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Preliminary chemical and isotopic characterization of high-altitude spring waters from eastern Nepal Himalaya

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	step towards a better definiti the understanding of the wat	on of a reliable scenario of water resources availability and will contribute to er cycle in the studied area.			
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Emanuele Costa, Enrico Destefanis, Chiara Groppo, Pietro Mosca, Krishna P. Kaphle, and Franco Rolfo

Abstract

Metamorphic degassing from active collisional orogens supplies a significant fraction of CO₂ to the atmosphere, thus playing a fundamental role even in today's Earth carbon cycle. Appealing clues for a contemporary metamorphic CO_2 production in active orogens are represented by the widespread occurrence, along the whole Himalavan belt, of CO_2 rich hotsprings mainly localized along major tectonic discontinuities. In contrast to these wellstudied hot-springs, almost no chemical and isotopic data are actually available for coldsprings, especially for those located at high-altitude and in remote areas of the Himalayas. In the framework of the Ev-K2-CNR SHARE (Stations at High Altitude for Research on the Environment) Project, we have started a preliminary chemical and isotopic study on highaltitude cold-springs located at different structural levels in the eastern Nepal Himalayas. Chemical and isotopic data obtained from the high-altitude cold-springs are compared with those obtained by previous authors from hot-springs located along the MCT. The isotopic signature of stable isotopes of hydrogen and oxygen could help to identify the waters sources in the investigated Himalayan sectors, to individuate mixing phenomena between waters of different provenience and possible connection with different circulation nets. These first measurements on high-altitude springs from remote areas of eastern Nepal represent a first step towards a better definition of a reliable scenario of water resources availability and will contribute to the understanding of the water cycle in the studied area.

Keywords

High-altitude springs • Chemical and isotopic study • Eastern himalayas • Hydrological cycle • Global carbon cycle

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19.1 Introduction and Aim of the Study

Mountain ranges have strong impact on the global carbon cycle: metamorphic degassing from active collisional orogens, in fact, supplies a significant fraction of the global solid-Earth derived CO_2 to the atmosphere, thus playing a fundamental role even in today's Earth carbon cycle (Evans 2011; Rolfo et al. 2014). Appealing clues for a contemporary metamorphic CO_2 production in active orogens are 41 represented by the widespread occurrence, along the whole Himalayan belt, of CO2 rich hot-springs mainly localized along the major tectonic discontinuities, such as the Main Central Thrust (Becker et al. 2008; Perrier et al. 2009). Peak

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values of the measured CO_2 flux at these gas discharges are exceptionally high and similar to values reported on volcanoes (19,000 g m⁻² day⁻¹; Perrier et al. 2009). In contrast to these well-studied hot-springs, almost no chemical and isotopic data are actually available for cold-springs, especially for those located at high-altitude and in remote areas of the Himalayas.

In the framework of the Ev-K2-CNR SHARE (Stations at High Altitude for Research on the Environment) Project, we have started a preliminary chemical and isotopic study on high-altitude cold-springs located at different structural levels in the eastern Nepal Himalayas (Khimti Khola, Likhu Khola and Dudhkund Khola catchments). Preliminary chemical and isotopic data obtained from these high-altitude cold-springs are hereby compared with those obtained by previous authors from hot-springs located along the Main Central Thrust.

These first measurements on high-altitude springs represent a first step towards a better definition of a reliable scenario of water resources availability and will contribute to the understanding of the water cycle in the studied area.

8 19.2 Sampling and Analytical Methods

69 19.2.1 Sampling

Eleven spring water samples were collected in the Numbur 70 and Dudh Khunda region of eastern Nepal Himalayas in the 71 post-monsoon season, November 2012. The investigated 72 springs are located in the Khimti Khola, Likhu Khola and 73 Dudhkhund Khola catchments (tributaries of the Sun Khosi 74 river), at an altitude between 1,800 and 4,500 m a.s.l. 75 (Fig. 19.1). Most of the springs are located in remote areas, 76 far from villages and accessible through poorly known 77 trails. Water sampling was further complicated by the high 78 altitude environment and by the fact that, due to logistic 79 reasons, the amount of collected water had to be minimized. 80 Temperature and pH were measured in situ at the source 81 vents using an HANNA HI2211 pH meter, calibrated every 82 morning with pH standards. Conductivity was measured 83 with an HANNA HI8820 N. Water samples for chemical 84 and isotopic analysis were collected in two polyethylene 85 bottles of 250 ml, capped without head space to minimize 86 degassing. The water samples to be used for DIC isotopic 87 analysis were added with SrNO3 and NaOH to precipitate 88 all the dissolved inorganic carbon as SrCO₃, as suggested in 89



