Geochemistry of the Paleocene Clastic Rocks From the Southwestern Jiangnan Basin, Central China Reveal Their Provenance, Tectonic Setting, and Palaeoenvironment

Kai Yan

Chinese Academy of Geological Sciences

Chun-lian Wang (✉ wangchunlian321@163.com)

Chinese Academy of Geological Sciences

Jiu-yi Wang

Chinese Academy of Geological Sciences

Xiao-can Yu

Chinese Academy of Geological Sciences

Xiao-hua Teng

Zaozhuang University

Rui-qin Li

Peking University

Li-hong Liu

Peking University

Research Article

Keywords: condition of oxidation, palaeoenvironmental, provenance, bulk-rock geochemistry

Posted Date: October 11th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-956386/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

This paper intends to learn about the provenance, tectonic setting and paleoenvironment of the Paleocene Shashi Formation in the southern Jiangnan Basin by the bulk-rock geochemistry. The K_2O/Al_2O_3 and SiO_2/Al_2O_3 ratios indicate that the major proportion of samples are litharenite. The chondrite-normalized REE distribution pattern of the Shashi Formation's mudstones are characterized by enriched LREE and flat HREE similar to those of UC with negative Eu anomalies. Combined with the geochemical element ratio discriminant diagram, such as $Al_2O_3-TiO_2$, $Zr-TiO_2$, $La/Sc-Co/Th$, and $Hf-La/Th$, so on, these samples were sourced from mixed felsic/basic rock. Moreover, the discriminant diagrams of $K_2O/Na_2O-SiO_2/Al_2O_3$, $La-Th-Sc$, and $Th-Co-Zr/10$ suggest that the samples were formed under the tectonic settings of active continental margin and continental island arc. The values of CIA, CIW, PIA, ICV, $Zr/Sc-Th/Sc$, and ternary diagrams of $A-(CN)-K$ and $Al_2O_3-Zr-TiO_2$ indicate that weathering in the source area was weak and source rocks have not been reformed by depositional recirculation and hydraulic sorting. And the palaeoenvironmental indicators of C-value, Ni/Co , V/Cr , $V/(V+Ni)$ and Sr/Cu , Ga/Rb indicate that the climate was cool and arid during the evaporite deposition period in the southern Jiangnan Basin, and the water was in the condition of oxidation.

Introduction

The Jiangnan Basin is a Mesozoic-Cenozoic rift basin in central China, which has experienced multi-stage tectonic movement. In the Paleocene, the Jiangnan Basin deposited abundant evaporites and potassium and lithium-rich brine ore¹⁻⁵. Due to the complex tectonic movement, extreme paleoclimate type and various material sources in the Jiangnan Basin, it is difficult for us to study the genesis of evaporite minerals. In view of the sedimentary characteristics of evaporite in a series of rifted basins in south China, Liu et al.^{3,6} proposed that the formation of evaporite deposits was controlled by tectonics, provenance and climate. Based on this view, a lot of studies on the origin of evaporites and deep brine have been carried out in recent years^{4,7-12}. And based on the analysis of geochemical data from the Paleocene Shashi Formation mudstone from Well ZK0303 in the southwestern Jiangnan Basin, this paper reveals the provenance, tectonic setting and sedimentary environment of the clastic sediments in the saline lake.

After many years of development, geochemical parameters have been widely used in paleoenvironmental conditions, tectonic setting and clastic rock provenance¹³⁻¹⁵. And the composition of clastic sedimentary rocks is controlled by a combination of factors such as parent rock composition, weathering (physical and chemical), transport, sedimentation, and diagenesis¹⁶. Some unstable components and chemical elements will be changed and lost in geological historical events, while some stable elements will be enriched and retained, and still maintain the characteristics of the source area. Variations in the content of many active elements, such as V, Cr, Ni, Co and U, influence of paleo-sedimentary environment and tectonic setting during their formation¹⁷⁻¹⁸. Trace elements (Th, Sc, Hf, Ti) and rare earth elements (La, Y) did not have obvious fractionation during the transfer to the sedimentary basin, thus preserving the characteristics of source materials and being reliable provenance indicators¹⁹. At present, the geochemical indexes and ratios have been widely used in the study of clastic rocks, which is also of great significance to the development of the basin.

Materials And Methods

Geological setting. The Jiangnan Basin located in the Yangtze Block of central China, is a large Mesozoic-Cenozoic rift basin, with a total area of 36,360 km²²⁰⁻²². It is bordered by the Qinling orogen in the north, the Dabie Terrance in the northeast, the Edong fold-thrust belt in the east, the Jiangnan orogen in the south, and the Huangling massif and the Xiang'exi fold-thrust belt in the west²³⁻²⁶ (Fig. 1A). The Presinian metamorphic basement of the Jiangnan Basin was formed during the Late Proterozoic. The basement of the Jiangnan Basin consists of two parts: the underlying crystalline basement and the overlying pre-rift strata. The crystalline basement of the Jiangnan Basin mainly consists of Archean-Proterozoic metamorphic and metasedimentary rocks²⁸. During the Sinian to the Early Triassic, with the influence of the regional Indosinian movement spreading to this area, the Jiangnan Basin uplifted to different degrees under the background of dramatic and rapid crustal rise, and the sea water slowly withdrew westward, forming a set of extensive coastal clastic rocks interbedded with Marine carbonate rocks²⁹⁻³⁰. The Middle Triassic to Jurassic sediments in the Jiangnan Basin were mainly terrestrial conglomerate, sandstone and mudstone, and interbedded with coal seams formed from Carboniferous to Early Triassic Period^{27,31}. Under the influence of the Yanshanian movement, a NW-trending fault belt was formed in the Jiangnan Basin from Late Jurassic to Early Cretaceous³²⁻³⁴. From the Late Cretaceous to Paleogene, the Jiangnan Basin experienced the active upwelling of the upper mantle induced by the rolling of the Pacific plate and the Indo-Asian collision, resulting in multi-stage rifting and the formation of extensive siliceous clasts, evaporites and a large number of basalts in the basin, and finally formed the present geographical characteristics³⁵⁻³⁶.

The Jiangnan Basin is composed of several secondary structural units and depressions. The Jiangling depression is the largest secondary negative tectonic unit in Jiangnan Basin, which was formed on the Yanshanian fold basement under the depression setting of Late Cretaceous to Paleogene (Fig. 1B). The growth and development of the Jiangling depression are controlled by Qingshuikou fault, Jishansi fault, Wen'ansi fault and Gongnan-Songzi fault, and divided into two independent units by Wancheng fault^{1,37-38} (Fig. 2). In 2016, we obtained a 2,302.03 m long well (ZK0303) in the southwest of the Jiangling depression. The core is mainly composed of purplish pink silty mudstone and dark gray mudstone, interbedded with anhydrite, glauberite and halite.

