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Chemical indices (CIA and WIP) as proxies for integrated chemical weathering in China: Inferences from analysis of fluvial sediments

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ABSTRACT

Rivers play a key role in earth surface processes by weathering and eroding the upper continental crust under variable climate regimes. How to quantitatively determine the chemical weathering intensity in the drainage basins using geochemistry of fluvial sediments remains unclear. The Chemical Index of Alteration (CIA) and the Weathering Index of Parker (WIP) have been used worldwide as proxies to evaluate the chemical weathering intensity in large watersheds and in specific weathering profiles. In this study, concentrations of major oxides in the suspended particulate matter (SPM) and fine-grained floodplain sediments from 13 major rivers in China from north to south were analysed and compiled for the estimation of chemical weathering in China. The gradual increase in CIA and decrease in WIP values with decreasing latitude of the catchments suggest enhanced weathering intensity in these river basins. A combined monsoon climate effect of temperature, runoff and precipitation primarily controls the chemical weathering in China. The provenance rock types and relief play minor roles in weathering, whereas an active tectonic setting and typhoon events play key roles in the weathering process in Taiwan. The CIA values of the finer SPM samples within a given river are overall greater than those in the corresponding coarser floodplain sediments, underscoring the effect of sediment grain size on CIA values.

The irregular seasonal variation of the CIA within a specific river further confirms the notion that the CIA does not reflect the instantaneous chemical weathering on continents. Although it is impossible to build a general model for regulating the chemical weathering of continents, this study reveals that the integrated chemical weathering intensity in large latitudinal watersheds can, with careful application, be quantitatively estimated using the proper geochemical proxies of river sediments.

1. Introduction

The weathering products of silicate rocks are particularly useful for evaluating continental weathering, which acts as a net sink for atmospheric CO_2 (Berner, 1992; Velbel, 1993; White and Blum, 1995; Gaillardet et al., 1999a, b; Dessert et al., 2003; Price and Velbel, 2003). Rivers deliver an immense amount of weathered terrigenous matter into the sea. This delivery plays a key role in earth surface processes, marine sedimentation and the biogeochemical cycle in the ocean. Approximately 20 billion metric tons of fluvial sediments are transported into the oceans every year, among which 70% of the total suspended sediment load comes from the southeast Asian countries and numerous islands in the Pacific and Indian Oceans (Milliman and Syvitski, 1992). Among the major Asian rivers, those originating in the Tibetan Plateau have attracted many researchers during the last two decades because they registered a history of tectonic uplift, chemical weathering and monsoon evolution, and they may have significantly affected marine chemistry during the Cenozoic (Raymo and Ruddiman, 1992; Dessert et al., 2001, 2003; Galy et al., 2007; Chakrapani et al., 2009). China contains several large rivers originating from the Tibetan Plateau and the surrounding region, including the three largest (from north to south): the Huanghe (Yellow River), Changjiang (Yangtze River) and Zhujiang (Pearl River).

The chemical weathering rates on continents are regulated by many factors, including the source rock type, climate regime, tectonic and topographic settings, vegetation, soil development, and human activities (Gibbs, 1970; Meybeck, 1987; Grantham and Velbel, 1988; Berner, 1992; Stallard, 1995; White and Blum, 1995; Gaillardet et al., 1999a, b; Oliva et al., 2003). Nevertheless, the mechanism of the chemical weathering processes at different spatial and temporal scales is poorly understood (Raymo and Ruddiman, 1992; McLennan, 1993; White and Blum, 1995; Yang et al., 2004; Viers et al., 2009; Li and Yang, 2010; Bouchez et al., 2011). Various sediment geochemical proxies

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have been proposed to study the intensity of chemical weathering on continents (Parker, 1970; Nesbitt and Young, 1982, 1989; Harnois, 1988; Fedo et al., 1995; Hamdan and Burnham, 1996; Nesbitt et al., 1996; Gaillardet et al., 1999b; Duzgoren-Aydin et al., 2002; Millot et al., 2002; Price and Velbel, 2003; von Eynatten et al., 2003), primarily based upon the variable geochemical behaviour of specific elements and isotopes in a hypergenic environment. Among these weathering indices, the Chemical Index of Alteration (CIA) proposed by Nesbitt and Young (1982) and the Weathering Index of Parker (WIP) (first introduced by Parker in 1970 and developed by Hamdan and Burnham, 1996) are the two most commonly applied indices.

Since Nesbitt and Young first proposed the CIA in 1982 to reconstruct the paleoclimate from Early Proterozoic sediments of the Huronian Supergroup, north of Lake Huron, it has been widely used to quantitatively evaluate the chemical weathering intensity in drainage basins (Grantham and Velbel, 1988; McLennan, 1993; Vital and Stattegger, 2000; Yang et al., 2004; Selvaraj and Chen, 2006; Li and Yang, 2010; Xiao et al., 2010). The CIA is defined as $Al_2O_3/(Al_2O_3 + Ca^*O + Na_2O + K_2O) \times 100$ (molar contents, with Ca^*O being CaO content in the silicate fraction of the sample). Generally, the CIA is interpreted as a measure of the extent of the conversion of feldspar to clays (Nesbitt and Young, 1989; Fedo et al., 1995; Yang et al., 2004). McLennan (1993) first calculated the CIA values of 16 rivers from different continents, and suggested a negative correlation between the sediment yield and weathering history. Recently, Li and Yang (2010) systematically calculated the CIA values of 44 rivers worldwide and suggested that, on a global scale, the CIA is sensitive to the land surface temperature, latitude at the river mouth and the soil depth in watersheds, and it actually reflects the integrated weathering history.

In Parker (1970) and Hamdan and Burnham (1996), the WIP was used for evaluating the weathering intensity of silicate rocks based upon the proportions of alkali and alkaline earth elements in weathered products. The WIP is defined as $100 \times (2Na_2O/0.35 + MgO/0.9 + 2K_2O/0.25 + CaO/0.7)$ (molar contents, with CaO being the content in the silicate fraction of the sample). According to the WIP definition, the smaller WIP values indicate stronger chemical weathering, which is opposite to CIA values. This index has been suggested to be most appropriate for the application to weathering profiles on heterogeneous parent rocks and is most likely not applicable to highly weathered mantles, because its formulation includes only highly mobile alkali and alkaline elements (Hamdan and Burnham, 1996; Duzgoren-Aydin et al., 2002; Price and Velbel, 2003). Considering the mobility of aluminium during chemical weathering, some studies suggested that the WIP may be more appropriate for evaluating weathering intensity than for the CIA, although both indices correlate well (Duzgoren-Aydin et al., 2002; Price and Velbel, 2003). Nevertheless, the WIP has rarely been used to examine the weathering intensity registered in various fluvial sediments worldwide compared with the widely documented CIA as introduced above.

In this study, we measured and compiled the contents of major oxides in the suspended and floodplain sediments of 13 rivers from mainland China and Taiwan and re-calculated their CIA and WIP values. These latitudinal rivers all flow eastward into the East China marginal seas, and the river basins cover different climatic regimes and provenance lithology. To better understand the effect of sediment grain size on the CIA and WIP, we calculated the CIA and WIP values in both the floodplain and suspended sediment samples. Furthermore, the sediment samples from the mainstream and major tributaries of each river were considered to provide a more comprehensive understanding of the chemical weathering in drainage basins. This study has four main objectives: 1) to examine the regional variations of the CIA and WIP in Chinese rivers; 2) to compare the application of both weathering indices to the fluvial sediments; 3) to investigate the seasonal variation of the CIA in the lower Changjiang mainstream; and 4) to demonstrate the potential influence of variable geologic and climatic settings on chemical weathering in these drainage basins.

