Large-scale organization of carbon dioxide discharge in the Nepal Himalayas: Evidence of a 110-km-long facilitated pathway for metamorphic CO_2 release

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Convergent zones play an essential role in the global carbon dioxide (CO_2) balance of the Earth (Kerrick and Caldeira, 1998). In addition to their role of atmospheric CO_2 sink through weathering (Gaillardet et al., 1999), large orogens are also the location of the production and release of CO_2-rich fluids (Irwin and Barnes, 1980). Major active fault zones appear therefore as a dynamically complex system where fluid circulation, crustal permeability and possibly earthquake occurrence might be interrelated (Ingebritsen and Manning, 2010; Manga et al., 2012). The Himalayas offers a privileged natural laboratory where this essential dynamical coupling can be studied. High seismic activity is concentrated on a mid-crustal ramp located in the Main Central Thrust (MCT) zone on the Main Himalayan Thrust accommodating the 2 cm year^{-1} convergence (Ader et al., 2012), where fluid occurrence might explain the high electrical conductivity observed by magneto-telluric sounding (Lemonnier et al., 1999). Seasonal variations of seismicity (Bollinger et al., 2007) and deformation (Chanard et al., 2014) can be accommodated by surface hydrological forcing, possibly leading to fluid overpressures at depth. Direct evidence of the fluid release in the MCT zone has been given recently. First, the high alkalinity of hot springs was observed to contribute to tremendous CO_2 fluxes in the main rivers (Evans et al., 2004). The high carbon isotopic ratios of the hot springs suggested the presence of a metamorphic decarbonation source at depth and of massive CO_2 degassing (Becker et al., 2008; Evans et al., 2008). Second, direct evidence of CO_2 emission from the ground was discovered in the Syabru-Bensi hydrothermal system (SBHS), central Nepal (Perrier et al., 2009), where it was found to be associated with a radon-222 signature, a valuable asset for long-term monitoring (Girault et al., 2009), and was subsequently mapped in detail (Girault et al., 2014),. In this study, we present the results of systematic search and measurement of CO_2 release from the ground in the vicinity of other significant hot springs from western to eastern Nepal (Figure 1).

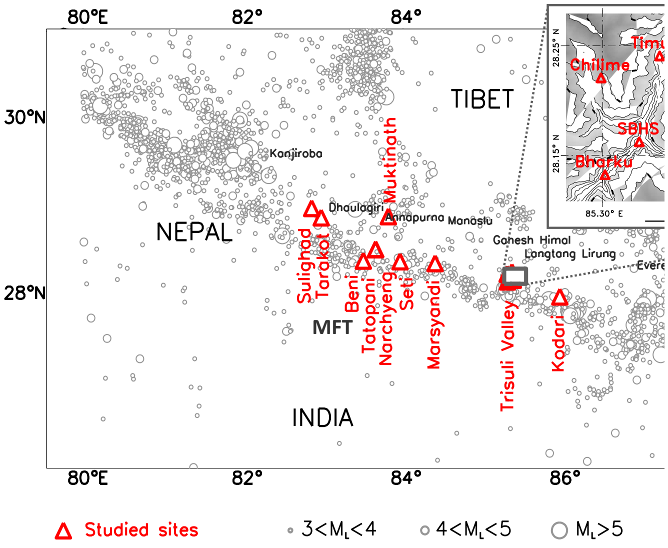

Figure 1. Overview of sites in the Nepal Himalayas. Main Central Thrust (MCT), Main Frontal Thrust (MFT) and highest summits (closed triangles) are shown. Earthquakes epicenters are taken from the 1995-2005 catalogue (Nepal National Seismological Centre). The inset shows location of sites in the upper Trisuli Valley. SBHS corresponds to the Syabru-Bensi hydrothermal system in central Nepal.

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Gaseous CO_2 and radon-222 (radioactive gas with half life of 3.8 d) release from the ground was investigated along the MCT zone in the Nepal Himalayas and quantified using the accumulation chamber technique. From >2200 CO_2 and >900 radon-222 flux measurements in the vicinity of 13 hot springs from western to central Nepal, we obtained total CO_2 and radon discharges varying from 10^{-3} to 1.6 mol s^{-1}, and from 20 to 1600 Bq s^{-1}, respectively. We observed a coherent organization at spatial scales of ≈10 km in a given region (Figure 2) (Girault et al., submitted): low CO_2 and radon discharges (Group III) around Pokhara (midwestern Nepal) and in the Bhote Kosi Valley (east Nepal); low CO_2 but large radon discharges (Group II) in Lower Dolpo (west Nepal); large CO_2 and radon discharges (Group I) in the upper Trisuli Valley (central Nepal).

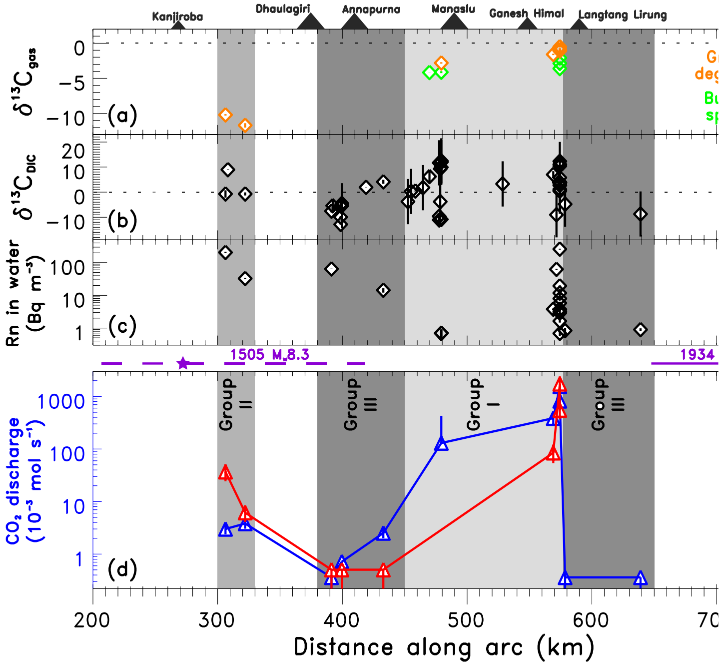

Figure 2. Characteristics of CO_2 degassing from the ground and from water along the Nepal Himalayan arc: (a) carbon isotope ratios of the gaseous CO_2 from the ground and from bubbles in springs, (b) carbon isotope ratios of water (dissolved inorganic carbon), (c) radon concentration in spring waters, and (d) CO_2 and radon discharges from the ground. Data include original and published works. Epicenter and rupture length of the two last megaquakes (1505 and 1934) are displayed.

This large-scale organization suggests different gas transport mechanisms. While the simultaneous degassing of dissolved CO_2 and radon from hot spring waters can be considered in Lower Dolpo, in the upper Trisuli Valley, by contrast, the CO_2 and radon discharge can likely be the evidence at the surface of a gaseous-dominated transport through a large-scale fault network (Girault and Perrier, 2014). A 110-km-long CO_2-producing segment, with high carbon isotopic ratios indicating most likely metamorphic decarbonation, is thus evidenced from 84.5°E to 85.5°E, which suggests interactions between geological conditions, crustal permeability, and, possibly, large Himalayan earthquakes. This hypothesis needs to be tested in detail. First, we need a better understanding of the mechanisms producing metamorphic CO_2 in the Himalayas (Groppo et al., 2013). Then, we need a more comprehensive mapping of CO_2 emission in the Himalayas.

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