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Assessing the influence of lithology on weathering indices of Changjiang river sediments

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ABSTRACT

We present major and trace element data in suspended particulate matter (SPM) collected in the Changjiang main channel and its tributaries. Suspended sediments are derived from a mafic source related to the Emeishan Large Igneous Province (ELIP) in the Upper Reach and from a more felsic source in the Middle/Lower Reaches. The difference in chemical composition between the two sources has a strong influence on the apparent weathering intensity. Although the apparent loss of soluble elements follows a climatic gradient from the Upper Reach to the Lower Reach, the co-variation of weathering indices with different proxies for igneous differentiation suggests that a lithologic control cannot be ruled out. By taking into account the variability in chemical composition of the parent rocks, we show that river suspended sediments from the upper reach may have not experienced less intense chemical weathering than those transported by rivers from the Lower/Middle Reaches characterized by higher runoff and surface temperature. We argue that the relationships observed for different indices of weathering with climate are probably an artifact and are mainly driven by the change in chemical composition of the sediment's parent-rocks.

1. Introduction

Eroded materials are transferred from land to the oceans mostly by rivers both in dissolved and solid forms. As rivers drain large areas, the study of the products of erosion provides integrated information. Geochemistry of sediments has provided new insights on the chemical composition of the upper continental crust (UCC) (Kamber et al., 2005), recycling of the crust through ages (Goldstein and Jacobsen, 1987), the impact of human activities on the environment (Song et al., 2010) for example. The study of suspended sediments has also been used to infer the regime and extent of physical erosion and chemical weathering (Gaillardet et al., 1999a; Das and Krishnaswami, 2007).

In a comprehensive study at the global scale, Gaillardet et al. (1999a) showed that in most of the world watersheds, chemical weathering of silicate rocks and physical erosion proceed out of a steady state. To explain the greater depletion of soluble elements measured in SPM than that predicted by a steady state model of erosion, the authors hypothesized that sediments transported by rivers include a part of recycled sediments which has undergone previous cycles of erosion/weathering. Consequently, no clear relationships between climatic parameters and weathering intensity were observed at the global scale. The authors conclude on the difficulty to use the geochemistry of SPM to infer modern or past chemical weathering and CO_2 consumption rates.

In a series of articles on Chinese river sediment geochemistry, Yang et al. (2004), Li and Yang (2010) and Shao et al. (2012) report relationships between the degree of weathering of suspended sediments from Chinese rivers and climatic parameters showing that the high runoff rivers transport the most altered suspended sediments and that low runoff rivers have the least altered sediments.

In this paper, we investigate the relationships between different indices of weathering intensity and we discuss the role of lithology on the apparent loss of soluble elements for the largest river in China. Finally we compare the results obtained for the Changjiang with the data compiled for the Pearl River draining the southern part of China.

2. Natural settings

The Changjiang drainage basin covers a total area of 181×10^4 km^2, about 1/5 of China (Fig. 1) and with a length of 6300 km, the Changjiang is the 3rd longest river in the world. In terms of solute discharge, with a flux of about 200.10^6 t/yr, the Changjiang ranks at the 2nd place after the Amazon (Gaillardet et al., 1999b) and in terms of sediment discharge, before the completion of the Three Gorges Dam, it ranked at the 5th place (Milliman and Syvitski, 1992). From its spring in the Qinghai–Tibet Plateau to the East China Sea, the Changjiang has a fall of over 5400 m. The Changjiang watershed is mainly composed of sedimentary rocks that consist of marine carbonates, evaporites and alluvium from Precambrian to Quaternary in age. Carbonate rocks are widely spread over the basin and are particularly abundant in the southern part (Yunnan, Guizhou and western Hunan Provinces) and the sub-basin of the Hanjiang. Emeishan flood basalts outcrop in the upper reach of the Changjiang and cover an area of about 250,000 km^2 (Zhang et al.,

