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Chemical weathering processes in the Yalong River draining the eastern Tibetan Plateau, China

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ABSTRACT

To better understand chemical weathering and controlling processes in the Yalong River of the eastern Tibetan Plateau, this study presents major ion concentrations and stable isotopes of the dissolved loads. The isotopic compositions (δ^{13}C-DIC, δ^{34}S and δ^{18}O-SO_4) of the dissolved loads are very useful to quantify solute sources and define the carbon budget related with chemical weathering in riverine systems. The isotopic composition of sulphate demonstrates that most of the sulphate is derived from sulphide oxidation, particularly in the upper reach of the Yalong River. The correlations between δ^{13}C-DIC, water chemistry and isotopes of sulphate, suggest that the carbon dynamics are mainly affected by carbonate weathering by sulphuric acid and equilibration processes. Approximately 13% of the dissolved inorganic carbon in the Yalong River originates from carbonate weathering by strong acid. The CO_2 consumption rates are estimated to be 2.8×10^5 mol/km^2/yr and 0.9×10^5 mol/km^2/yr via carbonate and silicate weathering in the Yalong River, respectively. In this study, the influence of sulphide oxidation and metamorphic CO_2 on the carbon budget is estimated for the Yalong River draining the eastern Tibetan Plateau.

1. Introduction

Rock weathering and the burial of organic carbon are the two main sinks of atmospheric CO_2 in the global carbon cycle and thus affect Earth's climate on short to geological timescales (Berner et al., 1983; France-Lanord and Derry, 1997; Ludwig et al., 1998; Gaillardet et al., 1999; Cole et al., 2007). The consumption of atmospheric CO_2 via silicate weathering would regulate the global CO_2 level and climate at geological time scales (10^6 year) due to the subsequent CO_2 sequestration as carbonate in the ocean (Berner et al., 1983). According to the "tectonics-weathering-climate" hypothesis, the Himalayan uplift would have been responsible for the global cooling and CO_2 drawdown during the Cenozoic (Raymo and Ruddiman, 1992). However, the influence of rock weathering on the evolution of long-term climate requires more accurate and systematic researches due to uncertainties in the chemical weathering fluxes and complexity of the factors that control these fluxes at the watershed scale (Gaillardet et al., 1999; West et al., 2005; Tipper et al., 2006; Calmels et al., 2007; Gaillardet and Galy, 2008; Noh et al., 2009). Thus, the carbon budget in the river systems should be evaluated more carefully for accurate global carbon cycle.

The water chemistry and rock weathering in Himalayan and Tibetan rivers have drawn extensive attention (Galy and France-Lanord, 1999; Dalai et al., 2002; Jacobson et al., 2002; Singh et al., 2005; Wu et al., 2005, 2008; Tipper et al., 2006; Hren et al., 2007; Moon et al., 2007; Noh et al., 2009). Several studies have demonstrated the complexity of carbon dynamics in the rivers and the various processes controlling rock weathering as well as sources of the dissolved inorganic carbon in the Himalaya region. It was reported that sulphuric acid should act as an important weathering agent in the Ganges–Brahmaputra (Galy and France-lanord, 1999) and the Indus (Karim and Veizer, 2000). Recent studies have shown significant quantities of metamorphic CO_2 were released during the tectonic uplift of the Himalayas, based on data from water chemistry and δ^{13}C of dissolved inorganic carbon (Evans et al., 2008; Becker et al., 2008). However, the chemical budget influenced by sulphuric acid and metamorphic CO_2 in the eastern Tibetan Plateau rivers are not well known (Wu et al., 2005, 2008; Qin et al., 2006; Moon et al., 2007; Noh et al., 2009). The carbon budget and dynamics should be updated to better understand the chemical weathering process and carbon cycle in the riverine system of the Tibetan Plateau.

In the present study, we focus on the carbon dynamics and rock weathering in the Yalong River draining the eastern Tibetan Plateau, SW China, using water chemistry and isotopic compositions of dissolved inorganic carbon and sulphate. The main objectives

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of this study are to identify the sources of solutes, to evaluate the contribution to rock weathering and carbon budget caused by sulphide oxidation and metamorphic CO_2, and so estimate silicate weathering and CO_2 consumption rates in the Yalong River.

2. Materials and methods

2.1. Characteristics of the investigated basin

The Yalong River basin is located in the eastern Tibetan Plateau, Southwest China, between 26°32′ and 33°58′N latitude and 96°52′ to 102°48′E longitude. The Yalong River, one of the largest tributaries of the Changjiang River, originates from the Bayan Har Mountains in the southern Qinghai Province at an elevation of nearly 5000 m. The River has a basin area of 1.28×10^5 km^2 with a mainstream river length of over 1571 km. The mean annual water discharge is 1914 m^3/s, with annually exports on average 2.55×10^{10} kg/yr as suspended particulate matter. About 75% of the total water discharge occurs during the wet season from June to October (Zhu, 2007; Feng et al., 2008). The major tributaries of the Yalong River are the Xianshui River, Qingda River, Liqiu River, Litang River, Jiulong River and Anning River (Fig. 1).

