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与 2008 年汶川地震相关的岷江溶解态离子组成变化

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摘 要：河流化学蕴含着有关化学风化过程、从陆地到海洋物质输移通量以及全球碳循环的重要信息。虽然河流化学的短时间尺度（月至十年级）变化已得到广泛认识，然而由于大多数观测记录的时间跨度有限，百年及更长时间尺度河流化学的变率还很难直接评估。特别是对于高强度、低频率事件（发生频率大于百年）对河流化学影响更是难以评估，因为它们发生的频次极低。2008 年汶川 8.0 级地震为评价这种巨大的、罕见的地质事件对河流系统水化学的影响提供了一次非常珍贵的自然实验场，特别是对于四川省境内的岷江流域。与已发表的 2008 年以前的数据相比，在地震后 2010 年上半年收集的岷江河水的溶解态元素组成表现出显著的差异。来自硅酸盐矿物的阳离子（特别是 Na^+ 和 K^+）浓度及 Na/Ca 和 K/Ca 比值均有增加，而 Si^{4+} 及 Ca/Si 比值变化很小，这表明地震时和地震后山崩 / 崩塌的粉碎过程形成了新鲜的硅酸盐矿物表面，从而提供易于溶解的离子进入河水。由此造成的河水化学插曲式的变化可能代表了一个以前尚未认识的过程，这对于量化长时间尺度河流溶解态物质输移和理解矿物风化过程均具有重要的指示意义。

关键词：河水化学；2008 汶川地震；地表过程；化学风化
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Changes in dissolved ion concentrations of the Min Jiang associated with the 2008 Wenchuan earthquake

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Abstract: The chemistry of rivers provides important information about chemical weathering processes, fluxes of material from the continents to the oceans, and the global carbon cycle. While short-term (monthly to decadal) variations in river chemistry are widely recognized, long-term (centennial and longer) variability is more difficult to assess directly because of the limited time-span of most observational records. In particular, the influence of high-magnitude, low-frequency events (with return times >100 years) is difficult to assess because they occur only very infrequently. The 2008 Wenchuan 8.0 Mw earthquake presents a potentially valuable natural experiment for shedding light on the effects of a major, rare geologic event on the dissolved chemistry of river systems, specifically on the Min Jiang in Sichuan Province, China. Dissolved element concentrations in Min Jiang samples collected after the earthquake, in early 2010, show significant differences when compared to published data on concentrations measured in samples collected prior to 2008. Increases in concentrations of cations derived from silicate minerals (particularly Na^+ and K^+), and in Na/Ca and K/Ca ratios, combined with little change in Si^{4+} concentrations, or in Ca/Si ratios, suggests that comminution processes in co-

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seismic and post-seismic landslides may produce fresh silicate mineral surfaces that provide easily leached cations to the river. The resulting episodic change in river chemistry may represent a previously undocumented process, with implications for quantifying long-term riverine transport of dissolved material, and for understanding mineral weathering processes.

Key words: river chemistry; 2008 Wenchuan earthquake; surface processes; chemical weathering

1 Introduction

The dissolved chemistry of rivers provides important information about natural environmental processes. In particular, river waters carry the imprint from the chemical reactions of water with rocks, sediments, and soils, and thus provide insights into the nature and rates of these reactions. The chemistry of rivers, from the scale of first-order streams draining small catchments (<1 km^2 area) to the world's largest rivers (many thousands of km^2 area), has provided much of the foundation for modern understanding of chemical weathering processes, and of associated fluxes from the continents to the oceans. In many but not all cases, the chemistry of river systems is constrained by very limited data, often from the analysis of single spot samples collected at one time (e.g. Gaillardet et al, 1999). Though accurately representing river chemistry at the specific moment when collected, it is difficult to assess how representative such single spot samples may be of integrated river chemistry over longer time periods. One problem, now generally recognized, is the short-term (e.g. seasonal) variability in dissolved chemistry, which may for example result from seasonal changes in the hydrologic regime (e.g. Tipper et al, 2006; Jin et al, 2010). However another problem that has received less attention is the potential change in river chemistry in response to discrete geologic events that may occur relatively infrequently. A significant influence from such events might mean that standard observational records do not capture a picture of dissolved chemistry that represents long-term reaction rates, or long-term integrated fluxes of dissolved material such as nutrients, alkalinity, and carbon to the oceans.

It is difficult to assess the effects of rare, large geologic events precisely because they only occur rarely, and are therefore challenging to observe directly. Moreover, measuring change associated with such an event requires sufficient background data to allow comparison with the observations made after the event. This study presents the initial results of work exploiting the 2008 Mw 8.0 Wenchuan earthquake as a natural experiment, investigating the effects of the earthquake on the dissolved chemistry of the Min Jiang river system in the Longmen Shan mountain range of Sichuan, China. This is an effective natural experiment because of the relatively high magnitude of the event, and the extensive background dataset on the chemistry of the Min Jiang prior to the earthquake.