Sampling and methods. A total of 55 samples were collected from Well ZK0303 based on the criteria of vertical differences, changes in sediment color, particle size and physical properties (Fig. 2). We split the core ZK0303 into two halves in the longitudinal, and selected the fresh part that was not contaminated. All samples were stored in plastic bags to avoid secondary pollution and oxidation as much as possible. Before the geochemical analysis all samples were air-dried, crushed to 200 mesh and thoroughly mixed. The major elements were analyzed by X-ray fluorescence spectrometer (XRF), and the trace and rare earth elements were tested by inductively coupled plasma mass spectrometry (ICP-MS).

Before the experiment, the samples were crushed in an agate mortar to less than 200 mesh. After that, the powdered samples were heated and poured into the mixture of anhydrous lithium tetraborate, lithium fluoride and ammonium nitrate to melt into glass sheets, which were continued to be heated in a muffle

furnace to determine loss on ignition. Finally, the fused samples were heated to 800°C and analyzed using a sequential X-ray fluorescence spectrometer (AB104L, Axios-mAX). Calibrations of accuracy and reproducibility were conducted using the GB/T 14506.14-2010 and GB/T 14506.28-2010 standards.

The content of trace and rare earth elements were measured by inductively coupled plasma mass spectrometer (ICP-MS, ELEMENT XR). Heat the powdered samples with HF and HNO₃. After evaporation to dryness, HNO₃ was added to dissolve the samples. Then, HNO₃ was added to samples again and heated to 130°C. Finally, the distilled water was added to the solution and the contents of trace elements were measured. All geochemical analyses were carried out in the Analytical Laboratory Beijing Research Institute of Uranium Geology.

Results

Major elements geochemistry. Among the major elements, the average contents of SiO₂ (45.34%), Al₂O₃ (13.64%) and CaO (8.14%) are the top three (Table 1). And the major element contents of all samples were allocated according to the Average Post-Archean Australian Shale (PAAS), almost all the contents of SiO₂, Al₂O₃, Fe₂O₃, TiO₂ and MnO in Well ZK0303 are lower than PAAS (Fig. 3A). In contrast, the contents of all CaO and MgO and most of Na₂O were higher than those of PAAS and show strong enrichment (Fig. 3A). Furthermore, the ratio of the major elements provides a more accurate classification of sandstone and shale than others, such as the Fe₂O₃/K₂O ratio can effectively distinguish lithic sands from feldspar arkoses, and SiO₂/Al₂O₃ can reflect the abundance of quartz in relative to clay⁴². For Well ZK0303, all samples are projected onto the regions of litharenite and sublitharenite on the Herron diagram (Fig. 4, Table 4).

Trace elements geochemistry. The three elements with the highest average content are Sr, Ba and Rb, and their average contents are 1948.53 ppm, 389.56 ppm and 148.44 ppm, respectively (Table 2). And the Sr/Cu ratios range from 8.48 to 840.48, the Ni/Co ratios range from 1.87 to 3.89, the V/Cr ratios range from 0.79 to 2.00, and the V/(V+Ni) are between 0.57 and 0.76, the Co/Th ratios are between 0.81 and 1.69 (Table 4). The preservation state of each element varies greatly if they are normalized to Upper Crust (UC) data. The contents of Sr and Cs are enriched relative to UC, the contents of Nb, Ta, Zr and Hf show strong depletion (Fig. 3B).

For REE, the Ce contents range from 17.5 to 88 ppm, averaging 62.51 ppm, the La contents range from 9.4 to 74.7 ppm, averaging 35.11 ppm, and the Nd contents range from 8.04 to 61.40 ppm, averaging 29.34 ppm (Table 3). They are the three most abundant REEs. The La/Th ratios are between 2.28 and 5.08, the La/Sc ratios are between 2.16 and 4.20. The LREE/HREE ratios range from 7.70 to 13.83, averaging 8.93 (Table 4). And the δ Ce ratios range from 0.79 to 0.93, averaging 0.87 (Table 4). In the chondrite-normalized diagram (Fig. 3C), all samples show a set of steep dips of the light REE (LREE) curves, whilst the curves of the heavy REE (HREE) are flat. And Eu contents represent negative anomalies, they are V-shaped in the standardized diagram.

Discussion

Provenance. The geochemical data carry a large of original geological information of clastic sediments, so they are often used to identify the provenance and reveal the characteristics of the source area^{43–45}. The major elements of the Shashi Formation samples are projected onto the discriminant function diagram proposed by Roser & Korsch⁴⁶, most of the samples are located in the field of quartzose sedimentary, some in field of felsic igneous provenance, and a small amount in intermediate igneous provenance (Fig. 5A). As essential immobile elements, the ratios of Al, Ti, and Zr can be used to reflect the type of the original rock^{47,50–52}. In the plots of TiO₂ versus Al₂O₃ and TiO₂ versus Zr, Hayashi et al.⁴⁷ divided the provenance into three types: mafic igneous rocks, intermediate igneous rocks, and felsic igneous rocks. And the samples of the Shashi Formation mainly belong to the source area of intermediate igneous rocks (Fig. 5B and C).

Apart from the major elements, some trace elements (La, Sc, Cr, Hf, Th, Zr, etc.) and REEs are of great significance in interpreting the provenance and composition of the source area because of their potential nature of low mobility during the post-depositional process^{49,53}. On the diagram of La/Th versus Hf⁴⁸, almost all of the samples fall in the mixed felsic/basic source rock region (Fig. 5D). And on the Co/Th versus La/Sc diagram proposed by McLennan et al.⁴⁹, these samples are located around andesite source rock (Fig. 5E). McLennan et al.¹⁵ believed that the relationship between Th/Sc and Zr/Sc could not only reflect the trace elements abundance in sediments, but also confirm the sedimentary recycling. The low Th/Sc and Zr/Sc ratios of the samples from the Shashi Formation indicate that the source rocks have not been modified by sedimentary recycling (Fig. 5F). In addition, the REE distribution and Eu anomaly in the sediments can also provide clues for the research of the source characteristics⁵⁴. The high LREE/HREE ratios and negative Eu anomalies of the Shashi Formation show the characteristics of felsic source rock (Table 4, Fig. 3C).

