



Hydrochemical characteristics of hot spring waters in the Kangding district related to the Lushan $M_S = 7.0$ earthquake in Sichuan, China

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Received: 2 October 2014 – Published in Nat. Hazards Earth Syst. Sci. Discuss.: 5 December 2014

Revised: 4 May 2015 – Accepted: 17 May 2015 – Published: 5 June 2015

Abstract. Hydrogeochemistry of 10 hot springs in the Kangding district was investigated by analyzing cation and anion concentrations in the spring water. The water samples were collected in the 5 days after the Lushan $M_S = 7.0$ earthquake, which occurred on 20 April 2013. The spring waters are classified into seven chemical types based on their hydrochemical compositions. Compared with hydrochemical data before the Lushan earthquake, concentrations of Ca^{2+} , HCO_3^- and total dissolved solid (TDS) in water samples from the Guanding, Erdaoqiao, Gonghe, Erhaoying, Tianwanhe and Caoko springs significantly increased, which may be the result of a greater increase in groundwater from carbonate rocks, and water–carbonate rock interactions, enhanced by the increment of CO_2 . Concentrations of Na^+ , Cl^- and SO_4^{2-} in water samples from the Guanding, Zheduotang, Xinxing and Gonghe springs decreased, indicating a dilution of shallow waters. Concentrations of Na^+ and SO_4^{2-} in water samples from the Erhaoying spring water increased, which may be attributed to water–granite interactions enhanced by H_2S . The results indicated that hydrochemical components of spring water could be used as an effective indicator for earthquakes.

Dadomo et al., 2009), the co-seismic response of hydrochemistry (Song et al., 2006; Yang et al., 2006; Reddy et al., 2011) and post-seismic geochemical changes in hot springs have been observed throughout the world (Thomas, 1988; Woith et al., 2013; Italiano et al., 2010; Zhou et al., 2010; Malakootian and Nouri, 2010; İnan et al., 2012). Claesson et al. (2004) observed changes in multicomponent constituents and $\delta^{18}\text{O}$ of groundwater due to a seismic event ($M = 5.1$) in northern Iceland. Isaksen et al. (1997) observed increased Cl^- concentration in spring water 5 days prior to an $M_L = 5.2$ earthquake. The geochemical anomalies may mainly have been caused by the alteration of groundwater in each circulating system under increasing crustal stress before and after the earthquakes (Song et al., 2006; Italiano et al., 2010; Wang et al., 2012; Miller et al., 2013).

The origins, contaminations, chemical classifications and heat reservoirs of hot spring waters in the Kangding district in western Sichuan have widely been investigated (Luo, 1994; Jia et al., 1997; Zhang and Hu, 2000; Li et al., 2005; Cao et al., 2006; Du et al., 2006; Shen, 2007; Liu, 2008; Lu et al., 2008). Chen et al. (2014) observed the geochemical variation in the water sampled from the hot springs in the Kangding district before the Wenchuan $M_S = 8.0$ earthquake in Sichuan Province, southwest China, on 12 May 2008.

This paper aims to investigate hydrochemical characteristics of spring water in the Kangding district before and after the Lushan $M_S = 7.0$ earthquake in Sichuan Province, southwestern China, and to investigate the relationship between geochemical variations and seismic activity.

1 Introduction

Great earthquakes are usually associated with the physical–chemical variations in groundwater. The short-term hydrogeochemical precursors for earthquakes (King et al., 1995; Favara et al., 2001; Quattrocchi et al., 2003; Du et al., 2008;