2 Study Site

The Min Jiang is a principal tributary of the Yangtze River and is one of the main rivers draining the Longmen Shan, a mountain range which defines the eastern margin of the Tibetan Plateau and the northwestern edge of the Sichuan basin. The Min Jiang and its tributaries have incised deep valleys with steep slopes (angles often >30°) across the dramatic topographic gradient of the Longmen Shan, which rise from the Sichuan basin at ~500 m to peaks over 6000 m, an increase in mean elevation of ~3500 m over less than 100 km (Zhang et al, 2011). The geology (see Fig.1; Burchfiel et al, 1995; Robert et al, 2010) reflects the history of ongoing India-Asia collision. The northwest of the region is dominated by the Mesozoic Songpan-Ganze flysch, an intensely folded, moderately metamorphosed detrital sequence that is intruded by granitic plutons. Between the Songpan-Ganze flysch and the plateau margin lies a series of green schist-facies shallow margin sediments, including detrital and carbonate deposits. The margin itself is defined by the basement core of Proterozoic granitoids and high-grade metamorphic rocks, including the Pengguan massif, which is bounded by the Wenchuan and Beichuan faults. Further to the east are frontal units of the Longmen Shan, consisting of Mesozoic detrital sediments. With the exception of these frontal sediments, the Min Jiang drainage in the study area

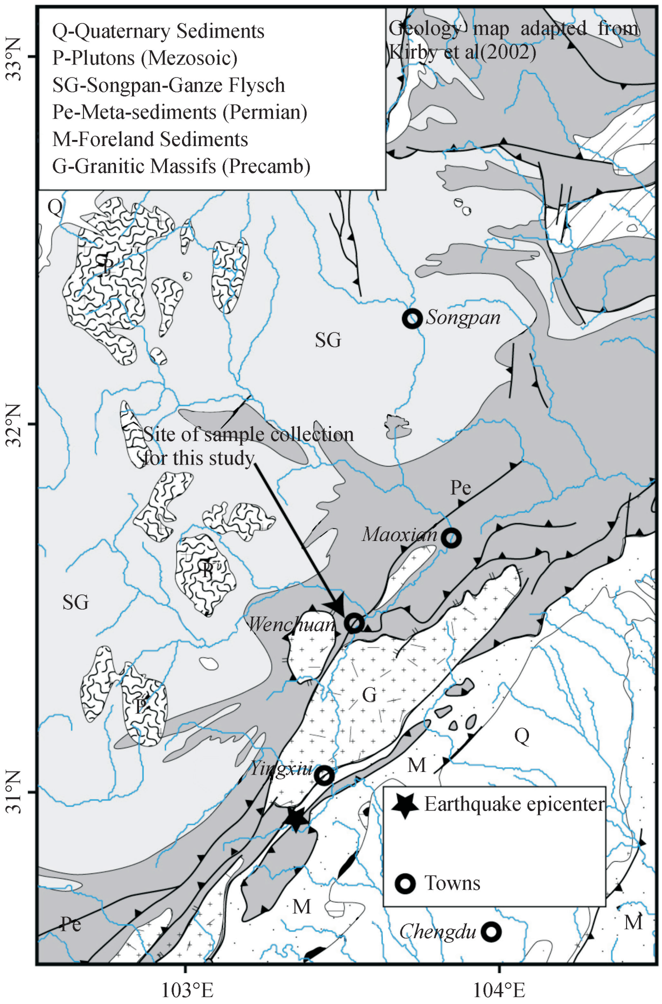

Fig.1 Map of the study region of the Min Jiang river basin, showing regional geology, the epicentre of the 2008 Mw 8.0 Wenchuan earthquake, and the location where samples were collected as part of this study (at the Weizhou hydrological station, in Wenchuan town).

The chemistry of samples collected in this study, in 2010, is compared to that reported by Qin et al (2006), for samples collected in May 2001 at a similar location in Wenchuan town (their sample CJ0203), and across the 2001 annual hydrograph near to the town of Yingxui.

includes the wide range of heterogeneous Longmen Shan lithologies.

The 8.0 Mw Wenchuan earthquake, also referred to as the 2008 Sichuan earthquake, occurred on May 12th, 2008, along a series of thrust faults at the mountain front of the Longmen Shan (Fig.1). Seismicity on the Longmen Shan fault zone is attributed to Indo-Eurasian collision. The Wenchuan earthquake generated a surface rupture along ~250 km length of the Longmen Shan (or Wenchuan) fault between Yingxui and Beichuan, and along ~72 km length of the secondary Pengguan (or Beichuan) fault (Hao et al, 2008). Rupture propagated from the epicentre towards the northeast during the main earthquake; aftershocks were distributed across the rupture zone.

