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Climatic and geological factors contributing to the natural water chemistry in an arid environment from watersheds in northern Xinjiang, China

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ABSTRACT

A natural water hydrochemical investigation was carried out on three watersheds in northern Xinjiang, China to evaluate the climatic, geological and anthropogenic influence on aqueous major element chemistry in an arid environment. Wide spatial variations are observed in the dissolved solids (TDS) and water chemistry. The hydrochemistry is typically carbonate and alkaline in nature, with Ca^{2+}, HCO_3^- and SO_4^{2-} dominating the major ion composition. Four major water types, Ca–HCO_3, Ca–NDA (non-dominant anion), Ca–SO_4 and NDC (non-dominant cation)–NDA or Na–NDA type, are identified in terms of the Piper model. The water chemistry agrees well with the "rock dominance" mechanism, with a TDS value of 80–600 mg/L and a $Na^+/(Na^+ + Ca^{2+})$ ratio of 0.1–0.6. Correlation analysis suggests that most of the ions derive from multiple sources. Stoichiometric analyses indicate that carbonate weathering is the primary source of dissolved ions, followed by silicate weathering and evaporite dissolution. The effects of local pollution have somewhat greater contribution on the oases and central areas of the Zhungarer watershed. Most parts of the rivers show an increasing trend in the dissolved load toward the lower reaches, which is primarily attributed to an evaporation process control along the water course. Variations in water chemistry show clear correlation with the regional lithological distribution, topography and atmospheric precipitation. Using rainwater as a baseline, contributions from atmospheric precipitation and rock weathering to the tributary chemistry are roughly evaluated to be in the range of 2–39% (average 13%) and 59–98% (average 86%), respectively, implying a high effective control of regional geology on stream chemistry compared with that of atmospheric input.

1. Introduction

The hydrochemistry of river water contains information on chemical weathering and the composition of the upper continental crust on a basin-wide scale, and reveals the exogenic cycles of elements in the continent–river–ocean system (Gibbs, 1970; Stallard and Edmond, 1981, 1983; Hu et al., 1982; White and Blum, 1995). Given that rivers carry weathered materials from continents to oceans, there are numerous factors controlling the geochemical processes, including climate, lithology, topography, vegetation, human activities, etc. (Berner and Berner, 1996). Lithological weathering results from a complex set of interactions between the lithosphere, atmosphere, hydrosphere and biosphere (Meybeck and Helmer, 1989; White and Blum, 1995; White, 2008). Although factors affecting the weathering processes are difficult to quantify, the weathering sources are primarily composed of three components: evaporites, carbonates and silicates (Meybeck, 1987; White and Blum, 1995). If rock weathering reactions serve as the main sources of major ions, stoichiometric analysis would still provide some qualitative information of the sources for river water, as weathering of different parent rocks yields different combinations of dissolved cations and anions in the resulting solution (Meybeck and Helmer, 1989, 2005; Zhang et al., 1995; Chen et al., 2002). The natural controls of riverine chemistry at the global scale have been widely studied, but regional studies performed within remote areas with extreme climate and limited human impacts are rare (Meybeck, 2005).

Northern Xinjiang in northwestern China, the geographical center of the Asian Continent, is an extremely arid region with sparse vegetation and an undeveloped economy. Most of its rivers originate from peripheral mountain glaciers and snow, and drain areas of diverse geology and climatic conditions, with lower reaches in the desert environment. Geochemical studies of these waters are of considerable importance for a better understanding of the influences of the geology and meteorology of their drainage areas, weathering of crustal rocks, evaporation under arid climates and the impact of human activities on the chemistry of naturally occurring water. Until now, few chemical data were available for the northern Xinjiang rivers, particularly for several international rivers such as the Yili, Ermin and Erlqis rivers,

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although the hydrogeochemistry of their neighboring watersheds, the Hexi–Corridor–Alashan watershed to the east and the Tarim watershed to the south, has been systematically investigated (Zhang et al., 1995; Yang and Williams, 2003; Zhu and Yang, 2007, 2010; Si et al., 2009). Hence, the geochemical studies of rivers in northern Xinjiang are important for understanding the geological and climatic control on the aqueous chemistry in this arid environment.

Due to the lithologic, climatic and topographic diversity in the arid northern Xinjiang watersheds, the detailed objectives of this paper are follows: (1) characterizing the physicochemical properties of the natural waters and their spatial distribution, (2) recognizing the predominant mechanism controlling the water chemistry and the source of water solutes, and (3) evaluating the effects of rock weathering, topography, climate and human activity on water chemistry.