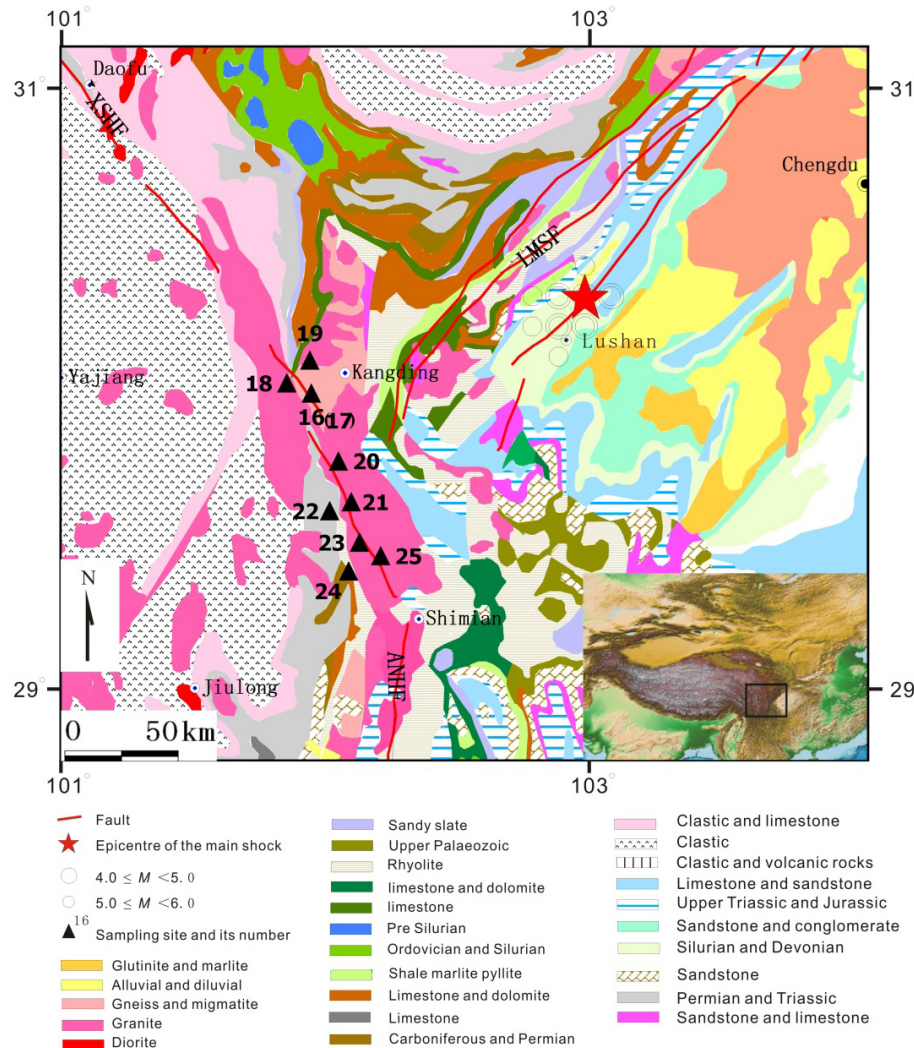


Figure 1. Geological map of the studied region: the insert shows a map of Asia; the square shows the location of the studied region. The sampling sites are distributed in the southeast segment of the XSHF zone.

2 Geological setting

The studied area is located in a “Y” shape intersection of the Longmenshan fault (LMSF), Xianshuihe fault (XSHF) and Anninghe fault (ANHF) (Fig. 1). These faults cut into each other and deeply into the lithosphere, and act as an important passage for upward migration of thermal fluids from the deep earth, which is indicated by the distribution of many hot springs with high temperature and Yanshanian granite widely exposed around the “Y” intersection area (Fig. 1) (Luo, 1994).

Historically, a number of great earthquakes ($M_S > 7.0$) have occurred surrounding the Kangding district since 1800. The most hazardous earthquakes were the 1850 Xichang $M_S = 7.5$ earthquake which occurred in the ANHF zone, the $M_S = 7.5$ earthquake of 25 August 1933 in the LMSF zone, the $M_S = 7.5$ earthquake of 1955 and the $M_S = 7.9$ earth-

quake of 1973 in the XSHF zone (Zhou et al., 2010), the 2008 $M_S = 8.0$ Wenchuan earthquake in the LMSF zone (Chen et al., 2014) and the $M_S = 7.0$ earthquake on 20 April 2013 in the Lushan district, Sichuan Province, southwest China, which is 95 km from the Kangding district (Fig. 1).

3 Methods

The spring waters were collected at 10 sites of wells and springs in the southeast segment of the XSHF zone (Fig. 1) on 23–25 April 2013. The water samples were sealed quickly after the sampling and stored in 250 ml plastic bottles. The water temperatures were measured in the field with a digital thermometer with an error of $\pm 1\%$. The concentrations of cations (K^+ , Na^+ , Mg^{2+} and Ca^{2+}) and anions (F^- , Cl^- , Br^- , NO_3^- and SO_4^{2-}) in the water samples were measured with a Dionex ICS 900 ion chromatography system

