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Sr-Nd isotope stratification along water depth: An example from Datong hydrological station of Yangtze River

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This study examines the effects of hydrologic sorting and mixing of sources on the Sr-Nd isotopic compositions of suspended sediments at different water depths. The samples were collected from three layers (surface, middle and bottom) at Datong hydrological station of Yangtze River during the flood season of 2010. Our results show that, $^{87}Sr/^{86}Sr$ values decrease from surface to bottom, ranging from 0.730332 to 0.720857. $\varepsilon_{Nd}(0)$ values range from −14.75 to −10.09, with surface sediments being the most negative. The isotope composition at the middle layer can best represent the mean isotopic composition of the total suspended sediments transported by a river. It is believed that the stratification of Sr-Nd isotope is attributable to mixing of sediments from different sources due to hydrological sorting. Sediments from the upper stream are found to be coarser, and tend to contribute more to the lower water column. Although Sr-Nd isotope is a well acknowledged tool to trace sediment provenance, the current study suggests that the grain size of the samples and the sampling locations should be taken into consideration when applying this method to provenance study.

Yangtze River, suspended sediment, Sr and Nd isotope, stratification

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Understanding of sediments "from source to sink" is a critical part of the earth surface processes, which has attracted a great deal of attention in the past years. A large variety of methods, such as elemental and isotopic geochemistry [1–8], heavy mineral [9,10], magnetic mineral [11–13], U-Pb dating of detrital zircons [14,15] and some other methods play an important role in provenance investigations of river sediments. Among these methods, Sr-Nd isotopic systemis widely applied to provenance study of rivers since they basically do not fractionate during weathering, erosion and transport. Although Sr-Nd isotopic system has been used for a long time [16–18], its application to river provenance study did notdevelop until recently [1,2,4,5,19–28]. For example, Clift and others use U-Nd-Pb isotopic system to investigate the provenance evolution of the Red River [23], Singhand others studied the source of the sediments of Ganges River through systemic study of Sr-Nd isotopic composition [5]. In addition, Sr-Nd isotope method plays an important role in the assessment of weathering condition of river drainage basin [28,29], as well as the contribution of continental weathering to Sr-Nd in the ocean [30–33].

Because of the restriction of sampling technique, most of the samples used could only be taken from river beds and alluvial plains. Suspended particulate matter (SPM) is also used, but most samples are taken from the surface of the river water. The basic assumption behind is that river bed sediments and surface suspended sediments can represent the mean composition of the material transported by a river. In other words, river bed sediments and suspended load have undergone sufficient mixing, therefore samples taken from any location of the river are representative of the whole river [24,34].

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However, it has been found recently that the chemical composition of suspended sediments varies along with water depth. In a study of the Amazon River, Bouchezand others point out that the concentration and grain size of suspended sediment vary along with depth due to the effects of hydrodynamic sorting. These variations are extremely important for the evaluation of fluxes of sediments transported to ocean by a river [35,36]. Researches on the sediments of Brahmaputra and Ganges River show that elemental composition of sediments varies along with grain size. It was also found that Al/Si value can be used as a surrogate index of grain size [37]. Investigation of suspended sediments of Brahmaputra and Ganges River indicate that the mineral composition difference exists at various water depths, while concentration of clay associated with Fe-oxyhydroxides is almost depth-independent [38].

Now that most rivers show a clear physic and chemical stratification in suspended sediments, can the Sr-Nd isotopic composition of surface sediment represent that of the whole matters transported by the river? The answer of this question is of great importance to river provenance study. Recently, after analyzing the suspended sediments collected at different water depth of Amazon River, Bouchez et al. [35] find that there is large difference among their Sr-Nd isotope. They believed that the difference in Sr-Nd isotope at different levels is due to mixing of different sources. The data they showed were not sufficient to make any general conclusions. There was no research carried out on the big rivers in China yet.

As the biggest river in China, the Yangtze River has complicated geologic settings and variable climate which make it the appropriate river system to test sediment "from source to sink" process. Recently, researchers have done lots of provenance studies on the Yangtze River [1–3,6,12, 19]. However, their samples were mostly sediments collected from river bed and SPM taken from the surface of river water. Discussions about the representative of provenance from these samples are barely mentioned. The sediments were affected by different hydrodynamic processes during transportation and sedimentation because of the large water depth of the Yangtze River. We chose the Yangtze River as our research area and through the study of variation of Sr-Nd isotope along with river depth, we discussed the effects of hydrodynamic sorting onto the isotopic composition of Sr-Nd of suspended load. Finally, we will try to discuss the applicability of isotope method in river provenance study.

1 Sampling and analytical methodology

Our samples were taken from Datong hydrological station, which is located at 30°6.61157′N, 117°7.6658′E. From Datong station upwards, the Yangtze River is no longer affected by the tide (Figure 1(a)). The drainage area above Datong station is 1.705×10^6 km^2, which accounts for 95% of the total drainage area. Hence, samples collected at Datong can be regarded as representing the whole catchment.

