

Global cooling controls on the chemical weathering as evidenced from the Plio-Pleistocene deposits of the North China Plain

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Received February 26, 2009; accepted May 14, 2009; published online July 27, 2009

Major element concentrations were analyzed on the sediments of a 203.6-m core from the North China Plain near Tianjin. The chemical index of alteration (CIA), $\text{Al}_2\text{O}_3\text{-(CaO+Na}_2\text{O)-K}_2\text{O}$ diagram and elemental ratios, such as Al/K and Ti/Na, were used to reveal information of chemical weathering in the source regions since the late Pliocene. Results show that the fluvial materials in the North China Plain were derived from vast regions, which were in the early Na and Ca removal stage and underwent numerous upper-crustal recycling processes. Proxies of chemical weathering show a decreasing trend, in parallel with the global cooling since the late Pliocene, suggesting a strong role of the global cooling in controlling the continental chemical weathering intensity.

the North China Plain, late Pliocene, chemical weathering, ice sheet, global cooling

Citation: Yao Z Q, Xiao G Q, Liang M Y. Global cooling controls on the chemical weathering as evidenced from the Plio-Pleistocene deposits of the North China Plain. *Chinese Sci Bull*, 2010, 55: 787–790, doi: 10.1007/s11434-009-0415-9

Chemical and physical denudation of silicates can potentially affect global climate change through influencing global carbon cycle [1,2]. Therefore, much attention has been paid to researches on silicate weathering [3–5]. Erosion materials produced from the continents would be transported to the depositional area by rivers. Their weathering products are a cumulative result of lithology, degree of physical and chemical weathering experienced by the source area and subsequent changes during transportation and deposition processes [6]. Consequently, weathering products are of particular value for understanding the silicate weathering and its underlying causes.

The North China Plain is under the influence of East Asian monsoon in the semiarid to humid zone [7]. Rivers, such as the Huanghe and Haihe Rivers, carry lots of detrital materials from the catchment area to the lower reaches. Up to date, studies on chemical weathering in the North China Plain are scarce because of a lack of long-term records with

well-constrained chronology, and thus the relation between chemical weathering and climate remains poorly understood. In this study, a 203.6-m core was recovered from the North China Plain near Tianjin. Based on the magnetostratigraphic results [8], we have measured the major elements of the sediments. By comparing with geochemical study of the loess-soil sequence from northern China, we tentatively discuss the changes of chemical weathering intensity and its likely causes.

The studied BZ2 core (117°8'E, 39°2'N) was recovered near the Bohai Bay using the rotary drilling method with a recovery of 89.3%. The textures of the sequence mainly consist of silty and silty-clay sediments with occasional interbedded fine-coarse sandy layers. The top 25 m consists of fluvial sediments intercalated with silty marine sediments. The lower portion (25–203.6 m) is dominated by fluvial deposits [8]. Stepwise thermal and alternating field demagnetization were performed on 461 samples from the BZ₂ core, and the results defined a basal age of ~3.2 Ma [8] (Figure 1). The timescale used in this study was obtained by

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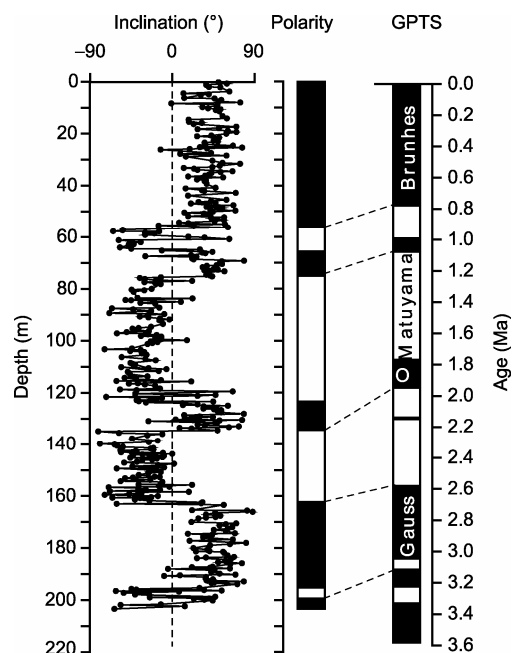


Figure 1 Magnetostratigraphy of the BZ₂ core and its correlation with geomagnetic polarity timescale (GPTS) [9].

linear interpolations based on the paleomagnetic reversal boundaries and optically stimulated luminescence dating [10].

The behaviors of major elements are closely related to the weathering process, and thus can be used to reveal the continental chemical weathering [11]. In this study, a total of 314 samples were taken at ~60 cm intervals for geochemical analysis. In order to minimize the grain size [12] and carbonates effects on the chemical compositions, the samples were treated with acetic acid to remove the carbonates following the method by Wei et al. [13] and the fine-grained fraction (<30 μm) was used for geochemical analysis. Concentrations of major elements were measured using a Philips PW4400 X-ray Fluorescence spectrometer. Calibration was done with reference samples after measuring every 30 samples. Analytical uncertainties are better than ±2%.