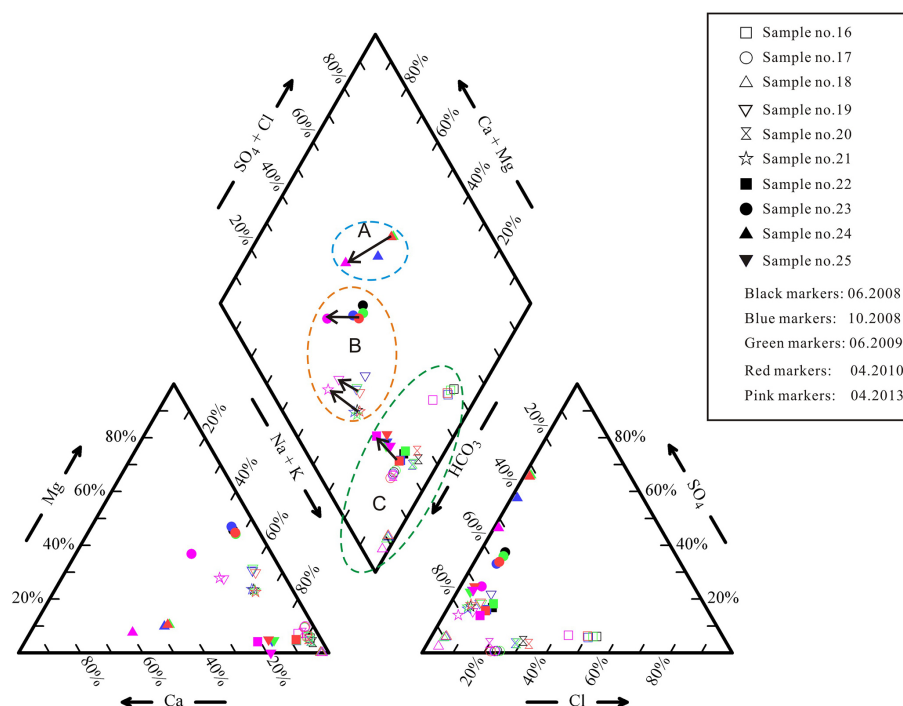


Figure 2. Piper diagram of the spring water samples.

in the Seismic Fluid Laboratory of the Institute of Earthquake Science, China Earthquake Administration, with the reproducibility within $\pm 2\%$. The CO_3^{2-} and HCO_3^- concentrations were measured by the standard titration procedures with a ZDJ 100 potentiometric titrator (reproducibility within $\pm 2\%$). For calibrating the chromatography, standard samples were measured before and after measuring each batch of water samples. Deviation of the measurements is within $\pm 2\%$. The data were evaluated by the ion balance (ib), calculated according to Eq. (1) (Woith et al., 2013):

$$\text{ib}[\%] = \frac{\sum \text{cations} - \sum \text{anions}}{0.5(\sum \text{cations} + \sum \text{anions})} 100. \quad (1)$$

4 Results

The physico-chemical parameters of the water samples are shown in Table 1. The ib values of measured chemical data are less than 5%.

The temperatures of the spring waters were in the range of 30.4 to 83.0°. The TDS (total dissolved solid) values ranged from 132.1 to 2130.5 mg L^{-1} . Concentrations of K^+ , Na^+ , Ca^{2+} and Mg^{2+} ranged from 0.0 to 53.3 mg L^{-1} , 35.0 to 518.4 mg L^{-1} , 3.7 to 80.5 mg L^{-1} and 0.0 to 48.1 mg L^{-1} , respectively. Concentrations of F^- , Cl^- , Br^- , SO_4^{2-} and HCO_3^- ranged from 0.0 to 27.1 mg L^{-1} , 2.4 to 336.2 mg L^{-1} , 0.0 to 1.3 mg L^{-1} , 6.7 to 161.9 mg L^{-1} and 60.0 to 1270.9 mg L^{-1} , respectively (Table 1).

5 Discussion

5.1 Chemical types of the spring waters

Using Shoka Lev's classification method, the spring water samples were classified into 7 types: Na-HCO_3 , NaMg-HCO_3 , $\text{NaMg-HCO}_3\text{SO}_4$, $\text{CaNa-SO}_4\text{HCO}_3$, $\text{CaNa-HCO}_3\text{SO}_4$, Na-ClHCO_3 and $\text{Na-HCO}_3\text{Cl}$ (Fig. 2, Table 1).

The water samples were plotted in blocks A, B and C (Fig. 2). Spring no. 24 occurred in Carboniferous carbonate; this is plotted in block A (Figs. 1 and 2). Its main chemical components were Ca^{2+} , Na^+ , SO_4^{2-} and HCO_3^- , and the proportion of Ca^{2+} was higher than 55% (Table 1), which indicated that the chemical type of spring no. 24 ($\text{CaNa-SO}_4\text{HCO}_3$ and $\text{CaNa-HCO}_3\text{SO}_4$) should mainly be attributed to groundwater–rock interactions between the underlying Devonian carbonate and groundwater, as calculated by Eqs. (3)–(5). Springs no. 16–18, 20, 22 and 25 (plotted in block C; see Figs. 1 and 2), occurred in granite and their main chemical components were Na^+ and HCO_3^- (Table 1), which should mainly be attributed to groundwater–granite interactions, as calculated by Eq. (2). In addition, Cl^- is known to be mainly derived from the deep earth (Chen et al., 2014). Cl^- concentrations for water samples from spring no. 16 reached up to 336.2 mg L^{-1} (Table 1), suggesting the upwelling of deep-earth fluids into the spring, and resulting in high $^3\text{He}/^4\text{He}$ ratios (between 1.43 and 3.73 Ra, $\text{Ra} = 1.39 \times 10^{-6}$) (Zhou, 2011) and high temperatures (between 80.0° and 70.2°) in the spring (Table 1).