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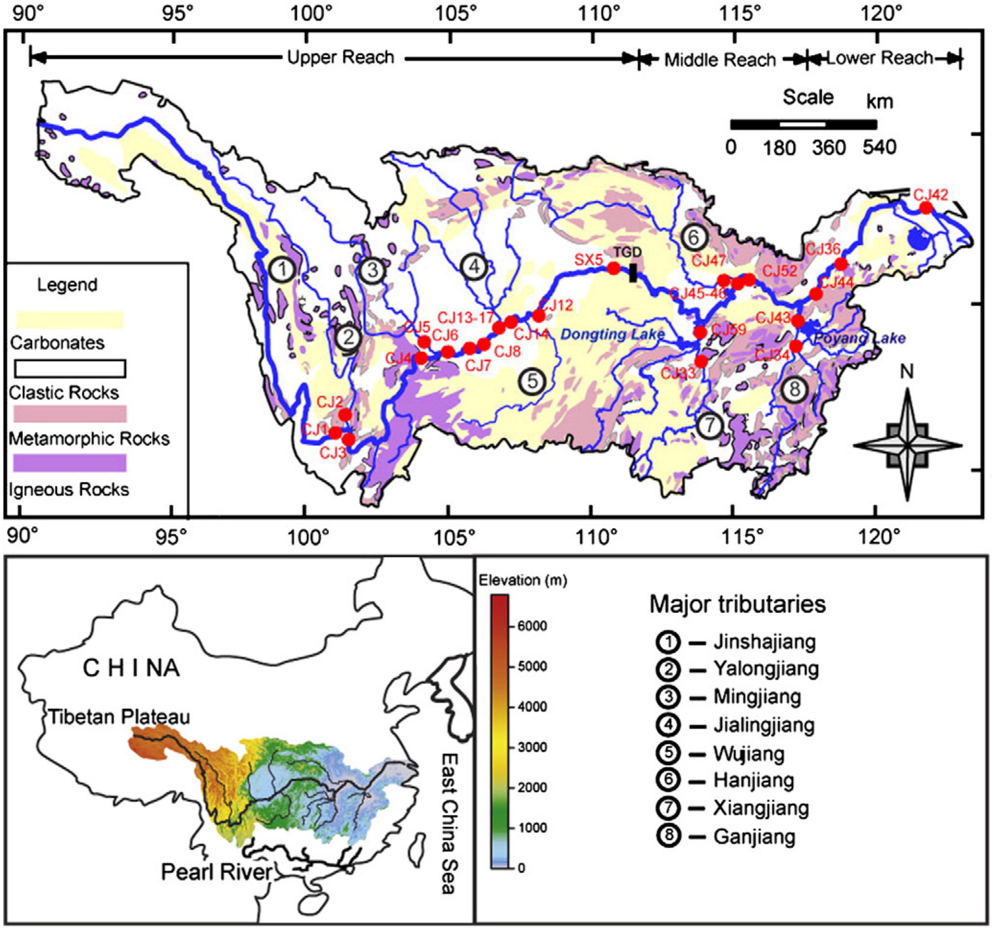

Fig. 1. Settings of the Changjiang basin and sampling locations (modified from Chetelat et al., 2008). The topographic map of the Changjiang basin is from Wang et al. (2011).

2006) whereas metamorphic/plutonic rocks widely outcrop in the Middle/Lower Reaches (Wang et al., 2013).

Shallow poorly developed soils (lithosols) are mainly present in the Upper Reach whereas in the Sichuan basin, cambisols and acrisols are well developed. Acrisols and luvisols are the major groups of soils present in the Middle and Lower Reaches (Panagos et al., 2011).

With the exception of the source area characterized by high elevation and an alpine climate, most of the Changjiang basin is submitted to a subtropical monsoon climate, temperate and humid (mean temperature 16–18 °C for the Middle and Lower Reaches) (Peel et al., 2007). The yearly rainfall amount averages 1100 mm and is unevenly distributed, decreasing gradually from southeast to northwest, from 1644 mm/yr for the Lower Reach and 1396 mm/yr for the Middle Reach to 435 mm/yr for the Upper Reach (Chen et al., 2001). The period from May to August accounts between 50% and 65% of the total annual precipitation (Chen et al., 2001). Surface runoff is the major water supply of the Changjiang watershed, accounting for 70–80% of the total water discharge (Chen et al., 2002). Runoff follows the seasonal and spatial variations of rainfall and increase from 250 mm/yr (CJ1) in the Upper Reach to 530 mm/yr (CJ36) in the Lower Reach (Table S1). The amount and distribution in both time and space of rainfall directly impact the sediment amounts, the sediments discharge being concentrated during the rainy season.

3. Methods

Suspended particulate matter (SPM) samples were collected in August 2006 along the Changjiang main channel and its main tributaries (Fig. 1) during the high water stage period (Chetelat et al., 2008). Samples were collected from the bank or from the middle of the river when a boat was available at a depth ranging from 50 cm to 1 m. In addition, some samples were collected in the main channel along two depth-profiles (CJ14 and CJ36). Between 10 and 20 l of water were collected in acid-washed containers and were filtered a few hours after their collection on pre-washed 0.2 μm Sartorius® cellulose acetate filters. The SPM samples collected on the filters were removed in the laboratory using Millipore® MilliQ water and the solution containing the SPM was gently evaporated at 55 °C.

For major and trace elements analysis, about 100 mg of powdered sample was dissolved in a $HF:HNO_3:HClO_4$ mixture. After complete dissolution, samples were evaporated to dryness and re-dissolved in HNO_3 2%.

Major elements (Table S1) were measured by ICP-OES and are published in (Chetelat et al., 2009) whereas trace elements (Table S2) were measured in this study by ICP-MS. Accuracy calculated as $100 * (Xmeas - Xstd) / Xstd$ with Xmeas as the measured concentration and Xstd as the recommended value and reproducibility ($1\sigma_{sd}$) was determined by the repeated analysis ($n = 8$) of a national standard (GSD4) (Table S3). For most of the major elements, the accuracy is better than 6% with the exception of K (11%) and the reproducibility is generally better than 10% with the exception of Na (11%). The accuracy of trace element analysis is better than 10% (usually around 5%) with the exception of Rb (15%), Cr (12%), Ba (11%), and U (11%). The reproducibility of trace element analysis is better than 10% with the exception of Rb, U and Ni (11%–13%).