The Wenchuan earthquake triggered >100000 landslides with a total cumulative area of 560 km^2 — more than 4% of land area in the region (Parker et al, 2009). The distribution of landslides appears to have been controlled by a combination of hillslope gradients, bedrock lithology, and the magnitude of ground shaking during the earthquake (Ouimet, 2010). Prior to the earthquake, the extent of landslides in the region was minimal, partly a reflection of the long (~4000—8000 yr) recurrence interval expected for large earthquakes on these faults (Densmore et al, 2007; Kirby, 2008). The 2008 Wenchuan event thus offers a unique opportunity to explore the effect of a major, singular disturbance. The highest co-seismic landslide density is focused along the Min Jiang valley between Maoxian in the north (upstream) and Yingxiu in the south (downstream), and this section of river is the focus of this study, looking at the dissolved chemistry of the river system before and soon after the earthquake.

3 Methods

Regular hydrologic monitoring of the Min Jiang is operated by the Chinese Hydrology Bureau (CHB) at the Weizhou Hydrological Station, in the town of Wenchuan (Fig.1). Samples for the present study were collected at this site at weekly intervals from 7 December 2009 through 3 May 2010. Each sample was collected from the river in a 1.0 L polypropylene bottle, and filtered at the adjacent hydrological station as soon as possible following collection, using vacuum filtration with 0.2 μm nylon membrane filters. Aliquots of filtered sample were collected in 60 mL polypropylene bottles pre-cleaned with 6 M quartz distilled HNO_3 and acidified to pH <2, and analyzed by ICP-AES, using a Leeman Labs Profile ICP-AES at the State Key Laboratory of Lake Sciences and Environment to determine concentrations of cations (Ca^{2+}, Mg^{2+}, Na^+, K^+, and Sr^{2+}) and Si^{4+}. One 30 mL filtered un-acidified sample was collected for anion analysis. Anions concentrations for F^-, Cl^-, NO_3^-, and SO_4^{2-} were determined by ion chromatography using a Dionex-600 at the Institute of Earth Environment, Chinese Academy of Sciences. The average replicate-sample reproducibility was 0.5%~1% (2σ). Dissolved inorganic carbon (DIC) was determined by Gran titration; HCO_3^- was calculated on the basis of being the only DIC species. The results of these analyses are presented in this paper.

The results for samples collected and analyzed in this study are compared to the data reported by Qin et al (2006) for samples collected from the Min Jiang in 2001, prior to the Wenchuan earthquake. Qin et al collected a single sample (CJ0203) at a site equivalent to the Weizhou Station, where sampling in the present study was completed. This was collected in May 2001, and therefore in a different season when compared to most of the samples in the present study. To account for potential bias from seasonal variability in dissolved chemistry, the data presented here is also compared to the monthly time series collected by Qin et al at Xuankou, downstream along the Min Jiang from the Weizhou Station. This makes it possible to compare the present dataset both to samples collected from equivalent locations, and at equivalent times of the year.

4 Results

Dissolved chemical concentrations for samples collected in December 2009—May 2010 from the Min Jiang at Weizhou are shown in Table 1. The cationic and anionic charges ($TZ^+ = 2Ca^{2+} + K^+ + 2Mg^{2+} + Na^+$ and $TZ^- = HCO_3^- + Cl^- + 2SO_4^{2-} + NO_3^-$) range from 3495 to 4139 μEq and from 3354 to 4092 μEq, respectively. Their Normalized Inorganic Charge Balance ($NICB = (TZ^+ - TZ^-)/TZ^+$) is ~5%, i.e. charge balance on anion and cation analyses for all samples was within 5%, equivalent to the estimated analytical precision. The most concentrated cation in the river waters is Ca^{2+}, with concentrations of 1006~1150 μM, followed by Mg^{2+} (560~745 μM). K^+ is the least abundant of the major cations. This is consistent with the composition of other river systems draining the Himalayan-Tibetan Plateau Region, which are also dominated by Ca^{2+} and Mg^{2+}, and generally dilute in K^+ (e.g. Galy and France-Lanord, 1999; Hren et al, 2007). The total cation concentration ($Ca^{2+} + Mg^{2+} + Na^+ + K^+$) is 1904~2264 μM, which is high relative to tributaries of the Brahmaputra (Hren et al, 2007) but is similar to some of the more concentrated rivers draining the frontal slope of the Himalaya in Nepal (Galy and France-Lanord, 1999). Ca/Na molar ratios are relatively high (2.67~3.78), typically characteristic of waters dominated by carbonate dissolution, but Ca/Sr molar ratios are relatively low (318~341), more consistent with a silicate source of dissolved cations (e.g. Blum et al, 1998). Cation concentrations show a slight decrease towards the end of the sampling period, in mid-March 2010, which may reflect the early onset of the rainy season (Fig.2). Other than this slight decrease, concentrations show little temporal variation at the weekly timescale, over the course of the sampling period.