Table 1. Physico-chemical parameters of the spring waters.

No.	Site	Date	Longitude (E)	Latitude (N)	pH	T °	TDS mgL ⁻¹	K ⁺ mgL ⁻¹	Na ⁺ mgL ⁻¹	Ca ²⁺ mgL ⁻¹	Mg ²⁺ mgL ⁻¹	F ⁻ mgL ⁻¹	Cl ⁻ mgL ⁻¹	Br ⁻ mgL ⁻¹	SO ₄ ²⁻ mgL ⁻¹	HCO ₃ ⁻ mgL ⁻¹	Is	Chemical type	
16	Guanding Spring	15 Jun 2008*	101.96	29.98	8.4	80.5	1306.1	41.2	396.8	13.2	13.6	2.6	336.2	0.5	52	440.3	-4.1	Na-ClHCO ₃	
		26 Oct 2008*			8.5	80.0	1395.4	40.6	367.2	13.4	13.6	13.6	2.5	328.5	1.1	50	485.5	-4.0	Na-ClHCO ₃
		25 Jun 2009*			8.4	83.0	1353.8	42.7	367.4	13.7	13.5	13.5	2.4	320.9	0.5	49.7	443.1	-4.1	Na-ClHCO ₃
17	Longougou Spring	17 Apr 2010*	101.96	29.98	8.5	83.0	1273.6	41.5	349.7	13.8	13.8	0.1	300.8	0	50.6	447.2	-4.0	Na-ClHCO ₃	
		25 Apr 2013			8.6	83.0	1453.6	44.3	346.2	23.7	16.2	16.2	2.2	261.8	0	52.8	506.4	-3.9	Na-HCO ₃ Cl
		15 Jun 2008*			8.1	70.8	2044.9	53.2	510.8	16	31.4	31.4	3.1	220.7	1	8.3	1200.4	-4.4	Na-HCO ₃
18	Zheduotang Spring	26 Oct 2008*	101.86	30.01	8.2	70.2	2130.5	52.7	518.4	17.4	31	3.2	227.4	1	8.6	1270.9	-4.3	Na-HCO ₃	
		25 Jun 2009*			8.2	73.1	2025.9	52.3	516.7	16.7	30.8	30.8	3	226.2	0.7	8.3	1171.3	-4.3	Na-HCO ₃
		17 Apr 2010*			8.3	70.2	2096.9	51.6	507.9	16.3	31.1	31.1	3.2	207.6	0	8.3	1270.9	-4.2	Na-HCO ₃
19	Erdoguo Spring	25 Apr 2013	101.95	30.09	8.3	73.2	2086.8	53.3	506.6	13.9	32.1	2.8	220.2	0	8	1250	-4.2	Na-HCO ₃	
		15 Jun 2008*			8.4	54.2	683.4	2	207.4	3.7	0	26.8	8.9	0	6.8	340	-4.1	Na-HCO ₃	
		26 Oct 2008*			7.9	39.1	843.4	23.5	150.5	22.1	44.1	44.1	1.2	43.9	0	114.6	443.5	-4.6	NaMg-HCO ₃
20	Xinxing Spring	26 Oct 2008*	102.06	29.75	7.8	39.4	919.7	22.5	150.7	22.1	44.7	1.4	40.4	0	107.1	530.9	-4.7	NaMg-HCO ₃	
		26 Jun 2009*			8.1	40.6	926.4	22.4	146.3	20.2	44.5	44.5	1.2	43.9	0	109.5	538.4	-4.4	NaMg-HCO ₃
		16 Apr 2010*			8	40.6	935.5	23.7	157.1	20.9	43.8	43.8	1.1	41	0.9	111.6	535.4	-4.5	NaMg-HCO ₃
21	Gonghe Spring	25 Apr 2013	102.11	30.62	8.3	41.0	1094.1	26.2	156.1	57.1	47.8	3.6	43.6	0	104.6	655	-4.2	NaMg-HCO ₃	
		16 Jun 2008*			7.9	45.6	1287.5	9.4	422.7	12.5	9.7	9.7	3.8	148	1	28.9	545.2	-4.6	Na-HCO ₃
		27 Oct 2008*			8.2	44.1	1167.8	9.7	365	12.8	9.4	9.4	3.8	144	1.3	24.7	597.2	-4.3	Na-HCO ₃
22	Ehaoying Spring	24 Jun 2009*	102.03	29.59	8.3	42.8	1289.9	9.2	360.6	12	9.4	3.4	148.4	1	24.1	597.2	-4.2	Na-HCO ₃	
