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Metamorphic zoning and geodynamic evolution of an inverted crustal section (Karakorum margin, N Pakistan), evidence for two metamorphic events

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Abstract The Karakorum Range comprises a crustal section of marbles and metapelites providing an opportunity to study the extent of high-temperature metamorphic reequilibration in an active orogen. Metamorphism culminated during the Mio-Pliocene, at 6–7 Ma. Peak metamorphic conditions increased from south to north, i.e. from (1) the Upper Anchizone grade (lawsonite, chlorite–smectite) to (2) lower granulite migmatite grade (HT∼800°C) conditions along strike of a 30-km section perpendicular to the structural fabric of the rocks. The metamorphic section can be separated into two domains:

1. A domain with low to transitional metamorphic conditions, with respect to the HT zone, where initial bedding is preserved. These moderate PT conditions prevailed during the main tectonic stacking event (50–37 Ma), prior to the Mio-Pliocene event. In this domain, metamorphism is governed by fluid-assisted grain-scale diffusion, as suggested by the progressive coarsening of minerals with increasing metamorphic grade and the preservation of sedimentary $\delta^{13}C$ signatures in carbonates. A low thermal gradient (17°C/km) is derived from *P-T* estimates of the prograde metamorphic sequences.
2. A higher-grade metamorphic domain where, by contrast, the metamorphic style is dominated by advection of heat with magmatic intrusions involving mantle melts during the recent tectonic history (20–3 Ma). Strong devolatilisation of CO_2 and partial melting of the metapelites triggered mixing up of carbonated and pelitic lithologies resulting in ultramafic restites and calc-silicate mobilisates. The $\delta^{13}C$ isotopic composition of carbonates is widely modified, though locally preserved.

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Introduction

The respective roles of fluid-assisted grain-scale diffusion and magmatic advection in heat and mass transport are widely discussed (Ferry and Gerdes 1998 and references therein). Precise field constraints based on the regional extent of metamorphic equilibration and the nature of percolating fluids are useful to unravel the complex metamorphic history dominated by such processes. The SE Karakorum margin (Fig. 1), or Karakorum Metamorphic Complex (KMC), presents a 20 km thick crustal section, in which the metamorphic conditions of the pelitic series have already been determined on a regional scale, with early Himalayan Barrovian metamorphism culminating at 0.8–1.0 GPa—650–700°C between 55 and 23 Ma, and late high temperature (HT) metamorphism culminating at 0.5–0.6 GPa—750–800°C between 6 and 7 Ma (Bertrand et al. 1988; Hanson 1989; Searle et al. 1989; Allen and Chamberlain 1991; Lemennicier et al. 1996; Rolland et al. 2001). Calc-silicate rocks are also found throughout the KMC metamorphic pile and are more frequent than pelites, especially in the lower-grade part. Previous studies (Bertrand et al. 1988; Searle et al. 1989; Allen et al. 1991; Lemennicier et al. 1996) were mainly concerned with the metamorphism of pelites, so the metamorphic evolution of the lower-grade part remains poorly known. In the calc-silicate lithologies, Na_2O and TiO_2 contents are low, and the sequence of crystallisation can be described in the K–Ca–(Mg/Fe)–AlSi–H_2O–CO_2 system (KCMAS-HC). In this