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Chemical weathering in the upper reaches of Xijiang River draining the Yunnan–Guizhou Plateau, Southwest China

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Abstract

Chemical and strontium isotopic compositions of Nanpanjiang River and Beipanjiang River in the upper reaches of Xijiang River draining the Yunnan–Guizhou Plateau, Southwest China, were measured with a main purpose to understand the rock weathering and associated CO_2 consumption rates in the karstic landform-dominated area. The chemical ion composition of the river water is characterized by dominance of Ca^{2+}, Mg^{2+} and HCO_3^-, and SO_4^{2-}, which account for more than 90% of total ion concentration. $^{87}Sr/^{86}Sr$ ratios of Nanpanjiang River water range between 0.7080 and 0.7140, while those of most Beipanjiang River water vary within a limited range from 0.7075 to 0.7085.

Weathering of carbonate rocks dominate chemistry of major ions especially in the water of Beipanjiang River, whereas weathering of silicate minerals in the upper reaches of Nanpanjiang River basin is obvious in addition to carbonate weathering, mainly according to the Sr isotopic composition of the river water. Analyses of the stoichiometry of the river water show that the water chemistry is controlled by carbonate dissolution not only by carbonic but also by sulfuric acid, and indicate that sulfuric acid plays an important role in carbonate weathering. The sulfate in river water is mainly from atmospheric input by coal-combustion industries and from oxidation of sulfide minerals during weathering of coal-containing strata and coal mining in the catchment. The chemical weathering rates of silicate and carbonate and associated CO_2 consumption rates by both carbonic and sulfuric acid and by only carbonic acid are respectively estimated. The results show that chemical weathering rates of carbonate and silicate weathering in Beipanjiang River basin are higher than those of Nanpanjiang River basin, showing linkages of geology and geography in the catchment to crustal weathering. The involvement of sulfuric acid in carbonate weathering greatly enhances the carbonate weathering but lowers the CO_2 consumption rates, indicating that sulfide acid is an important agent to rock weathering and the role of sulfide acid should further be clarified in view of the regional and global budget of CO_2.

Keywords: Yunnan–Guizhou Plateau; River water geochemistry; Strontium isotope; Chemical weathering; CO_2 consumption rate

1. Introduction

The hydrogeochemical investigation of river waters gives important information on chemical weathering of rock/soil, chemical and isotopic compositions of the drainage basin, weathering rates and CO_2 consumption

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by the acid degradation of continental rocks, and reveals the biogeochemical cycles of elements (Stallard and Edmond, 1983, 1987; Sarin et al., 1989; Elderfield et al., 1990; Palmer and Edmond, 1992; Zhang et al., 1995; Huh et al., 1998; Gaillardet et al., 1997, 1999; Viers et al., 2000; Qin et al., 2005). Since carbonate weathering largely dominates the chemistry of river waters, characterization of water chemistry of rivers draining carbonate-dominated terrain is crucial to precisely identify the various contributions of the different sources to the water solutes, and to estimate weathering rates of continental crust and associated CO_2 consumption (Fairchild et al., 1994; Petelet et al., 1998; Gaillardet et al., 1999; Fairchild et al., 2000; Liu and Zhao, 2000; Grasby and Hutcheon, 2000; Han and Liu, 2004).

The Xijiang River, a main channel of Pearl River, drains a large area of typical karst landform especially in its upper and middle reaches in Yunnan, Guizhou and Guangxi Provinces. The Nanpanjiang River and Beipanjiang River are the two main headwater tributaries of the Xijiang Rivers draining the Yunnan–Guizhou Plateau, In this study, we have carried out a systematic investigation on the hydrogeochemistry of the Nanpanjiang and Beipanjiang Rivers and their tributaries, particularly to characterize aqueous geochemistry and its controlling factors, and aim to understand the chemical weathering process and quantify rock weathering rates and associated CO_2 consumption rates. Furthermore, several studies have shown that sulfuric acid takes part in rock weathering (Galy and France-Lanord, 1999; Yoshimura et al., 2001; Han and Liu, 2004; Spence and Telmer, 2005; Lang et al., 2006). Since the rock/soil weathering by sulfuric acid is a process not considered in global CO_2 flux models at present, systematic study of the role of sulfuric acid in chemical weathering is important. Southwestern China, especially Guizhou Province, is impacted by serious sulfuric acid rain because of coal-combustion and by coal-mining due to wide distribution of coal-containing strata. So, another aim of the present work is to study the effect of sulfuric acid on the carbonate weathering.

2. General setting

The Yunnan–Guizhou Plateau (Southwest China) is located in the center of the Southeast Asian Karst Region where karstification is most developed, karst types are the most diversed, and the karst area is the largest in the world. The Nanpanjiang River and Beipanjiang River are the upper reaches of the Xijiang River rise in the Maxiong Mountain on the Yunnan–Guizhou Plateau, which is 2000 m high above the sea level. The karst area accounts for about 60% of the total drainage area in the Nanpanjiang and Beipanjiang river catchments. Nanpanjiang River is the mainstream of the Xijiang River, and winds through three provinces including Yunnan, Guizhou, and Guangxi, with a length of 914 km, an area of 56,880 km^2. Beipanjiang River is the largest tributary of Xijiang River in the upper reaches, which joins the main channel at Zhexiang County, with a total length of 444 km, an area of 26,590 km^2 (Fig. 1).

The Nanpanjiang and Beipanjiang river catchments are exposed to a warm subtropical climate. Mean annual air temperature is 14 °C to 22 °C over the entire drainage basin. Mean annual precipitation, averaged over several years, is from 800 to 1200 mm, and the precipitation decreases from south to north and from east to west. The precipitation in the rainy period (June to September) accounts for about 50–55% of the total annual precipitation. The elevation gradients of the Nanpanjiang and Beipanjiang rivers are abrupt, and the altitudes of the river catchments are about 2400 m in its riverhead and about 800 m at Zhexiang. Vegetation covers of the different area are variable, generally with higher vegetation covers in their lower reaches.

Fig. 1, a simplified geological map, shows the main rock types in the Nanpanjiang and Beipanjiang drainage basin. The strata exposed in the catchment are mainly Pre-Jurassic in age. The middle and lower reaches of the catchments are dominated by Permian and Triassic carbonate rocks (limestones and dolomites) and coal-bearing formations. In the upper reaches of the catchments are distributed detrital sedimentary rocks (shales, sandstones and siltstones) and magmatic rocks (basic and ultrabasic rocks, basalts exit there but are minor).

3. Sampling and analytical procedures

Water samples from mainstream and major tributaries of the Nanpanjiang and Beipanjiang rivers were collected from August to September of 2000 during the high-flow season. The sampling locations are shown in Fig. 1. Temperature, pH and electric conductance were measured in the field. River water was generally collected by using 10 l high density polyethylene (HDPE) containers, and immediately filtered through 0.22 μm Millipore membrane filters. The first portion of the filtration was discarded to clean the membrane. Alkalinity was titrated by hydrochloric acid within 12 h. Filtered solution for cations and trace elements analyses was acidified with ultra-purified 6 M HNO_3 to pH < 1.6 and stored in HDPE bottles, previously washed with