The water depth at Datong ranges between 24–28 m during flooding season. Water samples were taken from six levels along the profile. Samples were collected every two weeks for a whole year. This paper reports the data of samples collected during the period from June to August, 2010. The sampling dates were 12 June, 8 July, 26 July, 11 August and 29 August. The water discharges at the time of sampling were 46275, 56200, 62850, 56425 and 43325 m^3/s, respectively (data from http://xxfb.hydroinfo.gov.cn/nindex_ dataList. jsp?type=1).

Samples collected from the surface (S), middle (M) and bottom (B) were analyzed (Figure 1(b)). The 75 L of water was collected from each of these three levels and filtered through 0.45 μm Millipore membranes to collect suspended matter (SPM). The SPM on the membranes were washed into pre-cleaned beaker with pure water. Beakers are placed

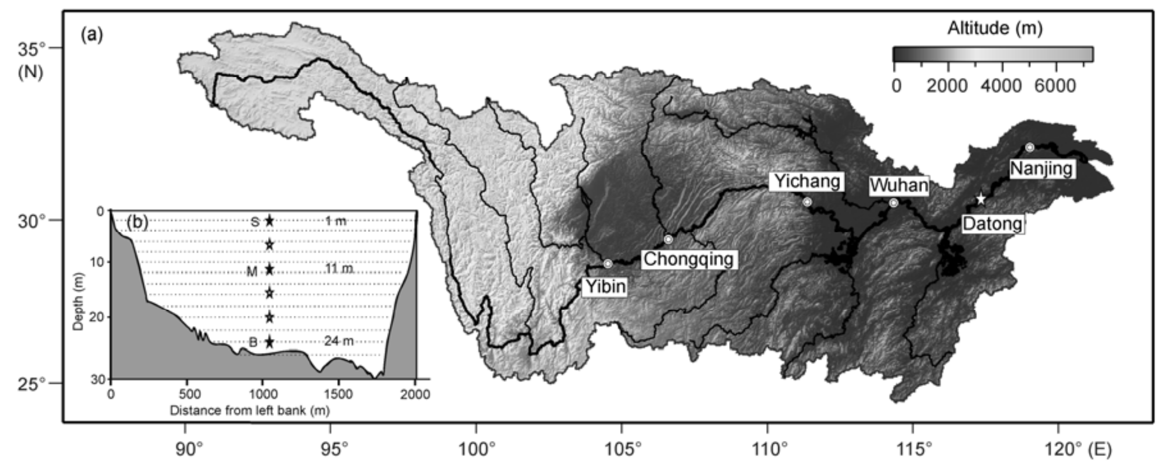

Figure 1 (a) Map of Yangtze River basin and location of Datong hydrological station; (b) sampling profile.

in an oven at a temperature of 40°C to dry up and weighted to calculate the concentration of SPM.

Grain size measurement: 10 mL 10% H_2O_2 was added to the SPM to remove the organic matters and 10 mL 10% HCl was added to remove the carbonate. The pretreated solution was then dispersed with proper amount of $(NaPO_3)_6$. Grain size was analyzed using a Malvern Mastersizer laser diffraction granulometer Mastersizer-2000. The measurement range is from 0.05 to 2000 μm, the relative error is lower than 1%.

The authigenic carbonate minerals may change the Sr isotopic compositions of the detrital sediments of the Yangtze River [17]. In order to exclude the effect of authigenic carbonate, 1 g samples were powdered to about 74 μm and decarbonated by leaching with 0.5 mol/L acetic acid at room temperature for up to 24 h. The slurry was centrifuged, the residue washed with Milli-Q water and dried up. About 200 mg of the pretreated samples were digested with a mixture of HNO_3+HF solution. Sr and Nd were separated using the standard ion exchange techniques and their isotopic ratios were determined using a Finnigan Triton thermal ionization mass spectrometer at the Department of Earth Science, Nanjing University. $^{87}Sr/^{86}Sr$ was normalized to $^{87}Sr/^{86}Sr$= 0.1194 and $^{143}Nd/^{144}Nd$ was normalized to $^{143}Nd/^{144}Nd$= 0.7219. The analytical blank was <1 ng for Sr and <60 pg for Nd, respectively. The reproducibility and accuracy of the Sr and Nd isotopic analyses were periodically checked by running the Sr standard SRM987 and Nd standard La Jolla, with a mean $^{87}Sr/^{86}Sr$ value of 0.710268 ± 20 (2r external standard deviation, *n*=15) and a mean $^{143}Nd/^{144}Nd$ value of 0.511840 ± 8 (2r external standard deviation, *n*=6), respectively.

