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The significance of mid-latitude rivers for weathering rates and chemical fluxes: Evidence from northern Xinjiang rivers

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SUMMARY

Rivers draining the sedimentary platform of northern Xinjiang (the center of Asian continent) are characterized by low discharge under a temperate and arid climate. The influence of rock mineralogy, climate, relief and human activity on natural water composition and export as a result of weathering is a major scientific concern both at the local and the global scale. While comprehensive work on the controlling mechanism of chemical weathering has been less carried out in the sedimentary platform of northern Xinjiang. Thus, the effects of climate and rock weathering on the inorganic hydrogeochemical processes are not well quantified at this climatic extreme. To remedy this lack a comprehensive survey has been carried out of the geochemistry of the large, pristine rivers in northern Xinjiang, the Erlqis, Yili, Wulungu, Jingou and numerous lesser streams which has not experienced the pervasive effects of glaciation and subsequent anthropogenic impacts. The scale of the terrain sampled, in terms of area, is comparable to that of the Huanghe and includes a diverse range of geologic and climatic environments. In this paper the chemical fluxes from the stable sedimentary basin of the northern Xinjiang platform will be presented and compared to published results from analogous terrains in the monsoon basins of China and world. Overall, the fluvial geochemistry of northern Xinjiang in westerly climate is similar to that of the Chinese rivers (Huanghe and Yangtze) in the East-Asian monsoon Climate, both in property–property relationships and concentration magnitudes. The range in the chemical signatures of the various tributaries is large; this reflects that lithology exerts the dominant influence in determining the weathering yield from the sedimentary terrains rather than the weathering environment. The effect of different rock weathering ranges from rivers dominated by aluminosilicate weathering, mainly of granites, sandstones and shales, to those bearing the signatures of dissolution of carbonates and evaporites and of continental playa deposits. Carbonates are the general predominant lithology undergoing dissolution particularly within the lesser arid areas. The pCO_2 in the study rivers is out of equilibrium with respect to atmospheric pCO_2, about up to ~20 times supersaturated relative to the atmosphere but not to such an extent as the Amazon in the floodplain. A roughly positive relationship is observed between solute concentrations and the drought index (DI) for natural waters in the region, indicating a coupled mountain-basin climate has a direct effect. The relative contributions of end-member solute sources to the total dissolved cations from each watershed have been quantitatively estimated using dissolved load balance models, showing the results as evaporite dissolution > carbonate weathering > silicate weathering > atmospheric input for the whole catchment. The areal total dissolved fluxes range from 0.05 to 2.53×10^6 mol/km^2/yr, 0.02–2.09×10^6 mol/km^2/yr and 0.01–1.04×10^6 mol/km^2/yr in the Yili, Zhungarer and Erlqis, respectively, comparable to those of Chinese and Siberia rivers draining sedimentary platforms, even though they are in drastically different climatic regimes. In general, the fluxes from rivers in sedimentary basins are comparable to those from orogenic zones, but are much higher than in the shield regions. The CO_2 consumption by aluminosilicate weathering (0.2–284×10^3 mol/km^2/yr) is much smaller than in active orogenic belts (19–1750×10^3 mol/km^2/yr in similar latitudes and 143–1000×10^3 mol/km^2/yr in the tropical basins), but comparable to those of the Chinese (7–106×10^3 mol/km^2/yr) and Siberia (16–112×10^3 mol/km^2/yr) rivers.

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1. Introduction

The influence of rock mineralogy, climate, relief and human activity on natural water composition and export as a result of weathering is a major scientific concern both as the local scale, because of the link between stream chemistry and geobiodiversity, and at the global scale, in relation to global climate changes (Nedeltcheva et al., 2006; Quevauviller and Umezawa, 2011). Thus, the fluvial flux of dissolved material from continents to oceans is a reflection of the environmental conditions prevailing over the continental surface. However, fluxes from individual drainages are as diverse as the terrains themselves and are poorly understood mechanisms (Edmond et al., 1995, 1996; Huh et al., 1998a,b; Huh and Edmond, 1999). Interpretation is complicated by the fact that the weathering of exposed aluminosilicates is a sink for atmospheric CO_2 and hence is itself a potential determinant on climate change. Climate and weathering environment may, therefore, be closely coupled.

The possible responses of the continental weathering regime to climatic variation on a variety of time scales are drawing much interest (Blum and Erel, 1995; Froelich et al., 1992; Raymo and Ruddiman, 1992). In order to understand the link between them, it is useful to study the current weathering patterns in middle latitudes relative to those in the tropics and high latitudes as a surrogate for climatic deterioration. The intermediate temperatures and the medium-temperature processes resulting from them make the middle latitudes a transitional environment. The weathering fluxes and patterns might be expected to be different from those in tropics (relatively hot and humid) and high latitudes (relatively cold and dry). Unusual magnitudes in the fluxes of certain elements or elemental ratios associated with mid-latitude fluvial weathering potentially could be used in interpreting the sedimentary record in terms of environmental change.

