Earth and Planetary Science Letters 278 (2009) 198–207

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

A direct evidence for high carbon dioxide and radon-222 discharge in Central Nepal

Frédéric Perrier [a,*], Patrick Richon [b,c], Svetlana Byrdina [a], Christian France-Lanord [d], Sudhir Rajaure [e], Bharat Prasad Koirala [e], Prithvi Lal Shrestha [e], Umesh Prasad Gautam [e], Dilli Ram Tiwari [e], André Revil [f,g], Laurent Bollinger [b], Simon Contraires [h], Sarah Bureau [b], Soma Nath Sapkota [e]

[a] *Equipe de Géomagnétisme, Institut de Physique du Globe de Paris, UMR 7154 et université Paris-Diderot, 4 Place Jussieu, 75005 Paris, France*
[b] *Département Analyse Surveillance Environnement, CEA, DAM, DIF, 91297 Arpajon, France*
[c] *Equipe de Géologie des Systèmes Volcaniques, Institut de Physique du Globe de Paris, UMR7154, 4 Place Jussieu, 75005 Paris, France*
[d] *Centre de Recherches Pétrographiques et Géochimiques/CNRS, BP20 54501, Vandoeuvre-les-Nancy, France*
[e] *National Seismic Centre, Department of Mines and Geology, Lainchaur, Kathmandu, Nepal*
[f] *Colorado School of Mines, Department of Geophysics, Golden, CO, United States*
[g] *CNRS-LGIT UMR 5559, Equipe Volcans, Université de Savoie, Chambéry, France*
[h] *Equipe Géomatériaux et Environnement, Institut de Physique du Globe de Paris, UMR 7154, 4 Place Jussieu, 75005 Paris, France*

ARTICLE INFO

Article history:
Received 17 September 2008
Received in revised form 29 November 2008
Accepted 2 December 2008

Editor: T.M. Harrison

Keywords:
carbon dioxide
geothermal system
gas flux
thrust fault
active tectonics
carbon budget
radon-222

ABSTRACT

Gas discharges have been identified at the Syabru–Bensi hot springs, located at the front of the High Himalaya in Central Nepal, in the Main Central Thrust zone. The hot spring waters are characterized by a temperature reaching 61 °C, high salinity, high alkalinity and $\delta^{13}C$ varying from +0.7‰ to +4.8‰. The gas is mainly dry carbon dioxide, with a $\delta^{13}C$ of −0.8‰. The diffuse carbon dioxide flux, mapped by the accumulation chamber method, reached a value of 19000 g $m^{-2}day^{-1}$, which is comparable with values measured on active volcanoes. Similar values have been observed over a two-year time interval and the integral around the main gas discharge amounts to 0.25±0.07 mol s^{-1}, or 350±100 ton a^{-1}. The mean radon-222 concentration in spring water did not exceed 2.5 Bq L^{-1}, exponentially decreasing with water temperature. In contrast, in gas bubbles collected in the water or in the dry gas discharges, the radon concentration varied from 16000 to 41000 Bq m^{-3}. In the soil, radon concentration varied from 25000 to more than 50000 Bq m^{-3}. Radon flux, measured at more than fifty points, reached extreme values, larger than 2 Bq $m^{-2}s^{-1}$, correlated to the larger values of the carbon dioxide flux. Our direct observation confirms previous studies which indicated large degassing in the Himalaya. The proposed understanding is that carbon dioxide is released at mid-crustal depth by metamorphic reactions within the Indian basement, transported along pre-existing faults by meteoric hot water circulation, and degassed before reaching surface. This work, first, confirms that further studies should be undertaken to better constrain the carbon budget of the Himalaya, and, more generally, the contribution of mountain building to the global carbon balance. Furthermore, the evidenced gas discharges provide a unique natural laboratory for methodological studies, and appear particularly important to study as a function of time, especially in relation to the seismic activity. For this purpose, the observed high radon-222 flux is a particularly interesting asset. Indeed, while the relationship between radon and carbon dioxide needs to be better understood, radon measurements, using the available radon sensors, constitute a powerful tool for robust and cost effective long term monitoring.