Table 1 Cation concentrations of samples collected during December 2009 and May 2010 from the Weizhou hydrological station on the Min Jiang

Sample ID	Sampling Date	Ca^{2+}	K^+	Mg^{2+}	Na^+	Si^{4+}	Sr^{2+}	F^-	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-
		Concentration (μM)										
wz09-1	7-Dec-09	1081	38.0	630	259	110.8	3.08	4.2	66.4	18.6	254	3303
wz09-2	14-Dec-09	1081	38.7	667	305	111.0	3.17	4.3	69.3	19.3	234	3165
wz09-3	21-Dec-09	1114	38.7	644	311	110.8	3.17	5.0	104.4	19.4	284	2946
wz09-4	28-Dec-09	1083	40.4	670	304	109.8	3.19	3.9	98.4	17.8	270	3120
wz10-1	4-Jan-10	1103	35.9	643	308	112.4	3.15	3.9	95.8	19.4	280	3002
wz10-2	12-Jan-10	1075	42.6	694	349	115.6	3.41	4.9	116.1	29.3	317	3116
wz10-3	18-Jan-10	1128	42.0	716	345	118.2	3.50	4.4	115.5	33.7	407	3024
wz10-4	25-Jan-10	1160	39.6	672	306	110.8	3.28	5.4	84.4	21.6	309	3047
wz10-5	1-Feb-10	1098	36.5	702	289	101.4	3.34	4.3	59.2	15.1	308	3091
wz10-6	8-Feb-10	1094	38.0	685	318	102.1	3.30	4.1	111.1	15.4	306	3043
wz10-7	15-Feb-10	1102	37.2	694	299	102.0	3.27	5.3	85.9	20.1	290	3129
wz10-8	22-Feb-10	1102	38.3	698	306	101.2	3.31	4.0	70.7	20.0	308	3045
wz10-9	1-Mar-10	1090	39.5	717	330	104.3	3.41	4.5	71.8	20.0	306	3163
wz10-10	9-Mar-10	1121	41.1	723	374	106.5	3.42	4.3	125.6	7.8	375	3209
wz10-11	15-Mar-10	1121	43.2	745	328	108.4	3.48	4.3	85.8	21.8	317	3171
wz10-12	22-Mar-10	1130	40.8	701	325	107.0	3.45	3.7	87.3	15.4	342	3088
wz10-13	28-Mar-10	1112	41.5	709	352	111.7	3.38	4.1	103.4	18.9	328	3141
wz10-14	4-Apr-10	1086	41.2	644	392	107.7	3.19	4.9	151.3	12.4	310	2956
wz10-15	12-Apr-10	1048	39.8	609	304	108.0	3.06	4.5	82.1	22.0	273	2871
wz10-16	19-Apr-10	1028	48.0	681	341	107.3	3.54	4.9	111.0	15.9	387	3005
wz10-17	26-Apr-10	1124	44.1	559	321	108.3	3.10	5.3	109.7	786.4	269	2029
wz10-18	3-May-10	1010	36.1	585	277	103.0	2.99	3.2	71.8	21.0	215	2832

The dominant anion in the analyzed samples is HCO_3^- (concentrations 2029~3303 μM), followed by SO_4^{2-} (215~407 μM), and Cl^- (59~151 μM). Samples collected in this study have significantly higher HCO_3^- concentrations than observed in the Brahmaputra system, though as in the case of the cation concentrations, the anion concentrations are in a similar range to some Himalayan rivers in Nepal (Galy and France-Lanord, 1999). There is little observable change in the anion concentrations over the course of the sampling period reported here (Fig.2)

5 Discussion

Fig.3 shows concentrations of major elements in samples collected in this study, compared with concentrations of the respective element analyzed by Qin et al (2006) in samples collected before the earthquake, in 2001. The key feature of this comparison is the significantly higher Na^+ concentrations (by a factor of ~3x) and K^+ (by a factor of ~2x) in 2010 compared to 2001, with no distinguishable change in concentrations of other measured elements (Ca^{2+}, Mg^{2+}, Sr^{2+}, and Si^{4+}). Among the anions, Cl^- concentrations are higher and more variable in the 2010 samples when compared with 2001, but SO_4^{2-} concentrations are similar. A simplified correction for Na^+ derived from silicate mineral sources can be made as:

$$Na_{sil} = Na^+ - Cl^-$$

on the basis that non-silicate Na^+ is either from evaporites (NaCl), in bedrock or delivered in