2 Results

The analyzed results of suspended sediments are given in Table 1. The $^{87}Sr/^{86}Sr$ values range from 0.720857 to 0.730332, with anaverage ratio of 0.723610, which decreases with depth. The average value of $^{87}Sr/^{86}Sr$ of surface, middle and bottom sediments is 0.726030, 0.722338 and 0.721430, respectively. The average value of $^{87}Sr/^{86}Sr$ of all samples is closest to the average value of $^{87}Sr/^{86}Sr$ of the sediments from the middle layer. Sr isotopic ratios of samples collected on 26 July are generally higher than others, with the maximum value of 0.730332. The $^{143}Nd/^{144}Nd$ values also show large variations, ranging from 0.511882 to 0.512121, with an average value of 0.511996; The $\varepsilon_{Nd}(0)$ values range from −14.75 to −10.09, with the minimum and maximum values being observed in surface sediment collected on 26 July and in bottom sediment collected on 11 August, respectively. The $\varepsilon_{Nd}(0)$ values increase with water depth. The average value of samples collected from the surface is −13.43; −12.59 from the middle level and −11.56 for samples from the bottom. The average value of $\varepsilon_{Nd}(0)$ for all the samples is −12.53, which is close to the average value of samples collected from the middle level. It can be seen from Table 1 that the difference between Sr-Nd isotopic composition of SPM collected at different depths is large. For example, the difference between the $^{87}Sr/^{86}Sr$ ratio of surface and bottom samples collected on 11 August is 0.01, and the difference between the $\varepsilon_{Nd}(0)$ values reaches 2.93 in samples collected on July 26. The Sr-Nd isotopic composition of samples collected on June 12 does not show a decrease or increase trend from top to bottom.

Table 1 Sr-Nd isotopic composition, mean grain size and concentration of suspended sediments from Datong

Number	Sampling time & level	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(0)$	$^{87}Sr/^{86}Sr$	Mean grain size (μm)	Concentration of suspended (mg/L)
1	2011-06-12-S	0.511932±6	−13.77±0.12	0.723898±5	30.5	108
2	2011-06-12-M	0.511990±3	−12.64±0.06	0.722127±3	36.1	145
3	2011-06-12-B	0.511981±7	−12.82±0.13	0.722007±9	101.2	233
4	2011-07-08-S	0.512002±6	−12.41±0.11	0.724667±5	27.9	102
5	2011-07-08-M	0.512017±6	−12.11±0.12	0.723085±2	36.6	111
6	2011-07-08-B	0.512064±2	−11.20±0.04	0.720443±3	99.8	127
7	2011-07-26-S	0.511882±8	−14.75±0.15	0.730332±2	18	154
8	2011-07-26-M	0.511914±8	−14.12±0.16	0.727533±1	46	141
9	2011-07-26-B	0.512032±1	−11.82±0.02	0.724469±2	54.1	141
10	2011-08-11-S	0.511982±5	−12.80±0.09	0.725298±2	14.9	147
11	2011-08-11-M	0.512038±3	−11.70±0.06	0.721792±2	39.3	171
12	2011-08-11-B	0.512121±3	−10.09±0.05	0.716378±3	126.7	361
13	2011-08-29-S	0.511950±5	−13.42±0.10	0.725943±2	11.2	79
14	2011-08-29-M	0.512003±7	−12.39±0.13	0.722364±3	65.6	118
15	2011-08-29-B	0.512029±8	−11.88±0.16	0.720857±3	94.1	117

Sediment concentration increases with water depth (Figure 2(a)). Drain size distribution indicates that samples from the surface are finer (average grain size is 20 μm), and coarser at the middle level (average grain size is around 40 μm), and reaches maximum size at the bottom (average grain size is around 110 μm) (Figure 2(b)). The distribution of grain size shows that suspended sediments are composed of clay, silt and sand. Clay content remains almost constant with depth, ranging from 6% to 10%. Silt comprises the main part of the sediment, but shows a large variation ranging from 70% at the surface to 40% at the bottom. Sand content increases from 2% at the surface to 50% at the bottom (Figure 2(c)).

3 Discussion

3.1 Concentration and grain size of suspended sediments

Affected by the velocity of river water, the concentration of SPM in the main stream of the Yangtze River decreases from upper reaches to lower reaches, with the maximum value being observed in Yunnan-Zhongdian (980 mg/L). It drastically decreases downstream the Three Gorges and achieves a minimum value at Hukou and stays consistent (100 mg/L) before entering the ocean [19,39]. At the sampling profile of Datong station, concentration of SPM increases from surface towards bottom (Figure 2(a)).