1. Introduction

One pending problem, in the estimation of the global carbon budget, remains quantifying the contribution of carbon from active orogenic zones such as the Himalayan Range (Galy and France-Lanord, 1999; Quade et al., 2003; France-Lanord et al., 2003). While, over long time scales, carbonate alteration preserves the carbon balance, silicate alteration behaves as a carbon sink (Gaillardet et al., 1999). In the Himalaya, silicate alteration is important due to the strong monsoonal forcing and the high topography (Evans et al., 2004). However, in regions of active tectonics, carbon dioxide can also be released by metamorphic reactions (Irwin and Barnes, 1980). This contribution is poorly known, but, in the case of the Himalayan Range, appealing clues have been identified in the hot springs located in the High Himalaya, mostly in the vicinity of the Main Central Thrust (MCT) (Evans et al., 2008; Becker et al., 2008; Giggenbach et al., 1983). The hot springs waters have a large alkalinity, up to 100 mmol·kg^{-1}, and

* Corresponding author.
E-mail address: perrier@ipgp.jussieu.fr (F. Perrier).

0012-821X/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsl.2008.12.008

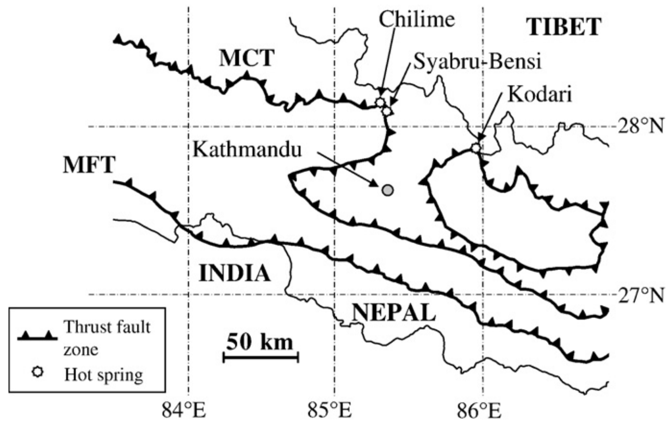

Fig. 1. Simplified map of Nepal showing the location of the Syabru–Bensi, Chilime and Kodari hot springs. The contours of the Main Central Thrust (MCT) and Main Frontal Thrust (MFT) are indicated.

have a $\delta^{13}C$ ranging up to +13‰. Modelling of this isotopic fraction suggests a large degassing, which may potentially completely override the weathering sink of CO_2.

A strong source of metamorphic CO_2 opens other interesting possibilities. The upper part of the decarbonation zone at 300–600 °C coincides with a zone of clustered microseismicity located under the front of the High Himalaya at mid-crustal depths (Bollinger et al., 2004, 2006). This cluster, associated with an electrically conductive zone (Lemonnier et al., 1999), appears to be generated at the updip end of the ductile portion of the Main Himalayan Thrust (MHT), the main continental active fault on which the MCT roots (Avouac et al., 2001). The hot springs are located on the surface a few kilometers north of this zone. This suggests a mechanism where carbon dioxide produced by metamorphism is transported to the surface, preferentially along fault networks that are permanently activated by microseismic activity and connected with the hot springs. The metamorphic fluids would mix with meteoric shallow water circulation before reaching surface (Evans et al., 2008; Becker et al., 2008).

Searching for direct gas discharge points in the High Himalaya, thus, has a twofold purpose. First, the large flux estimated from the thermodynamic modelling of the isotopic anomalies suggests that CO_2 release should be observable directly. Second, monitoring such gas discharges as a function of time may constrain the time evolution of the metamorphic source or the transport properties of the mid-crust, which are both possibly modulated by the seismic cycle.

The gas discharge points may also be associated with enhanced radon-222 flux. Radon-222 is a radioactive alpha emitter, with a half-life of 3.8 days, and the decay product of radium-226, a member of the uranium-238 family. It accumulates in the pore space before being transported to the rock or ground surface (Tanner, 1964). High radon concentrations have been observed in volcanic and geothermal areas in the presence of large discharge of carrier gases which can be water vapour or carbon dioxide (e.g., Baubron et al., 1991). Radon has also been used together with other gases (CO_2, He, CH_4) to survey seismogenic faults (e.g., Ciotoli et al., 1998). Transient radon signals, observed in the vicinity of an artificial lake with varying water level, also suggest that radon measurements may be particularly sensitive to stress changes (Trique et al., 1999). Radon flux measurements, however, remain rare in tectonically active zones. In this paper, we report the results of carbon dioxide and radon flux measurements at the Syabru–Bensi hot springs in Central Nepal.