source area-palaeoweathering. In arid climate, the source rocks are dominated by physical weathering, in which they can only be mechanically broken down into smaller grain sizes without significant changes in mineralogical and chemical composition⁵⁵. And the chemical weathering plays a dominant role in humid climates and strongly controls the major and trace element composition of siliceous clastic sediments^{13,19,49,56–57}. It directly affects the removal of mobile elements (Na, K, Ca) and the enrichment of immobile elements (Al, Si) in the sediments¹³. The chemical index of alteration (CIA= Al₂O₃/(Al₂O₃ + CaO* + Na₂O + K₂O) × 100, Nesbitt and Young¹³; CaO*= CaO - 10/3 × P₂O₅, McLennan et al.⁴⁹) and Al₂O₃-(CaO + Na₂O)-K₂O (A-CN-K) ternary diagram (Nesbitt & Young⁵⁸) can determine the mobility of elements during chemical weathering and potassium metasomatism during diagenesis, and evaluate the weathering history and source rock composition. Besides, chemical index of weathering (CIW= Al₂O₃/(Al₂O₃ + CaO + Na₂O) × 100, Harnois⁵⁶), plagioclase index of alteration (PIA= 100× (Al₂O₃ - K₂O)/(Al₂O₃ + CaO* + Na₂O - K₂O), Fedo et al.¹⁹), and index of compositional variability (ICV= (Fe₂O₃ + K₂O + Na₂O + CaO + MgO + TiO₂)/Al₂O₃, Cox et al.⁵⁹) are also important bases for assessing the source area-palaeoweathering.

The values of CIA in the all samples vary from 13.207 to 67.751 (average = 49.474) (Table 1). In general, a CIA value of 55 or less represents unweathered, while 100 represents fully weathered (Nesbitt & Young^{13,60}). The lower CIA value reflects that the samples of Shashi Formation in the study area were not

affected by chemical weathering in the source area. In the ternary diagram of A-CN-K (Fig. 6A), All the samples are near the boundary of A-CN and are distributed along the line between clinopyroxene and PAAS, away from the A-K boundary that represents high weathering. And the values of CIW range from 13.697 to 81.992 (average = 57.117) (Table 1), the values of PIA range from 10.376 to 77.200 (average = 50.908) (Table 1), the values of ICV range from 1.207 to 8.965 (average = 2.150) (Table 1), They all represent a low degree of weathering in the source area (Harnois⁵⁶, Fedo et al.¹⁹; Ivanova et al.⁶¹). In addition, the diagram of Th/Sc versus Zr/Sc indicates that the original rock has not been recycled by deposition (Fig. 5F), while the ternary diagram of Al₂O₃-Zr-TiO₂ indicates that hydraulic sorting is not obvious (Fig. 6B, Garcia et al.⁶²). Hence, the samples from the Shashi Formation are likely to retain the chemical composition of the source rock.

Tectonic setting. At present, it is generally believed that the bulk-rock geochemistry of siliciclastic sediments is affected by the tectonic movement of source rocks, so it is often used to distinguish the tectonic setting of sedimentary basins^{14,43,53}. Some trace elements (such as La, Th, Sc, and Zr) with relatively low mobility can not only be used to trace the source rock but also be an important basis to distinguish tectonic setting. The tectonic setting of sediment development can be roughly divided into four types: oceanic island arc (OA), continental island arc (CA), active continental margin (ACM), and passive margin (PM)^{40,53}. On the diagram of Th-Co-Zr/10 (Fig. 7A), most samples of the Shashi Formation fall around the ACM field, but on the diagram of La-Th-Sc (Fig. 7B), most of samples are located at the CA. And on the diagram of SiO₂/Al₂O₃ versus K₂O/Na₂O (Fig. 7C), most of samples are located at ACM field, and some samples in CA field.

Overall, the above geochemical characteristics are consistent with the regional geological evolution. Since the Himalayan period, under the combined action of Pacific plate subduction, gravity isostatic and mantle adjustment, the crust of the Jiangnan Basin has been extended, cracked and collapsed^{35-36, 63}. It has experienced five tectonic stages and developed a large number of extensional normal faults. The direction of these faults has changed from old to new with clockwise and orderly deflection. Paleocene is the main period of the second phase tectonic movement in Jiangnan Basin, when the subsidence center shifted to the southwest^{33,37,64}. Due to the control of faults, several contiguic subsidence centers developed in the Jiangling Depression of the southwest of Jiangnan Basin during the Paleocene (Fig. 8)^{1,64-66}.

In conclusion, the Jiangnan Basin underwent strong tectonic movement in the Paleocene under the tectonic backgrounds of the active continental margin and continental island arc, and the subsidence center shifted to the southwest and divided into several independent regions, which received mixed felsic/basic source rocks from the periphery.

Palaeoclimate. Worash⁶⁷ believes that the distribution, composition and relative concentration of some trace elements in mudstone may indicate the palaeoclimate and palaeoenvironment. Zhao et al.⁶⁸ and Cao et al.⁶⁹ proposed using C-value as an indicator of palaeoclimate. The calculation formula of C-value is as follows: C-value = $\Sigma(\text{Fe} + \text{Mn} + \text{Cr} + \text{V} + \text{Ni} + \text{Co}) / \Sigma(\text{Ca} + \text{Mg} + \text{Sr} + \text{Ba} + \text{K} + \text{Na})$. This is because the Fe, Mn, Cr, V, Ni and Co elements are relatively enrich in humid conditions, while in arid conditions, evaporation precipitates saline minerals, resulting in the concentration of Ca, Mg, K, Na, Sr and Ba elements. And some current studies have shown that palaeoclimate conditions can impact the ratios of Ga/Rb, Rb/Sr and Sr/Cu in sediments⁷⁰⁻⁷¹. Gallium is related to kaolinite, suggesting strong chemical weathering associated with warm and humid climatic conditions⁷². Rubidium is enriched in illite, reflecting a dry and cold climate associated with weak chemical weathering⁷³. In the warm sedimentary environment, the ratio of Rb/Sr in sediments decreases, while the ratio of Sr/Cu increases⁷⁴⁻⁷⁵. And the Sr/Cu ratio between 1.3 and 5.0 represents humid environments, while the Sr/Cu ratio is higher than 5.0 in arid climates⁷⁶.

On the major elements diagram⁷⁷, all samples are located at arid field (Fig. 9A). And the C-value range from 0.05 to 0.51, Sr/Cu ratios range from 5.67 to 840.48, and Ga/Rb ratios range from 0.09 to 0.15 (Table 4). According to the C-value and Sr/Cu ratio⁶⁸⁻⁶⁹, the climatic conditions of the Paleocene Shashi Formation were between arid and semi-arid/semi-humid (Fig. 9B). Moreover, the projection points in the Sr/Cu ratio Ga/Rb discriminant map indicate that the Jiangnan Basin had a cool and arid climate during the Paleogene (Fig. 9C).