SPM of the Yangtze River include two parts, the fineparticles are derived from the whole drainage and can't supplied by local river bank; the coarser particles mainly come from the upper reaches which can also be supplied by local river bank immediately [40]. Due to the huge altitude difference over the Yangtze basin, the grain size of SPM carried by water in the upper reaches is larger than that in the lower reaches [19]. Water discharge during this sampling time was higher than Mao, which can leads to higher water power to carry coarser particles at water surface. This can explain the mean grain size of SPM collected at water surface of this study was larger than that collected by Mao [41] in Nanjing. As mentioned before, SPM can be divided as clay, silt and sand according to their grain size. The percentage of

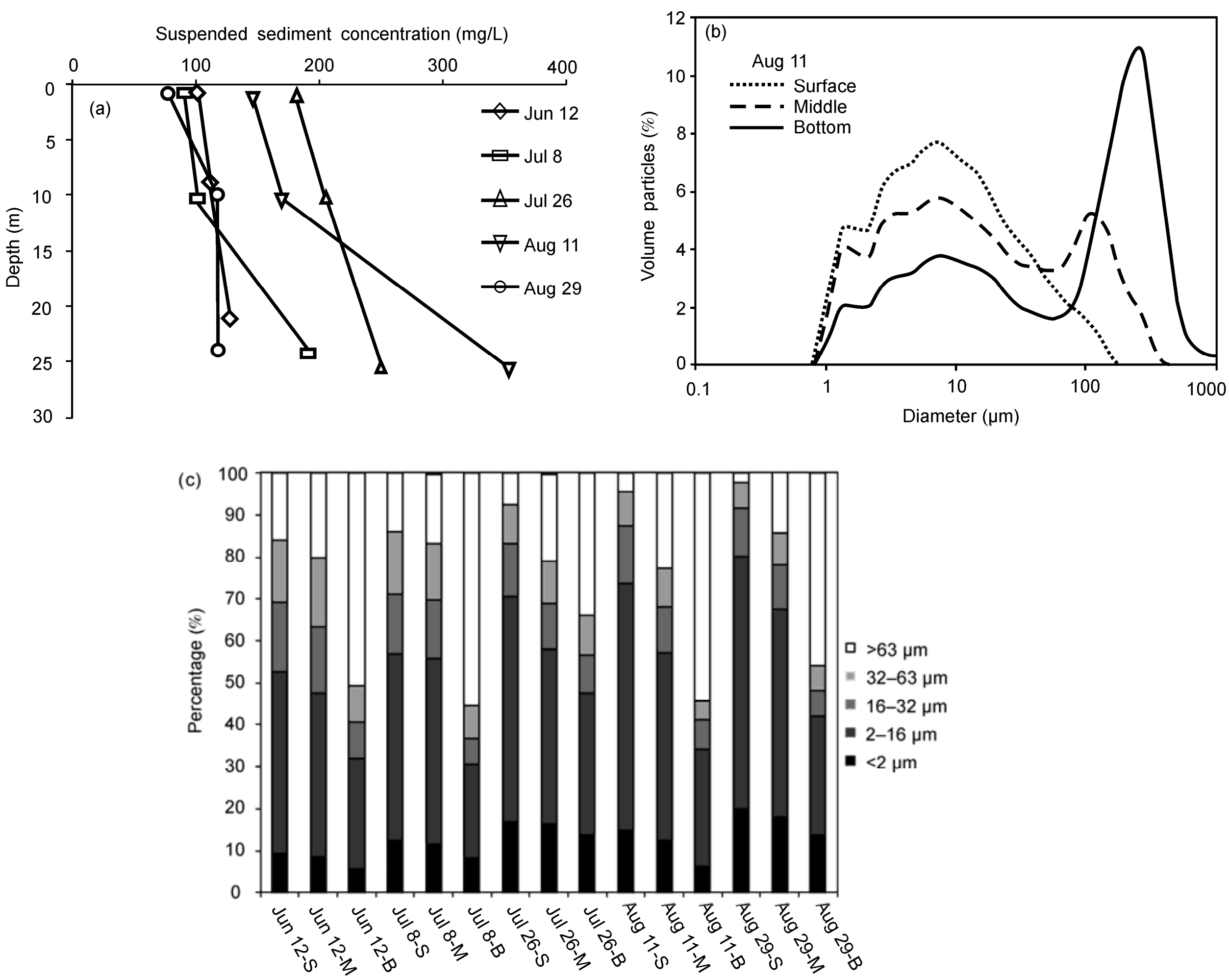

Figure 2 (a) Suspended sediment concentration in depth profile; (b) representative grain size distributions in depth profiles: 11 August; (c) percentage of different grain size of SPM from Datong.

clay displays a rather constant value with depth, while sand shows great increase with sampling depth. These observations agree with the results of sediment transport dynamics in a turbulent stream.

Researches show that hydrodynamic sorting can not only lead to variation of grain size and concentration of SPM along with depth, but also make difference in element and mineral composition [42].