2. River settings

A total of 13 rivers draining eastern China from north to south were selected for the calculations of the CIA and WIP (Table 1; Fig. 1). The total drainage basin area of these rivers accounts for approximately 50% of the land area of China, covers a wide spectrum of geographical zones from a frigid temperate climate zone with dark brown soil in the northeast to a subtropical climate with red soil in the south (Chen and Wang, 1996). The rivers in northeast China include the Heilongjiang, Wusulijiang, Nenjiang, Songhuajiang, Tumenjiang, Liaohe, Yalujiang, and Luanhe rivers. The drainage areas and sediment loads of these rivers are less than those of the Changjiang, Huanghe and Zhujiang rivers. The mean annual temperature and precipitation in these watersheds reach approximately 5.1 °C and 599 mm, respectively (Table 1). Geologically, these catchments primarily consist of granite, sandstones and Quaternary siliciclastic sediments.

The Huanghe drains approximately 75×10^4 km^2 with a basin lying between 32°10′–41°50′N and 95°53′–119°05′E. It carries a concentrated sediment load after draining the Loess Plateau before flowing into the vast North China Plain and entering the Bohai Sea. The catchment consists of variable source rocks, from the oldest Precambrian metamorphic rocks to late Quaternary fluvial–lacustrine sediments. The Loess Plateau located in the middle valley is 100–300 m in thickness and approximately 3×10^5 km^2 in area, which contributes approximately 90% of the suspended load in the lower Huanghe mainstream (Yang et al., 2004). The watershed has a typical arid and temperate climate with an annual mean precipitation of approximately 476 mm.

The Changjiang originated from the Tibetan Plateau with an elevation above 5000 m, drains approximately one-fifth of the continental area of China before entering the East China Sea. The catchment, lying between 24°27′–35°44′N and 90°33′–122°19′E, has a drainage area of 1.8×10^6 km^2. The upper basin is characterised by complex source rock types, including widely distributed Palaeozoic carbonate rock in the south, Jurassic red sandstone in the Sichuan Basin, and Mesozoic and Cenozoic igneous rocks in the source area. The middle-lower basin primarily consists of Palaeozoic marine and Quaternary fluvial–lacustrine sedimentary rocks; the intermediate to felsic igneous rocks are common but sporadic (Yang et al., 2004). The major part of the Changjiang watershed that is located in the humid sub-tropic zone is influenced by the typical East Asian monsoon climate. The annual atmospheric precipitation ranges from less than 400 mm in the river source area to more than 2000 mm in the highlands of the middle-lower reaches, with an average of 1100 mm (Chen and Wang, 1996).

The Zhujiang is the largest river in south China with a length of 2214 km and a drainage area of approximately 45×10^4 km^2. It flows to the South China Sea, and consists of three main branches named the Xijiang (west branch), Beijiang (north branch) and Dongjiang (east branch). The subtropical climate causes an annual average temperature of approximately 21 °C and precipitation of 1550 mm.

Table 1

Properties of the major rivers in China.

Rivers	Lat. (°)	Temp. (°C)	Prec. (mm)	Runoff (mm/yr)	Drainage area (10^3 km^2)	Sediment yield (t/km^2/yr)
Northeast rivers	44	5.1	599	211.6	1843	849.3[a,b,c]
Huanghe	35.2	13	476	65	750	2126.4[b]
Changjiang	30.8	15	1100	500	1800	261.2[b]
Taiwan rivers	24	23	2878	2595	0.77	8154[d]
Zhujiang	23.5	21	1550	831	454	205.9[b]

Lat. = latitude; Temp. = temperature; Prec. = precipitation.

[a] Chen and Wang (1996).

[b] Li (2003).

[c] Li et al. (2009).

[d] Liu et al. (1981).

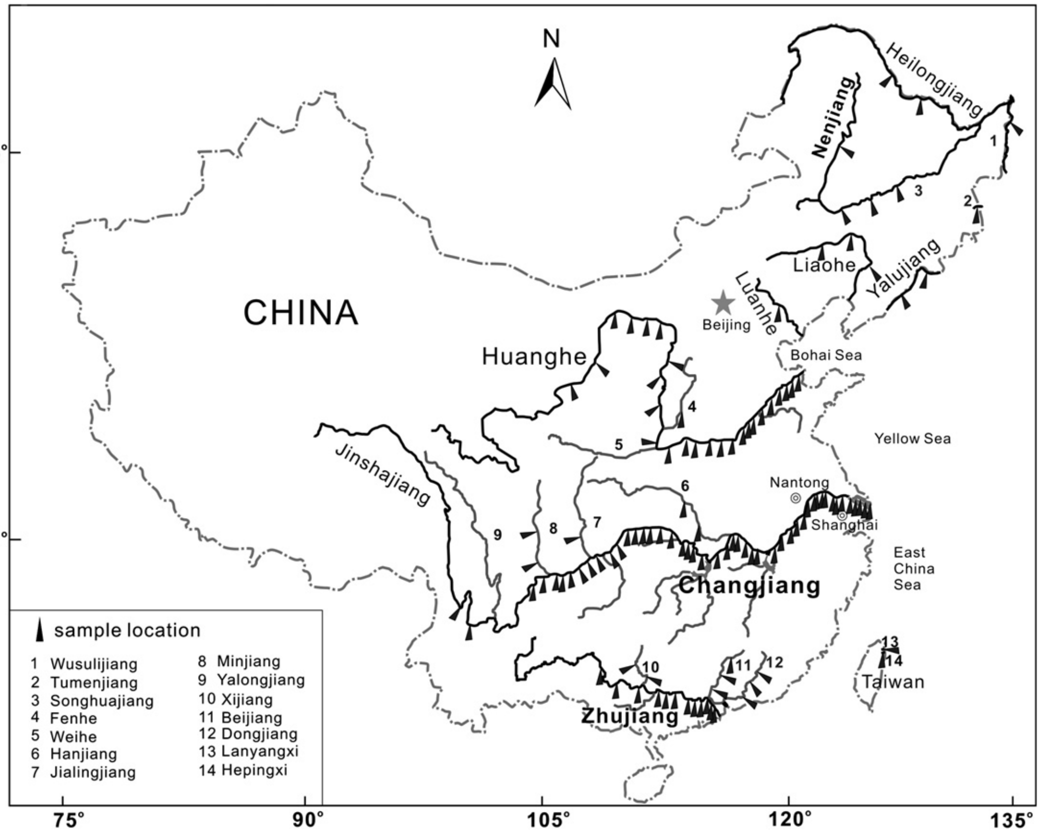

Fig. 1. A schematic map showing the studied major rivers in China with the locations of the suspended particulate matter (SPM) samples.

The Zhujiang mostly drains the low relief of south China (Cathaysia Block), which is primarily composed of Mesozoic granite rocks and Palaeozoic sedimentary rocks in the eastern part and Permian–Triassic limestone in the western valley (Zhang and Wang, 2001).

3. Data sources and methodology

We collected the contents of major oxides in suspended particulate matter (SPM) and floodplain/bank sediments from north-eastern to southern rivers (Fig. 1). Most of these geochemical data were obtained from the recently published literature (Tables 2 and 3). In addition to the existing published data, we also measured elemental concentrations in some fluvial sediments, including the seasonal suspended samples collected in the lower Changjiang mainstream at Nantong, approximately 90 km away from the river mouth. All of the sediment samples were combusted in a muffle furnace at 600 °C for 2 h before acid digestion. Approximately 30 mg of powdered samples were digested with 4 ml of HNO_3 and 1 ml of $HClO_4$ for 24 h in a tightly closed Teflon vessel on a hot plate at less than 150 °C, heated to dryness, and then digested with a mixture of 4 ml of HF and 1 ml of $HClO_4$. Afterwards, the solution was evaporated to dryness and extracted with 10 ml of 1% HNO_3. The concentrations of the major elements were determined with ICP-AES (IRIS Advantage) in the State Key Laboratory of Marine Geology at Tongji University. The analytical precision and accuracy were monitored by national geo-standards GSR-5, GSR-6, and GSR-9.