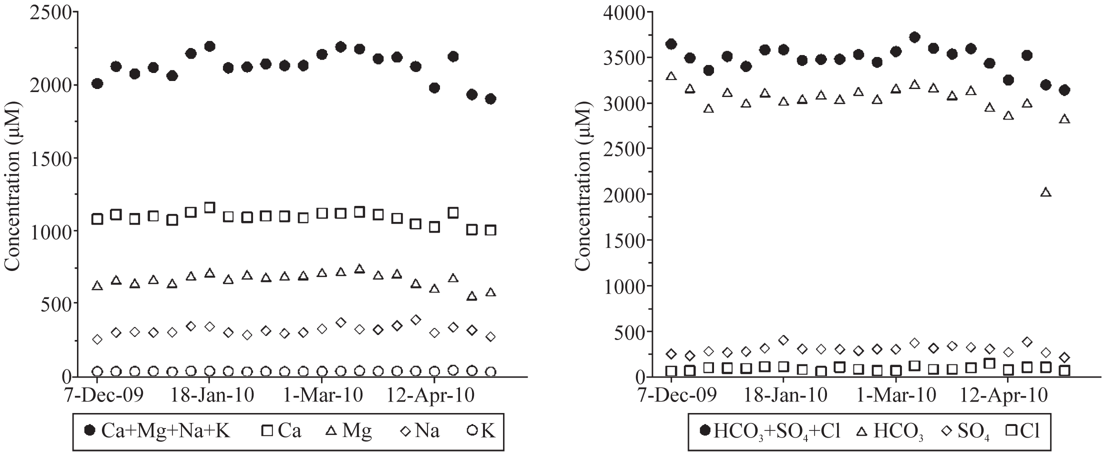

Fig.2 Concentrations of major cations in Min Jiang river water samples collected weekly between December 2009 and May 2010

Ca^{2+} is the dominant cation, followed by Mg^{2+} and then Na^{+}, with low concentrations of K^{+}. HCO_3^{-} is the dominant anion, followed by SO_4^{2-} and Cl^{-}. There is little variability in the cation or anion concentrations over the sampling period represented here, with only a slight dilution towards the end of this period possibly reflecting the beginning of the rainy season in the Longmen Shan.

atmospheric dust, or from atmospheric sea salts. Na_{sil} is ~2—3x higher in 2010 compared to 2001. Elemental concentrations, even corrected concentrations such as Na_{sil}, may be influenced by relative dilution at varying river discharge, as evidenced by the degree of seasonal variation in the 2001 dataset. Na^{+}, Si^{4+}, Sr^{2+}, Cl^{-}, and SO_4^{2-} concentrations, and to a lesser extent Mg^{2+} and K^{+} concentrations, all show dilution during the rainy season (May—August). Significantly different flow conditions in 2010 as compared to 2001 could potentially bias the comparison of elemental concentrations between these years.

Elemental ratios avoid this potential complication, because they are not directly influenced by relative dilution. Elemental ratios also show seasonal variation in many river systems, which may be driven by changes in contribution of water from different hydrologic pathways, with distinct chemical compositions (e.g. Tipper et al, 2006). Molar ratios of Na/Ca, Sr/Ca, and Na/Si all show seasonal changes in the Min Jiang system, evident in the data collected across the full annual cycle in 2001 (Fig.4). These variations are consistent with contribution during the dry season from a source with high Na/Ca and Sr/Ca, possibly representing groundwater flowpaths with relatively long residence times that provide the opportunity for acquisition of cations (particularly Na^{+}) from dissolution of silicate minerals. There are very distinct changes in the elemental ratios of the Min Jiang dissolved chemistry between 2001 and 2010. For the time of year when the 2010 samples were collected, the ratios of Na/Ca, K/Ca, and Na/Si all show marked increases as compared to 2001, while the Sr/Ca and Ca/Si ratios show little change. Similarly, the ratios of Na_{sil}/Ca and Na_{sil}/Si show significant increases between 2001 and 2010. The Mg/Ca ratio changed only very slightly. Observed changes indicate a shift towards a source more enriched in Na^{+}, K^{+}, and to a lesser extent Mg^{2+}, following the earthquake. There is the possible slightly indication of an increase in the Cl/SO_4 ratio, but this is not convincing.

The changes observed between the 2001 and 2010 samples are significantly greater than the compositional variability observed in the long-term record of dissolved chemistry collected by the CHB, and reported by Qin et al (2006). In fact, these authors reported a slight trend towards increasing Ca^{2+} concentrations over time between the 1970s and 2000, along with decreasing ratios of Na/Ca, which is the opposite of what is observed in the present comparison between 2001 and 2010. This lends confidence to the assertion that differences between the 2001 and 2010 datasets can be attributed to the specific effects of the Wenchuan earthquake.

