid in the Penninic Tomül nappe: HP or LP formation? A reply to a comment by R. Oberhänsli, R. Bousquet and B. Goffé

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In a comment to Rahn et al. (2002), Oberhänsli et al. (2003) discuss some of the key issues regarding high pressure (HP) minerals in Bündnerschiefer units of the eastern Central Alps. We appreciate their comment and acknowledge the opportunity to further discuss the data from the investigated rocks in order to clarify the issues presented by Oberhänsli et al. (2003).

With reference to earlier reports (Goffé and Oberhänsli, 1992; Oberhänsli et al., 1995; Bousquet et al., 1998, 2002), Oberhänsli et al. (2003) emphasise the relevance of carpholite (cp) and chloritoid (cld) in Bündnerschiefer of the eastern Central Alps (western Grisons). According to their interpretation, the occurrence of cp in metapelites and of glaucophane in ophiolitic fragments close to the Adula nappe indicates an Eoalpine HP event, remnants of which are found between the Tauern window in the E and the Petit St. Bernard Pass in the W (Bousquet et al., 1998, 2002). The traces of HP metamorphism were variably overprinted by the Mesoalpine event, which in the western Grisons reached conditions of medium-grade greenschist facies. Oberhänsli et al. (2003) further emphasise that at maximum pressure conditions of 1.2–1.3 GPa and temperatures of 400 °C cp coexisted with cld, hence cld is part of the HP paragenesis. On the basis of the mineral reaction between cp and cld, the occurrence of the latter in the Bündnerschiefer of western Grisons was taken as an indicator of HP metamorphism despite the fact that in this area, cp does not occur in textural vicinity to cld (Oberhänsli et al., 1995, Bousquet et al., 1998, 2002). Similar to the Bündnerschiefer of the Engadine Window, the Bündnerschiefer of the Western Grisons have been divided into two sub-units on the basis of the presence or absence of HP minerals, but without considering the local stratigraphy and geology (Steinmann, 1994).

During our investigation, we have had several occasions to discuss our findings and results with R. Oberhänsli and R. Bousquet. We were thus aware of the presence of cp close to our working area in the Penninic Tomül nappe at Piz Beverin, as illustrated in figure 1 of Oberhänsli et al. (2003). It was not our intention to deny their findings nor to question their interpretation of a proposed subduction zone along the southern end of the Valais ocean. However, the rocks investigated by Rahn et al. (2002) from the Bündnerschiefer of the Tomül nappe do not contain cp nor any other texture or relic phase referring to a HP metamorphic past. Instead, Rahn et al. (2002) compared the Bündnerschiefer cld with known cld occurrences from Helvetic units and came to the conclusion that all features suggest a greenschist facies rather than a HP origin for the investigated cld in the Penninic Tomül nappe.

In order to underline this conclusion from Rahn et al. (2002), equilibrium phase diagrams were calculated using the computer program THERIAK-DOMINO (De Capitani, 1994) for the reported bulk-rock composition. The result is a P–T grid of thermodynamically stable mineral assemblages for that composition. The boundary between two stability fields represents one or more bounding reactions. Thermodynamic calculations were done using the database JUN92 of Berman (1988), supplemented by thermodynamic data for ferro- and magnesio-cp, magnesio- and ferro-cld from Le Bayon (2003), and for phengite (phe) from Massone and Szpurka (1997). The resulting composition of the cld was slightly more

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Mg-rich than measured (Rahn et al., 2002, Table 2), the celadonite content of phengite, calculated as a solid solution of muscovite and celadonite only, was comparable to the white mica found to be in textural equilibrium with cld. For the phases cp, cld and chl, single-site mixing models were used, which consider the Fe–Mg exchange between cp and cld Fe and Mg endmembers, and between clinochlore and daphnite for chl.

The geometry of the calculated diagrams is illustrated in Fig. 1. According to this geometry metapelitic rocks with ⩾15 wt% Al and very little to no calcite show the same assemblage: quartz–phengite–chlorite–paragonite (qtz–phe–chl–pg) plus one Al-rich phase incorporating the remaining Al. With increasing temperature, this phase is kaolinite (kln), pyrophyllite (prl), or andalusite (and) at low pressures, whereas at moderate to high pressures it is cp, cld or kyanite (ky). For a few samples, chlorite stability is restricted to the low pressure part of the cp and cld stability fields. The stability fields of cp and cld are surrounded by narrow P–T zones in which two Al-phases coexist, while for the Al-bearing phases without divalent cations, the transition from one stability field to the other is a single line in all phase diagrams.

From the position of the qtz–chl–phe–cld–pg stability field it is evident that the presence of cld may indicate conditions of LP to very HP conditions and minimum temperatures of around 380 °C. For the Helvetic rocks at Kunkels pass, the absence of chl may strongly reduce the minimum temperature for cld formation (Rahn et al., 2002). A HP boundary for the observed paragenesis of the Tomül nappe and Gotthard sedimentary cover is given by the breakdown of cld + chl, a reaction that commonly occurs at pressures >1.5 GPa.