For comparison, the CIA values of the upper continental crust (UCC) (Taylor and McLennan, 1985), North American shale composite (NASC) (Gromet et al., 1984) and Central East China crust (CEC, Gao et al., 1998) were also calculated.

In this study, the method from McLennan (1993) was adopted to approximately correct the $Ca^{*}O$ content by assuming a specific molar ratio of CaO/Na_2O in the silicate mineral. In fact, the CIA reflects the proportion of Al_2O_3 versus the labile oxides, and thus indicates the extent of the silicate weathering, for instance, from plagioclase to clays (Nesbitt and Young, 1982, 1989; Fedo et al., 1995; Price and Velbel, 2003). As a consequence, the CIA values of approximately 45–55 indicate virtually no weathering, and the average UCC has a CIA value of approximately 47, while a value of 100 indicates intense weathering with the complete removal of alkali and alkaline earth elements from the parent rocks (McLennan, 1993). Generally, the larger CIA values mean stronger silicate weathering, but a linear relationship is difficult to establish between weathering intensity and the CIA value (von Eynatten et al., 2003). Furthermore, the CIA is dependent on the geochemistry and lithology of the un-weathered parent rock and on the character of weathered sediment (Price and Velbel, 2003; Garzanti et al., 2010). Obviously, clayey sediment may have a greater CIA value than sandy sediment, which implies that sediment grain size may have a significant effect on CIA estimation.

Apart from the CIA, the A–CN–K (Al_2O_3–$Ca^{*}O+Na_2O$–K_2O) diagram was proposed to intuitively reflect the trends and the degree of silicate weathering and to evaluate the parent rock composition (Nesbitt and Young, 1989; Fedo et al., 1995; Nesbitt et al., 1996; von Eynatten et al., 2003; Yang et al., 2004; Li and Yang, 2010).

4. Results

The concentrations of Al_2O_3, $Ca^{*}O$, Na_2O, K_2O and MgO in the suspended, floodplain/bank sediments and calculated CIA and WIP values of Chinese rivers are listed in Tables 2–4 and Fig. 2. The CIA values of the investigated SPM vary between 58.8 and 91.3 with an average of 71.4, close to the previous estimate of the world average of 72.1 (Li and Yang, 2010), while the CIA of the floodplain sediment samples ranges from 44.5 to 84.3 and averages 61.3, which is much

Table 2
Major elemental concentrations and calculated CIA values of suspended particulate matter from major Chinese rivers.

Rivers	Al_2O_3 (wt%)	Na_2O (wt%)	CaO (wt%)	K_2O (wt%)	MgO (wt%)	WIP	CIA	Raw data sources
Northeast rivers								
Nenjiang	11.26	0.97	1.85	3.18	1.49	42.4	62.9	Chen et al. (2000)
Heilongjiang	11.84	1.29	2.70	3.00	2.45	47.2	61.2	Chen and Wang (1996)
	11.61	1.64	2.23	2.52	2.28	46.7	58.8	Chen et al. (2000)
Songhuajiang	11.39	1.33	2.80	3.01	2.24	47.2	59.9	Chen et al. (2000)
Wusulijiang	13.79	1.17	3.79	3.27	4.13	52.8	65.1	Chen et al. (2000)
Yalujiang	13.69	1.31	3.25	3.46	2.75	52.2	63.0	Chen and Wang (1996)
Tumenjiang	13.62	1.17	2.81	3.09	3.33	49.0	65.4	Chen and Wang (1996)
Liaohe	12.84	1.25	4.21	2.60	3.53	46.3	64.9	Chen and Wang (1996)
Luanhe	11.23	1.37	3.55	2.95	2.94	49.1	59.2	Chen and Wang (1996)
Huanghe	14.17	1.48	8.12	2.05	2.83	42.4	66.6	Qu and Yan (1990)
	17.30	1.05	6.62	3.25	6.67	58.3	71.2	McLennan (1993)
	13.69	1.43	8.13	2.22	2.96	43.6	65.8	Chen and Wang (1996)
	13.34	1.32	9.32	2.38	2.76	43.1	65.8	Gaillardet et al. (1999b)
	10.63	1.19	6.78	2.23			62.7	Li and Yang (2010)
	9.42	1.26	7.96	1.96	1.82	36.3	60.1	This study
	11.85	1.13	5.60	2.50	2.40	41.0	64.9	This study
	14.17	1.05	7.19	2.27	1.90	36.7	70.5	This study
	9.92	0.89	6.27	1.90	1.20	29.8	66.5	This study
Changjiang	15.87	1.08	4.34	2.41	3.00	41.3	72.0	Qu and Yan (1990)
	15.96	0.94	3.78	2.74	2.89	42.2	72.5	Gaillardet et al. (1999b)
	13.58	0.67	4.27	2.56	4.14	41.0	73.2	Chen et al. (2000)
	17.81	0.77	4.13	3.25			74.6	Li and Yang (2010)
	8.81	0.65	3.86	1.71	1.93	27.4	68.7	This study
	11.23	0.65	3.97	1.98	2.34	30.8	72.4	This study
	11.91	0.78	3.75	2.50	3.50	40.0	69.3	This study
	10.14	0.57	3.94	1.79	3.20	30.7	72.7	This study
	8.89	0.72	3.98	2.07	3.33	35.2	65.8	This study
	13.08	0.72	4.11	2.36	3.87	39.1	72.7	This study
	9.87	0.72	3.98	1.99	3.30	34.4	68.5	This study
	13.13	0.73	3.77	2.50	3.09	38.3	72.0	This study
	14.45	1.12	2.29	2.56	2.30	41.1	69.1	This study
	19.74	0.71	3.99	3.45	3.46	47.1	76.4	This study
	17.40	0.71	4.35	3.14	3.25	43.9	75.3	This study
	17.64	0.70	4.37	3.21	3.29	44.5	75.3	This study
	16.48	0.96	3.79	3.20	2.77	46.0	71.3	This study
	18.30	1.03	3.50	2.79	2.52	42.6	73.9	This study
Taiwan River								
Lanyang	30.78	1.38	0.91	3.11	0.64	43.3	79.5	This study
Heping	23.77	1.48	4.60	2.60	0.86	41.6	75.6	This study
Zhujiang	34.91	0.32	0.85	2.12	1.08	24.7	91.3	Wang and Zhang (1999)
	8.67	0.30	1.08	2.10	1.34	25.1	72.7	Wang and Zhang (1999)
	17.13	0.32	1.00	2.23	1.23	26.1	83.1	Wang and Zhang (1999)
	18.81	0.32	0.53	2.28	1.25	26.6	84.2	Wang and Zhang (1999)
	20.97	0.40	2.52	2.41	2.00	30.7	84.2	Qu and Yan (1990)
	22.29	0.27	0.56	2.41	1.00	26.4	86.4	Qu and Yan (1990)
	29.47	0.27	0.28	2.53	0.67	26.5	89.0	Qu and Yan (1990)
	13.00	0.25	1.76	2.41	0.75	25.5	79.0	Chen et al. (1986)
	10.90	0.45	1.39	2.65	1.18	31.0	71.4	Chen et al. (1986)
	13.69	0.21	0.11	2.82	0.45	27.7	79.8	Chen et al. (1986)
UCC	15.19	3.90	4.20	3.37	2.20	79.7	48.0	Taylor and McLennan (1985)
NASC	16.91	1.01	3.40	3.80	2.83	52.1	69.4	Gromet et al. (1984)
CEC	13.65	2.75	3.31	2.55	2.52	60.4	53.5	Gao et al. (1998)
World rivers (44)	16.4	1.21	3.57	2.55			72.1	Li and Yang (2010)
Chinese rivers (13)	15.1	0.89	3.73	2.58			71.4	This study

Note: UCC = upper continental crust; NASC: North American shale composite; CEC: Central East China crust.

less than the average of the SPM samples (Fig. 2). The WIP values of the SPM samples vary from 24.7 to 58.3 and average 38.8, while the WIP of the floodplain samples ranges from 26.4 to 59.4 with an average of 44.4, which is greater than the average of the SPM sample.