3.2 Variations of Sr-Nd isotopic composition along depth

(1) Variation of Sr isotopic composition. Although Sr-Nd isotopic system has been well applied in provenance study, grain size and chemical weathering will affect the Sr isotopic composition of sediment to some extent [16,30]. In addition, on a short time scale, Sr isotopic composition of water and sediments that are derived from weathered rock changes along with time due to the different weathering rates of different minerals in rocks [43,44]. The Sr-Nd isotopic compositions of SPM also show distinct seasonal variations [19,20,25].

In this study, seasonal changes in isotopic compositions of Sr-Nd can be excluded since samples are all collected in one flood season. The Sr isotopic compositions of SPM collected at Datong are closed to the values of the Yangtze River basin reported by Yang et al. [1], which also indicates that the suspended samples collected from the lower stream of Yangtze River are well mixed. Grain size of SPM increases and the Sr isotopic composition decrease along with depth (Figure 3(a)). Researches show that the Sr isotopic composition has certain dependence with particle size, which means that fine particles have more radiogenic Sr isotope and higher $^{87}Sr/^{86}Sr$ ratios [1,35,45]. The results from this study are consistent with previous conclusions. It shows that Sr isotopic composition is correlated with grain size, which means that the $^{87}Sr/^{86}Sr$ ratios decrease when grain size increase (Figure 3(b)). The $^{87}Sr/^{86}Sr$ ratios of SPM collected at different depth of Amazon River decrease as the grain size increase, which indicates that the particle size is an important factor that can influence Sr isotopic composition. Our study further shows that as isotopic composition of Sr is affected by particle size, we cannot simply attribute changes of $^{87}Sr/^{86}Sr$ ratios to provenance change.

The average $^{87}Sr/^{86}Sr$ value of samples collected in this study is 0.723610, close to average $^{87}Sr/^{86}Sr$ value (0.723380) of all the samples collected from the middle level of Datong station. This indicates that the isotopic composition of suspended sediments collected at middle level can well represent that of the material transported by the river. The $^{87}Sr/^{86}$ratio of this study are much higher than the average $^{87}Sr/^{86}$value of upper continental crust (0.716). The carbonates dissolved in the pretreated process were mainly marine carbonates which have a high concentration of Sr and low $^{87}Sr/^{86}Sr$ isotopic ratios, hence the aicd-insoluble residues have higher $^{87}Sr/^{86}Sr$ ratios. The average $^{87}Sr/^{86}Sr$ ratios of surface sediment in this study is 0.726000, which is close to the surface samples collected by Yang et al. [1] and Mao et al. [19], slightly higher than the values of bulk suspended phases (containing the carbonate fraction) observed by Wang et al. [46], much higher than the $^{87}Sr/^{86}Sr$ value of sediments collected in the lower stream by Yang et al. [1]. We can observe from Table 2 that there is no big difference among Sr isotopic compositions of surface sediments collected during the flood seasons of different years. However, great difference can be seen between the $^{87}Sr/^{86}Sr$ values of surface sediment and sediment that are finer than 63 μm that are collected at the same place. From the grain size distribution of surface sediment in this study (Figure 2(c)) we can find that there are particles coarser than 63 μm even in surface sediment. Artificially remove the part of sediment coarser than 63 μm will change the isotopic composition of sediments which will affect the explanation of sediment source. Hence, grain size has great influence on Sr isotopic composition of sediments and attention should be paid when comparing Sr isotopic compositions of different samples, especially when investigating the provenance of the sediments which have been deposited in the geological past.

Based on the discussions mentioned above, we can tell that the application of Sr isotope to provenance study has many restrictions. Sr isotope alone does not work well,

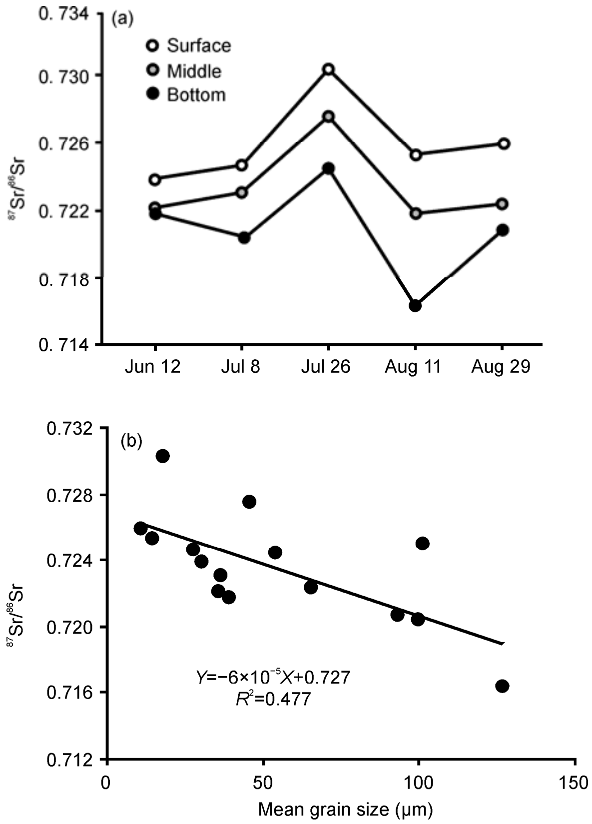

Figure 3 (a) Sr isotopic compositions of suspended sediments from Datong station; (b) correlation between Sr isotopic composition and grain size.