Particulate inorganic carbon (PIC) concentrations (Table S1) were manometrically measured on a manual vacuum extraction line. After reaction of the sample (about 200 mg) with concentrated phosphoric acid, the pressure of CO_2 was converted into mass of carbon using a calibration curve obtained by measuring the pressure of CO_2 for different known amounts of Na_2CO_3. Based on the error on the coefficient of the linear regression calculated for the calibration curve, the error on the PIC concentration for the SPM samples is better than 2%.

In addition, for few samples, we carried out some leaching experiments (Table S4) with HCl 0.1 N at 80 °C for 2 h to analyze the Ca, Mg and Sr concentrations in the carbonate fraction (calcitic and dolomitic phases) (Millot et al., 2003).

The grain size distributions of the SPM samples (Table S5) were analyzed by laser diffraction (Mastersizer 2000, Malvern Instrument).

4. Results and discussion

Major and trace element data are listed in Tables S1 and S2.

Calcium is particularly abundant in the suspended sediment samples collected from the Changjiang main channel and tributaries located in the Upper Reach. For these samples, the Ca contents vary from 4% to 7% whereas for the SPM samples collected from the Middle/Lower Reaches, the Ca concentrations are below 2%. Especially, sediments from the Dongting Lake and Poyang Lake catchments (Fig. 1) can be distinguished from others as they are characterized by Ca contents lower than 1%. Outcrops of carbonate rocks are widespread across the Changjiang basin (Fig. 1) and hence, the Ca content of the SPM samples probably reflects a mixture between carbonate and silicate rocks. Contribution of carbonate to the Ca content of the SPM samples is evidenced by the good correlation between PIC and Ca concentrations (Fig. 2). To estimate the Ca content derived from the carbonate contribution, we assumed that the PIC was present as $Ca_{0.8}Mg_{0.2}CO_3$ where the stoichiometric coefficients were calculated from the average of the Mg/Ca ratios measured in the leaching experiments. The proportion of Ca derived from carbonate rocks varies from 10% to 90% with the lowest values observed in the samples from the Dongting Lake watershed.

The Mg content is variable and ranges from about 1% to 6% with the highest values observed in the samples collected in the Upper Reach. By using the same approach as for Ca, the contribution of carbonate rocks to the Mg content of the SPM varies from 1% to 40%. In the following discussion, element concentrations noted with * are corrected from carbonate contribution.

In order to compare the major element (Na, K and Mg*) contents with the composition of the upper continental crust, we have normalized Na, K, and Mg* to Sm, Th and Al, respectively. Normalizing mobile elements to immobile elements with similar magmatic compatibilities avoids to a certain extent the effects of igneous differentiation and thus the variability in chemical composition of the portion of continental crust drained by the river (Gaillardet et al., 1999a). Gaillardet et al. (1999a) introduced the α_X indices defined as $\alpha_X = (Y/X)_{SPM} / (Y/X)_{UCC}$ where Y is an immobile element with a similar magmatic compatibility as the mobile element X. In this notation SPM and UCC refer to the concentration in the sediment sample and in the upper continental crust (Taylor and McLennan, 1985), respectively. Values greater than 1 indicate a depletion of X relative to the UCC whereas values lower than 1 indicate an enrichment. All the samples are depleted in Na relative to the UCC and are characterized by α_{Na} values defined as $(Sm/Na)_{SPM} / (Sm/Na)_{UCC}$ ranging from 2 to 47 (Fig. 3). Samples show less pronounced depletion in K, with α_k values defined as $(Th/K)_{SPM} / (Th/K)_{UCC}$ ranging from 1.5 to 4. Only the sediment samples from the Yalongjiang (Fig. 1) displays no depletion in K relative to the UCC with a α_k value of 1 (Fig. 3). Most of the samples collected from the Upper Reach are enriched in Mg* relative to the UCC and show α_{Mg^*} values defined as $(Al/Mg^*)_{SPM} / (Al/Mg^*)_{UCC}$ ranging from 0.6 to 1.3 contrasting with the SPM samples from the Middle/Lower Reaches characterized by α_{Mg^*} values ranging from 0.9 to 2.1 (Fig. 3).

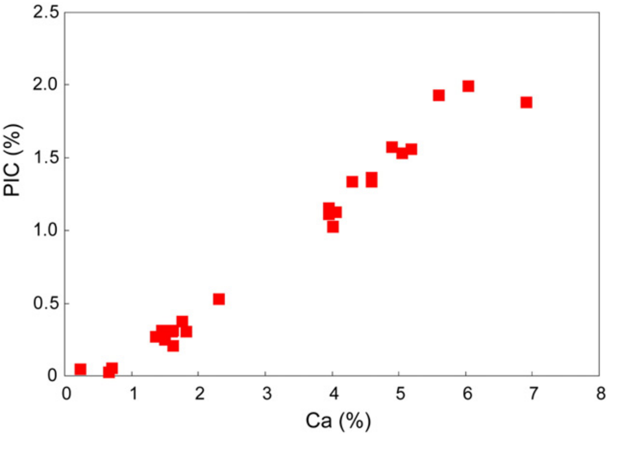

Fig. 2. Relationship between the Ca concentrations and the PIC contents measured in the suspended sediments collected from the Changjiang main stream and its tributaries.