Fig. 19.1 Simplified geological map of the central-eastern sector of the Numbur and Dudh Khunda area, eastern Nepal Himalaya (modified from Mosca et al. 2013) showing sample locations. *MCT* Main central thrust. *Inset* shows the location of the study area (*black 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

De Groot (2004). A subsequent filtration of the samples that ⁹⁰ would have precipitated enough carbonate could have led to ⁹¹ isotopic measurement of the Dissolved Inorganic Carbon. ⁹²

19.2.2 Geological Setting

The Khimti Khola, Likhu Khola and Dudhkhund Khola 94 rivers cross the main tectonostratigraphic units of eastern 95 Nepal Himalaya, flowing across the Greater Himalayan 96 Sequence (GHS) and the Lesser Himalayan Sequence and _97 crossing the Main Central Thrust Zone (MCTZ). Three of 98 the investigated springs are located in the structurally lower 99 GHS domain (GHS-L) (i.e. within the MCTZ), and seven 100 are located in the upper GHS domain (GHS-U) (Fig. 19.1). 101

The GHS-L mainly consists of a metasedimentary 102 sequence (mostly metapelites and minor calc-silicate rocks 103

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and impure marbles) recording an increase in metamorphic grade upward, passing from the staurolite zone to the sillimanite zone and, locally, to anatexis (Groppo et al. 2009; Mosca et al. 2013). The GHS-U is characterized by highgrade metamorphic rocks (metapelites, metacarbonate rocks and orthogneiss), often anatectic, recording a progressive decrease in peak-pressure structurally upward (Groppo et al. 2012, 2013). Most of the analyzed springs are hosted in silicate rocks, except springs A1 and A11 that are hosted in metasedimentary rocks including impure marbles and calcsilicate levels.

19.2.3 Analytical Methods

Samples for chemical analysis were collected in pre-cleaned 116 HDPE 250 ml bottles, without any addition of acid sub-117 stances, because the same sample has to be suitable for both 118 cations and anions determinations. Analysis were done at the 119 Dept. Earth Sciences (Univ. Torino), using a Metrohm IC 120 732 Ion Cromatography System for anions quantification, 121 and a Spectro Iris Advantage II ICP-AES for cations eval-122 uation. Isotopic analysis were performed on five represen-123 tative samples from different structural levels at ISO4 124 Laboratories in Turin, using a Picarro L2120-i Isotope 125 Analyzer, with a precision of $\pm 3 \ \delta \% (3\sigma)$ for deuterium and 126 $\pm 0.6 \ \delta$ %(3 σ) for ¹⁸O. So far, none of the samples was 127 submitted to DIC isotope analysis for the evaluation of δ^{13} C; 128 only sample A1 is rich enough in DIC to ensure the neces-129 sary amount of carbonate suitable for the determination. 130

19.3 Results

19.3.1 Geochemical Features 133

The analyzed springs are characterized by low discharge tem-134 perature varying between 3 and 16 °C, with a negative corre-135 lation between temperature and altitude (Table 19.1). They are 136 characterized by a very low salinity (TDS < 150 mg/L) and a 137 correspondent very low conductivity (<200 µS/cm). The pH 138 varies between 6.5 and 7.3 and the samples are $Ca-Mg-HCO^{3-}$ 139 in composition (Fig. 19.2a). No significant compositional 140 variations are observed between the GHS-L and the GHS-U 141 springs; the springs hosted in metacarbonate rocks show the 142 highest TDS. 143

Overall the characteristics of the analyzed cold-springs 144 are coherent with those described by previous authors in 145 other areas of central Nepal Himalaya (e.g. cold-springs of 146

the Marsyandi Valley: Evans et al. 2001; Becker et al. 147 2008). Cold-springs composition is significantly different 148 from that of the well-known hot-springs located along the 149 MCT, which are typically Na-Cl to Na-Ca-Cl type waters 150 with high total dissolved solids (TDS up to 8,500 mg/L), 151 vary in temperature between 20 and 60 °C and have a pH in 152 the range 5.5–7 (e.g. Evans et al. 2004; Becker et al. 2008; 153 Perrier et al. 2009). 154

19.3.2 Isotopical Features

The very low total dissolved solids of the measured samples hampered the possibility of analyzing their carbon isotopic composition. Five of the water samples were submitted to isotopic determination to measure hydrogen and oxygen values. These are typical of meteoric waters and show a very good correlation with the Global Meteoric Water Line (GMWL) of precipitation (IAEA 1970, 2005), lying directly upon or very near the GMWL (Fig. 19.2b). A difference is clearly visible between samples collected at minor altitude (A1 and A2) and those collected at higher altitude. The close correlation suggests the absence of any evaporation process prior of the infiltration of rain runoff, or exchange reactions between the infiltrated water and the host rocks. Topography and altimetry indicate that a short distance could be traveled through the hosting geological formation between recharge area and spring location; therefore, the short residence time, combined with the low water temperature, prevented reactions with silicates.