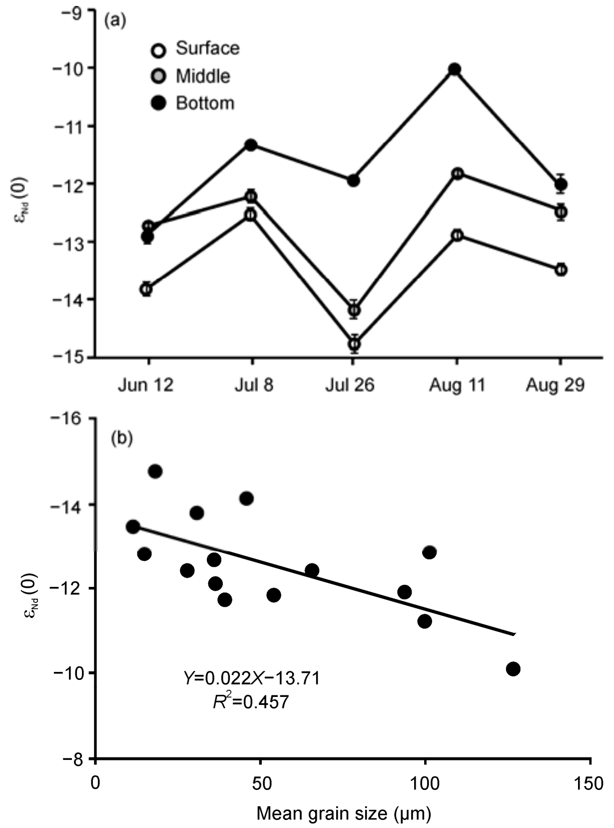

Figure 4 (a) Nd isotopic compositions of SPM from Datong; (b) correlation between Nd isotopic composition and grain size.

which means that combined Nd isotope with Sr isotope method is needed. If one can exclude the effect of grain size and weathering, or if the sediment source has huge difference, then Sr isotope can be an excellent tracing tool. For example, it can be used to trace crust and mantle source, and trace sediments from different drainage basins [3].

(2) Variation of Nd isotopic compositions. Previous researches indicate that Nd isotopic compositions of sediments are barely affected by particle size and sedimentation. Comparing to the half-life of Nd, the time which is needed for erosion, weathering and transport of sediment is relatively short, during which the $^{143}Nd/^{144}Nd$ ratio almost remain unchanged. Under this condition, the Nd isotope can be used in provenance study.

Through investigation of Sr-Nd isotopic composition of SPM collected from the Yangtze River, Yang et al. [1] found that the distribution of Nd isotopic composition shows a clear regional variation. The $\varepsilon_{Nd}(0)$ values decrease from Jinsha River (upper reaches) to lower reaches which was decided by the distribution of rocks over the Yangtze drainage basin. Source rocks distribute over the Yangtze River basin are very complicated. Acid igneous rocks in the upper stream, and Emeishan basalt in the upper basin both have high $\varepsilon_{Nd}(0)$ ratios, while the middle-lower basin primarily consists of Quaternary fluvio-lacustrine sedimentary rocks and granite [19,47–49]. The downriver decrease of $\varepsilon_{Nd}(0)$ may reflect the increase of relative contribution of suspended materials from the upper reaches to the lower reaches. In this way, the $\varepsilon_{Nd}(0)$ ratios of SPM collected at the lower reaches can basically reflect the contribution of different sources.