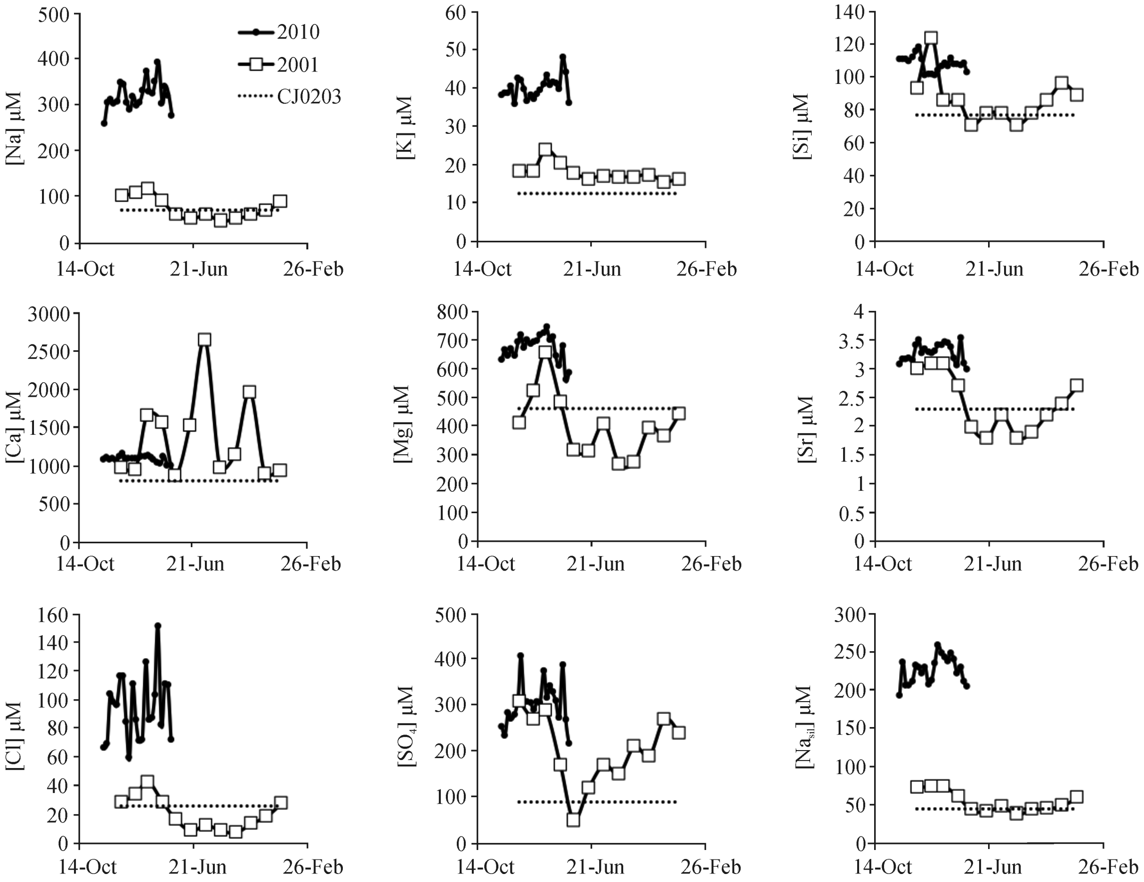

Fig.3 Comparison of observed major element concentrations in 2010, as compared to 2001, when samples were collected by Qin et al (2006).

The 2001 time series (open squares) were collected at Xuankou, slightly downstream of the 2010 sampling site, at Weizhou. The dashed line represents the value of the single sample (CJ0203) collected near to the Weizhou site in May 2001, later in the year than the samples collected in 2010. Cation concentrations in the 2001 time series from Xuankou, and in the May 2001 single sample from Weizhou, are similar, and chemically distinct from the samples collected in 2010. The concentrations of Na^+, K^+, and Cl^-, and to a lesser extent Mg^{2+}, show significant increases in 2010, as compared to 2001, while the concentrations of other elements remain largely unchanged.