Overall, the average CIA values both in the SPM and floodplain samples increase from the rivers in northeast China, the Huanghe, and Changjiang, and Taiwan rivers to the Zhujiang in the southernmost, regardless of river scales, physical geography and provenance geology. In contrast, the WIP values in the SPM and floodplain samples yield the opposite trends, showing decreasing values from the rivers in the northeast of China to the southernmost Zhujiang (Fig. 2). The average CIA value of the SPM sample is always greater than that of the floodplain sample within each specific river, whereas the average WIP yields smaller values in the SPM than in the corresponding floodplain samples. Furthermore, the CIA values in a specific river may have wide variations from upstream to downstream. For example, the CIA values of the SPM samples in the Changjiang vary between 65.8 and 76.4, and they average 70.3 in the upper reaches and 73.3 in the mid-lower reaches. Nevertheless, the variation of the CIA within a river system overall is less than the variation among different rivers.

According to the classification of weathering intensity by Nesbitt and Young (1989), the SPM samples of these rivers constitute a broad scope of weathering degree from weak to strong weathering, while most of them fall into the intermediate stage (Fig. 3). The rivers in northeast China have the weakest silicate weathering, while the Zhujiang has the strongest weathering. The drainage basins of the Huanghe and Changjiang primarily undergo weak and moderate silicate weathering, respectively, which is consistent with the previous study

Table 3
Major elemental concentrations and calculated CIA values of the floodplain sediments from major Chinese rivers.

Rivers	K_2O (wt%)	Na_2O (wt%)	CaO (wt%)	Al_2O_3 (wt%)	MgO (wt%)	WIP (wt%)	CIA (wt%)	Raw data sources
Northeast rivers								
Ersong	3.07	3.14	1.16	12.33	0.27	58.8	53.7	Li (2003)
	2.49	2.48	1.12	8.03	0.77	49.0	47.6	Li (2003)
Liaohe	2.66	2.57	1.60	8.80	1.50	54.6	46.7	Li (2003)
	2.62	2.32	1.72	7.86	1.43	52.0	44.5	Li (2003)
	2.80	2.39	1.27	7.54	1.37	52.9	44.8	Li (2003)
Yalujiang	3.39	2.72	1.08	12.94	0.97	59.4	56.1	Li et al. (2010)
Huanghe	1.98	2.28	8.60	10.48	2.42	49.8	52.1	Li (2003)
	2.08	1.74	7.07	9.80	1.78	42.7	55.1	Li (2003)
	1.90	2.22	8.12	10.48	2.13	47.7	52.8	Li (2003)
	1.96	1.87	9.09	10.45	2.08	44.0	55.7	Li (2003)
	2.13	1.73	6.66	10.35	1.97	43.5	56.4	Li (2003)
	2.11	1.95	6.79	9.63	2.12	46.3	52.5	Li (2003)
	1.82	2.02	4.10	11.03	1.42	42.7	56.1	Li (2003)
	2.39	1.52	7.78	11.26	2.25	44.1	59.7	Li (2003)
	2.33	2.39	5.78	10.92	2.15	53.3	51.3	Li (2003)
	2.28	1.70	4.84	9.94	1.50	43.2	55.2	Li (2003)
	2.24	2.47	6.43	11.31	2.13	53.4	51.8	Li (2003)
	1.98	2.18	6.12	11.03	1.77	46.9	54.2	Li (2003)
	2.35	2.48	8.19	11.11	2.45	55.4	50.9	Li (2003)
	2.16	1.89	7.24	9.50	2.12	46.0	52.6	Li (2003)
	2.16	1.81	7.13	11.22	2.07	45.0	57.5	Li (2003)
	2.17	1.95	4.63	9.48	1.63	45.5	51.9	Li (2003)
	2.06	2.02	5.18	11.14	1.68	45.5	55.6	Li (2003)
	2.29	2.22	5.61	10.48	1.92	50.4	51.7	Yang et al. (2004)
Changjiang	2.08	0.93	4.23	15.55	3.45	38.0	74.5	Li (2003)
	2.53	0.94	6.26	14.81	3.63	42.5	71.7	Li (2003)
	2.51	0.94	6.08	13.22	2.80	40.0	69.4	Li (2003)
	2.40	1.13	5.60	13.24	3.03	41.9	67.7	Li (2003)
	2.46	0.94	4.05	15.45	3.05	40.2	72.8	Li (2003)
	2.41	1.08	4.34	15.87	3.00	41.3	72.0	Li (2003)
	2.07	1.36	4.83	11.71	1.70	38.0	63.5	Li (2003)
	2.21	1.43	4.89	10.33	1.38	39.1	59.3	Li (2003)
	2.72	1.70	4.52	12.11	1.27	46.3	58.6	Li (2003)
	2.02	1.71	6.22	13.05	4.11	48.3	62.5	This study
	1.96	2.06	8.81	10.67	3.22	49.4	54.5	This study
	2.00	1.48	9.30	10.79	5.00	48.0	60.4	This study
	1.71	1.73	7.94	10.29	3.66	44.6	57.7	This study
	1.72	1.48	9.25	10.07	4.52	44.2	59.9	This study
	1.66	1.59	9.32	8.86	4.68	45.4	55.7	This study
	2.13	1.83	4.48	13.15	2.72	46.8	61.1	This study
	2.07	1.56	8.44	12.50	4.17	47.2	62.9	This study
	1.93	1.47	7.24	11.47	3.69	43.6	62.4	This study
	2.41	1.43	7.20	13.30	3.79	47.5	64.5	This study
	2.59	1.48	4.48	15.24	3.49	48.8	66.4	This study
	2.10	1.83	5.17	12.77	2.27	45.3	60.5	This study
	1.54	1.83	10.14	9.56	2.34	40.7	55.3	This study
	1.99	1.27	4.62	12.07	2.92	39.7	65.6	This study
	2.41	1.42	10.47	13.54	5.64	52.5	65.1	This study
	1.84	1.37	10.47	10.29	5.39	46.4	61.2	This study
	1.63	2.01	5.36	12.30	4.66	50.0	59.4	This study
	1.88	1.44	12.17	11.20	7.05	52.2	62.2	This study
	2.55	1.50	7.14	14.54	3.77	49.4	65.4	This study
	2.12	1.43	8.83	12.64	4.44	46.9	64.4	This study
	1.93	1.64	5.31	11.45	1.88	40.5	60.4	This study
	2.01	1.81	9.16	10.54	4.10	49.3	56.5	This study
	2.12	2.36	3.85	13.20	2.29	51.6	56.8	This study
	2.12	0.40	0.83	15.87	1.36	26.4	81.4	This study
	2.47	1.15	1.43	11.54	1.78	39.2	64.1	This study
Zhujiang	2.00	0.57	3.05	13.71	1.15	26.8	77.3	Li (2003)
	2.07	0.59	1.02	13.00	1.20	27.7	75.6	Li (2003)
	2.42	0.49	0.91	10.39	1.08	29.3	71.1	Li (2003)
	2.49	0.38	0.63	21.16	0.83	27.9	84.3	Li (2003)
	2.22	0.47	1.83	20.97	1.68	29.0	84.1	Li (2003)
	2.22	1.37	1.57	15.56	1.38	38.5	69.2	Zhang and Wang (2001)
	2.35	1.25	1.06	14.81	1.22	37.8	69.3	Zhang and Wang (2001)
	2.63	1.44	0.60	18.76	0.88	41.4	74.8	Zhang and Wang (2001)
	2.37	1.35	1.13	16.06	1.19	39.0	70.1	Zhang and Wang (2001)
	2.47	1.35	1.46	17.23	1.63	41.1	70.8	Peng et al. (2003)
River average	2.22	1.63	5.34	12.23	2.51	44.4	61.3	This study

by Yang et al. (2004). In comparison, the silicate weathering degree in the Taiwan river basins belongs in the intermediate stage, which is close to a previous report (Selvaraj and Chen, 2006).