4.1. Sediment provenance

Immobile element ratios are of great interest to decipher the provenance of sediments. Because of their difference in compatibility during magmatic processes, Cr and Co contents normalized to Th are good tracers of magmatic differentiation. As Cr and Co are more compatible than Th, the residual melt during differentiation is enriched in Th relative to Co and Cr. Thus, The Cr/Th and Co/Th ratios in sediments may be used as indicators of the mafic versus felsic natures of the parent rocks (Singh, 2009; Ghosh and Sarkar, 2010). In the Changjiang basin, river sediments display a wide range of Co/Th and Cr/Th ratios from 0.9 to 5 and from 2.5 to 19, respectively. In Fig. 4, sediments from the rivers of the Changjiang basin clearly define a mixing between felsic and mafic sources. Samples from the Dongting Lake and Poyang Lake watersheds (Fig. 1) fall into the domain of granitic rocks whereas the sample collected in the Yalongjiang (CJ2) has the signature of more mafic rocks. The negative Eu anomalies normalized to the chondritic values (0.49–0.67) measured in the suspended sediments from the Dongting Lake and Poyang Lake sub-basins and the positive Eu anomaly (1.11) observed in the sample collected in the Yalongjiang corroborate the observation that the sediments are derived from felsic and mafic rocks, respectively. However, hydrodynamic sorting of SPM within the river water column might result in a variation of the chemical composition of the sediments with depth (Garzanti et al., 2011; Bouchez et al., 2011; Lupker et al., 2012, 2013). In this regard, Bouchez et al. (2011) addressed the geochemical behavior of major and trace elements as a function of the particles size in the Amazon system. Whereas some

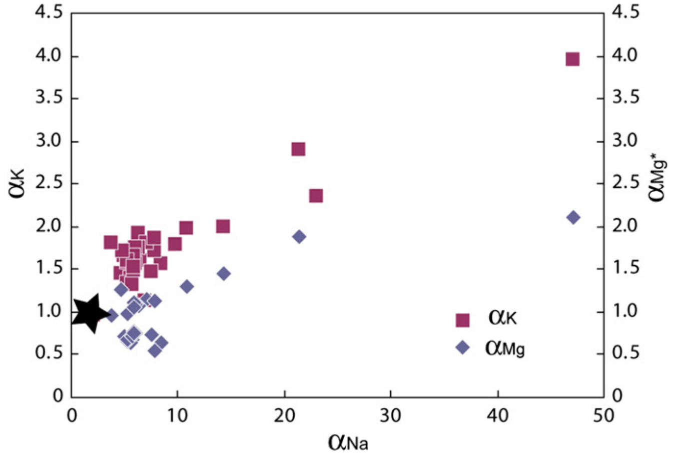

Fig. 3. Variations of α_{Mg^*} and α_K measured in the suspended sediments as a function of α_{Na}. The asterisk on Mg indicates that the concentrations of Mg have been corrected from the contribution of carbonate rocks. The composition of the UCC is indicated by a star.

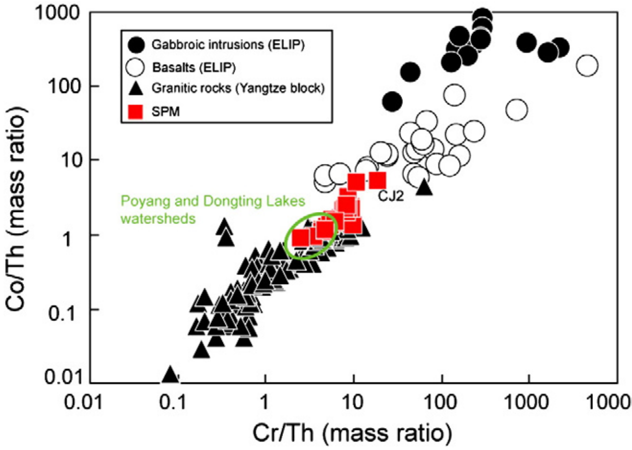

Fig. 4. Relationship between the Cr/Th and Co/Th ratios measured in the suspended sediments transported by the Changjiang basin rivers (red squares). Values for the granitic rocks from the Yangtze block (full triangles), basalts (open circles) and associated gabbroic intrusions (full circles) from the ELIP are reported for comparison (Xu et al., 2001; Li et al., 2003; Wang et al., 2007; Shellnutt et al., 2009; Zhang et al., 2012).