One possible explanation for the change in elemental composition of the dissolved load in association with the earthquake could be an enhanced contribution from groundwater to the river discharge. Groundwater is likely to be relatively enriched in Na^+ and K^+, because of the longer time for reaction with silicate material (e.g. Tipper et al, 2006; Cartwright et al, 2007). It may also be enriched in Cl^- derived from deep brines, or from evaporite minerals in bedrock at depth. There is evidence for significantly hydrologic changes associated with earthquake events elsewhere (e.g. Whitehead et al, 1983; Lee et al, 2002), including the release of significant groundwater into river systems. However, it is unlikely that such a change could continue to affect the Min Jiang over a period of >18 months, which would be necessary for it to explain the chemical data from 2010. Moreover, while the increase in Na^+, K^+, and Cl^- concentrations agrees with a groundwater explanation, the broader geochemical signatures before and after the earthquake are less consistent with groundwater. For example, the pattern of seasonal variability in Ca/Si from 2001 suggests that groundwater is relatively enriched in Si^{4+} relative to Ca^{2+} (with higher Ca/Si in the dry season, when groundwater is expected to dominate total flow). However, in the comparison between 2001 and 2010 samples, there is no change in the Ca/Si ratio, even though the ratios of Na/Ca and K/Ca change significantly. The possibility cannot be excluded that the earthquake released groundwater with a geochemical signature distinct from groundwater characteristic of the normal annual hydrograph, but overall, the geochemical

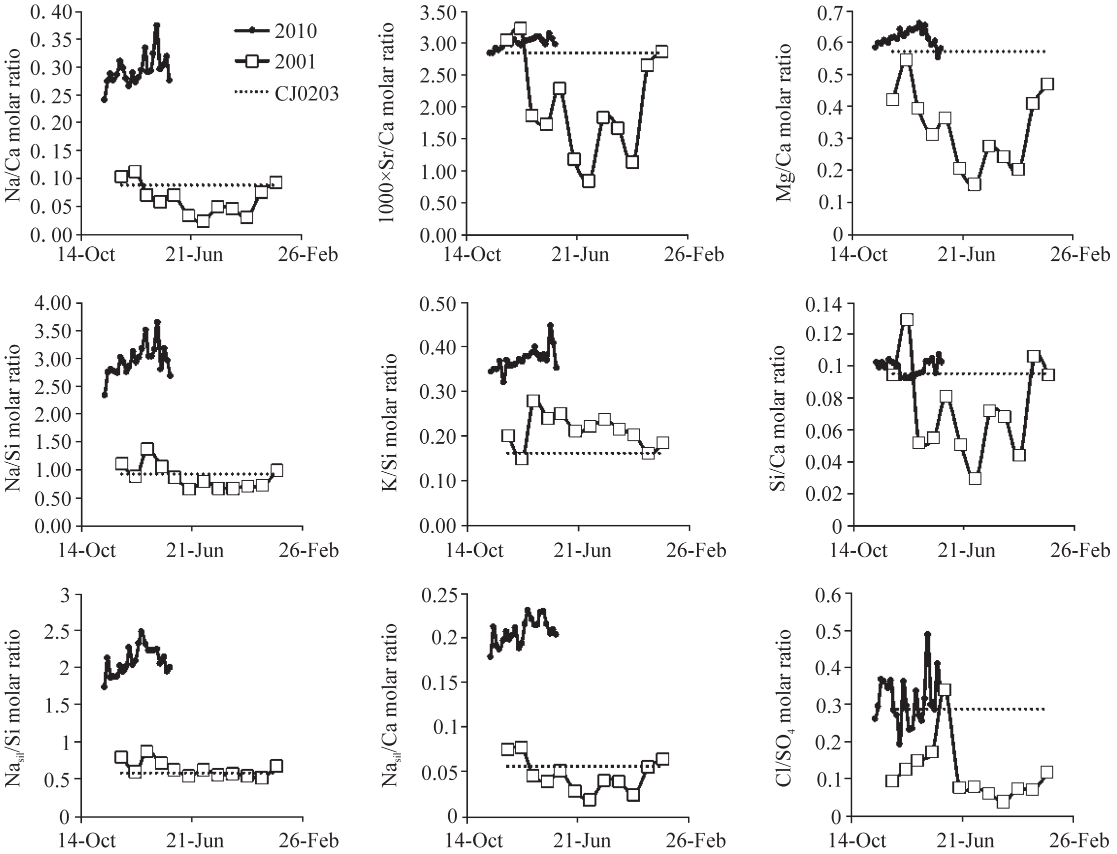

Fig.4 Changes in elemental ratios of the Min Jiang between 2001 and 2010

The increases in Na$_{sil}$/Ca, Na$_{sil}$/Si, and K/Si ratios are all indicative of a shift towards a greater contribution from silicate mineral sources, as compared to carbonate weathering. The lack of change in Sr/Ca and Ca/Si between 2001 and 2010, in contrast to the marked seasonal changes in both ratios, suggests that the increase in contribution from Na$^+$ and K$^+$ is not from a change in river system hydrology leading to increased post-earthquake contribution from groundwater. There is possibly a slight increase in the Cl/SO$_4$ ratio, but this is not significant when taking into account the scatter in the data, and the difference between CJ0203 in 2001 (the dashed line), and the other 2001 samples.

evidence suggests that the changes in Min Jiang dissolved chemistry associated with the earthquake were probably not driven by changes in the hydrology of the river system.