		23 Apr 2010*			8.4	48.2	1038.5	9.2	303.1	12	9	9	3.9	156.2	0.3	21.3	523.4	-4.1	Na-HCO ₃
		24 Apr 2013			8.4	48.7	1028.5	9.1	281.2	13.3	12.9	12.9	3.4	82.9	0	20.6	545	-4.1	Na-HCO ₃
23	Tianwanhe Spring	16 Jun 2008*	102.14	29.49	8.2	48.8	577.9	9.9	108.4	19.3	22.1	1.9	18.4	0	60.3	337.5	-4.3	Na-HCO ₃	
		27 Oct 2008*			8	47.6	598.2	10	106.5	20.1	22.1	22.1	2	17.8	0	60.1	339.5	-4.5	Na-HCO ₃
		24 Jun 2009*			8.2	50.0	610.2	9.6	107.6	18.5	21.3	21.3	1.9	17.4	0	65.1	369	-4.5	Na-HCO ₃
24	Caoke Spring	23 Apr 2010*	102.1	29.39	8.1	44.8	585.9	9.4	111.8	19.3	21.5	2.6	17.9	0	64.1	339.3	-4.4	Na-HCO ₃	
		24 Apr 2013			8.3	45.2	642.7	9.8	92.7	35.9	28.5	28.5	2.2	13.7	0	54.9	405	-4.2	Na-HCO ₃
		17 Jun 2008*			8.4	65.5	597.3	18.3	154.1	13.5	4.6	4.6	2.7	37.1	0	59.3	307.6	-4.1	Na-HCO ₃
25	Shimian Well	27 Oct 2008*	102.03	29.59	8.5	67.4	645.1	18.3	156.5	13.5	4.6	2.9	36.8	0.5	62.2	349.9	-4.0	Na-HCO ₃	
		25 Jun 2009*			8.2	63.0	585.6	18.5	153	13.2	4.7	4.7	3	35.3	0.2	62.4	295.1	-4.3	Na-HCO ₃
		24 Apr 2010*			8.2	67.4	631.7	18.3	150.4	13	4.8	4.8	0.4	36	0	59.9	349	-4.3	Na-HCO ₃
26	Ehaoying Spring	24 Apr 2013	102.03	29.59	8.4	68.0	863.6	24.1	186.9	48.6	5.8	3	44.4	0	70.4	480.4	-4.1	Na-HCO ₃	
		17 Jun 2008*			7.9	53.0	613.9	17.6	76.9	13.1	45.3	45.3	2.4	24.6	0.2	152.3	281.5	-4.6	NaMg-HCO ₃ SO ₄
		25 Jun 2009*			8.2	53.7	632.2	16.9	73.4	12.7	45.7	45.7	2.2	23.4	0.6	139.6	317.7	-4.3	NaMg-HCO ₃ SO ₄
27	Tianwanhe Spring	24 Jun 2009*	102.14	29.49	7.8	54.0	611.7	17.6	79.1	12.8	43.6	1.7	24.9	0.3	145.2	286.5	-4.7	NaMg-HCO ₃ SO ₄	
		24 Apr 2010*			8.1	53.2	644.8	17.4	79.1	12.7	44.4	44.4	2.3	25.7	0	145.4	317.7	-4.5	NaMg-HCO ₃ SO ₄
		23 Apr 2013			8	52.9	867.9	21.4	79.9	55.8	48.1	48.1	4.5	28.9	0	139.4	490	-4.5	NaMg-HCO ₃ SO ₄
28	Shimian Well	28 Oct 2008*	102.22	29.44	8.3	30.4	150.3	2.4	38.6	7	1.2	11.1	2.6	0	17.8	69.6	-4.5	Na-HCO ₃	
		23 Jun 2009*			7.9	31.3	149.1	2.4	37.6	6.5	1.2	1.2	10.9	2.4	0	17.3	70.8	-4.6	Na-HCO ₃
		24 Apr 2010*			8.1	31.2	137.8	2.3	35.1	6.9	1.2	1.2	10.2	2.4	0	17.2	62.5	-4.4	Na-HCO ₃
29	Shimian Well	23 Apr 2013	102.22	29.44	8.3	32.0	132.1	0	35	7	0	12.3	2.4	0	15.4	60	-4.2	Na-HCO ₃	

The * data were from Chen et al. (2014). "n.d." denotes that no samples were collected. Is was the speciation-saturation indexes of calcite in the water samples.