elemental ratios like Si/Al show clear variations with the grain size along depth profiles, the authors showed that in the case of the Amazon, the ratios of insoluble elements like Cr, Th and REE were fairly constant with depth and reflected the composition of the UCC eroded by the river. In order to assess the effects of physical sorting on the Cr/Th (Co/Th) ratios and Eu anomalies, we have plotted them (Supplementary material, Fig. S1) as a function of D90 (grain diameter at which 90% of the sediment by volume is finer than) (Bouchez et al., 2011). No obvious relationship is observed between the grain size distribution and the different ratios suggesting that Cr/Th (Co/Th) ratios and Eu anomalies reflect the composition of the parent rocks at the basin scale. Basalts associated to the Emeishan Large Igneous Province (ELIP) are widely distributed in the Changjiang Upper Reach (Zhang et al., 2006), especially in the lower valley of the Yalongjiang and have similar chemical signature as the one observed in the suspended sediments transported by the Yalongjiang (Xu et al., 2001). In contrast, Phanerozoic and to a lesser extent Neoproterozoic granites are well exposed in the Middle and Lower Reaches (Wang et al., 2013). Contribution from these two end-members to the composition of the suspended sediments collected in the Changjiang main channel can be observed by the variations of the Eu anomaly and Cr/Th and Co/Th ratios from upstream to downstream (Fig. 5). Hence, in addition to a climatic gradient, one particular feature of the Changjiang basin is a lithologic gradient from the Upper Reach characterized by the outcropping of mafic rocks to the Middle/Lower Reaches dominated by more felsic rocks.

4.2. Cation depletion and weathering indices: climatic or lithologic controls?

Various indices of alteration have been proposed to quantify the loss of cations during silicate weathering based on the ratio of mobile elements relative to immobile elements. The chemical index of alteration, defined by Nesbitt and Young (1982) as $\mathrm{CIA} = \mathrm{Al_2O_3} / (\mathrm{Al_2O_3} + \mathrm{CaO^*} + \mathrm{Na_2O} + \mathrm{K_2O}) \times 100$ (molar proportions where CaO* stands for the content of CaO in the silicate fraction) has often been used to quantify the intensity of weathering. In a recent series of papers (Li and Yang, 2010; Shao et al., 2012), this proxy was applied to the study of sediments from Chinese rivers. Based on relationships between CIA and different climatic parameters (temperature and runoff) the authors concluded by the absence of lithologic effects and by a dominant climatic control on the apparent silicate weathering intensity.

In our set of samples, CIA values range from 60 (Changjiang, CJ1) to 81 (Ganjiang, CJ34) and globally decrease from the Changjiang upper reach to the lower reach. As shown in Fig. 6, CIA values co-vary with α_{Na} and α_K values with the highest CIA values associated to the strongest depletions in K and Na relative to the UCC.

At the basin scale, CIA and runoff variations are correlated (Fig. 7) supporting a priori the view of a climatic control on weathering intensity highlighted by Li and Yang (2010) based on the analysis of Chinese river sediments.

However, as described in the previous section, the parent rocks of the sediments encompass a wide range of chemical compositions. The influence of igneous processes and variability in the chemical composition of the parent material on weathering indices have been previously addressed (Price and Velbel, 2003; Buggle et al., 2011). Recently, Kamei et al. (2012) highlighted the overprint of magmatic differentiation on the apparent degree of chemical weathering of saprolite samples developed on granitic rocks characterized by a wide range of chemical compositions.

In the case of the SPM samples collected in the Changjiang basin, CIA values display an inverse relationship with both Cr/Th and Eu anomalies (Fig. 8) illustrating the role of lithology on the apparent loss of soluble elements. SPM samples displaying the highest CIA values originate from the Dongting Lake (CJ33 and CJ59) and Poyang Lake (CJ34) subcatchments and are characterized by pronounced negative Eu anomalies down to 0.50 and low Cr/Th ratios. By contrast, samples with the lowest CIA values have mafic-rock characteristics showing an Eu anomaly close to 0.8 and higher Cr/Th ratios. Hence, in the example of the Changjiang basin, the variations of the CIA measured in the river sediments appear to be a function of the chemical composition of the source material and reflect more the variability of lithology than the loss of soluble elements by chemical weathering.

4.3. Influence of lithology on chemical weathering indices

In order to explore the effects of igneous and sedimentary processes, we have plotted the Sr*/Nd (with Sr* the concentration of Sr corrected from carbonate contribution using the average Sr/Ca ratio measured during the leaching experiments) ratio as a function of the Eu anomalies in Fig. 9 (Gao et al., 1998). Both Eu and Sr are sited into plagioclase during magmatic differentiation but during chemical weathering Sr is released into solution whereas Eu like Nd and other REE is less mobile and is retained in the weathering profile. Two observations can be made: 1) Sediments from the Changjiang and its tributaries follow an igneous differentiation trend illustrating the variability in chemical composition of the parent igneous rocks and 2) Sr in SPM is depleted compared with the parent rocks. An estimation of the initial Sr*/Nd ratio of the source rocks for each sub-basin can be deduced by projecting vertically the data on the correlation line that goes through the different igneous rocks present in the Changjiang basin. This is a first order calculation as river sediments are probably not directly derived from igneous rocks but are a mixture of igneous rocks and recycled sedimentary rocks (Gaillardet et al., 1999a). However, it is a useful framework to illustrate the source effects on the apparent loss of soluble elements. The calculated Sr*/Nd ratio of the source rocks varies significantly from about 5 to 22 at the scale of the basin compared with the value of 13.5 for the UCC (Taylor and McLennan, 1985). By analogy with the α notation of Gaillardet et al. (1999a), the α_{Sr} ratio, defined as $(\mathrm{Nd/Sr^*})_{SPM} / (\mathrm{Nd/Sr})_{UCC}$, varies from 3 to 33 when the average composition of the UCC (Taylor and McLennan, 1985) is used to normalize the $(\mathrm{Nd/Sr^*})_{SPM}$ ratio. In the case where $(\mathrm{Nd/Sr^*})_{SPM}$ is normalized to the (Nd/Sr) ratio calculated for each sub-basin, the α_{Sr} index varies within a narrower range from to 2.5 to 11. At the scale of the basin, the relative depletion in Sr observed in the SPM samples depends on the choice of the composition of the UCC. The biggest change is observed for the Ganjiang with an α_{Sr} index decreasing from 33 to 11 when