Instead, the suggestion here is that geochemical changes indicate enhanced release of Na$^+$ and K$^+$, and to a lesser extent Mg^{2+}. Both in 2001 and 2010, the dissolved load is probably largely dominated by carbonate weathering, explaining the dominance of Ca^{2+} (Fig.5). In the samples from 2001, the contribution of Na$_{sil}$ and Si^{4+} appears to be consistent with a mixing between calcite dissolution and the weathering of plagioclase to secondary clays, such as Na-beidellite (Fig.5). However, in the 2010 samples collected after the earthquake, the relative increase in Na$_{sil}$ concentrations suggests an excess release of Na$^+$, beyond what would be expected for stoichiometric silicate mineral dissolution. Excess release of Na$^+$ and K$^+$ would explain the changes in the elemental ratios between 2001 and 2010 (Fig.4). At least in the case of Na$^+$, this excess cannot be attributed to Na$^+$ from evaporites, because the Na$^+$ concentration shown in Fig.5 has been corrected for evaporite contributions, relative to Cl$^-$. There is no evidence to suggest that the increase in K$^+$ is likely to be from evaporites. The enhanced cation release might be attributable to rapid leaching of cations from fresh silicate mineral surfaces produced by landslides. The damage associated with glacial comminution is thought to lead to non-stoichiometric release of cations during chemical weathering in glacial environments, for example leading to anomalously rapid K$^+$ leaching from biotite (Anderson et al, 1999). While comminution during glacial grinding and landsliding are clearly

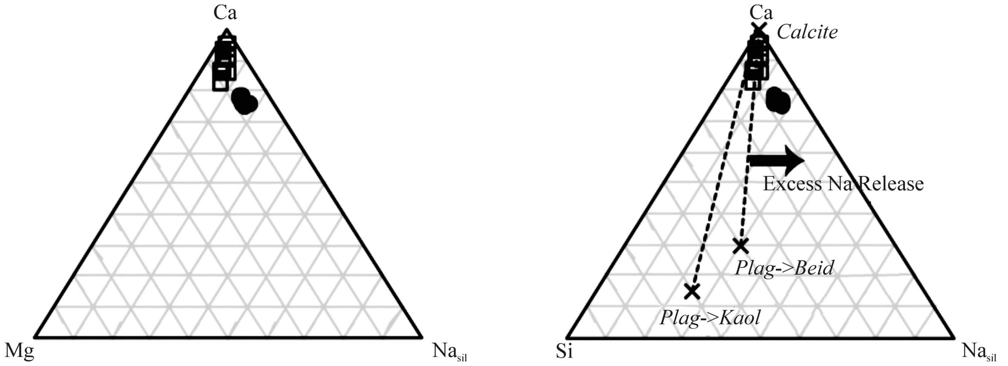

Fig.5 Ternary plots showing relative compositions of Min Jiang river waters in 2001 and 2010.

In all cases the river water cation composition is dominated by Ca^{2+}, probably reflecting a dominance of carbonate dissolution. The 2010 samples show a distinct shift towards increased relative Na_{sil} concentrations, as seen in the cation ratios in Fig. 4. While the 2001 samples are consistent with mixing between calcite and plagioclase weathering, the 2010 samples have higher relative Na_{sil} concentrations than could be explained by these processes. This suggests that these samples are influenced by enhanced Na^+ (and K^+) release, which may be associated with earthquake-triggered landslides.

mechanistically different, the data here provide initial evidence suggesting that they may have similar effects on cation release, and that in the case of landsliding this can lead to significant and rapid changes in river chemistry. Confirming the importance of this process will require further investigation, including a wider range of analyses on the samples collected in 2010, as well as collection of a longer-term dataset of post-earthquake samples, which is ongoing work.

6 Conclusions

Significant changes in the dissolved chemistry of the Min Jiang are observed when comparing the cation concentrations measured on samples collected in early 2010, with the concentrations measured in samples collected in 2001. The changes point to relative increases in the contribution from silicate mineral sources, leading to higher concentrations of Na^+, K^+, and to a lesser extent Mg^{2+} in Min Jiang dissolved load in 2010 than those in 2001. Coincident changes in the ratios of Na/Ca and K/Ca indicate that this is not a dilution effect. The lack of change in Ca/Si and Ca/Sr ratios suggests that the observed changes are not due to increased contribution from groundwater sources, but are more likely to result from enhanced release of Na^+ and K^+. This may be the result of preferential cation leaching from damaged mineral surfaces, associated with the intense landslide activity triggered by the Wenchuan earthquake. This provides initial evidence that high-magnitude, low-frequency events may have a significant, previously-unrecognized effect on river chemistry.

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