On the A–CN–K diagram, the main trend of silicate weathering in these drainage basins displays preferential leaching of CaO and Na_2O and then K_2O, and relative enrichment of Al_2O_3 (Fig. 3). Plagioclase is

Table 4
Major elemental concentrations and calculated CIA values of suspended particulate matter from the lower Changjiang mainstream at Nantong.

Samples	Sampling date	Mz	Al_2O_3 (wt%)	CaO (wt%)	K_2O (wt%)	Na_2O (wt%)	MgO (wt%)	WIP	CIA
NT-1	2008.4.3	7.75	19.28	2.36	2.79	1.43	2.23	46.3	71.4
NT-2	2008.4.10	7.17	18.97	2.57	2.89	0.99	2.19	42.1	74.8
NT-3	2008.4.18	7.84	20.74	1.31	3.05	0.77	2.03	40.5	78.0
NT-4	2008.4.24	7.37	18.76	2.13	2.94	0.97	2.18	42.3	74.6
NT-5	2008.4.29	7.30	17.33	2.42	2.67	0.95	2.29	40.0	74.2
NT-6	2008.5.9	7.39	20.42	2.80	2.62	0.91	2.28	39.1	77.8
NT-7	2008.5.15	7.72	24.26	1.89	2.15	1.10	1.95	36.4	80.3
NT-8	2008.5.21	7.81	24.53	2.25	2.68	1.49	2.25	46.2	75.8
NT-9	2008.5.27	7.28	17.51	2.93	2.67	0.95	2.38	40.3	74.4
NT-10	2008.6.6	7.07	12.93	4.19	2.01	1.04	2.23	35.2	69.8
NT-11	2008.6.15	7.68	20.31	2.81	2.96	0.86	2.46	41.9	77.1
NT-12	2008.6.2	7.01	17.21	3.84	2.68	1.25	2.44	44.0	71.0
NT-13	2008.6.27	7.64	20.23	1.77	2.87	0.84	2.13	40.0	77.5
NT-14	2008.7.4	7.53	19.88	2.18	3.02	0.90	2.40	42.8	76.1
NT-15	2008.7.11	7.75	21.03	1.84	3.05	0.93	2.41	43.4	76.7
NT-16	2008.7.18	7.01	18.18	3.64	2.63	0.99	2.39	40.5	74.8
NT-17	2008.7.24	7.38	19.06	4.19	2.97	1.17	2.76	46.4	72.9
NT-18	2008.8.2	7.14	16.82	3.83	2.68	0.98	2.43	40.9	73.2
NT-19	2008.8.8	7.11	16.82	4.36	2.82	1.16	2.70	44.8	71.0
NT-20	2008.8.14	7.69	18.14	3.60	3.01	1.00	2.82	45.0	73.4
NT-21	2008.8.22	6.85	15.82	4.65	2.72	1.01	2.69	42.2	71.6
NT-22	2008.8.29	7.43	15.58	5.67	2.65	0.89	3.14	41.6	72.8
NT-23	2008.9.6	7.59	17.62	6.03	3.15	1.06	3.27	48.1	71.8
NT-24	2008.9.11	7.58	18.16	4.27	3.01	1.03	2.85	45.4	73.2
NT-25	2008.9.19	7.10	14.99	5.79	2.60	1.18	2.93	43.9	69.1
NT-26	2008.9.26	7.50	16.41	5.71	2.81	1.10	3.26	45.7	71.1
NT-27	2008.10.4	7.34	16.57	6.33	2.78	1.16	3.30	46.2	70.8
NT-28	2008.10.11	7.52	17.97	4.74	3.03	0.90	2.95	44.3	74.2
NT-29	2008.10.18	7.31	15.88	4.77	2.67	1.21	2.76	44.3	69.8
NT-30	2008.10.25	7.16	17.97	4.19	2.84	0.97	2.80	43.1	74.1
NT-31	2008.11.1	7.54	17.75	4.48	2.92	1.01	2.77	44.2	73.2
NT-32	2008.11.8	7.51	21.50	2.29	3.06	0.84	2.59	42.9	77.9
NT-33	2008.11.15	7.35	16.98	4.23	2.75	1.08	2.58	43.0	72.2
NT-34	2008.11.22	7.52	18.61	3.13	2.95	0.73	2.39	40.1	76.9
NT-35	2008.11.29	7.27	17.89	4.64	2.84	0.93	2.64	42.3	74.4
NT-36	2008.12.6	6.89	19.40	3.16	2.82	0.85	2.45	40.6	76.8
NT-37	2008.12.14	7.17	17.16	3.74	2.67	1.01	2.40	41.1	73.3
NT-38	2008.12.20	7.57	20.12	3.01	2.95	0.96	2.53	43.2	76.0
NT-39	2008.12.27	7.16	18.91	3.80	2.88	0.91	2.65	42.4	75.5
NT-40	2009.1.3	7.54	19.44	3.40	2.98	0.98	2.61	44.0	75.0
NT-41	2009.1.8	7.51	18.35	3.26	2.85	1.21	2.47	45.0	72.2
NT-42	2009.1.15	7.35	16.80	4.00	2.71	1.01	2.55	41.7	72.9
NT-43	2009.1.20	7.52	18.38	3.60	2.83	0.94	2.68	42.3	74.9
NT-44	2009.2.4	7.27	17.99	3.38	2.83	1.11	2.41	43.6	72.8
NT-45	2009.2.10	6.89	17.11	4.20	2.74	1.20	2.62	44.5	71.1
NT-46	2009.2.18	7.67	19.32	2.41	2.87	1.28	2.64	46.5	72.5
NT-47	2009.2.28	7.23	16.53	3.32	2.62	1.26	2.47	43.7	70.3
NT-48	2009.3.8	7.47	18.42	2.53	2.61	0.97	2.20	39.5	75.4
NT-49	2009.3.15	7.14	15.54	3.49	2.45	1.15	2.27	40.4	70.7
NT-50	2009.3.22	7.30	18.51	1.88	2.70	0.87	2.09	38.8	76.1
NT-51	2009.4.3	7.69	19.33	1.60	2.65	1.01	2.02	39.8	75.8
Mean-1	Winter season		18.43	3.09	2.81	1.02	2.42	42.3	74.2
Mean-2	Summer season		18.17	3.93	2.76	1.04	2.64	42.9	73.6
Mean-3	All samples		18.30	3.50	2.79	1.03	2.53	42.6	73.9

Note: Mz = mean grain size; winter season refers to November to next April; summer season refers to May to October.

more susceptible to weathering than potassium feldspar, and thus, Ca and Na are leached preferentially over K (Nesbitt and Young, 1982, 1989). Overall, the weathering trend in the investigated Chinese river basins is parallel to the A–CN line, which implies the removal of the Ca- and Na-bearing silicate minerals from the parent rocks, and the K-bearing minerals remain less attacked. In contrast, the Zhujiang samples are parallel to the A–K line and approach the A apex more than the other river samples, most likely reflecting strong removal of K-bearing minerals from the parent rocks (Fig. 3). Despite the different weathering intensities registered in these sediments, most of the investigated river samples seem to be weathered from similar parent rocks, which is similar to the average compositions of CEC (Gao et al., 1998) and UCC (Taylor and McLennan, 1985) (Fig. 3). Furthermore, the average CIA of the Changjiang samples approaches the values of the world river average (Li and Yang, 2010) and that of NASC (Gromet et al., 1984). The rivers in Taiwan, however, exhibit different weathering directions by deviating from the main trend in the A–CN–K diagram (Fig. 3), suggesting that the average composition of weathered source rocks in the small river basins are more easily influenced by local provenance geology.