Weathering processes are sequentially characterized by the early Na and Ca removal stage, the intermediate K removal stage and the more advanced Si removal stage [14]. These trends can be determined using the A-CN-K (Al_2O_3 - CaO^* - Na_2O - K_2O) triangular diagram [14] (CaO^* is the amount of CaO in silicates). The plot for the BZ₂ core sediments (Figure 2) shows that all of them are in the early Na and Ca removal stage. The data points are distributed along the weathering trend line of the Upper Continental Crust (UCC), implying that the fluvial materials in the North China Plain were derived from vast regions and underwent numerous upper crustal recycling processes [15].

Chemical weathering can modify the major element contents of rocks and sediments. The behaviors of elements are

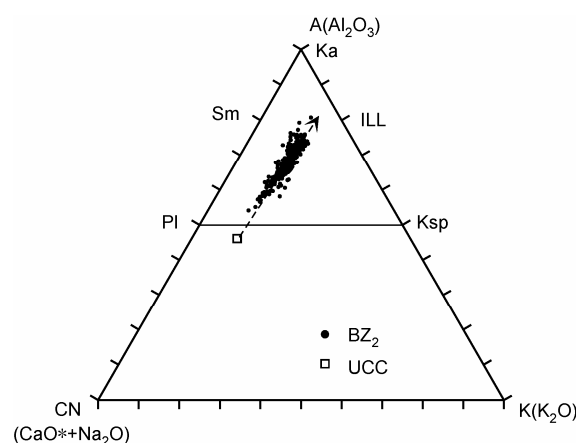


Figure 2 A-CN-K (Al_2O_3 -(CaO^* + Na_2O)- K_2O) diagrams of the BZ₂ core samples. PI, Pagioclase; Ksp, K-feldspar; Sm, smectite; ILL, illite; Ka, kaolinite; UCC from [15].

different during chemical weathering processes [11]. Some elements, such as Na, Ca and K, are mobile and easily removed from parent rocks and sediments, and thus generally depleted in weathering products [14,16]. Other elements, such as Al and Ti, are conservative during chemical weathering processes, and they tend to be enriched or kept constant in weathering products comparing with parent rocks and sediments [11]. Therefore, element ratios of Al/K, Al/Na and Ti/Na have been widely used to examine the degree of chemical weathering [11,17–19]. In the same way, the chemical index of alternation (CIA) is also widely used to evaluate the chemical weathering of terrestrial sediments [17]. It is defined as $\text{CIA} = \text{Al}_2\text{O}_3 / (\text{Al}_2\text{O}_3 + \text{CaO}^* + \text{Na}_2\text{O} + \text{K}_2\text{O}) \times 100$ (CaO^* is the amount of CaO in silicates). Using the CaO content after removing carbonate, CIA ranges from 54.1 to 80.7 (averaging 67.4) for the core sediments.

Since ~3.2 Ma, a gradual decrease in chemical weathering intensity can be observed (Figure 3). The CIA values decrease from about 80 at ~3.2 Ma to about 60 in the Holocene (Figure 3c). Ratios of Al/K and Ti/Na also show a decreasing trend from ~3.2 Ma to present (Figure 3a, b). All these indicate that chemical weathering intensity in the core deposits decreased continuously since the late Pliocene.

The elemental ratios in detrital sediments may be influenced by several factors, such as chemistry weathering in the source regions, hydraulic sorting and changes of provenance [20]. Sorting of compositionally distinct grains during fluvial transporting may influence the nature and composition of clastic sediments [21]. However, the elements we select here to reconstruct the chemical weathering are Al, Ti, Na, Ca and K. The behaviors of these elements during chemical weathering have well been defined, and they are dominantly hosted in fine grain size fractions in sediments [22]. Moreover, the textures of the BZ₂ core sequence mainly consist of fine silty and silty-clay sediments, and we