General Circulation Models predict that the global warming effects of carbon dioxide and other greenhouse gases will be amplified two to four times in the high latitudes relative to lower latitudes (Cuffey et al., 1995; Hansen et al., 1983). How fast and how far the weathering regime will respond are important questions. One of the major goals of river geochemistry studies is to estimate the present-day inorganic denudations of the continents and their associated CO_2 consumption. This paper will focus on the consumption of atmospheric CO_2 through rock weathering (mainly carbonate and silicate weathering). Observations show that the fluvial chemistry of world rivers in both stable and tectonically active regimes is dominated by the rapid weathering of biogenic and inorganic carbonates and evaporites and the slower dissolution of sedimentary aluminosilicate rocks, shales and sandstones, with relatively minor contributions from primary basement formations (Berner and Berner, 1996; Meybeck, 1987). Approximately 80% of the land surface is covered by sediments (Ronov, 1982) in the form of platform cover and uplifted margins in continental foldbelts. The concentration of total dissolved solids in waters draining sedimentary rocks is at least twice that in waters draining igneous and metamorphic terrains (Holland, 1978). Systematic work on the chemical manifestation of such geology in reasonably unperturbed river systems has been done mainly on platform in tropical and temperate regions, e.g., China (Chen et al., 2002, 2005; Hu et al., 1982; Wu et al., 2005; Zhang et al., 1990, 1995a; Zhang et al., 2007), southern Asia (Ahmad et al., 1998; Harris et al., 1998; Hren et al., 2007; Sarin et al., 1989), central Africa (Gaillardet et al., 1995; Negrel et al., 1993) and in the continental foldbelts of the Americas (Edmond et al., 1995, 1996). Analogous works from the high-latitude regions such as Eastern Siberia are also systematically reported (Huh et al., 1998a,b; Huh and Edmond, 1999). However, there is very little comparative data from middle latitudes of central Asia predominantly due to the difficulty of access (Meybeck, 2005). Besides, the response of weathering regimes to regional and global climate change at all time scales, in particular the effect on atmospheric pCO_2, is currently a question of some importance since anthropogenic climatic impacts are expected to be strongly enhanced at northern latitudes as compared to the global average (Cuffey et al., 1995; Hansen et al., 1983).

The rivers of northern Xinjiang (Fig. 1), northwestern China, the geographical center of the Asian Continent, are ideal for such studies in that the climate is extreme, due to their aridity, the basins have never been glaciated except in the highest alpine areas (Rhodes et al., 1996; Sun et al., 2010). The region contains a very wide range of geologic and tectonic environments and the complete spectrum of climatic and vegetational zones characteristic of continental interiors at middle and high latitudes. The river basins are pristine, with populations and economic activities at similar much lesser scales as compared to those of the Huanghe and Yangtze in central China and the Yukon and the Mackenzie in North America. Previously reported data on the fluvial geochemistry have been restricted to water resource, quality, distribution and its formation (XCETCAS, 1965; Zhang et al., 2008a; Zhu et al., 2011, 2012). Through a comparison with equivalent tropical and high-latitude terrains, the Chinese and world platforms, the influence of climate on weathering processes and fluxes in large sedimentary basins of northern Xinjiang will be firstly examined and quantified. The rivers in sedimentary platforms in turn will be compared to those in active orogenic zones, such as the Fraser and Mackenzie draining the Rockies.

2. Regional setting

2.1. Location

Northern Xinjiang (Junggar, Zunggar), at the boundary between the Arctic and the Indian Ocean watersheds, is a large endorheic depression and sedimentary platform limited by the high mountain ranges of the Tianshan to the south, the Altai Shan to the northeast, and by a broken series of mountains and plateau around 3000 m to the west. The Northern Xinjiang is the northwesternmost part of China and the geographical and aridity center of the Asian Continent. It occupies an area of $\sim 6.03 \times 10^5$ km^2 between 42°N at the north edge of the Tianshan Mountains and 50°N at the south edge of the Arltai Mountains and between 78°E (east of Kazakstan) and 90°E (slightly west of the Bogeda Mountains and the Beitashan Mountains). 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. 1). The topography is generally flat in the center plain and is rather cragged in the peripheral mountainous areas (Fig. 1c). The wide piedmonts and pediment plains are marked by the Gobi desert, grassland for herding and oasis areas with intensive agricultural activities. The borders of the basin are composed of exposed igneous and metamorphic rocks and unconsolidated detrital sediments, the interior is a stable craton with a sedimentary cover several kilometers thick, Precambrian to Quaternary in age, composed of marine carbonates and evaporites and continental deposits: sandstone, shale, red beds, and coal. This catchment geology, mountains in the headwaters and massive, long-lived sedimentary basins in the interior, is similar to those of the Tarim River to the south and the Huanghe and Yangtze to the east.

2.2. Climate and runoff

The regional climate, characterized by a severe of continental climates with warm, dry summers and cold, wet winters (Zhu