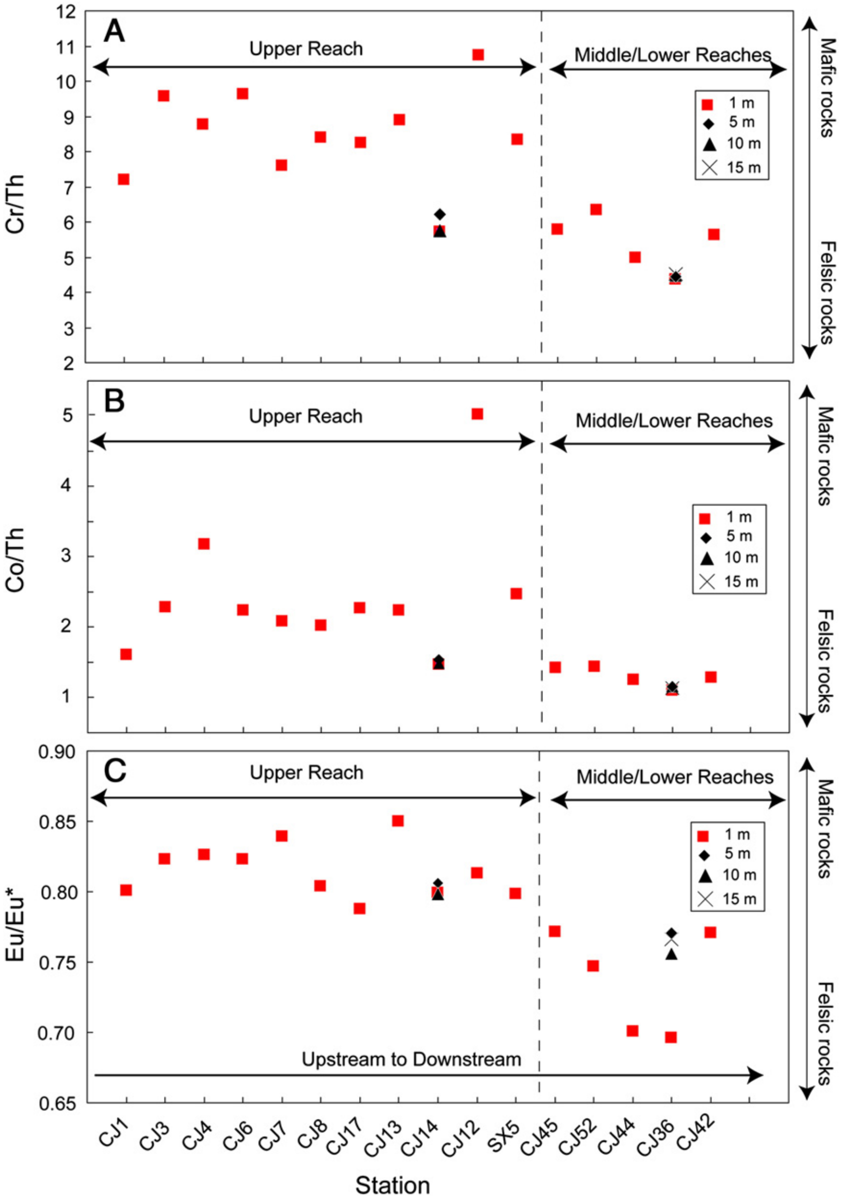

Fig. 5. Evolutions of the Cr/Th ratio (A), Co/Th ratio (B) and europium anomaly (C) measured in the SPM along the Changjiang main channel.

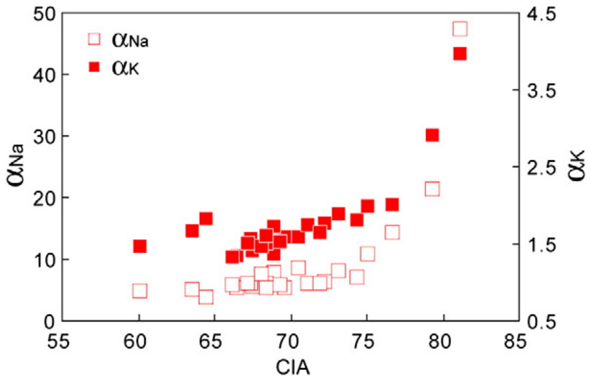

Fig. 6. Relationships between the chemical index of alteration (CIA) measured in the sediments from the Changjiang basin rivers and the alpha indexes, α_{Na} and α_K.

