

## Petrologic assesment of deep CO<sub>2</sub> production in the active Himalayan orogen

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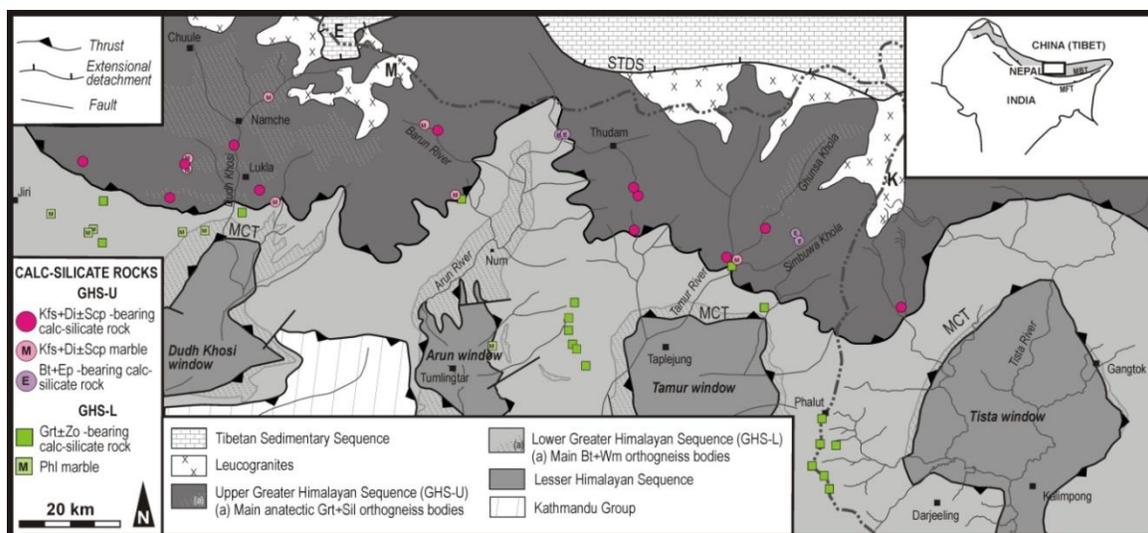
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Active collisional orogens may have strong impact on the global carbon cycle through metamorphic degassing, which would supply a significant fraction of the global solid-Earth derived CO<sub>2</sub> to the atmosphere, thus playing a fundamental role even in today's Earth carbon cycle.

The Himalayan belt, a major active “hot” collisional orogen, is a likely candidate for the production of significant amounts of metamorphic CO<sub>2</sub> that may have caused changes in long-term climate of the past, present and near future. Large metamorphic CO<sub>2</sub> fluxes are likely to be triggered by rapid prograde metamorphism of big volumes of impure carbonate rocks coupled with facile escape of CO<sub>2</sub> to the Earth's surface. So far, the incomplete knowledge of the nature, magnitude and distribution of the CO<sub>2</sub>-producing processes hampered a reliable quantitative modeling of metamorphic CO<sub>2</sub> fluxes from the Himalayan belt, as well as from any other collisional orogens.

We focus on the metamorphic decarbonation processes occurring during the Himalayan collision in the framework of the Ev-K2-CNR SHARE (Stations at High Altitude for Research on the Environment) Project. Consequently, the distribution of different types of metacarbonate rocks in the Eastern Himalaya, their petrography and petrological data about the nature of the CO<sub>2</sub>-producing reactions in garnet-bearing calc-silicate rocks are discussed.