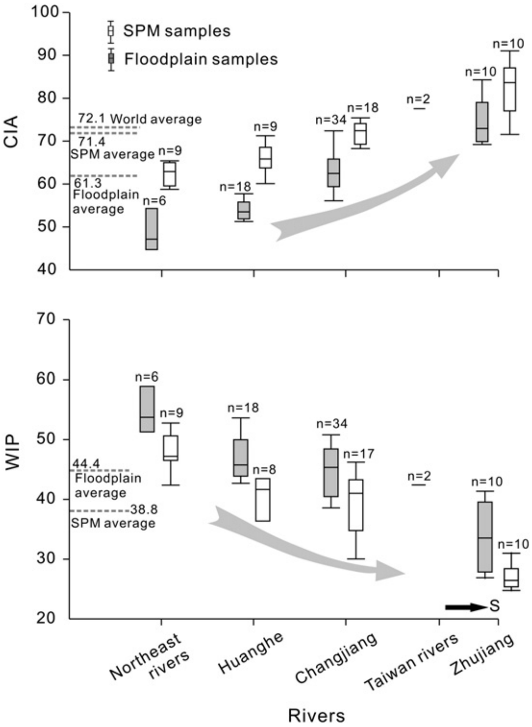

Fig. 2. Comparison of the average CIA and WIP values among the major rivers in China and between the floodplain and SPM samples in the same river; n refers to the numbers of river samples investigated. The overall increase of the CIA and decrease of WIP values from the northeast rivers to the southernmost Zhujiang River suggest gradual enhancing of weathering intensity towards south China.

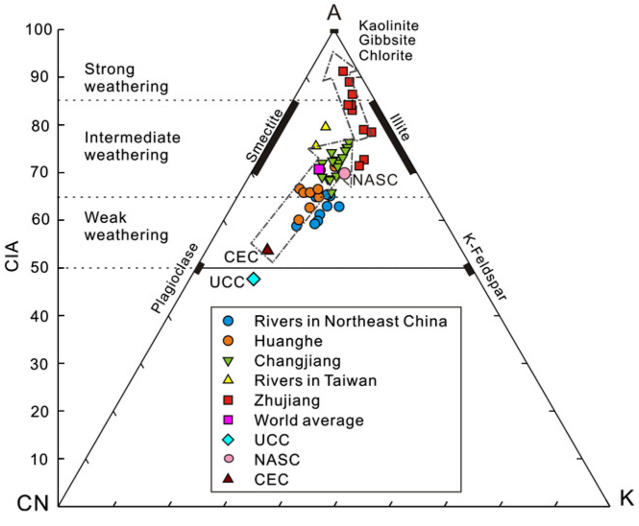

Fig. 3. The A–CN–K diagram of the SPM samples from the Chinese rivers. Note that most of the investigated rivers indicate weathering trends in parallel with the A–CN line.

5. Discussion

5.1. Controlling factors of chemical weathering in continents

The variations of the CIA and WIP in Chinese rivers suggest that different catchments experienced remarkably variable silicate weathering, enabling the potential construction of a consistent weathering history in continents. Despite the different opinions on the mechanism of chemical weathering, the key factors include provenance lithology, climate, tectonic relief, physical erosion, vegetation and hydrology (Velbel, 1993; Stallard, 1995; White and Blum, 1995; Gaillardet et al., 1999a; Millot et al., 2002; Yang et al., 2004; Tipper et al., 2006). The rock type is the first factor, if not a dominant one, in the chemical denudation (Meybeck, 1987). Numerous, more recent studies further highlight the control of source rock types on river water chemistry. However, the causal links between the chemical weathering and source rock types is difficult to define, as suggested by Li and Yang (2010), because the heterogeneous parent rocks cause the variable compositions of source rocks subject to weathering in different catchments, as is the case in China.

To date, determining whether chemical weathering on the continents is weathering-limited or transport-limited or significantly coupled with physical weathering is controversial (Raymo and Ruddiman, 1992; White and Blum, 1995; Gaillardet et al., 1999a, 2003; Yang et al., 2004; Viers et al., 2009; Li and Yang, 2010). Regarding climate forcing, some studies suggested that runoff basically controls the chemical weathering (Millot et al., 2002; Tipper et al., 2006), while others considered that temperature rather than runoff is more important (White and Blum, 1995; Dessert et al., 2001). Oliva et al. (2003) suggested temperature alone cannot control chemical weathering while major runoff (>1000 mm) matters. The relationship between physical weathering and chemical weathering largely depends on the climate regime (Stallard and Edmond, 1983). In the tectonically active catchment, the physical weathering exerts a dominant control on chemical weathering, while in a transport-limited regime, physical weathering plays a minor role on chemical denudation (Viers et al., 2009). To date, the tectonic-driven precipitation and climate variability have been considered the primary controlling factors on weathering and erosion, but their relative roles remain intensely debated (Raymo and Ruddiman, 1992; Dadson et al., 2003).

5.2. Constraints of CIA and WIP variations in Chinese drainage basins

5.2.1. Climatic constraint

Previous studies suggest that climate exerts a dominant control on silicate weathering in major drainage basins in China (Yang et al., 2004; Li and Yang, 2010). In this study, the CIA exhibits a better correlation with the average temperature, precipitation and runoff in the investigated rivers than the WIP does, although they vary almost synchronously (Fig. 4), suggesting the dominance of climate on chemical weathering in China and implying that the CIA may be more sensitive to climate variability than the WIP. The studied river basins from north to south are located in the frigid temperate to temperate zones (northeast rivers), the temperate zone (Huanghe), the warm temperate to subtropical (Changjiang), and the subtropical zones (Taiwan rivers and Zhujiang) (Chen and Wang, 1996). The studied drainage basins are mostly latitudinally distributed, which causes the annual averages of temperature, precipitation and runoff in these river basins to increase with decreasing latitude. In comparison, most of the other watersheds in the world are not latitudinal (see Fig. 1 in Li and Yang, 2010), which may cause poor correlations between the CIA and the annual temperature and runoff (Li and Yang, 2010).

Exceptions are the Taiwan rivers, which have greater runoff and precipitation but weaker chemical weathering than the Zhujiang (Figs. 2 and 3). The Taiwan rivers are well known for large rates of physical denudation and chemical weathering in the world, mainly because of the rapid uplift and abundant orographic rainfall associated with the Asian summer monsoon, frequent typhoon activities and storm-triggered landslides (Dadson et al., 2003; Milliman and Kao, 2005; Selvaraj and Chen, 2006; Kao and Milliman, 2008). In this sense, the chemical weathering in Taiwan is relatively restricted compared to that in the Zhujiang catchment because of the short residence time of eroded sediment in the island and the weak development of soil profile. In comparison, the major catchments in mainland China are mostly situated on tectonically stable craton or block, and the monsoonal climate, including temperature, precipitation and runoff, may comprehensively regulate the chemical weathering. The river basins in the south and low latitudes, where the stronger summer monsoon brings more precipitation and major runoff, are subjected to more intense chemical weathering than those in the north and west, where the monsoonal precipitation is much less.