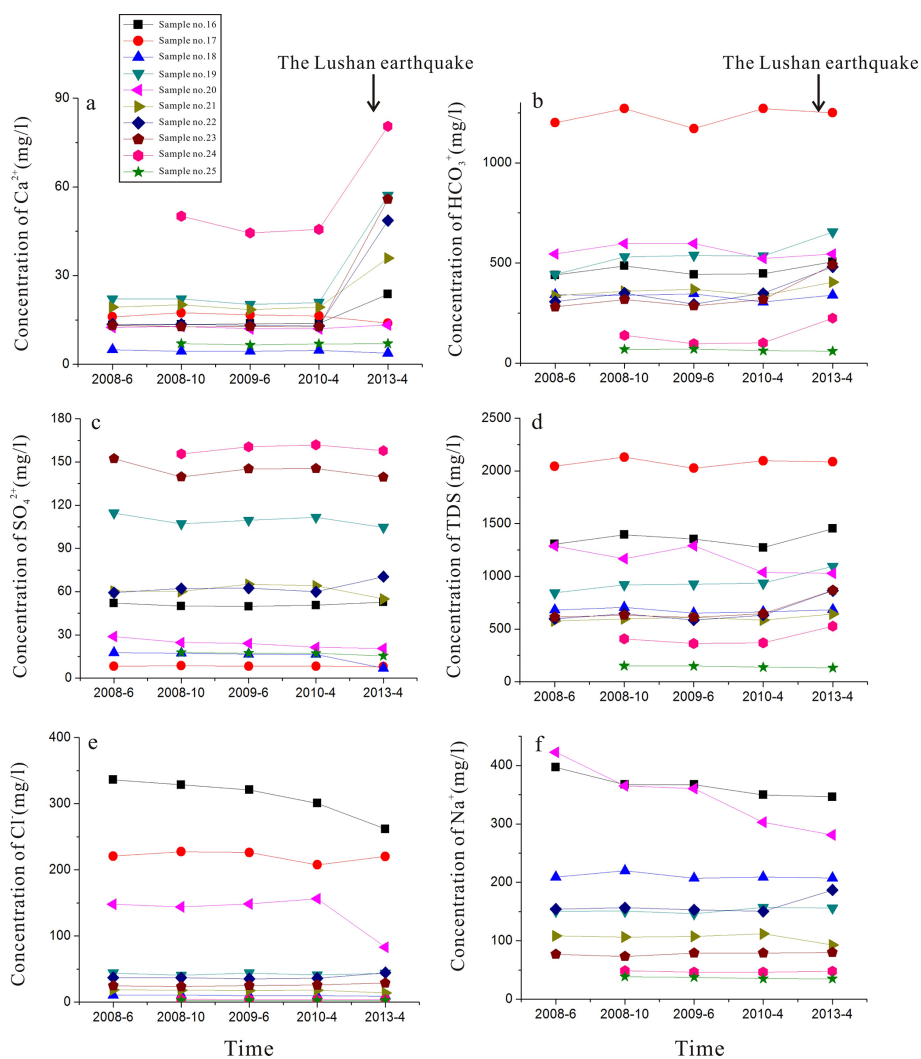
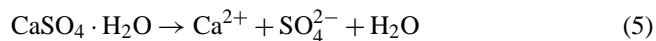
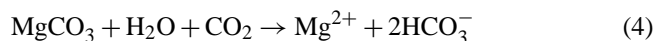
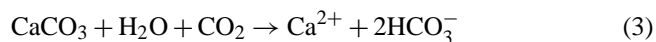
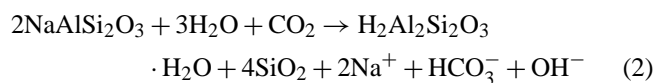


Figure 3. Temporal ion variations in the spring waters before and after the Lushan earthquake.

Springs no. 19, 21 and 23, which occurred in granite, were plotted in block B (Figs. 1 and 2). Although their main chemical components included Ca^{2+} , Mg^{2+} , Na^+ , HCO_3^- and SO_4^{2-} , these springs may have flowed through the deeper Carboniferous carbonate too, therefore, both groundwater–granite interactions and groundwater–carbonate interactions could have made contributions to the chemical types of the springs (Fig. 1), as calculated by Eqs. (2)–(5).