The upper, middle, and lower reaches of the river are geographically divided by Ganzi and Dahewan. The landscape exhibits a plateau strath terrace for the upper main channel and deep gorges for the middle and lower reaches of the Yalong River (Zhu, 2007). The upper and middle reaches of the Yalong River are tectonically situated in the Ganzi-Aba folding belt, with to the Xianshuihe fault and the Batang fault, in the studied area. Triassic sediments including low grade metamorphic rocks outcrop in the upper and middle reaches, which are dominantly sandstone rocks intercalated with sparse granitoid intrusive rocks, Permian carbonate, shale and minor ophiolitic melanges. The areas in the lower reaches are of exposed Palaeozoic carbonates and low-grade metamorphic rocks with minor basalt, gneiss, schist, granite and conglomerate based on geological survey (Bureau of Geology Mineral Resources of Sichuan Province, 1991).

A seasonal monsoonal climate dominates a wide area of the Yalong River basin and controls the temporal and spatial distribution of precipitation. A cold climate associated with less abundant rainfall dominated the headwater of the basin. The mean annual rainfall varies from 500 to 800 mm in the upper reach, from 1000 to 1800 mm in the middle reach and from 900 to 1300 mm in the lower reach. The runoff of the Yalong River primarily originates from precipitation, snow melting and groundwater. About 90% of the annual precipitation occurs from May to October. The grassland covers approximately 68% of the catchment, and forest land covers approximately 20% of the catchment (Yu et al., 2008). The population density and cultivated land ratio are very low in the Yalong River basin except the suburb of the Panzhihua City (2.4 million inhabitants) and the Anning plain located in the lower reach. The cultivated land is mainly distributed in the Anning plain at the eastern part of the basin.

2.2. Sampling and analytical techniques

Water samples were collected in August 2008 and February of 2010, corresponding to the high flow season and the low flow season, respectively. Temperature, electrical conductivity and pH of the water samples were measured in the field. Alkalinity was determined by HCl titration. Water samples were filtered through 0.45 μm cellulose-acetate filter paper into a series of bottles for analysis. Major cations (Mg^{2+}, Ca^{2+}, K^+, and Na^+) and Si concentrations were measured by ICP-OES with a precision better than 5%. Anions (SO_4^{2-}, Cl^-, and NO_3^-) were determined by ionic chromatography Dionex 90 with a precision of 5%. The concentrations of dissolved organic carbon (DOC) were analysed as CO_2 by catalytic combustion (Elemental high TOC II + N, Germany) after water acidification with HCl to remove all inorganic carbon. The values of partial pressure of CO_2 (pCO_2) and calcite saturation index (SIc)

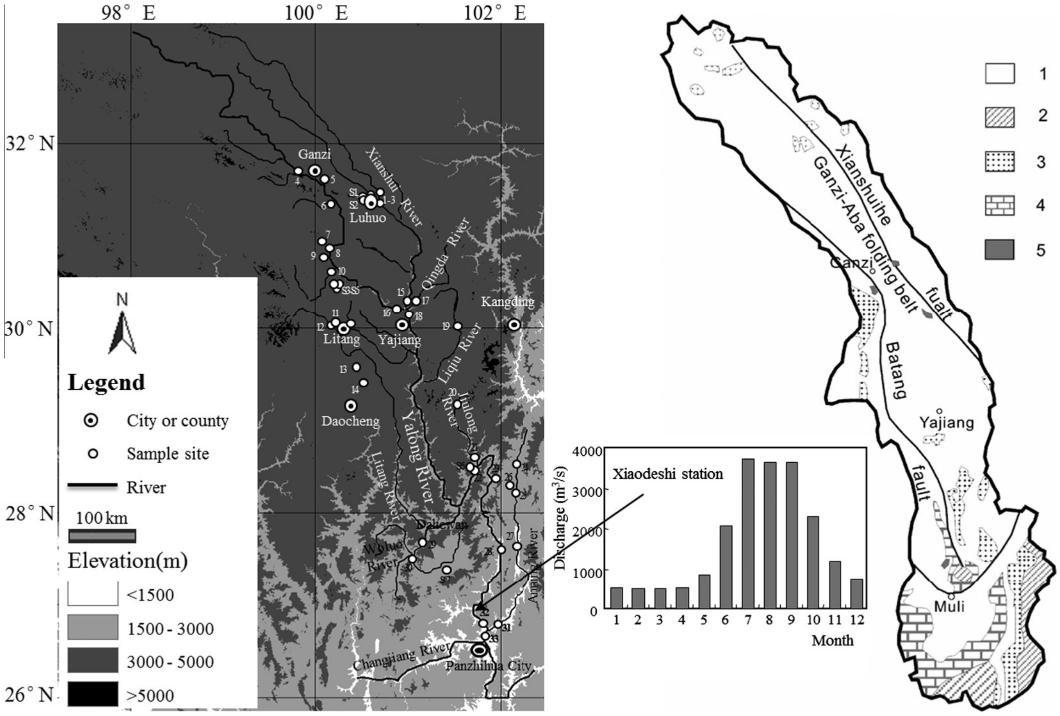

Fig. 1. Topographic map with sampling site and simplified geology at the Yalong River. Mean monthly discharge at monitoring station refer to Cen et al. (2012) (No. 32). Keys: 1. Mesozoic sediments including low-grade metamorphic rocks; 2. High-grade metamorphic rocks; 3. Granites; 4. Carbonate rocks with clastic rocks; 5. Ophiolitic melanges.