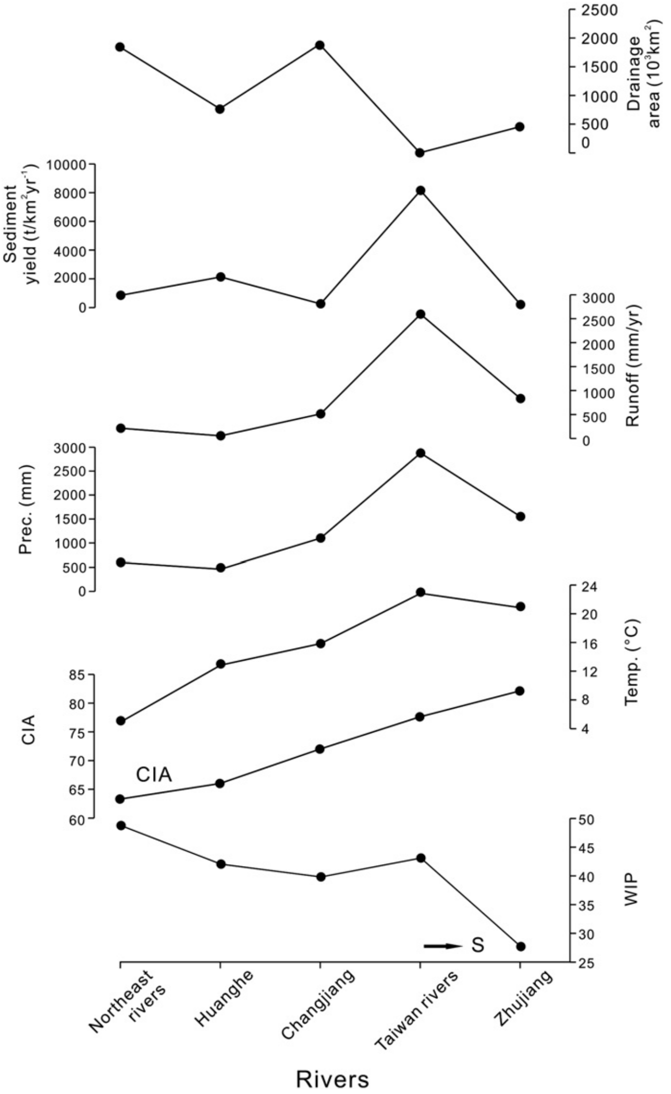

Fig. 4. Comparisons of the two indices (CIA and WIP) with average precipitation (Prec.), runoff, temperature (Temp.), sediment yield and drainage area between these rivers. Synchronous variability of the CIA and WIP with climate parameters, including precipitation, temperature and runoff, implies that monsoonal climate plays a dominant role in regulating chemical weathering in the catchments.

5.2.2. Constraints of sediment grain size on the CIA and WIP values

According to the calculation equation, the CIA primarily reflects the relative proportions of Al-, Ca-, Na- and K-bearing silicate minerals in sediments. Given different speciation of these major elements in minerals and variable geochemical behaviours during weathering, the sediment grain size may greatly influence the CIA value, which has been neglected in previous studies (Garzanti et al., 2010). In general, mud contains abundant clay minerals, while sands are more feldspathic and rich in quartz. The intensive chemical weathering causes the destruction of primary minerals and the production of fine-grained secondary minerals (Nesbitt et al., 1996). Thus, the chemical weathering and grain-size sorting influence each other.

As shown above, the CIA values in the SPM samples of the Chinese rivers are overall greater than those in the floodplain samples within the same river system (Fig. 2). The Changjiang sediments display a good correlation between the mean grain size (Mz) and the CIA relative to the Huanghe sediments (Fig. 5A, B), and the fine-grained SPM samples of the Changjiang have greater CIA values than the coarser floodplain samples (Fig. 5B). This observation obviously suggests that the sediment grain size can significantly affect the CIA values of fluvial sediments (Garzanti et al., 2010), and the greater CIA in the fine-grained sediments is primarily a result of the enrichment of aluminium in the weathering profile relative to the easily leached elements, including calcium, sodium and potassium.

In comparison, the WIP exhibits no obvious correlation with the grain size of the Changjiang sediments (Fig. 5C). This observation suggests that the WIP is an index independent of the sediment grain size, while the CIA relies on the grain size composition to a considerable extent. Recent work by Garzanti et al. (2010) suggested that settling equivalence and selective-entrainment effects in the fluvial environment could explain the discrepancy in the calculation of the CIA and WIP.

5.3. Correlation between two weathering indices

Both the CIA and WIP incorporate four elements (Al, K, Na, Ca versus Mg, K, Na, Ca, respectively) and have different calculation equations. The incorporation of Al and K in the CIA calculation is considered to be inappropriate because Al may also be mobile during intense weathering (Price and Velbel, 2003), and the precipitation of K-bearing phases during weathering leads to the selective fixation of potassium (von Eynatten et al., 2003). The application of the WIP to strong weathering profiles also remains uncertain mainly because the WIP only incorporates mobile elements (Price and Velbel, 2003). Another uncertainty in the utility of these weathering indices is their relationship with sediment grain size. The high correlation exists between the CIA and mean grain size but weak and no correlation between the WIP and grain size (Fig. 5), seemingly implies that the WIP is more appropriate than the CIA in evaluating weathering intensity.

In this study, both the CIA and WIP exhibit regular trends from the rivers in northeast China to the southernmost Zhujiang with decreasing latitude (Fig. 2), and both co-vary with the annual averages of precipitation, temperature and runoff within these river basins (Fig. 4). In all of the studied rivers, the CIA and WIP values in all of the SPM samples correlate well (Fig. 6A), exhibiting greater CIA and smaller WIP values with stronger weathering. This observation suggests that these two weathering indices, despite their different correlations with sediment grain size, can be applicable to evaluate the weathering intensity at the basin scale (Duzgoren-Aydin et al., 2002; Price and Velbel, 2003).

However, the CIA and WIP exhibit very different trends in special rivers, such as the Changjiang. The CIA values of both the SPM and floodplain samples from the upper Changjiang reaches are overall greater than those from the mid-lower reaches (Fig. 6B), which suggests that the mid-lower Changjiang basin undergoes stronger chemical weathering than the upper watershed. Many of the other lines of evidence, such as the illite crystallisation index and river water chemistry, suggest increasing weathering intensity towards the mid-lower Changjiang valley (Li, 2003; Mao et al., 2010). The WIP, however, does not always follow the trend of the CIA, yielding smaller values in the SPM samples from the upper reaches (Fig. 6B). The upper Changjiang basin is characterised by diverse parent rock types, high relief, active tectonic uplift, overall poor vegetation and

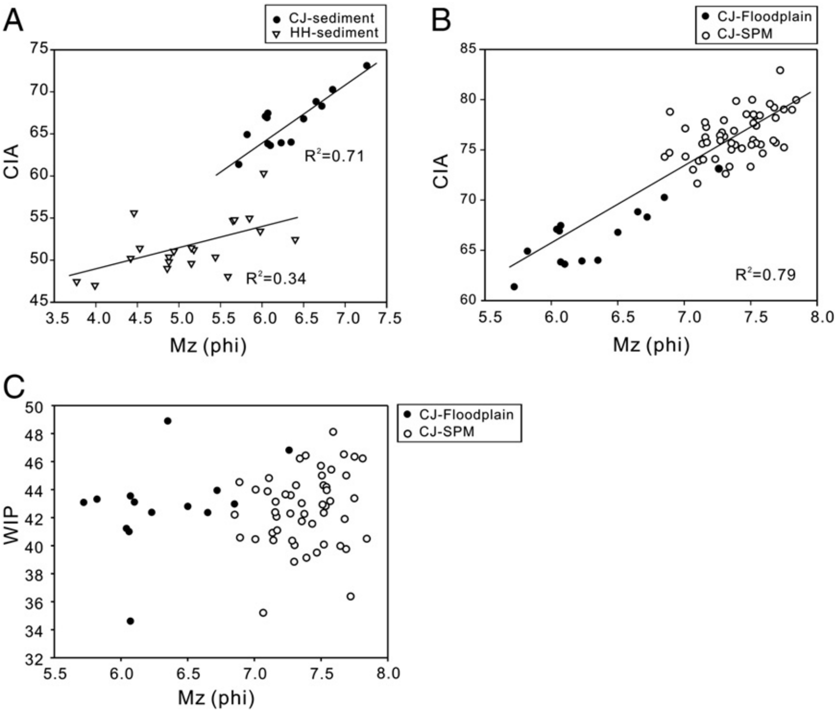

Fig. 5. Correlation of weathering indices with mean grain size (Mz) in the sediments. A) Relationship between the CIA and Mz in the floodplain sediments from the Changjiang and Huanghe; B) relationship between the CIA and MZ in the SPM and floodplain sediments from the Changjiang; C) relationship between the WIP and Mz in Changjiang sediments. Compared to the CIA, the WIP exhibits poor correlation with sediment grain size.

