Geoderma 155 (2010) 107–114

Contents lists available at ScienceDirect

Geoderma

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

Temporal variation of seepage water chemistry before and after the Hengchun Ms 7.2 earthquake in south Taiwan

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ARTICLE INFO

Article history:
Received 3 June 2009
Received in revised form 25 November 2009
Accepted 8 December 2009
Available online 3 January 2010

Keywords:
Tectonic earthquake
Seepage water
Water chemistry
Earthquake precursor
Taiwan

ABSTRACT

A destructive magnitude (*M*) 7.2 earthquake (21.9° N, 120.6° E) occurred in Hengchun of Taiwan at 8:26 pm on 26 December 2006. Seepage water chemistry was monitored twice a month from four routinely monitored points in the Kengting Uplifted Coral Reef Nature Reserve (KUCRNR) around Hengchun from January 2002 to December 2007. The different variants were presented for pH, conductivity, Na, K, Ca, Mg, NH_4, F, Cl, NO_3, SO_4, and HCO_3. It was observed that the occurrence of the Hengchun Ms 7.2 earthquake caused both temporary and permanent modification in the water chemistry of the seepage water studied. The significant increase of Cl concentration in seepage water were found 2 years prior to the earthquake, and remained steady until the present. Cl-rich waters are therefore expected to have been introduced within the KUCRNR water systems. Ca showed nearly the same trend as HCO_3 with high peak concentrations before the Hengchun Ms 7.2 earthquake, and then decreased with time after the earthquake. The high Ca and HCO_3 contents may be due to intense interaction processes between the thermal waters and the carbonate reservoir. The Ca and HCO_3 species would be added to the water during flow through the rocks. The effect of limestone may explain this result, because the sedimentary rock in this area majorly includes limestone.

1. Introduction

A destructive magnitude (*M*) 6.7 (7.2 by US geological survey) earthquake (21.9° N, 120.6° E) occurred in Hengchun of Taiwan, which is about 90 km south of Kaohsung, at 8:26 pm on 26 December 2006. Seismologist in Taipei located the epicenter of the first quake some 21.9 km off Hengchun. It was followed by the second tremor, measured 6.4 on the Richter scale, and originated 21.3 km off Fangliao near Pingtung. The quake was considered as the largest earthquake in a century in Pingtung area. There are two remarkable damage characteristics of the earthquake. Firstly, more than ten international communication fiber-optic cables on the sea floor were broken during the earthquake. Secondly, the reactor of the 3rd Nuclear Power Plant of Taiwan was shut down manually in response to the emergency (Pan et al., 2007).

The phenomenon of satellite thermal infrared (TIR) images showed TIR anomaly appearing in the nearby area of epicenter before the earthquake. The anomaly began to appear on the east of Philippines six days before Hengchun earthquake, and gradually moved toward west. Two days before the earthquake the, the anomaly moved to Philippines. After that, the anomaly changed the motion direction from toward west to toward north, with the drawing near to the earthquake, the anomaly was gradually close to the epicenter, meanwhile the strength and the scope of anomaly was gradually becoming larger and larger. One day before the earthquake, the strength of anomaly was up to the top of past days and the brightness temperature increased about 10 (Liu et al., 2007).

The employment of hydrogeochemical methods in earthquake prediction began in the 1970s. Experiences of several authors (Thomas, 1988; Tsunogai and Wakita, 1995; Toutain et al., 1997; Bella et al. 1998; Favara et al., 2001; Hartmann et al., 2005; Song et al., 2006; Liu and Sheu, 2007) have shown that earthquake-related hydrologic and chemical changes occur in groundwater, spring, and stream water located in seismically active areas. Seismic events are the geophysical phenomena that most frequently cause modifications in the physico-chemical parameters of the deep fluids. Significant hydrogeochemical changes observed prior to and simultaneously with earthquakes are not the same as regards behavior, type and intensity. Some physico-chemical parameters, which can be considered as geochemical precursors in one area, do not show any significant variations in another one. Moreover these variations may be temporary, in particular, with the proximity of earthquakes and then they disappear or they may be persisting while the system undergoes structural changes due to seismic activity. The recognition of these seismically induced phenomena is strictly related to the geographic location of sampling points with respect to the active tectonics and to the time interval between sampling (Favara et al., 2001).

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doi:10.1016/j.geoderma.2009.12.001

The Kengting Uplifted Coral Reef Nature Reserve (KUCRNR), located at the southern tip of the main island of Taiwan, is the only intact ecosystem characterized by an evergreen broadleaf forest on an uplifted coral reef landscape in Taiwan. *Ebenaceae* and *Euphorbiaceae* are the dominant plant families in this region, and diverse plant communities have further developed on the different landscapes (Wang et al., 2004). Taiwan is situated in the northeasterly trending collision zone of the Eurasian Plate and Philippine Sea Plate. The active tectonics results in uplifted coral reefs, such as KUCRNR (Ho, 1988). This ecosystem is unique because of the uplifted coral reef landform and vegetation. Liao et al. (2006) investigated the litter production, decomposition processes, and nutrient returns monitored over a 12-month period in the KUCRNR. Tsai et al. (2007) illustrated the effects of typhoon disturbances upon spatial and temporal variations in the soil microbial biomass and respiration in the KUCRNR. However, no published water chemistry studies could be found on uplifted coral reef landscapes, particularly those focusing on implications of seepage water chemistry by earthquake in humid tropical forests. Therefore, the aim of the present work was to study the systematic water chemistry dynamics recorded from January 2002 to December 2007 in the KUCRNR. Four seepage waters selected among those most clearly showing evidence of energy (heat) released from deep reservoirs, were periodically monitored.