Suspended sediments collected at lower reachesare a mixture of the erosion products of the whole drainage basin. Because the upper, middle and lower basins of the Yangtze River have different rocks and climates, their weathering products will also vary in chemical and physic properties which can lead to fractionation of elemental and mineral composition along with depth during transport [35,38]. Hydrodynamic sorting ability of the Yangtze decreases downriver as a result of decreasing elevation. Particle size of the suspension will also decrease with hydrodynamic sorting ability. Hence, grain size of SPM collected in the upper reaches is large than SPM in the lower reaches [19]. Meanwhile, the distribution of source rock also lead to increase of the $^{87}Sr/^{86}Sr$ ratios from upper to lower reaches, about 0.721889 for the upper reaches and 0.725826 for the middle-lower reaches. On the other hand, the $\varepsilon_{Nd}(0)$ values decrease downriver with an average value of −10.8 for upper reaches and −12.3 for middle-lower reaches. In this study, grain size of SPM collected from vertical river profiles increases with water depth while the $^{87}Sr/^{86}Sr$ ratios decrease with water depth (Figure 3(a)). The $\varepsilon_{Nd}(0)$ values show an increase from the surface to the bottom (Figure 4(a)), with the minimum value (−14.75) being observed in surface sample and maximum value (−10.09) in bottom. The $\varepsilon_{Nd}(0)$ of samples collected at channel bottom is similarly to SPM from upper reaches while the $\varepsilon_{Nd}(0)$ of samples collected from channel surface is similarly to that observed in middle-lower reaches sediment. Considering the grain size and isotopic composition characteristicof SPM from Datong station and from the Yantgze drainage, we may infer that the vertical variation of isotopic composition of Sr-Nd indicates different proportion of different sources to different depth of sediments. Thus, we further infer that the SPM from upper reaches is preferentially transported near the channel bottom and SPM from middle-lower reaches is preferentially transported near the channel surface. In other words, compared to surface sediment, proportion of sediment from upper reaches is relative higher in bottom sediments. But we should also make it clear that not all the suspended sediments in bottom samples are from upper reaches, or the coarse part that larger than 63 μm are totally from upper reaches. It means that contribution from upper reaches in bottom sediment is larger than it in surface sediment. The particles from the upper reaches can be clay, silt and sand. During our sampling time, the Three Gorges Dam opens from time to time, strong hydrodynamic power can bring material from upper reaches to lower reaches. However, in this study, we cannot determine whether the particles are come directly from upper reaches or come from the resuspension of sediment in middle-lower reaches. The answer to this question still needs more researches.

Provenance studies in the Yangtze River mainly focused on sediments and suspended sediments collected from river surface. However, after investigation of fluvial sediments and suspended sediments from river surface, Yang et al. [1] reported that the isotopic compositions of these two maters are not the same. Fluvial sediments collected from different locations at the same site even have different Sr-Nd isotopic compositions. From the results of this study, we observe that mixture of particles from different sources cannot be homogeneous even in flood season. Difference of isotopic composition can be observed along with depth and this difference seems to increase with water discharge. We know that hydrodynamic sorting can lead to fractionation of grain size, so is the Nd isotopic composition related to grain size? As shown in Figure 4(b), Nd isotopic composition of SPM is related with mean grain size. This linear correlation may indicate that in this study Nd isotopic composition is influenced by grain size. This inference is not contradictory with the conclusion we mentioned above. Similar conclusion was also derived by Rao et al. [50] after investigation of Sr-Nd isotopic composition of samples from desert. From all the discussion above we can tell that fractionation of Nd isotopic composition of SPM was not come from geochemistry processes like weathering and so on. Materials from different sources have different grain size which will lead to hydrodynamic sorting during their transportation and sedimentation. This hydrodynamic sorting will finally result in fractionation in isotopic composition.

The variation of Nd isotopic composition of SPM collected at Datong is similar to suspended sediments collected be over the Yangtze River by Yang et al. [1]. Interlayer variation amplitude in the $\varepsilon_{Nd}(0)$ of SPM collected at Datong can be even equal to spatial variations of SPM collected over the Yangtze Drainage, and larger than the seasonal variation of suspended sediments collected from the channel surface at Nanjing (Figure 5). Remarkable difference of Sr-Nd isotopic compositions among SPM of different depth is observed through comparison with other data. So, compared with suspended sediments collected from river surface, we think that samples collected from the middle layer of a river profile can well represent the characteristic of material carried by the whole river (Table 2). Thus, we think the data calculated by samples collected from river surface (which was the general method in researches) cannot well represent the situation of rivers. After analyzing the Sr-Nd isotopic composition of SPM collected from channel surface for more than one year in Nanjing, Mao et al. [19] calculated the end member values of the $^{87}Sr/^{86}Sr$ and $\varepsilon_{Nd}(0)$ in the samples to be 0.728254 and −11.26, respectively. However, from the results of this study, we think the calculated end member values of the $^{87}Sr/^{86}Sr$ is slightly higher, while $\varepsilon_{Nd}(0)$ is lower than they should be.

Suspended sediments that represent different sources will sink in different place during transport according to their grain size. Understanding the variation of Sr-Nd isotopic compositions of SPM from different depths can help to explain the source of different sediments in the past. Moreover, we should take the grain size of sediments into consideration in the provenance study of the Yangtze River.

