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Invited research article

Human impact on erosion patterns and sediment transport in the Yangtze River

Xilin Sun [a,b,*], Chang'an Li [b], K.F. Kuiper [a], Zengjie Zhang [b], Jianhua Gao [c], J.R. Wijbrans [a]

[a] *Cluster Geology and Geochemistry, VU University Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands*
[b] *School of Earth Sciences, China University of Geosciences, Wuhan 430074, China*
[c] *Ministry of Education Key Laboratory for Coast and Island Development, Nanjing University, Nanjing 210093, China*

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ABSTRACT

Sediment load in rivers is an indicator of erosional processes in the upstream river catchments. Understanding the origin and composition of the sediment load can help to assess the influence of natural processes and human activities on erosion. Tectonic uplift, precipitation and run-off, hill slopes and vegetation can influence erosion in natural systems. Agriculture and deforestation are expected to increase the sediment yield, but dams and reservoirs can trap much of this sediment before it reaches the ocean. Here, we use major element composition and $^{40}Ar/^{39}Ar$ ages of detrital muscovites to constrain the sediment contribution of various tributaries to sedimentation in the Yangtze delta. The sediment contribution calculated from muscovite data was compared with that estimated from current sediment load data from gauging stations. Muscovite data show that the main contributor to the Yangtze delta sands is the Min River, while the current sediment load suggests that the Jinsha and Jialing rivers are the most important current contributors to delta sediments. We suggest that this difference reflects an "old" and "young" erosion pattern, respectively as medium grained muscovite could be transported much slower than suspended sediment load in the complex river-lake systems of the Yangtze River basin. These two different erosion patterns likely reflect enhanced human activity (deforestation, cultivation, and mining) that increasingly overwhelmed long-time natural factors controls on erosion since ~1900 cal years B.P.

1. Introduction

Erosion patterns are generally controlled by the interaction of a number of processes in natural systems, including precipitation, run-off, active tectonic processes, hillslope steepness and vegetation (Anders et al., 2008; Roering et al., 2007). However, it is recognized that human activities can significantly change the erosion patterns and rates (Bayon et al., 2012; He et al., 2014; Hu et al., 2013; Reusser et al., 2015; Wan et al., 2015). Human activities such as agriculture and deforestation can dramatically increase the sediment yield (Hooke, 2000), while dam constructions can slow down sediment transport to the oceans (Yang et al., 2011). Understanding "old" erosion patterns before the impact of human activities is critical for constraining human societal influence on erosion patterns.

The Yangtze is a suitable place to examine changes in erosion patterns caused by human activities. The Yangtze River is the largest river (6300 km long) at the periphery of the Tibetan Plateau and historically fourth largest in the world in terms of sediment discharge before dam constructions; 480 million tons per year (Wang et al., 2011). More than 400 million people - 6.6% of the world's population - are living in its catchment. Widespread settlement sites found in the Yangtze basin date back to five thousand years ago (Wu et al., 2012). The western part of the Yangtze River basin covers much of the eastern Tibetan plateau. Tectonic activity, steep topography, strong precipitation and low evaporation and therefore high run-off on the edges of the eastern Tibetan plateau are expected to drive fast erosion in this area (Godard et al., 2010; Liu-Zeng et al., 2011; Ouimet et al., 2010). Pollen records and sediment volume in prograding deltaic sediments over the past 6000 years suggest that the natural erosion rates were significantly disturbed by human activities (Saito et al., 2001; Yi et al., 2003). Detrital U—Pb zircon data suggest that the disturbance of the landscape by human settlement enhanced sediment production after ~5000 BCE in the Yangtze River basin (He et al., 2014). However, the amount of studies about human impact on erosion patterns in the Yangtze River basin is limited.

In this study, we use the $^{40}Ar/^{39}Ar$ age distribution of detrital muscovite to determine the erosion and sediment transport processes of the Yangtze River system and to delineate the spatial pattern of erosion in the Yangtze River drainage basin. Because muscovite has a lower hardness and closure temperature (350–450 °C, Haines et al. (2004)) compared to zircon (>900 °C, Lee et al. (1997)), it is less likely to survive multiple orogenic erosion-depositional cycles compared to zircon and may contain, therefore, more information on the most recent orogenic uplift and erosion patterns

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[*] Corresponding author.
E-mail address: sunxi-lin@163.com (X. Sun).

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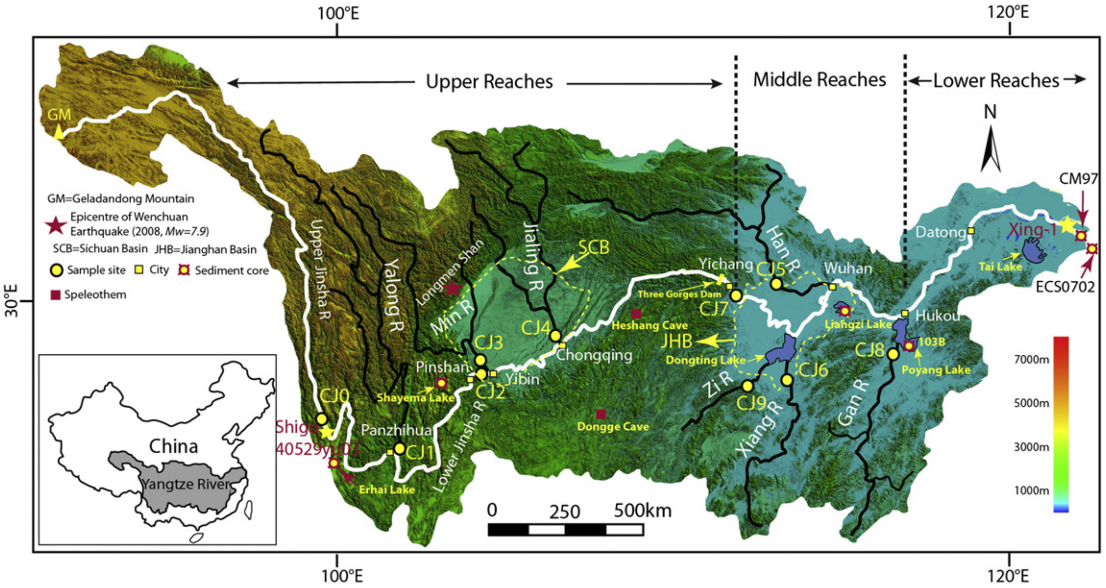