2. Study site

Taiwan region is located in the jointed position of Eurasia plate, Philippine Plate and South Sea Subplate. There are many earthquakes happened every year in the region due to action of plate movements. On the southwest of Taiwan island South Sea Subplate dives toward Philippine Plate at northeast direction, that results in the formation of Manila Trench and Luzon Volcano Arch. As a result Taiwan Island becomes the turning position of plate motion from subduction to obduction, therefore it also becomes a geology area of crustal stress focus and frequent earthquake (Liu et al., 2007).

The longitudinal Valley between the Central Range and the Coastal Range represents the most obvious onshore plate boundary between the Eurasian plate and the Philippine Sea plate (Ho, 1988). In southern offshore of Taiwan, this Longitudinal Valley extends as the arc–prism boundary, which separates the volcanic arc domain (North Luzon Ridge) to the east and the accretionary prism domain (Hengchun Ridge) to the west. The N–S trending submarine Hengchun Ridge in the west of this boundary gradually shoals and emerges northward as the Hengchun peninsula and as the Central Range in further north. There are three main tectonostratigraphic units of the Hengchun peninsula, the Middle–Late Miocene deep-marine turbidites in the central peninsula, the Plio-Pleistocene shallow-marine foreland sequences in the west, and the Kenting Mélange at the boundary between these two major units.

The KUCRNR, with an area of approximately 138 ha, is located on the Hengchun Peninsula, at the southern tip of the main island of Taiwan (Fig. 1). This nature reserve is the only fully conserved forest underlain primarily by Miocene rocks capped with uplifted coral reef and recent sediments in Taiwan. The underlying formation is Hengchun Limestone, composed of organic reef material comprising the remains of various organisms, including corals, foraminifers, mollusks and calcareous algae. These organisms are more abundant in the lower part of the limestone unit than in the upper part. Where limestone is well developed, it is gray to creamy white, and either massive and compact or porous. The Hengchun Limestone is of Middle to Late Pleistocene age origin (Ho, 1988). Consequently, the coral reef and recent sediments were uplifted about 500,000 years ago in the Hengchun Peninsula to form the present landscape. This work focused on a long-term monitoring plot within the reserve situated at approximately 120°48′ E, 20°58′ N. The elevation ranges from 200 to 300 m above sea level and slopes downward toward the south.

High temperatures and humidities, heavy rainfall, and typhoons from spring to autumn characterize the climate of the study area. The annual average air temperature is around 23 °C, with a peak average of approximately 30 °C in July, and the lowest average of about 16 °C in January. The seasonal variation between dry in winter and wet in summer causes a wet–dry tropical climate (Cwa) based on the Köppen climate classification (Wang et al., 2004). However, the annual rainfall in the study area ranges between 1800 and 2400 mm, with most precipitation falling from June to September (Fig. 2).

3. Sampling and chemical analysis

Seepage water sampling was designed to represent average annual concentrations of dissolved constituents in base flow. Seepage water samples were grab-sampled twice a month from four (W1, W2, W3, and W4) routinely monitored points (Fig. 1). As a rule, sampling was performed on a day without rainfall. In this paper, the sampling period was from January 2002 to December 2007. Samples were collected in brown polyethylene 500-mL bottles that were first cleaned with chromic acid cleaning solution, rinsed three times with distilled water, and then rinsed in the seepage water several times before retaining a sample.

Samples were immediately transported to the water chemistry laboratory at Taiwan Forestry Research Institute. The pH and conductivity of samples were determined on unfiltered samples within a few days after arrival at the laboratory. pH was determined using a glass electrode (Metrohm 691, Swiss). Electrical conductivity was determined using a conductivity meter (WTW LF 340, Germany). Afterwards water samples were filtered using membrane filters with a pore size of 0.45 μm (Schleicher and Schuell, NC45) and stored at 4 °C until they were analyzed. Concentrations of Na, K, Ca, Mg, NH_4, F, Cl, NO_3, and SO_4 were determined by ion chromatography (DX-120, USA). Alkalinity (HCO_3) was measured by titration with 0.005 N H_2SO_4 to pH 4.52 (APHA, 1995).

Throughout all these determinations, seepage water certified reference materials were used to check analytical procedures. Quality control procedures for water samples involved the use of certified reference materials (SLRS-4, National Research Council Canada; GBW 08627c, State Bureau of Technical Supervision, China) returning accuracy of within ±5%. On an equivalent basis, the sum of all major cations ($H+Na+K+Ca+Mg+NH_4$) should equal the sum of all major anions ($F+Cl+NO_3+SO_4+HCO_3$). The usual assumption made in testing the quality of stream water data is Ri = 1 = cations/anions, which represents the ideal situation. An indication of the usefulness of Ri as a QA parameter is given by the fact that there is a very good correlation between the sums of cations and anions in the original data set, with $R^2 = 0.99$ for $N = 576$ (Fig. 3).

4. Results and discussions

The period of record used for analyzing temporal water chemistry trends were the years from 2002 to 2007. The different variants are presented for pH, conductivity, Na, K, Ca, Mg, NH_4, F, Cl, NO_3, SO_4, and HCO_3 in Fig. 4. Temperature and precipitation data (Fig. 2) are also given for the same periods. It is observed that the occurrence of the Hengchun Ms 7.2 earthquake caused both temporary and permanent modification in the water chemistry of the seepage water studied. For example, the concentration of Ca and HCO_3 showed a sharp increase before the earthquake. The values that followed remained permanently higher than those recorded before the earthquake shocks. These compositional modifications can be explained by permanent changes in aquifers, caused by tectonic events.

Tectonic earthquakes may be interpreted as the result of complex preparatory processes occurring around a source region. Many considerations, such as basic elastic theory, but also compilations of various kinds of precursors (Hauksson, 1981; King, 1986; Thomas, 1988;