(3) Comparison with other rivers in the world. Suspended loads at different depth of river channel were collected by

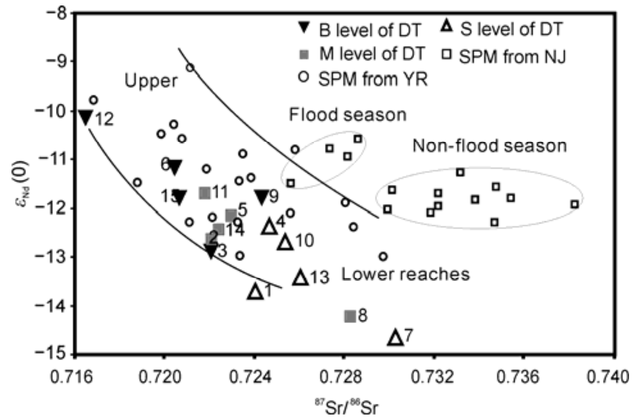

Figure 5 $^{87}Sr/^{86}Sr$ versus $\varepsilon_{Nd}(0)$ diagram of suspended loads observed in this study together with other relevant data: the SPM of the Yangtze River from the upper to lower reaches [1]; the SPM collected at Nanjing for more than 1 year [19]. The numbers are corresponding to those in Table 1.

Table 2 Comparison of Sr-Nd isotopic compositions of this study with other relevant data a)

Sampling location	$^{87}Sr/^{86}Sr$	$\varepsilon_{Nd}(0)$	Sample properties	Sampling time
UCC [16]	0.7160	−17	UCC	
Datong [46]	0.7252	ND	SPM (contain carbonate)	1997-10
Hukou [1]	0.7284	−12.40±0.29	SPM from surface	2004-08
Datong [1]	0.7234	−10.90±0.23	sediment < 63 μm	2003-04
Nanjing [19]	0.7277	−11.30±0.35	SPM from surface	2007-06–2007-08
Average of this study	0.7236	−12.53±1.18	SPM	2010-06–2010-08
Average of surface samples	0.7260	−13.43±0.90	SPM	2010-06–2010-08
Average of middle samples	0.7223	−12.59±0.92	SPM	2010-06–2010-08
Average of surface samples	0.7214	−11.56±1.00	SPM	2010-06–2010-08

a) UCC data from Goldstein et al. [16], SPM collected at Datong from Wang et al. [46], SPM and fluvial sediment of the Yangtze River fromYang et al. [1], SPM collected at Nanjing from June to August from Mao et al. [19].

Bouchez [35] in two tributaries and the main stream of Amazon River. Sr-Nd isotopic compositions were analyzed to discuss their distribution along water depth and the possible influencing factors. Among the suspended samples collected from different depths of Solimões River, the $^{87}Sr/^{86}Sr$ ratios decrease from the water surface to bottom while the $^{143}Nd/^{144}Nd$ increase with water depth (0.512101−0.512534). On the other side, in the samples from Amazon, the $^{87}Sr/^{86}Sr$ ratios show the same change trend as in Solimões while the $^{143}Nd/^{144}Nd$ ratios turn out to be the opposite of Solimões since the $^{143}Nd/^{144}Nd$ ratios decrease from water surface to bottom (0.512127–0.512229). However, this trend only exists in suspended sediment while a high value of $^{143}Nd/^{144}Nd$ was observed in bedload sample (0.512333).

The $^{143}Nd/^{144}Nd$ values of suspended samples collected from lower reaches of the Yangtze River in this study increase with water depth which is similar to the Solimões River but different from the main stream of Amazon River. The two different trend exist in Nd isotopic composition of suspended load may be caused by different distribution of rock in drainage basin or by hydrodynamic sorting of suspended load.

In a word, the $^{87}Sr/^{86}Sr$ ratio of SPM decreases from water surface to bottom while the change of $^{143}Nd/^{144}Nd$ ratio and its reason were uncertain. Elemental and Sr isotopic compositions of SPM were thought to be related with particle size [23] while the Nd isotopic composition of samples is only related with its source.

4 Conclusions

Through the study of suspended sediments from different depths of a water profile at Datong station during flood season, it is observed that hydrological sorting exits in the Yangtze River sediments. Sediment concentration and grain size increase steadily with water depth while important gradient in isotopic composition was observed in our study. A major result of this study is that the $^{87}Sr/^{86}Sr$ ratios of suspended sediment decrease from surface to bottom, which means that the $^{87}Sr/^{86}Sr$ ratios increase when grain size decreases, just like other rivers in the world; while the $^{143}Nd/^{144}Nd$ ratios increase with water depth. Depth variations can be as large as spatial variations and seasonal variations of the suspended surface sediments. Grain size of suspended sediment varies from upper to lower reaches due to the difference of topography and climate over the Yangtze River. Taking consideration of the variation of grain size and isotopic composition in this study, we think that the stratification of Sr-Nd isotopic composition may indicate different proportion of different sources to different depth of sediments.

Another result of this study is that Sr-Nd isotopic composition of suspended sediment collected at water surface can't well represent the characteristics of the whole sediment transported by the river. Due to the random of sampling, isotopic composition of fluvial sediments can have huge difference even if they are collected from the same location. Our results show that within limitation of sampling technique, isotopic composition of samples collected at the middle of a river profile can well represent isotopic composition of products transported by the river at that time. However, the representatives of our samples were slightly restricted since our samples were all collected in flood season. More researches are needed to further explain the phenomenon in this study.

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