Redox conditions. The solubility of trace elements such as U, Ni, V, Mo, Cr and Co is controlled by the redox conditions, so they are generally enriched in sediments formed in reducing environment⁷⁹⁻⁸². In the study of late Jurassic redox environment in northwestern Europe, Jones & Manning⁸³ concluded that the ratios of Ni/Co, V/Cr, and V/(V+Ni) are reliable substitutes for redox conditions. And they also established a set of trace-element indicators for evaluating the redox conditions (Table 5). The Ni/Co ratios of samples vary between 1.87 and 3.69, all ratios are less than 5.0 (Table 4). The V/Cr ratios are between 0.79 and 2.00, and only one ratio is 2.00 (Table 4). For V/(V+Ni) ratios, all of them are less than 0.77 (Table 4). On the diagrams of V/Cr versus Ni/Co (Fig. 10A), all samples fall in the oxic field. And on the diagram of V/(V+Ni) versus Ni/Co (Fig. 10B), they are located at oxic and dysoxic fields.

Table 5
Geochemical proxies of redox environment.

Palec-oxygenation Facies	Oxygen Content (mL/L)	V/Cr	Ni/Co	V/(V+Ni)
Anaerobic, extremely dysaerobic	<0.20	>4.25	>7.00	>0.77
Dysaerobic, secondary aerobic	0.20-2.00	2.00-4.25	5.00-7.00	0.60-0.77
Aerobic	>2.00	<2.00	<5.00	<0.60

Furthermore, after many years of study on rare earth distribution patterns, it is found that the cerium anomaly is very sensitive to the change of sedimentary environment^{40,69,84}. Ce is present as Ce³⁺ under reducing conditions and separates from other REE³⁺ in the form of Ce⁴⁺ under oxidized conditions. The ratios of δCe can sensitively reflect the redox conditions in the sedimentary environment. A δCe ratio larger than 1 or a positive anomaly indicates a reducing

environment, whilst a ratio below 0.95 or a negative anomaly indicates an oxidized environment^{85–87}. All δCe ratios of samples between 0.79 and 0.93 indicate that the sedimentary environment of the Shashi Formation in the Jiangnan Basin was oxidized condition (Table 4).

Conclusions

(1) The REE distribution and $\text{Al}_2\text{O}_3\text{-TiO}_2$, Zr-TiO_2 , La/Sc-Co/Th , and Hf-La/Th ratios of the clastic rocks in Shashi Formation indicate that the southwestern Jiangnan basin received felsic/basic materials during the Paleocene. The values of CIA, CIW, PIA, ICV, and ternary diagram of A-(CN)-K indicate that weathering in the source area was weak; the values of Zr/Sc-Th/Sc and the ternary diagram of $\text{Al}_2\text{O}_3\text{-Zr-TiO}_2$ indicate source rocks have not been reformed by depositional recirculation and hydraulic sorting. Therefore, the Paleocene Sediments of the Shashi Formation in the southwestern Jiangnan Basin have largely preserved the chemical characteristics of the source rock.

(2) Based on the analysis of the data of main and trace elements and rare earth elements, the Paleocene clastic rocks in the Jiangnan Basin were formed under the tectonic background of active continental margin with frequent faulting activities. As a result, the southwest area of the Jiangnan Basin was divided into several interconnected depositional centers during the Paleocene.

(3) The ratios of Sr/Cu , Ga/Rb , and C-values reflect the cool and arid climate of the Paleocene in the Jiangnan Basin. And the ratios of Ni/Co , V/Cr , V/(V+Ni) and δCe indicate that the water was in oxidized condition during the deposition of saline lake.

Declarations

Acknowledgments

The work was supported by the Central Public Welfare Scientific Research Basic Scientific Research Business Expenses (No. KK2005), the National Natural Science Foundation of China (Nos. U20A2092, 42002106, 41907262 and 41502089), the National Basic Research Program of China (973 program (No. 2011CB403007) and the China Geological Survey (No. DD20190606). We are grateful to reviewers for their Critical and constructive review.

Author contributions

K.Y. and C.L.W. designed the research and prepared the original manuscript. J.Y.W, X.H.T. and L.H.L. revised the manuscript. X.C.Y. and R.Q.L. participated in sample collection and processing. All authors reviewed the manuscript.

Competing Interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to C.L.W.

Data availability

Data is available based on request.

References

1. Wang, C. L., Liu, C. L., Xu, H. M., Wang, L. C. & Zhang, L. B. Carbon and oxygen isotopes characteristics of Paleocene saline lake facies carbonates in Jiangling depression and their environmental significance. *Acta Geosci. Sin.*, **34**, 567–576 (2013).
2. Wang, C. L., Liu, C. L., Wang, J. Y., Yu, X. C. & Yan, K. Palynology and stratigraphy of the thick evaporate-bearing Shashi Formation in Jiangling Depression, Jiangnan Basin of South China, and its paleoclimate change. *China Geol.*, **2**, 283–291 (2020).
3. Liu, C. L. Characteristics and formation of potash deposits in continental rift basins: a review. *Acta Geosci. Sin.*, **34**, 515–527 (2013).
4. Shen, L. J. *et al.* Paleocene mineral assemblage characteristics of Jiangnan depression and their significance for potash formation. *Miner. Deposits (Beijing, China)*, **33**, 1020–1030 (2014).
5. Liu, C. L. *et al.* Plate tectonic control on the distribution and formation of the marine potash deposits. *Acta Geol. Sin. (Chin. Ed.)*, **89**, 1893–1907 (2015).
6. Liu, C. L. *et al.* A tentative discussion on regional metallogenic background and mineralization mechanism of subterranean brines rich in potassium and lithium in south China block. *Miner. Deposits (Beijing, China)*, **35**, 1119–1143 (2016).
7. Wang, C. L., Liu, C. L., Yu, X. C., Li, H. N. & Liu, J. L. The extremely hot and dry climatic events and potash enrichment in salt lakes. *Acta Geol. Sin. (Engl. Ed.)*, **90**, 769–770 (2016).
8. Wang, C. L., Liu, L. H., Wang, J. Y., Yu, X. C. & Yan, K. Micron-Nanometer Evaporite Mineral Compositions in the Jiangling Depression, Jiangnan Basin, China, by Means of Scanning Electron Microscopy. *J. Nanosci. Nanotechnol.*, **16**, 310–325 (2021).
9. Li, H. N. *et al.* A research on early Eocene homogenization temperature of fluid inclusions in halite and its paleoclimatic significance in Jiangling depression. *Miner. Deposits (Beijing, China)*, **35**, 1205–1216 (2016).
10. Yu, X. C. *et al.* Sedimentary characteristics and palaeoclimatic significance of glauberite in Paleocene lacustrine deposits of the Jiangling depression, central China. *Geosci. J.*, **22**, 1–16 (2018).