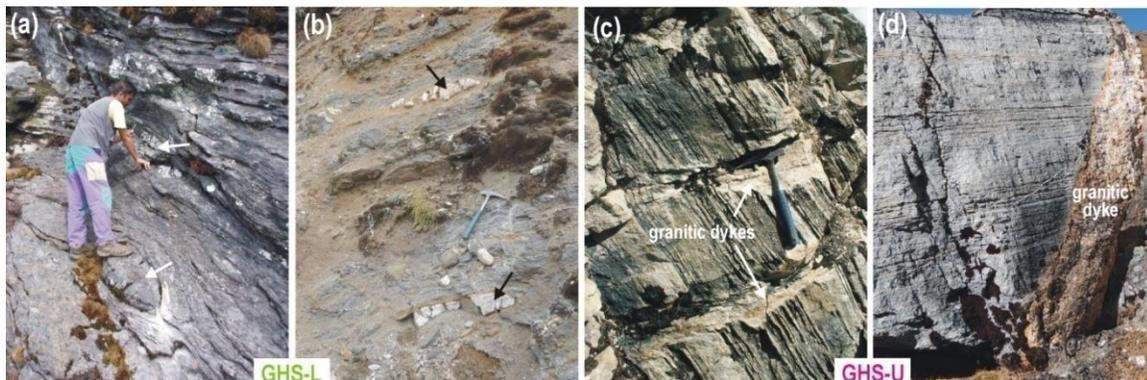
**Figure 1.** Simplified geological map of the central-eastern sector of the Himalayan belt (modified from Goscombe et al. 2006, Dasgupta et al. 2004, Mosca et al. 2012, Mosca et al. 2013) showing sample locations (squares: Grt+Zo calc-silicate assemblages and Phl marbles of the GHS-L; circles: Kfs+Di+Scp calc-silicate rocks and marbles of the GHS-U). The double-dashed grey line is the approximate political boundary between Nepal to the south, west, China (Tibet) to the north, India (Sikkim) to the east. MCT: Main Central Thrust; STDS: South Tibetan Detachment System; E: Everest, K: Kangchenjunga, M: Makalu. Inset shows the location of the study area (white rectangle) in the framework of the Himalayan chain. The grey shaded belt approximates the location of the Greater Himalayan Sequence. MFT: Main Frontal Thrust; MBT: Main Boundary Thrust.

In the eastern Himalaya, calc-silicate rocks are widespread in the lower (GHS-L) and upper (GHS-U) structural levels of the Greater Himalayan Sequence (Fig. 1). Different modes of occurrence have been distinguished for these lithologies:

- (i) in the GHS-L, calc-silicate rocks generally occur as dm to metre-thick levels or boudins within medium- to high-grade, locally anatectic, staurolite- and/or kyanite-bearing metapelites (Fig. 2a,b);

- (ii) in the GHS-U, calc-silicate rocks are hosted in anatectic kyanite-sillimanite-bearing gneisses (i.e. Barun Gneiss) and often occur as tens to hundreds of meter thick, folded or boudinated, levels occasionally associated to layers of impure marbles. The transition between the paragneiss and the calc-silicate granofels is generally gradual and is characterized by the progressive disappearance of biotite, the appearance of clinopyroxene and the modal increase of plagioclase (Fig. 2c,d).

A banded structure is locally observed in the calc-silicate rocks, defined by the different modal proportion of the rock-forming minerals in adjacent layers. This suggests that calc-silicate rocks derive from former marly intercalations within a thick sedimentary sequence.



**Figure 2.** Field occurrence of calc-silicate rocks from the GHS-L (a,b) and GHS-U (c,d). The arrows in (a) and (b) indicate the calc-silicate boudins.

Mineral assemblages are systematically different in the GHS-L and GHS-U (Fig. 1):

- (i) in the GHS-L, the equilibrium assemblage consists of plagioclase + clinopyroxene + quartz + garnet. Garnet is locally very abundant and it is often intergrown with quartz. Microstructural evidence suggests that garnet grew at the expense of zoisite, clinopyroxene and calcite, the latter being only locally observed as inclusion in garnet. Coarse-grained graphite is abundant.
- (ii) in the GHS-U, calc-silicate rocks consist of K-feldspar + clinopyroxene + calcite + scapolite + plagioclase + quartz ± zoisite, relict biotite and muscovite. The ubiquitous mineral scapolite occurs both in the matrix and as oriented inclusions in clinopyroxene and zoisite; it is locally partially replaced by fine-grained dusty aggregates of plagioclase + calcite and/or it is overgrown by coarse-grained epidote.

The nature of the CO<sub>2</sub>-producing reactions in the calc-silicate rocks may be petrologically investigated using activity-corrected P-T phase diagrams at fixed fluid composition, isobaric T-X(CO<sub>2</sub>) phase diagram sections, and phase diagram projections in which fluid composition is not explicitly constrained (Groppo et al. 2013). Petrologic data demonstrate that both garnet- and scapolite-bearing calc-silicate rocks may act as CO<sub>2</sub>-source during prograde heating, releasing internal-derived CO<sub>2</sub>-rich fluids through garnet forming reactions and scapolite consuming reactions.

However, if the system remains closed, fluid-rock interactions may induce hydration of the calc-silicate assemblages and the in-situ graphite precipitation, thereby removing carbon from the fluid. The interplay between these two contrasting processes – i.e. production of metamorphic CO<sub>2</sub>-rich fluids vs. carbon sequestration through graphite precipitation – must be taken in account when dealing with a global estimate of the role exerted by decarbonation processes on the orogenic CO<sub>2</sub>-cycle.

#### References

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