5.2 Chemical variations in the spring waters

The hydrochemical parameters of water samples from the springs varied significantly after the Lushan $M_S = 7.0$ earthquake. The concentrations of Ca^{2+} , HCO_3^- and TDS in water samples from springs no. 16, 19 and 21–24 increased from 9.9 to 43.1 mg L^{-1} , 59.1 to 172.3 mg L^{-1} and 56.7 to 231.9 mg L^{-1} , respectively (Fig. 3a, b and d). SO_4^{2-} concentrations in water samples from springs no. 18 and 21 decreased by 9.7 and 9.2 mg L^{-1} , respectively, while that of the water samples from spring no. 22 increased by 10.6 mg L^{-1} (Fig. 3c). Cl^- concentrations in the water samples from springs no. 16 and 20 decreased by 39.1 and 73.3 mg L^{-1} , respectively (Fig. 3e). Na^+ concentration in the water samples from springs no. 20 and 21 decreased by 21.9 and 19.1 mg L^{-1} , but that of the water samples from spring no. 22 increased by 36.5 mg L^{-1} (Fig. 3f). Furthermore, water samples from springs no. 19 and 21–24 moved toward the

Ca + Mg and HCO_3^- corners in the piper diagram (Fig. 2), and the chemical types of the water samples from springs no. 16 and 24 changed from Na-ClHCO_3 to $\text{Na-HCO}_3\text{Cl}$, and $\text{CaNa-SO}_4\text{HCO}_3$ to $\text{CaNa-HCO}_3\text{SO}_4$, respectively (Table 1).

Enhanced water–rock interactions and a greater increase in different fluids were proposed as two possible mechanisms for the variations in geochemical parameters before and after earthquakes (Etioppe et al., 1997; Song et al., 2005; Du et al., 2010; Reddy et al., 2011; İnan et al., 2012; Dadomo et al., 2013).

The hydrochemical variations were observed 3–5 days after the main shock. In addition, 106 aftershocks with M_L higher than 3.0 occurred in the 5 days after the main shock (Fig. 4). Therefore, the Lushan earthquake and its aftershocks may have played an important role in variations in the hydrochemical parameters of water samples from the springs. When the earthquakes occurred, the pore pressure in the rocks would have been enhanced while the seismic wave propagated through, leading to the expulsion of different groundwaters and resulting in chemical variations in water samples from the springs (Du et al., 2013). The obvious increase in the concentrations of Ca^{2+} , HCO_3^- and TDS in water samples from springs no. 16, 19 and 21–24 should be attributed to a greater increase in groundwater, rich in Ca^{2+} , HCO_3^- and TDS, from the underlying Devonian carbonate (Fig. 1). High $^3\text{He}/^4\text{He}$ ratios (between 1.43 and 3.73 Ra, $\text{Ra} = 1.39 \times 10^{-6}$) of gas samples (Zhou, 2011), high temperatures (between 44.8 and 83.0 °C; see Table 1) and high concentrations of Na^+ , Cl^- and SO_4^{2-} in water samples (Chen et al., 2014) from springs no. 16, 18 and 21 suggest the contribution of mantle fluids into these springs. Therefore, the decrease in concentrations of Na^+ , Cl^- and SO_4^{2-} in water samples from springs no. 16, 18 and 21 may be attributed to the dilution of groundwater, with depleted levels of Na^+ , Cl^- and SO_4^{2-} , from the underlying Devonian carbonate. The decrease in concentrations of Na^+ and Cl^- for samples from spring no. 20 may be attributed to a greater increase in shallow groundwater.

In addition, CO_2 was the main gas phase of water samples from springs no. 16, 19 and 21–24, with concentrations reaching up to 90.0 vol. % (Zhou et al., 2010). Experiments on CO_2 –water–rock interaction have indicated that injection of CO_2 into geothermal waters promotes the release of Ca^{2+} from the surrounding carbonate rock, as calculated in Eq. (3) (Ueda et al., 2005; Liu et al., 2012). The dissolution rate of carbonate rocks can be enhanced by increasing the dissolved CO_2 into geothermal waters, in response to the elevated partial pressure of CO_2 (Robert et al., 2005). When the earthquakes occurred, the seismic wave propagated through the rocks and the expulsion of CO_2 was enhanced, which might have strengthened the partial pressure of CO_2 in the spring waters and accelerated its dissolution rate, then enhanced the dissolution rate of carbonate rocks. In addition, the speciation–saturation indexes of calcite in water sam-

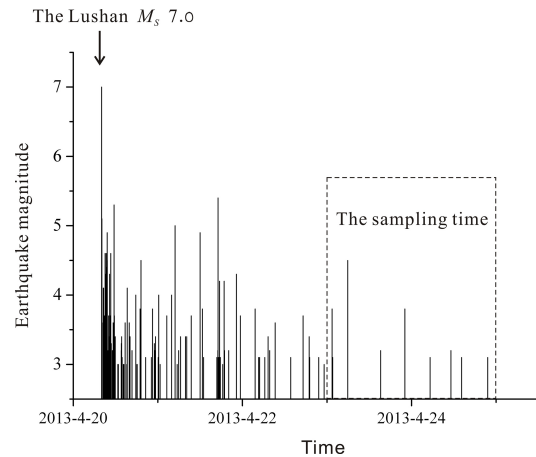
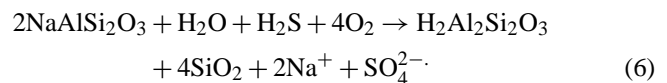