11. Yan, K. *et al.* Sulfur isotopic characteristics of Eocene series in the Yanjing- Shenjindu sub-depression in the southern Jiangling depression and its implication for paleoclimate and provenance. *Acta Geol. Sin. (Chin. Ed.)*, **92**, 1647–1660 (2018).
12. Yu, X. C., Liu, C. L., Wang, C. L., Li, F. & Wang, J. Y. Eolian deposits of the northern margin of the south China (Jiangnan Basin): reconstruction of the Late Cretaceous East Asian landscape in central China. *Mar. Pet. Geol.*, **117**, 104390 (2020).
13. Nesbitt, H. W. & Young, G. M. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature*, **299**, 715–717 (1982).
14. Bhatia, M. R. Plate tectonics and geochemical composition of sandstones. *J. Geol.*, **91**, 611–627 (1983).
15. McLennan, S. M., Hemming, S. R., Taylor, S. R. & Eriksson, K. A. Early Proterozoic crustal evolution: geochemical and Nd-Pb isotopic evidence from metasedimentary rocks, southwestern North America. *Geochim. Cosmochim. Acta*, **59**, 1153–1177 (1995).
16. Johnsson, M. J. The system controlling the composition of clastic sediments. *Geol. Soc. Amer. Spec. Pap.*, **284**, 1–19 (1993).
17. Xie, Q. F., Zhou, L. F., Cai, Y. F., Liu, Y. & Liu, Z. W. Geochemistry and geological significance of the Permian mudstone in the South Qilian Basin, China. *Bull. Mineral., Petrol. Geochem.*, **34**, 354–361 (2015).
18. Gao, L. F. *et al.* Geochemical characteristics of marine strata and the evolution of paleoceanographic environment from Late Jurassic to Early Cretaceous in Gonggar, Southern Tibet. *Earth Sci. Front.*, **24**, 195–204 (2017).
19. Fedo, C. M., Nesbitt, H. W. & Young, G. M. Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance., **23**, 921–924 (1995).
20. Gilder, S. A., Keller, G. R., Luo, M. & Goodell, P. C. Timing and spatial distribution of rifting in China., **197**, 225–243 (1991).
21. Yu, X. Q., Shu, L. S., Deng, P., Wang, B. & Zu, F. P. The sedimentary features of the Jurassic-Tertiary terrestrial strata in southeast China. *J. Stratigr.*, **27**, 224–263 (2003).
22. Teng, X. H. *et al.* Sedimentological and mineralogical records from drill core SKD1 in the Jiangnan Basin, Central China, and their implications for late Cretaceous-early Eocene climate change. *J. Asian Earth Sci.* **182**, 103936.1-103936.14(2019).
23. Hu, S., Kohn, B. P., Raza, A., Wang, J. & Gleadow, A. J. W. Cretaceous and Cenozoic cooling history across the ultrahigh pressure Tongbai–Dabie belt, central China, from apatite fission-track thermochronology., **420**, 409–429 (2006).
24. Shen, C. *et al.* Provenance and hinterland exhumation from LA-ICP-MS zircon U-Pb and fission-track double dating of Cretaceous sediments in the Jiangnan Basin, Yangtze block, central China. *Sediment. Geol.*, **281**, 194–207 (2012).
25. Li, X. Y. *et al.* Has the Yangtze craton lost its root? A comparison between the North China and Yangtze cratons., **655**, 1–14 (2015).
26. Wu, L. L. *et al.* Multiple provenance of rift sediments in the composite basin-mountain system: constraints from detrital Zircon U-Pb geochronology and heavy minerals of the early Eocene Jiangnan Basin, Central China. *Sediment. Geol.*, **349**, 46–61 (2017).
27. Chen, W. T., Zhou, M. & Zhao, X. Late Paleoproterozoic sedimentary and mafic rocks in the Hekou area, SW China: Implication for the reconstruction of the Yangtze Block in Columbia. *Precambrian Res.*, **231**, 61–77 (2013).
28. HBGM (Hubei Bureau of Geology and Mineral Resources). *Regional Geology of the Hubei Province* (Geological Press, Beijing, 1990).
29. Dai, S. W. Discussion on the regional structural features of Jiangnan Basin since the indosinian movement. *J. Geomech.*, **04**, 82–86 (1996).
30. Yao, W. H., Li, Z. X., Li, W. X., Su, L. & Yang, J. H. Detrital provenance evolution of the Ediacaran-Silurian Nanhua foreland basin, South China. *Gondwana Res.*, **28**, 1449–1465 (2015).
31. Shu, L. S., Faure, M., Wang, B., Zhou, X. M. & Song, B. Late Palaeozoic-Early Mesozoic geological features of South China: Response to the Indosinian collision events in Southeast Asia. *C. R. Geosci.*, **340**, 151–165 (2008).
32. Dai, S. W., Liu, S. F. & Chen, X. Y. *The coupling of the Jiangnan and adjacent hinterland* (Northwest University Press, Evanston, 2000).
33. Wang, B. J. The structural evolution and favorable exploration areas in Jiangnan Basin. *Earth Sci. (Wuhan, China)* **1–135**(2006).
34. Hu, S. B. *et al.* Late Mesozoic and Cenozoic thermotectonic evolution along a transect from the north China craton through the Qinling orogen into the Yangtze craton, central China., **25**, TC6009 (2006).
35. Liu, M., Cui, X. J. & Liu, F. T. Cenozoic rifting and volcanism in eastern China: a mantle dynamic link to the Indo-Asian collision?, **393**, 29–42 (2004).
36. Li, W., Lu, S., Xue, H., Zhang, P. & Wu, S. The formation environment and developmental models of argillaceous dolomite in the Xingouzui Formation, the Jiangnan Basin. *Mar. Pet. Geol.*, **67**, 692–700 (2015).
37. Yang, C. Q., Chen, K. Q., Cheng, Z. Q. & Zhan, H. J. Constituent evolution and exploration potential in Jiangnan depression. *Nat. Gas Ind.*, **23**, 51–54 (2003).
38. Yu, X. C., Liu, C. L., Wang, C. L. & Xu, H. M. Provenance of rift sediments in a composite basin-mountain system: constraints from petrography, whole-rock geochemistry, and detrital zircon U-Pb geochronology of the Paleocene Shashi Formation, southwestern Jiangnan Basin, central China. *Int. J. Earth Sci.*, **107**, 1–26 (2018).
39. McLennan, S. M. Rare earth elements in sedimentary rocks: influence of provenance and sedimentary processes. *Rev. Mineral. Geochem.*, **21**, 169–200 (1989).
40. Taylor, S. R. & McLennan, S. M. *The Continental Crust: Its Composition and Evolution* (Blackwell Scientific Publications, Oxford, UK, 1985).
41. Boynton, W. V. Geochemistry of the rare earth elements: Meteorite studies. In P. Henderson (Ed.), *Rare earth element geochemistry* (Amsterdam:Elsevier, 1984).
42. Herron, M. M. Geochemical classification of terrigenous sands and shales from core or log data. *J. Sediment. Petrol.*, **58**, 820–829 (1988).
43. Roser, B. P. & Korsch, R. J. Determination of tectonic setting of Sandstones-mudstone suites using SiO₂ content and K₂O/Na₂O ratio. *J. Geol.*, **94**, 635–650 (1986).