From the rocks investigated by Rahn et al. (2002), neither the presence of cp nor prl could be reported. The metamorphic conditions retained in these rocks were restricted to the stability field of the Al-phase of cld alone and its coexistence with chl. The strong dependence of cld presence on bulk rock composition in these rocks suggests that, with the exception of minor amounts of ab, the observed mineral paragenesis corresponds to one single equilibrium assemblage. Computed mineral assemblages were compiled from all cld-bearing rocks of the two localities of the Tomül nappe at Piz Beverin and the Gotthard massif cover at Curaglia–Mutschnengia (Fig. 2). Rocks from the Tomül nappe were supposed to have undergone HP metamorphism before LP greenschist facies overprint, whereas those from the Gotthard nappe only experienced LP conditions. The stability fields of the paragenesis qtz–phe–chl–cld–pg (and minor amounts of Fe phases)

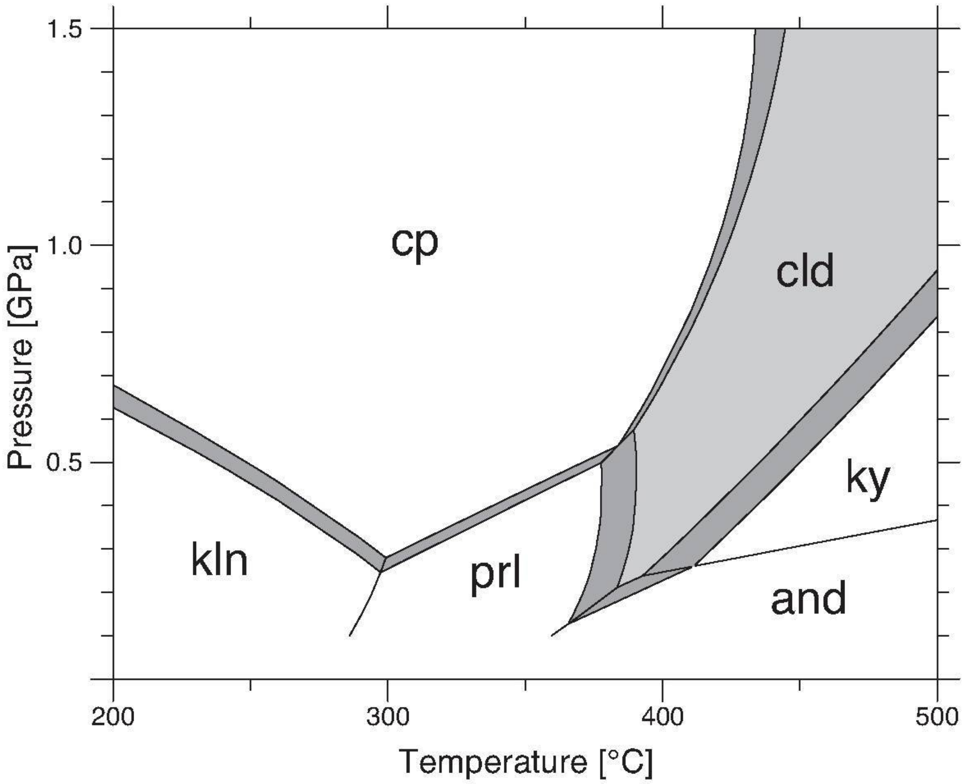

Fig. 1 General geometry of the stability fields of the main Al-bearing phases in calcite-free Al-rich low-grade metapelites (example: Cld 07, Rahn et al., 2002). Mineral abbreviations after Bucher and Frey (2002). The grey shaded zones between the stability fields represent areas of coexistence of two Al phases.

from each locality show a strong overlap, and an inner zone of stability of coexisting cld and chl for all samples. For both localities minimum temperatures of 400–420 °C are indicated, given the absence of prl.

By using the coexistence of cld and chl for additional temperature estimations (after Vidal et al., 1999; see Rahn et al., 2002) it is evident that the equilibrium parageneses observed in the investigated rocks indicates equilibrium temperatures below 450 °C at both localities. Due to the positive slope of the cp to cld transition, this temperature bracket restricts pressure conditions to values below 1.0 GPa, and rather points to equilibration at low to moderate pressures of 0.3 to 0.6 GPa. The close similarity between the two investigated rocks is interpreted as a consequence of similar bulk rock composition and equilibration at similar metamorphic conditions. The absence of any high-pressure evidence in the rocks of the Tomül nappe at Piz Beverin is no proof that HP conditions had not been previously reached, but is seen as a confirmation that these rocks were thoroughly overprinted and reequilibrated. They thus represent a single point of the P–T path only.