19.4 Conclusions and Further Studies

Our preliminary data obtained from Himalayan high-altitude cold-springs show waters with low salinity contents and an isotopic signature that clearly indicates a provenience from meteoric rain-fall. Low temperature of the waters, as well as the low content in chloride and other ions, suggest that these springs are unrelated to geothermal activity. Overall, chemical and isotopic data are in good agreement with the few data on Himalayan cold-springs already available in the literature.

Since the isotopic determinations are related to a single 185 sampling campaign, they do not allow further hypothesis 186 about water circulation and seasonal change, or variations in 187 the hydrological cycle. However, these are amongst the first δD and $\delta^{18}O$ data for high-altitude cold-springs from remote areas of eastern Nepal Himalaya. New sampling 190

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 Table 19.1 Location, field observations

4	NH ⁺⁺ F ⁻ (mg/l) (mg/l)	0.02	0.08		0.01	0.00	0.01	0.01		0.13 0.00	
	Mg ⁺⁺ (mg/l)	4.50	0.42	0.31	0.29	0.28	0.32	0.46	0.42	0.46	0.42
	Ca ⁺⁺ (mg/l)	12.70	1.71	0.85	2.22	0.81	1.80	2.74	0.60	1.28	1.40
	K ⁺ (mg/l)	1.57	0.61	0.92	0.32	0.3	0.44	0.39	0.47	0.57	0.68
	Na ⁺ (mg/l)	0.83	1.44	0.68	0.5	0.14	0.39	0.24	0.04	0.64	0.55
	TDS	134.4	25.15	14.51	17.11	8.27	14.39	23.66	10.29	15.97	14.28
	Conductivity (µS cm ⁻¹)	172	28	18	21	L		25	×	16	15
	Hd	73	71	68	69	72	2	٢	68	69	63
	T °C	16.1	15.0	60	30	51	56	36	92	69	79
	Estimated discharge rale (<i>l</i> /sec) and field observations	10–20 <i>l</i> /sec; several discharge points in the alluvial sediments	11/sec and discontinuous; few discharge points at ihe base of an alluvial tar	<0.1 l/sec, single discharge point in the alluvial sediments	01-0.2 l/sec. few discharge points from (he rock outcrop	2 l/sec, few discharge points at the base of an alluvial fan	1 l/sec: single discharge point in the alluvial sediments	0.1–0.2 l/sec; single discharge point from Vie	0.1–0.2 l/sec; single discharge point from Vie colluvial sediments	0.1–0.2 l/sec; single discharge point from Vie colluvial sediments	0.1–0.3 l/sec, single discharge point in the alluvial
	Host rocks	Wm+ CM Slladic schist and Phl + Wm imoure	Fine-grained two- micas Grl-beanng oneiss	Two-micas Grl- and Ky- beafing aneiss	Bt + Grt + Sil anatectc gneiss	Bt + Grt + Sii anatectc gneiss	Fine-grained Bt gneiss ivilh Sil + Qtz nodules	Bt + Grt + Sil anatectc gneiss	Two-micas Grt- bearing quartzilic mica schist	Bt + Grt + 311 anatectc augen- crneiss	Bt + Grt + Sil anatectc augen-
	GPS coordinates	N27°36'27.0'' E86°17'47.4''	N27°38'32.9'' E86°19'08.0''	N27°42'57.0'' E86°23'4.8''	N27°43′57.3′' E86°25′21.6′'	N27°43′54.9′ E86°26′15.4″	N27°45'48.0'' E86°28'03.4''	N27°45′11.0′ E86°30′37.5″	N27°36'43.2" E86°20'47.8"	N27°38'00.1" E86°32'04.6"	N27°39′23.1″ E86°33′04.7″
	Altitude (m a.s.l.)	1805	1960	3930	4510	4370	4140	4380	3090	3700	3870
	Sample	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10

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Fig. 19.2 a Piper diagram of the investigated water samples, showing their Ca-Mg-HCO3 composition. b Projection of the isotopic data of the studied Himalayan cold-spring along with a projection of the Global Meteoric Water Line (in green). The studied samples are in

campaigns, planned for the next future, will increase the 191 sampling density of both cold- and hot- springs thus 192 allowing to achieve a better understanding of the hydro-193 logical cycle in the area. 194

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good agreement (within the instrumental uncertainty) with rain waters with no (or very few) evaporation and/or exchange with the mineralogical assembly of the host rock. In both the diagrams, orange symbols GHS-L springs; blue symbols GHS-U springs

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