44. Cullers, R. L. The controls on the major- and trace-element evolution of shales, siltstones and sandstones of Ordovician to Tertiary age in the wet mountains region, Colorado, USA. *Chem. Geol.*, **123**, 107–131 (1995).
45. Armstrong-Altrin, J. S. *et al.* Geochemistry of the Jurassic and upper Cretaceous shales from the Molango Region, Hidalgo, Eastern Mexico: implications of source-area weathering, provenance, and tectonic setting. *C. R. Geosci.*, **345**, 185–202 (2013).
46. Roser, B. P. & Korsch, R. J. Provenance signatures of sandstone-mudstone suites determined using discriminant function analysis of major-element data. *Chem. Geol.*, **67**, 119–139 (1988).
47. Hayashi, K. I., Fujisawa, H., Holland, H. D. & Ohmoto, H. Geochemistry of ~1.9 Ga sedimentary rocks from northeastern Labrador, Canada. *Geochim. Cosmochim. Acta*, **61**, 4115–4137 (1997).
48. Floyd, P. A. & Leveridge, B. E. Tectonic environment of the Devonian Gramscatho Basin, South Cornwall: framework mode and geochemical evidence from turbiditic sandstones. *J. Geol. Soc. (London, U. K.)*, **144**, 531–542 (1987).
49. McLennan, S. M., Hemming, S., McDaniel, D. K. & Hanson, G. N. Geochemical approaches to sedimentation, provenance, and tectonics. *Spec. Pap. – Geol. Soc. Am.*, **284**, 21–40 (1993).
50. Stumm, W. & Morgan, J. J. *Aquatic Chemistry* (Wiley, New York, 1981).
51. Wesolowski, D. J. Aluminum speciation and equilibria in aqueous solution: I. The solubility of gibbsite in the system Na-K-Cl-OH-Al(OH)₄ from 0 to 100°C. *Geochim. Cosmochim. Acta*, **56**, 1065–1091 (1992).
52. Ayers, J. C. & Watson, E. B. Rutile solubility and mobility in supercritical aqueous fluids. *Contrib. Mineral. Petrol.*, **114**, 321–330 (1993).
53. Bhatia, M. R. & Crook, K. A. Trace element characteristics of graywackes and tectonic setting discrimination of sedimentary basins. *Contrib. Mineral. Petrol.*, **92**, 181–193 (1986).
54. Cullers, R. L. The controls on the major and trace element variation of shales, siltstones, and sandstones of Pennsylvanian-Permian age from uplifted continental blocks in Colorado to platform in Kansas, USA. *Geochim. Cosmochim. Acta*, **58**, 4955–4972 (1994).
55. Wanas, H. A. & Assal, E. M. Provenance, tectonic setting and source area-paleoweathering of sandstones of the Bahariya Formation in the Bahariya Oasis, Egypt: An implication to paleoclimate and paleogeography of the southern Neo-Tethys region during Early Cenomanian. *Sediment. Geol.*, **413**, 105822 (2020).
56. Harnois, L. The CIW index: a new chemical index of weathering. *Sediment. Geol.*, **55**, 319–322 (1988).
57. Middelburg, J. J., Van der Weijden, C. H. & Woititz, J. R. W. Chemical processes affecting the mobility of major, minor and trace elements during weathering of granitic rocks. *Chem. Geol.*, **68**, 253–273 (1988).
58. Nesbitt, H. W. & Young, G. M. Formation and diagenesis of weathering profiles. *J. Geol.*, **97**, 129–147 (1989).
59. Cox, R., Lowe, D. R. & Cullers, R. L. The influence of sediment recycling and basement composition on evolution of mudrock chemistry in the southwestern United States. *Geochim. Cosmochim. Acta*, **59**, 2919–2940 (1995).
60. Nesbitt, H. W. & Young, G. M. Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic considerations. *Geochim. Cosmochim. Acta*, **48**, 1523–1534 (1984).
61. Ivanova, V. V. *et al.* Geochemical indicators of paleoclimatic changes in the Cenozoic deposits of the Lower Aldan Basin. *Geochem. Int.*, **53**, 358–368 (2015).
62. Garcia, D., Coelho, J. & Perrin, M. Fractionation between TiO₂ and Zr as a measure of sorting within shale and sandstone series (northern Portugal). *Eur. J. Mineral.*, **3**, 401–414 (1991).
63. Xu, Z. Y., Lin, K., Liu, C. Y., Wang, Y. J. & Guo, F. A discussion on amalgamation course between the south China and north China Blocks: evidences from deformational characters in the Jiangnan superimposed Basin. *Chin. J. Geol.*, **39**, 284–295 (2004).
64. Liu, J. Y. *et al.* The erosion distribution of major unconformities and its tectonic significance of Cretaceous-Neogene Jiangnan Basin. *Geol. Sci. Technol. Inf.*, **28**, 1–8 (2009).
65. Shen, J. J. *et al.* Sedimentary characteristics of gypsum-salt rocks in Palaeogene Shashi Formation of Jiangling depression. *Acta Geosci. Sin.*, **35**, 425–433 (2014).
66. Wang, D. L. *et al.* Mesozoic-Cenozoic episodic subsidence and Migration of Jiangnan Basin in extensional composite Basin-Mountain system. *Earth Sci. (Wuhan, China)*, **43**, 4180–4192 (2018).
67. Worash, G. Geochemistry provenance and tectonic setting of the Adigrat sandstone northern Ethiopia. *J. Afr. Earth Sci.*, **35**, 185–198 (2002).
68. Zhao, Z. Y., Zhao, J. H., Wang, H. J., Liao, J. D. & Liu, C. M. Distribution characteristics and applications of trace elements in Junggar Basin. *Nat. Gas Explor. Dev.*, **30**, 30–33 (2007).
69. Cao, J. *et al.* Trace and rare earth elements geochemistry of Jurassic mudstones in the northern Qaidam basin, northwest China. *Chem. Erde-Geochem.*, **72**, 245–252 (2012).
70. Jin, Z. D. & Zhang, E. L. Paleoclimate implications of Rb/Sr ratios from lake sediments. *Sci. Technol. Eng.*, **2**, 20–22 (2002).
71. Bai, Y. *et al.* Rare earth and major element geochemistry of Eocene fine-grained sediments in oil shale- and coal-bearing layers of the Meihe Basin, northeast China. *J. Asian Earth Sci.*, **97**, 89–101 (2015).
72. Roy, D. K. & Roser, B. P. Climatic control on the composition of Carboniferous-Permian Gondwana sediments, Khalaspir basin, Bangladesh. *Gondwana Res.*, **23**, 1163–1171 (2013).
73. Beckmann, B., Flögel, S., Hofmann, P., Schulz, M. & Wagner, T. Orbital forcing of Cretaceous river discharge in tropical Africa and ocean response. *Nature*, **437**, 241–244 (2005).