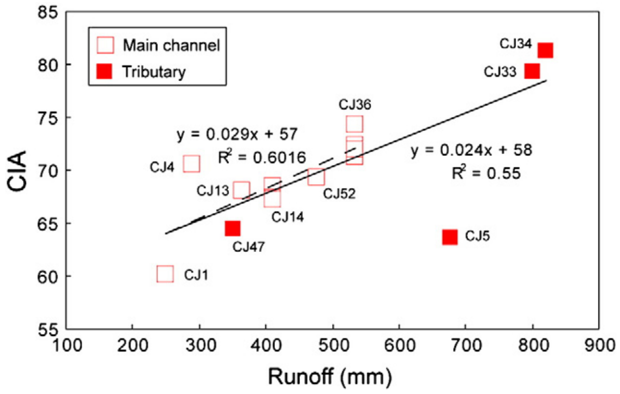

Fig. 7. Relationship between the runoff and the chemical index of alteration (CIA) observed for the rivers of the Changjiang basin. The linear regressions calculated for the whole set of data (full line) and only for the samples collected along the Changjiang main channel (dashed line) are shown for reference.

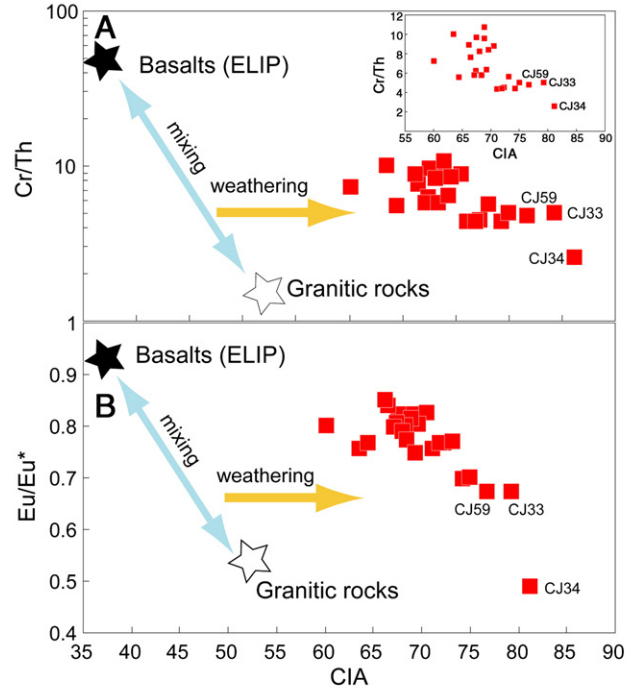

Fig. 8. Relationships linking the CIA measured in the sediments from the Changjiang basin rivers with the Cr/Th ratio (A) and the europium anomaly (B). Median values for the basalts from the ELIP and for the granitic rocks from the Yangtze block are symbolized by a full star and an open star, respectively (Xu et al., 2001; Li et al., 2003; Wang et al., 2007; Zhang et al., 2012).

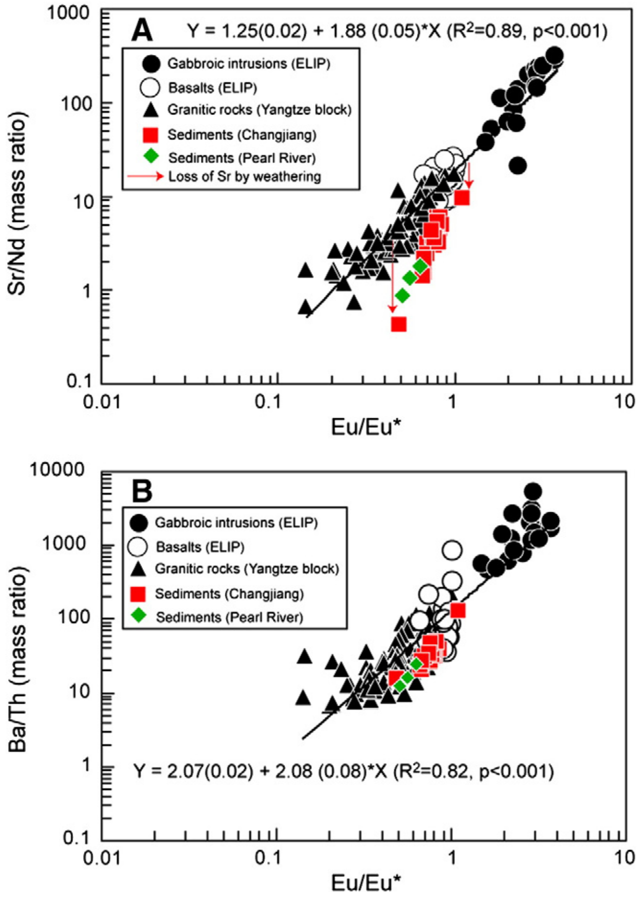

Fig. 9. Relationships linking the europium anomaly measured in the suspended sediments transported by the rivers from the Changjiang basin (red squares) and the Pearl River basin (green diamonds) with the Sr/Nd ratio (A) and the Ba/Th ratio (B). The coefficients of the regression curves are calculated based on the data compiled for the basalts (open circles) and associated gabbroic intrusions (full circles) from the ELIP and the granitic rocks from the Yangtze block (full triangles) (Xu et al., 2001; Li et al., 2003; Wang et al., 2007; Shellnutt et al., 2009; Zhang et al., 2012).

normalizing with the average composition of the UCC or the (Nd/Sr) ratio calculated for Ganjiang basin, respectively.