Fig. 1. A schematic map showing the drainage basin, sampling locations and main distributaries of the Yangtze River. Sample locations are shown as filled circles. The stars represent sample sites by Hoang et al. (2010).

of the eastern Tibet Plateau. In recent years, the $^{40}Ar/^{39}Ar$ dating of detrital muscovite from ancient and modern sediments has proven to be a useful tool for reconstructing exhumation histories and sedimentary processes (Clift et al., 2006; Hoang et al., 2010; Najman et al., 1997). The ages of detrital muscovite grains from modern sediments in the delta and headwater of the Yangtze River are dated by Hoang et al. (2010). We combine these ages with new $^{40}Ar/^{39}Ar$ data for modern sediments from the Yangtze River basin. Our approach characterizes the muscovite age distribution along different segments of the Yangtze River.

The transport time of medium sized muscovite grains (200–500 μm) from the headwaters to the delta can be long (millennial timescales) because these muscovite grains are expected to be transported as bed load in the complex river-lake systems of the Yangtze River basin (Wei et al., 1986). Thus these medium sized muscovite grains are expected to record the "old" erosion patterns (millennial) of the Yangtze River basin. Modern erosion patterns can be constrained by the modern suspended sediment load data and compared with the muscovite data in the delta that represent older erosional processes. Comparison of these datasets can therefore shed light on the impact of humans on erosion.

2. The Yangtze River system

The Yangtze River catchment area covers a total area of 181 × 10^4 km^2 and the Yangtze River is the third longest river in the world. The Yangtze River can be divided into three catchment areas: (1) the upstream Yangtze covers its headstream to Yichang; (2) the middle Yangtze traverses from Yichang to Hukou; (3) and the lower Yangtze passes through Hukou and the delta (Fig. 1). The Yangtze River originates west of the Geladandong Mountain (highest altitude: 6621 m) on the Tibetan Plateau and flows into the East China Sea. On the eastern Tibetan Plateau, the river flows southward through deep mountain valleys and makes abrupt turns northwards and southwards from Shigu (Fig. 1). The river flows west to east through the Sichuan Basin and cuts through the Three Gorges region before descending into the Jianghan Basin. From the Three Gorges region the Yangtze River travels through a complex system of lakes and multiple river channels developed on the plains before reaching the delta.

3. Sampling and analytical methods

3.1. Sample description

In total, ten river sand samples were collected from three locations along the main Yangtze River and seven major tributaries (Fig. 1). Sample information is given in Table 1. Collection of ten modern sediments was conducted in October 2012 following the summer monsoon season. This time period was selected because the sediment we collected was newly-deposited sediment due to high precipitation and high discharge during the summer monsoon season. High precipitation during summer should have caused intense erosion and maximum delivery of bedrock muscovite populations into the Yangtze River system. Approximately

Table 1
Summary of sample numbers and sample locations.

Type	Number	Rivers	Longitude	Latitude	Locations	Data source
Tributary	CJ1	Yalong River	101°48′01″	26°36′29″	Panzhihua	This study
	CJ3	Min River	104°33′46″	28°48′26″	Yibin	This study
	CJ4	Jialing River	106°23′49″	29°53′13″	Beibei	This study
	CJ5	Han River	112°33′30″	31°11′09″	Zhongxiang	This study
	CJ6	Xiang River	112°55′19″	28°03′10″	Changsha	This study
	CJ8	Gan River	115°51′21″	28°40′50″	Nanchang	This study
	CJ9	Zi River	112°18′13″	28°36′54″	Yiyang	This study
Mainstream	CJ0	Upper Jinsha River	99°57′23″	26°58′09″	Shigu	This study
	CJ2	Lower Jinsha River	104°36′13″	28°45′04″	Yibin	This study
	CJ7	Yangtze River	111°27′02″	30°27′39″	Yichang	This study
	40529yu03	Upper Jinsha River	99°57′87″	26°52′14″	Shigu	Hoang et al. (2010)
	Xing-1	Yangtze River	121°30′08″	31°19′35″	Delta	Hoang et al. (2010)

Note: We collected sample CJ0 from Shigu near sample 40529yu03 in Hoang et al. (2010) and analyzed the chemical compositions of muscovite grains from this sample. Here we use $^{40}Ar/^{39}Ar$ muscovite ages from sample 40529yu03 and muscovite geochemistry from sample CJ0 to represent the upper Jinsha River.