74. Lerman, A. D. I. & Gat, J. *Physics and Chemistry of Lakes* (Springer-Verlag, Berlin, 1989).
75. Cao, H. S., Guo, W., Shan, X. L., Ma, L. & Sun, P. C. Paleolimnological environments and organic accumulation of the Nenjiang Formation in the southeastern Songliao Basin. *Oil Shale*, **32**, 5–24 (2015).
76. Lerman, A. & Lakes *Chemistry, Geology, Physics* (Springer-Verlag, New York, 1978).
77. Suttner, L. J. & Dutta, P. K. Alluvial sandstone composition and paleoclimate I. Framework mineralogy. *J. Sediment. Res*, **56**, 329–345 (1986).
78. Sarki Yandoka, B. M., Abdullah, W. H., Abubakar, M. B., Hakimi, M. H. & Adegoke, A. K. Geochemical characterisation of Early Cretaceous lacustrine sediments of Bima Formation, Yola sub-basin, Northern Benue trough, NE Nigeria: Organic matter input, preservation, paleoenvironment and palaeoclimatic conditions. *Mar. Pet. Geol*, **61**, 82–94 (2015).
79. Francois, R. The study on the regulation of the concentrations of some trace metals (Rb, Sr, Zn, Cu, V, Cr, Ni, Mn and Mo) in Saanich inlet sediments, British Columbia. *Canada. Mar. Geol*, **83**, 285–308 (1988).
80. Arthur, M. A. & Sageman, B. B. Marine black shales: depositional mechanisms and environments of ancient deposits. *Annu. Rev. Earth Planet. Sci*, **22**, 499–551 (1994).
81. Yuri, Z. N., Eder, V. G. & Zamirailova, A. G. Composition and formation environments of the Upper Jurassic–Lower Cretaceous black shale Bazhenov Formation (the central part of the West Siberian Basin). *Mar. Pet. Geol*, **25**, 289–306 (2008).
82. Hetzel, A., März, C., Vogt, C. & Brumsack, H. J. Geochemical environment of Cenomanian-Turonian black shale deposition at Wunstorf (northern Germany). *Cretaceous Res*, **32**, 480–494 (2011).
83. Jones, B. & Manning, D. A. C. Comparison of geochemical indices used for the interpretation of palaeoredox conditions in ancient mudstones. *Chem. Geol*, **111**, 111–129 (1994).
84. Zhao, Z. H. 1997. Principles of Trace Element Geochemistry (Science Press, Beijing, 1997).
85. Holser, W. T. Evaluation of the application of rare–element elements to paleoceanography. *Palaeogeogr. Palaeoclimatol. Palaeoecol*, **132**, 309–323 (1997).
86. Shields, G. & Stille, P. Diagenetic constraints on the use of cerium anomalies as palaeoseawater redox proxies: an isotopic and REE study of Cambrian phosphorites. *Chem. Geol*, **175**, 29–48 (2001).
87. Teng, G., Liu, W. H., Xu, Y. C. & Chen, J. F. Correlative study on parameters of inorganic geochemistry and hydrocarbon source rocks formative environment. *Adv. Earth Sci*, **20**, 193–200 (2005).
88. Hatch, J. R. & Leventhal, J. S. Relationship between inferred redox potential of the depositional environment and geochemistry of the Upper Pennsylvanian (Missourian) stark shale member of the Dennis Limestone, Wabaunsee County, Kansas, USA. *Chem. Geol*, **99**, 65–82 (1992).

Tables

Table 1. The content of major elements from Well ZK0303, Jiangnan Basin (unit in %)