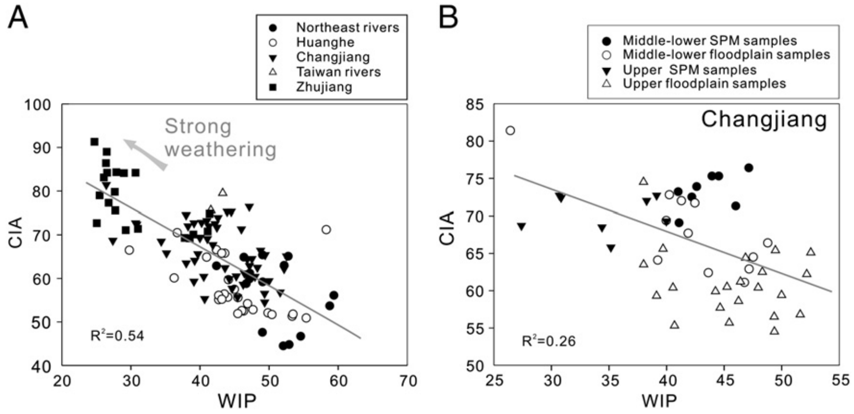

Fig. 6. Correlation between the CIA and WIP in the sediments from major Chinese rivers (A) and in the SPM and floodplain sediments from the Changjiang (B). The correlation between the CIA and WIP in a specific river is not so obvious as shown between different rivers.

soil development. Thus, the intense physical erosion reveals more fresh rocks exposed to weathering. However, the chemical weathering in the upper basin is overall weaker than in the mid-lower valley because of an unfavourable monsoon climate (Li, 2003; Mao et al., 2010). At present, we cannot answer what causes the poor indication of the WIP for weathering intensity within a specific river basin, although it seems that different calculations (elements incorporated) matter. In fact, the difference of the CIA between these studied Chinese rivers is more obvious than that of the WIP, also suggesting that in some sense, the CIA is more sensitive to integrated weathering in large drainage basins, at least in the case of China.

5.4. Seasonal variation of CIA indicating weathering intensity?

The dissolved loads in the river water can directly reflect the instantaneous chemical weathering in the watershed, while the particulate matter, including suspended and floodplain sediments, may have undergone recycled weathering and thus may reflect an integrated weathering process (Grantham and Velbel, 1988; Johnsson and Stallard, 1989; Viers et al., 2009; Li and Yang, 2010; Bouchez et al., 2011). In this study, the suspended samples were collected weekly from April, 2008 to April, 2009 in the lower Changjiang mainstream at Nantong, with the main goal being to testify whether the CIA can reflect the instantaneous silicate weathering in the drainage basin.

The CIA in the suspended samples of the lower Changjiang mainstream varies between 69.1 and 80.3 and averages 73.9 (Fig. 7). The large and irregular fluctuation of the CIA occurs in the one-year samples, both showing decreasing trends during the summer/flood season from May to October (averaging 73.6) and during the winter/dry season from November to next April (averaging 74.2). The CIA does not display much larger values as expected during the summer season, which accounts for approximately 70–90% of the annual monsoon precipitation in the entire basin. The irregular seasonal variation of the CIA in the lower Changjiang mainstream confirms the idea that the CIA cannot directly reflect instantaneous silicate weathering in the drainage basin, most likely because of the complex sources of the suspended loads into the lower mainstream. The average CIA in the SPM samples of the upper Changjiang is approximately 70.3, which is less than that in the mid-lower reaches (73.4) and seemingly reflects the increasing intensity of silicate weathering from the upper to lower reaches. The upper Changjiang valley above Yichang, which occupies 56% of the entire basin area with variable provenance rock types and climate regimes, overall, has lower temperature and less precipitation than the more humid mid-lower valley. The soil and floodplain are also more developed in the mid-lower basin because of the greater runoff and low relief. Thus, it is inferred that the greater CIA values in the mid-lower reaches are the result of stronger chemical weathering. The larger CIA values in May, June and July are mainly caused by the major contribution of suspended sediment from the mid-lower reaches at that time when the plum rain (Meiyu) happens. During the period from August to October, the monsoonal rain shifts to the upper reaches, which may erode and transport more suspended sediment with lower CIA values from the upper valley to the lower mainstream. During the dry season, the sources of sediment into the lower mainstream become complex because of less but variable precipitation in the basin. Moreover, the water impoundment of the Three Gorges Reservoir during the dry season can trap a large volume of the suspended sediments eroded from the upper reaches. Both factors can change the transport pattern of fine-grained sediments from the

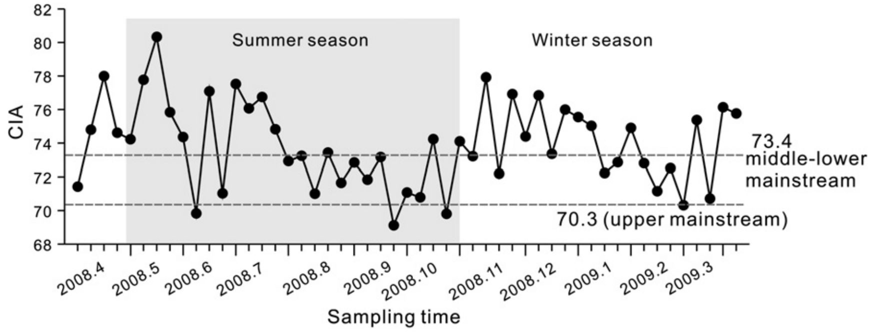

Fig. 7. Seasonal variation of the CIA in the SPM samples from the lower Changjiang mainstream at Nantong. The shaded area indicates summer season from May to October. The averages of the CIA values in the upper reaches and in the mid-lower reaches are shown for comparison.

watershed to the estuary and, thus, influence the variation of the CIA in sediment. Nevertheless, this topic is beyond the scope of the present study and deserves more research attention in the future.

6. Conclusions

The aim of this paper is to present a general view on the variability of the CIA and WIP values and the constraints on chemical weathering in Chinese watersheds. The increased weathering intensity in the Chinese drainage basins from north to south is indicated by the increasing CIA and decreasing WIP in the suspended and floodplain sediment samples. Both indices of the CIA and WIP can reflect the weathering intensity in Chinese river basins, despite the heterogeneity in the provenance geology, climate and parent rock types. These investigated catchments constitute a broad and consistent spectrum of chemical weathering from weak to intermediate/moderate to strong stages. Chemical weathering in the Chinese drainage basins, especially in the tectonically stable mainland, is predominantly regulated by the monsoonal climate, as evidenced by the high correlations between the two indices and the annual averages of temperature, runoff and precipitation in the catchments. The optimum climate in the Taiwan river basins, however, does not lead to intensified silicate weathering, mainly because strong tectonic uplift and typhoon-driven erosion rapidly transport the sediments to the sea; thus, the sediments have a short residence time for chemical weathering.

Chemical weathering in the drainage basins is constrained by complicated factors, which makes it impossible to establish a simple and uniform law for regulating the chemical erosion on continents. The different correlations between the mean grain size and two proxies suggest that the settling equivalence and the selective-entrainment effect in the fluvial environment may considerably influence the values of the CIA and WIP.

The seasonal suspended samples from the lower Changjiang mainstream do not show regular variation in the CIA during the summer and winter seasons, which confirms that the CIA as a proxy cannot directly reflect the instantaneous chemical weathering on continents but indicates the integrated weathering intensity registered in sediments with superimposed grain-size effects. Thus, we should be prudent in using the CIA and WIP as reliable proxies to reconstruct the paleoweathering intensity and paleoclimate changes at short time scales.

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