2. The Syabru–Bensi hot springs in Central Nepal

2.1. The hot springs

The Syabru–Bensi hot springs, like the other important hot springs of Central Nepal (Chilime and Kodari), are located at the foot of the High Himalaya, in the MCT zone (Fig. 1). This thrust fault zone, which has complex geologic and geometric structures (e.g., Upreti, 1999), places Paleoproterozoic to Ordovician rocks of the Great Himalayan Crystalline (GHC) complex over Proterozoic–Cambrian rocks of the Lesser Himalayan Sequence (LHS). The MCT, currently inactive, is considered to branch to the active MHT at depth (Bollinger et al., 2006; Yin, 2006). The Syabru–Bensi and Chilime hot springs are located in the northern part of the Trisuli valley (Fig. 2). These hot springs emerge in a gneiss and schist zone located in the northern part of the

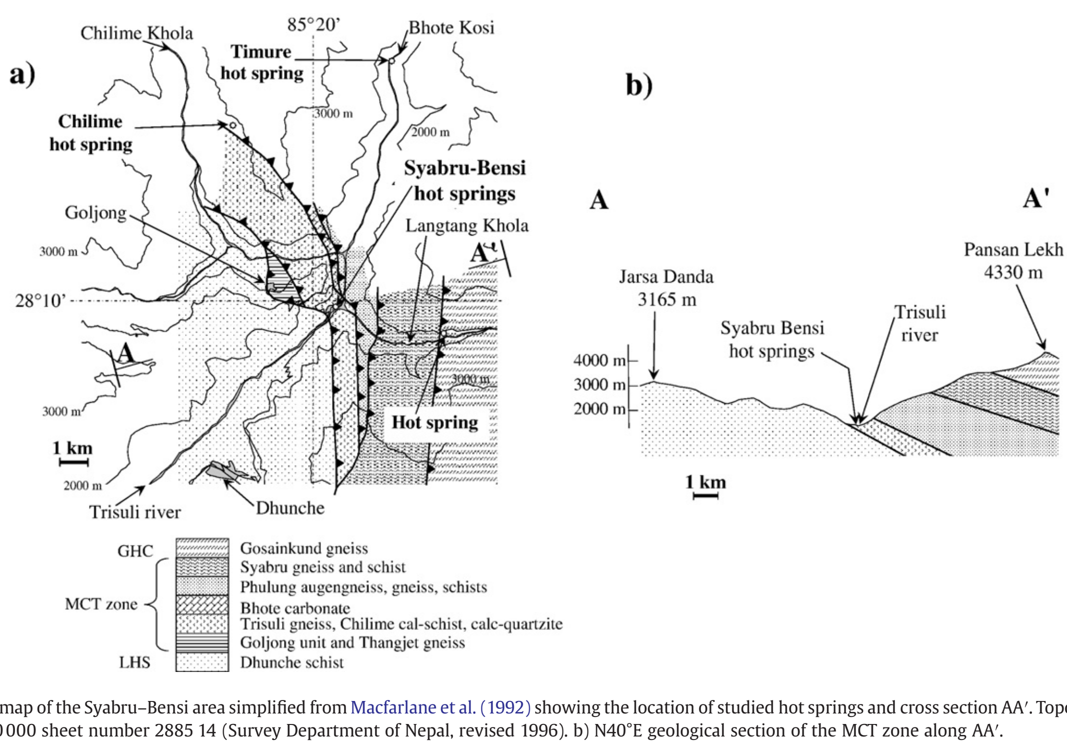

Fig. 2. a) Geological map of the Syabru–Bensi area simplified from Macfarlane et al. (1992) showing the location of studied hot springs and cross section AA′. Topographic contours are taken from the 1:50 000 sheet number 2885 14 (Survey Department of Nepal, revised 1996). b) N40°E geological section of the MCT zone along AA′.