2. Materials and methods

2.1. Regional setting

Northern Xinjiang, the north part of the Xinjiang Autonomous Region in NW China ranges between 78° and 90° E and 42° and 50° N. It is approximately 603,000 km^2 in area, bounded by the Tianshan Mountains to the south and the Altai Mountains to the north. It can be briefly described in terms of its geomorphology as "one basin sandwiched between two mountains" (Fig. 1). Elevations increase from <500 m above sea level (asl) in the center of the Zhungarer basin to >3000 m asl in the south and north ranges (Fig. 1c). The topography is generally flat in the central plain and is rather craggy in the peripheral mountainous areas. The wide piedmonts and pediment plains are marked by the Gobi and sandy desert, grassland for herding and oasis land with intensive agricultural activities. Northern Xinjiang is controlled by an arid temperate continental climate, which has prevailed in central Asia at least since the latest Oligocene (Sun et al., 2010). The mean annual air temperature is about 5 °C, with a minimum of −10 °C to −20 °C in January and a maximum of 28 °C to 33 °C in August (Fig. 2b). The regional precipitation is derived mainly from westerlies, with a mean annual precipitation of 60–150 mm in the central plain and 200–500 mm in the surrounding mountains (Fig. 1b). While the potential evapotranspiration reaches approximately 1000–3500 mm per year, it varies in aridity both seasonally and along the elevation gradient across northern Xinjiang, due to the distribution patterns of seasonal precipitation, temperature and relative humidity (Fig. 2b–d) and the orientation of delivery of moisture by the westerlies.

According to the hydrological classification in China (Ma, 2002), northern Xinjiang is divided into three drainage systems (Fig. 1a). Two of them, the Zhungarer and Yili watersheds, are inland continental watersheds in nature, and the third, the Erlqis watershed, drains into the Arctic Ocean. Many of the rivers in these watersheds display dendritic to sub-dendritic drainage patterns elongated in an E–W direction,

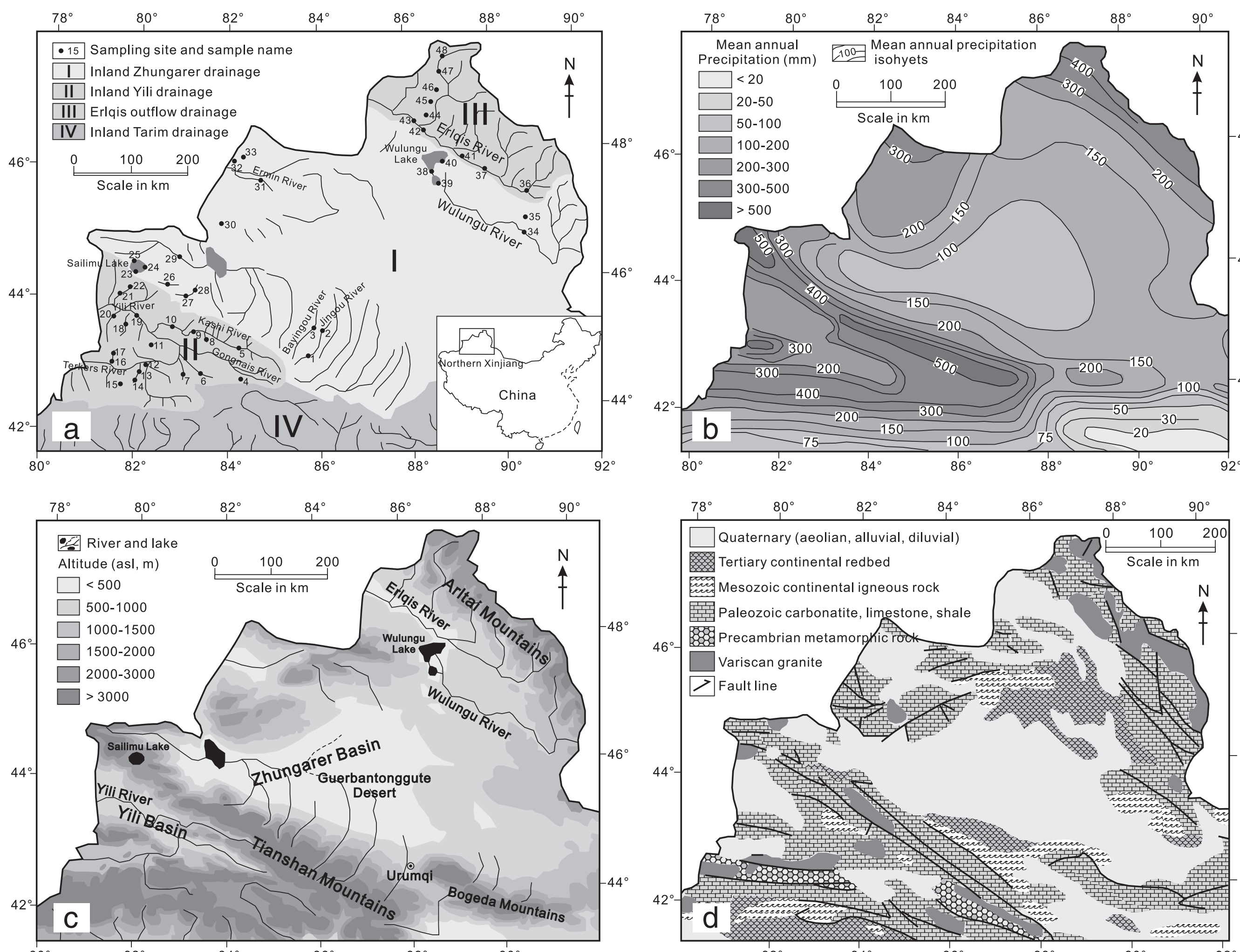

Fig. 1. Hydrological setting and sampling locations map (a), mean-annual-precipitation-isohyets distribution map (b), topographical map (c) and geological map (d) of northern Xinjiang.