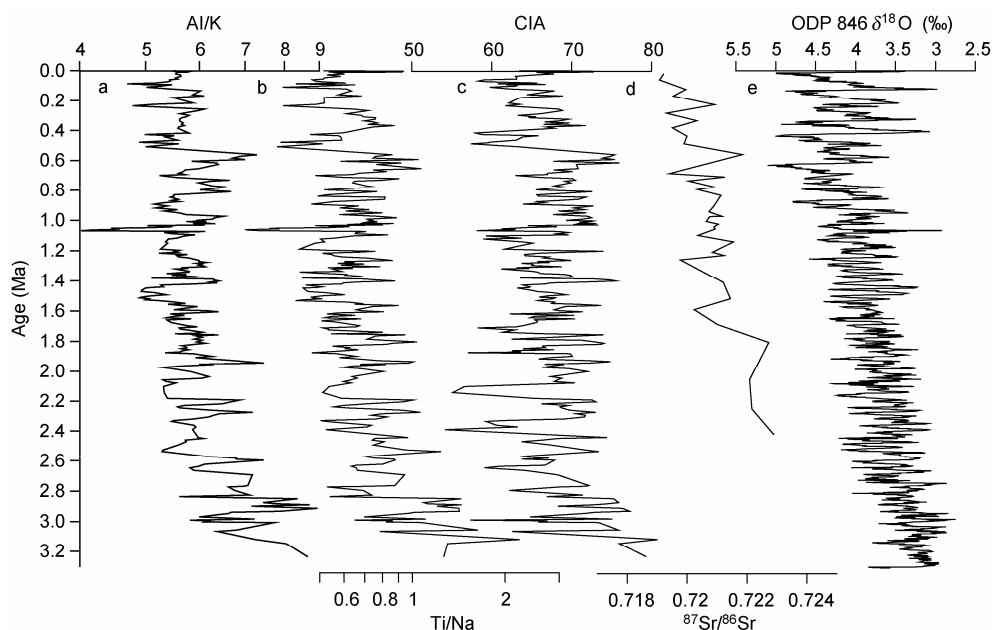


Figure 3 Comparisons of Al/K, Ti/Ni and CIA values for the BZ₂ core sediments (a,b,c), $^{87}\text{Sr}/^{86}\text{Sr}$ at the Luochuan loess-soil sequence from the Loess Plateau (from [31]; d) and marine $\delta^{18}\text{O}$ at the ODP site 846 (from [28, 29]; e).

have used the fine fraction (<30 μm) for geochemical analysis to minimize the potential effect of grain size on the chemical weathering. Therefore, the ratios of these elements are not likely to be affected by hydraulic sorting during transportation.

Provenance changes of the sediments may also influence the elemental ratios in the BZ₂ core sediments [20]. The central-northwestern China, especially the drainage of the Huanghe, Haihe and Luanhe Rivers, make up the source region for the sediments in the North China Plain [23,24]. Enhanced uplift of the Tibetan Plateau since the late Pliocene [25] induced the further development of landform pattern of high in the west and low in the east. Rivers, such as the Huanghe and Haihe Rivers, carry lots of detrital materials from the source region to the depositional area. Although floods and shifts in course of the Huanghe River happened frequently [26], the provenance changes resulted from its shifts may not influence the whole weakening trend of the geochemical weathering intensity on the 10^5 – 10^6 years timescale, because of the characteristics of frequent flooding and shifting within short-time period [23]. Moreover, detrital materials of the BZ₂ core underwent numerous upper-crustal recycling processes during transportation and their compositions became uniform relatively. This is supported by the A-CN-K triangular diagram of the core sediments (Figure 2). Therefore, the CIA and other geochemical proxies from the sediments in the core primarily reflect the chemical weathering intensity of the Huanghe and Haihe drainage basins.

Chemical weathering intensity is largely controlled by temperature and precipitation [27]. High precipitation and warm temperature can enhance the chemical weathering

intensity, whereas either low temperature or precipitation can decrease the chemical weathering intensity [27]. Marine $\delta^{18}\text{O}$ records [28,29] show a general trend toward colder global climate associated with the expansion of polar ice sheets since the late Pliocene. The overall decreasing trends of the chemical weathering intensity indicated by CIA values and other elemental ratios (Figure 3a–c) are in parallel with the global cooling [28,29] (Figure 3e), suggesting that the gradual lowering of the temperature may be responsible for the observed weakening chemical weathering intensity since the late Pliocene. Moreover, the strengthened aridity associated with the increased ice sheet volume [30] is also very important to the decreases of chemical weathering intensity. This is supported by the pollen studies from the North China Plain, which indicated colder and drier climatic condition since the late Pliocene [24]. The result of this study is also consistent with the chemical weathering variations indicated by $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the Luochuan loess-soil sequence from the Chinese Loess Plateau [31] (Figure 3d), which further support our explanation for the observed weakening chemical weathering intensity.

In addition, the global cooling could lead to the acceleration of erosion in the earth surface [32], and thus more detrital materials of low maturity would be added during fluvial transportation. Therefore, increased sedimentation rates globally since 2–4 Ma ago [33] may partly induce the weakening chemical weathering intensity in the study area since ~3.2 Ma.

We thank Dr. Chen Yukun for providing the core sediments, Ge Junyi and Zhou Xin for helpful discussions. We are also grateful to the editor and reviewers for their valuable suggestions that helped to improve the manuscript.

This work was supported by the National Natural Science Foundation of China (Grant No. 40730104) and National Basic Research Program of China (Grant No. 2004CB720203).

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