The question arises, finally, how the conditions summarised in Oberhänsli et al. (2003) on one side, and those from our study may be linked to a common P–T path. Such a path might provide interesting preliminary information about the early

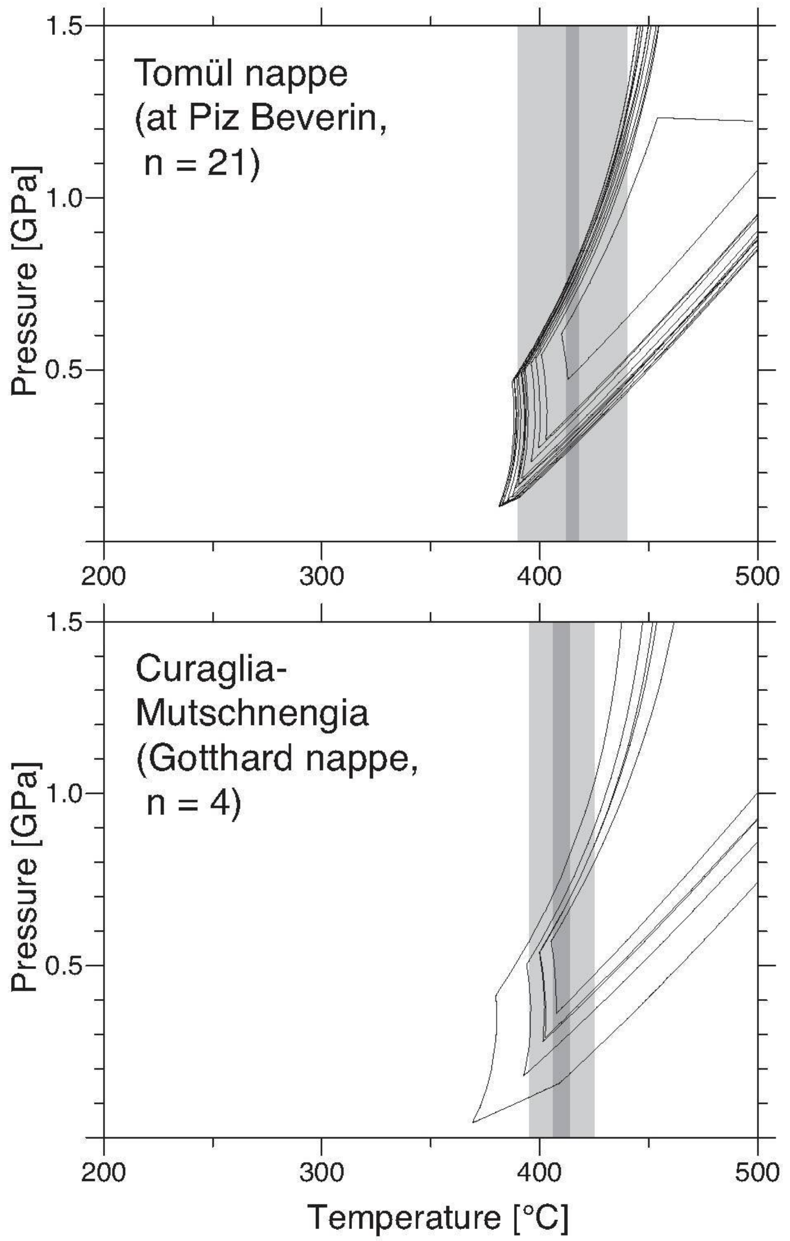

Fig. 2 Stability fields of the paragenesis qtz–ms–chl–cld–pg in metapelitic rocks of the Tomül nappe at Piz Beverin, western Grisons (above) and the sedimentary cover of the Gotthard nappe at Curaglia–Mutschnengia (below), as calculated by THERIAK-DOMINO (De Capitani, 1994). Temperature estimates on the basis of the cld–chl thermometer (Vidal et al., 1999) are shown by the standard error of the mean temperature value (dark grey bar) and the 1σ standard deviation (light grey zone).

exhumation history of the Bündnerschiefer in the western Grisons. In a first approach, the direct combination of the P–T data derived by Oberhänsli et al. (2003) and this study may be used to propose isothermal exhumation of the rocks from lower to middle crust levels, and from a typically subduction-related environment to a situation with a normal crustal temperature gradient. Bousquet et al. (2002) proposed a time interval between 40 and 35 Ma as the time of convergence and subduction at the southern margin of the Valaisan trough. The derived shape of the P–T evolution and the indicated time frame suggest a close link of the subduction of the Bündnerschiefer with the subduction of the northern Adula nappe (for P–T and chronological data, see Roselle et al., 2002, their figure 12, and references therein). The transition from the subduction-related HP environment to Lepontine metamorphism may have been close to isothermal, requiring special conditions for the exhumation of a common Bündnerschiefer-Adula tectonic fragment (Roselle and Engi, 2002). The absence of any information about the later retrograde evolution (e.g. the absence of retrograde prl) indicates the cessation of metamorphic reactions, perhaps due to the absence of a driving fluid.

Conclusions

Subsequent to a HP metamorphic event (Oberhänsli et al., 1995; Bousquet et al., 1998, 2002), the investigated rocks of the Bündnerschiefer experienced medium greenschist facies with P–T conditions of 420 ± 30 °C and pressures between 0.3 and 0.6 GPa. In many aspects these rocks are identical to cld-bearing rocks from the nearby Gotthard massif cover, and thus are interpreted to indicate low-pressure greenschist facies conditions, which in the western Grisons Bündnerschiefer follow a still locally preserved HP event. Combination of the P–T information for the Bündnerschiefer suggests a common exhumation history of the Tomül nappe and the northern front of the Adula nappe.

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