Figure 4. The aftershocks after the Lushan earthquake.

ples from the springs, calculated by the formula proposed by Oddo and Tomson, were less than zero (Oddo and Tomson, 1982), which indicates that calcite in water samples from the springs was unsaturated, and its dissolution could proceed. Therefore, the increment of dissolved CO_2 in the spring waters accelerated the interaction between water and calcite contained in carbonate rocks which widely exist in the strata, resulting in the increase of TDS and concentrations of Ca^{2+} and HCO_3^- in waters from springs no. 16, 19 and 21–24. The chemical types of the water samples from springs no. 16 and 24 changed from Na-ClHCO_3 to $\text{Na-HCO}_3\text{Cl}$ and from $\text{CaNa-SO}_4\text{HCO}_3$ to $\text{CaNa-HCO}_3\text{SO}_4$, respectively. The milli-equivalent values of Ca^{2+} and HCO_3^- of the water samples from springs no. 16, 19 and 21–24 increased lineally ($R^2 = 0.93$, Fig. 5), indicating the enhanced dissolution of carbonate rocks.

During the sampling at spring no. 22, we intensively smelled H_2S gas, which indicated a considerable amount of H_2S content being emitted from the spring. Therefore, the increase of concentrations of Na^+ and SO_4^{2-} in samples from spring no. 22 may be attributed to water–rock interactions between granite and groundwater, enhanced by H_2S as calculated in Eq. (6):



6 Conclusions

The following conclusions can be drawn from our study:

1. Based on Shoka Lev's classification method, the water from hot springs in the Kangding district can be classified into 7 chemical types: Na-HCO_3 , NaMg-HCO_3 , $\text{NaMg-HCO}_3\text{SO}_4$, $\text{CaNa-SO}_4\text{HCO}_3$, $\text{CaNa-HCO}_3\text{SO}_4$, Na-ClHCO_3 and $\text{Na-HCO}_3\text{Cl}$.

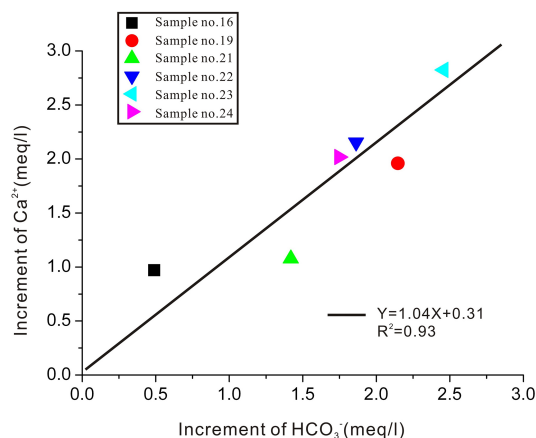


Figure 5. The plot of Ca^{2+} vs. HCO_3^- milli-equivalent, showing Ca^{2+} and HCO_3^- were most probably derived from the decomposition of carbonates. The abscissa indicates the Ca^{2+} increment of the water samples being relative to Ca^{2+} concentration in 2010, and the ordinate indicates the HCO_3^- increment of the water samples compared to that collected in 2010.

- The concentrations of Ca^{2+} , HCO_3^- and TDS in water samples from the Guanding, Erdaoqiao, Gonghe, Erhaoying, Tianwanhe and Caoke springs increased significantly after the Lushan earthquake, with the amplitudes ranging from 9.9 to 43.1 mg L^{-1} , 59.1 to 172.3 mg L^{-1} and 56.7 to 231.9 mg L^{-1} respectively, which resulted from a greater increase in groundwater from carbonate rocks and water–carbonate rock interactions.
- The concentrations of Na^+ , Cl^- and SO_4^{2-} in water samples from the Guanding, Zheduotang, Xinxing and Gonghe springs decreased after the Lushan earthquake, which may be related to the dilution of shallow waters which had depleted levels of Na^+ , Cl^- and SO_4^{2-} . However, the increase in the concentrations of Na^+ and SO_4^{2-} in the water from the Erhaoying spring after the Lushan earthquake may be the result of water–rock interactions between granite and groundwater, enhanced by H_2S .

Acknowledgements. This research was jointly supported by the Basic Science Research Plan of the Institute of Earthquake Science, China Earthquake Administration (2013IES010102; 2012IES0309) and the Natural Science Foundation of China (41402298; 41303076).

Edited by: F. Guzzetti

Reviewed by: G. Martinelli and another anonymous referee

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