The index α_{Ba} defined as $\alpha_{Ba} = (Th/Ba)_{SPM} / (Th/Ba)_{UCC}$ is less sensitive to the presence of carbonate and is also a good example of the influence of the rock composition on the weathering indexes. The α_{Ba} index ranges from 0.4 (Yalongjiang) indicating an enrichment in Ba relative the UCC to 3 (Ganjiang) and is well correlated with the α_{Na} and α_K indices (Supplementary material, Fig. S2). Although Th and Ba have similar compatibilities, the Ba/Th ratio is sensitive to the degree of igneous differentiation as illustrated in Fig. 8. By using the same approach as for the Sr/Nd ratio, we have re-estimated the α_{Ba} ratio by normalizing the Ba/Th calculated for each sub-basin (ranging from 27 to 146). In that case, the α_{Ba} value ranges from 1.1 to 2.7 and no difference in the loss of Ba is observed between the upper reach (average 2.1) and the middle/lower reaches (average 2).

Thus, heterogeneity of the source rocks and deviation of their chemical composition from the average composition of the UCC (Taylor and McLennan, 1985) might explain the lower enrichment in K relative to Th compared with the UCC observed in the sediments collected from the Changjiang upper reach. Gabbroic intrusions associated to the ELIP display variable but generally large enrichments in Na and K with Na/Sm and K/Th average values of 1.6 and 2.5, respectively (Shellnutt et al., 2009). Contribution of these mafic/ultramafic intrusions has been previously pointed out to explain the geochemistry and mineralogy of riverbed sediments from the upper Changjiang and its tributaries (Yang et al., 2009; Wu et al., 2011). Hence using a constant value to normalize the Na/Sm and K/Th ratios measured in sediments may be misleading and may not reflect the loss of soluble elements effectively undergone during chemical weathering.

In the case of Mg, the relationship between Mg* and the Co/Th ratio (Supplementary material, Fig. S3) supports the view that the content of Mg derived from silicate rocks is partly controlled by magmatic process and reflects the difference in composition of the sediments source-rocks. Enrichment in Mg is also observed in riverbed sediments of the Yalongjiang and upper Changjiang (Wu et al., 2011) and is consistent with the composition of the Emeishan flood basalt and the associated mafic intrusions characterized by higher Mg/Al ratios (average 0.7–0.8) (Xu et al., 2001; Shellnutt et al., 2009) than the granitic rocks from the Yangtze block (average Mg/Al = 0.08) (Li et al., 2003; Wang et al., 2007; Zhang et al., 2012). If these two values are used to normalize the Mg/Al ratio measured in the suspended sediments from the Yalongjiang and Ganjiang instead of the average value of the UCC (Mg/Al = 0.16, Taylor and McLennan, 1985), the loss of Mg is greater for the former sample. Hence, the apparent weaker degree of chemical weathering revealed by the CIA or the alpha indexes normalized to the average composition of the UCC which characterizes the sample from the Yalongjiang and more generally the sediments from the Upper Reach of the Changjiang may be explained by the difference in lithology compared with the rivers draining the Dongting Lake and Poyang Lake sub-basins in the Changjiang Middle/Lower Reaches. By extension we have compared the results obtained for the Changjiang basin rivers with the data compiled for the Pearl River basin (Fig. 1) for which both trace and major elements are available (Zhang and Wang, 2001). Similar conclusions can be drawn as the different indices of weathering display co-variation with proxy of igneous differentiation (Fig. 9). Especially, the α_{Ba} index corrected from the variability of rock composition shows no difference between the two basins. These two examples of large rivers in China illustrate the importance of the composition of the source-rocks and the ambiguity of the relationship between the loss of soluble elements observed in the suspended sediments from these two Chinese rivers and climatic parameters.

5. Conclusions

(1) The Changjiang basin is characterized by a lithologic gradient and suspended sediments are derived from a mafic source related to the Emeishan Large Igneous Province in the Upper Reach whereas suspended sediments are derived from a more felsic source in the Middle/Lower Reaches.
(2) Although the apparent loss of soluble elements follows a climatic gradient from the upper reach to the lower reach, the cross-relationships of weathering indices with different proxies for igneous differentiation suggest that a lithologic control cannot be ruled out.
(3) By taking into account the variability in the chemical composition of the sediment's parent rocks, we have shown that river suspended sediments from the upper reach may have not experienced less intense chemical weathering than those transported by rivers from the Lower/Middle Reaches characterized by higher runoffs and surface temperatures.
(4) This example illustrates the importance of the composition of the source-rocks and the ambiguity of the relationship between the loss of soluble elements observed in the suspended sediments from the Chinese rivers and climatic parameters.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.chemgeo.2013.09.018.

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