No.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	MnO	CaO	MgO	K ₂ O	Na ₂ O	P ₂ O ₅	FeO	LOI	CIA	CIW	PIA	IP
ZK1	43.840	14.490	5.470	0.609	0.123	7.670	5.870	3.370	1.190	0.159	1.540	16.910	55.326	63.497	57.172	1
ZK2	58.400	10.130	3.790	0.508	0.072	8.100	2.770	2.360	1.930	0.116	1.450	11.370	45.768	51.231	44.621	1
ZK3	27.910	8.730	3.210	0.342	0.108	15.980	7.870	1.910	1.700	0.122	1.680	11.540	31.275	33.573	28.307	3
ZK4	52.830	11.960	4.280	0.639	0.109	8.450	3.970	2.550	2.310	0.111	0.900	12.300	48.032	53.512	47.525	1
ZK5	25.560	8.040	2.760	0.299	0.051	15.980	7.300	1.970	3.910	0.121	1.450	20.090	27.257	29.208	23.751	3
ZK6	15.650	4.140	1.650	0.169	0.034	11.850	8.090	1.120	14.440	0.061	0.840	16.730	13.207	13.697	10.376	8
ZK7	16.130	4.270	1.790	0.158	0.037	14.320	4.440	1.100	12.620	0.047	0.940	14.270	13.280	13.751	10.583	8
ZK8	43.880	13.520	5.170	0.611	0.077	6.340	4.530	3.420	3.820	0.125	1.780	16.620	50.668	58.117	50.899	1
ZK9	37.080	9.650	3.610	0.440	0.060	10.500	5.810	2.620	4.200	0.100	1.350	17.980	36.228	40.180	32.856	2
ZK10	28.370	8.890	3.370	0.355	0.058	13.380	4.720	2.290	6.300	0.106	1.200	15.160	29.141	31.506	25.456	3
ZK11	35.550	9.570	3.790	0.413	0.082	13.380	7.060	2.520	2.390	0.134	1.940	22.080	34.910	38.444	31.511	3
ZK12	26.330	7.250	2.800	0.305	0.070	15.290	8.030	1.680	4.750	0.101	1.290	22.460	25.320	26.898	22.039	4
ZK13	40.970	12.080	4.740	0.523	0.076	10.420	3.650	2.740	3.300	0.185	2.240	16.170	43.261	47.968	41.616	2
ZK14	55.940	11.790	4.340	0.605	0.077	8.760	2.020	2.870	1.990	0.101	1.600	11.030	47.022	53.100	46.138	1
ZK15	51.700	16.260	6.490	0.664	0.056	5.280	2.670	4.120	2.250	0.114	1.440	9.900	59.063	69.457	62.934	1
ZK16	49.330	16.760	6.300	0.610	0.045	4.870	3.600	4.830	1.820	0.148	2.510	11.130	60.317	73.007	65.815	1
ZK17	50.120	11.010	4.770	0.644	0.055	11.910	2.490	2.630	2.010	0.121	1.900	13.800	40.543	44.890	38.271	2
ZK18	22.910	6.290	2.180	0.259	0.080	19.370	7.740	1.230	1.610	0.102	1.900	10.690	22.337	23.357	19.689	5
ZK19	49.940	16.840	6.570	0.676	0.058	3.850	5.140	4.330	1.690	0.194	2.720	17.050	64.612	77.485	71.883	1
ZK20	43.870	14.420	5.550	0.577	0.051	8.570	4.490	3.680	1.440	0.140	1.610	10.640	52.164	60.175	52.950	1
ZK21	41.730	15.220	6.060	0.522	0.087	7.280	6.930	3.870	1.460	0.200	1.900	10.770	56.031	65.341	58.435	1
ZK22	45.320	16.360	6.860	0.580	0.053	5.550	5.510	4.400	1.290	0.173	2.220	9.600	60.540	72.315	65.630	1
ZK23	48.270	16.640	6.230	0.629	0.055	5.570	3.980	4.140	1.920	0.159	2.010	14.690	59.986	70.508	64.234	1
ZK24	40.030	13.350	5.300	0.504	0.061	10.500	5.550	3.380	1.090	0.138	2.260	13.330	47.918	54.534	47.251	1
ZK25	47.690	17.130	6.270	0.635	0.052	5.210	4.290	4.600	1.250	0.155	1.930	11.900	61.901	74.242	67.827	1
ZK26	45.970	15.970	6.250	0.555	0.043	5.130	6.150	4.120	1.320	0.173	2.200	12.690	61.510	73.112	66.861	1
ZK27	51.740	10.460	3.870	0.604	0.079	9.250	4.220	2.330	1.440	0.133	1.560	12.790	45.406	50.515	44.241	2
ZK28	48.540	16.680	6.830	0.667	0.057	5.170	4.500	4.320	1.080	0.153	2.020	14.850	62.378	74.398	68.287	1
ZK29	45.900	15.570	6.030	0.555	0.048	6.310	4.970	4.050	0.971	0.158	2.020	11.980	59.035	69.745	63.039	1
ZK30	47.590	17.580	6.820	0.622	0.056	4.430	5.650	4.340	1.090	0.175	2.190	11.970	65.459	78.075	72.841	1
ZK31	48.270	17.070	6.440	0.629	0.068	4.780	4.940	4.360	1.080	0.169	1.910	11.210	63.869	76.319	70.585	1
ZK32	51.330	12.460	4.660	0.625	0.058	9.670	3.430	3.000	1.210	0.124	1.520	12.960	48.059	54.347	47.474	1
ZK33	48.350	17.610	6.950	0.642	0.054	4.510	3.980	4.740	0.988	0.164	2.280	11.520	64.502	78.054	72.217	1
ZK34	47.810	14.600	6.070	0.648	0.072	8.790	3.950	3.760	1.040	0.146	1.740	12.600	52.701	60.977	53.708	1
ZK35	48.630	16.420	6.210	0.630	0.072	6.400	4.350	4.200	1.100	0.149	1.70	11.340	59.443	70.101	63.569	1
ZK36	42.850	14.590	4.870	0.564	0.100	8.870	6.600	3.430	1.000	0.146	2.040	16.450	53.242	60.859	54.324	1
ZK37	46.390	16.340	5.710	0.656	0.088	5.770	6.760	3.800	1.210	0.182	2.260	13.100	61.629	71.940	66.302	1
ZK38	50.100	14.150	5.750	0.663	0.062	7.890	3.960	3.390	1.180	0.158	1.840	12.170	54.249	62.353	55.742	1
ZK39	40.040	13.50	4.960	0.522	0.060	10.470	3.980	3.310	0.904	0.126	1.570	11.120	48.624	55.206	48.193	1
ZK40	39.470	9.790	3.080	0.517	0.062	13.900	2.960	2.280	0.980	0.101	1.440	11.330	36.786	40.233	34.054	2
ZK41	48.450	16.380	6.190	0.596	0.081	4.570	6.400	3.940	1.050	0.156	2.11	11.780	64.437	76.257	70.924	1
ZK42	52.520	11.720	4.640	0.634	0.106	9.540	3.200	2.550	1.640	0.135	1.590	12.910	46.880	52.205	46.080	1
ZK43	47.690	13.290	5.390	0.651	0.069	9.420	4.480	3.170	0.962	0.149	1.980	13.500	50.445	57.345	50.587	1

ZK44	36.280	12.750	4.570	0.457	0.068	16.500	4.340	3.160	1.270	0.153	2.450	17.890	38.438	42.486	35.717	2
ZK45	49.470	16.790	7.010	0.658	0.054	4.840	4.340	4.530	0.863	0.172	2.250	10.720	63.479	76.598	70.502	1
ZK46	50.460	15.800	5.600	0.714	0.054	6.790	3.660	4.040	0.960	0.153	1.890	11.660	58.346	68.576	61.895	1
ZK47	51.780	16.310	6.580	0.663	0.066	4.910	3.920	4.050	1.170	0.154	1.940	10.320	62.908	74.554	68.773	1
ZK48	54.150	13.760	5.000	0.631	0.089	6.850	3.370	3.230	1.310	0.144	1.720	10.910	55.776	64.179	57.825	1
ZK49	38.270	11.790	4.630	0.484	0.106	16.440	3.310	2.860	0.996	0.107	2.080	14.170	37.158	40.839	34.334	2
ZK50	51.270	9.040	3.540	0.569	0.110	11.150	4.270	1.940	1.170	0.123	1.780	14.450	39.493	43.150	37.349	2
ZK51	46.840	16.560	5.870	0.607	0.071	5.860	5.280	4.410	0.943	0.177	2.600	12.020	60.920	72.718	66.166	1
ZK52	49.500	17.710	7.050	0.652	0.054	3.440	4.860	4.540	0.963	0.154	3.490	9.070	67.751	81.992	77.200	1
ZK53	50.030	11.600	4.910	0.649	0.058	11.300	3.190	2.880	1.090	0.140	1.740	13.870	43.934	49.313	42.241	2
ZK54	47.640	14.620	5.240	0.595	0.081	7.490	4.310	3.700	1.040	0.148	2.000	13.090	55.470	64.528	57.605	1
ZK55	55.450	12.250	4.700	0.610	0.062	7.220	3.640	3.010	1.250	0.136	1.880	11.580	52.628	60.444	53.545	1

Table 2. Contents of trace elements from Well ZK0303, Jiangnan Basin (unit in ppm)

No.	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Cs	Ba	Pb	Th	U
ZK1	14.30	90.70	75.90	15.70	36.80	36.00	83.70	18.80	141.00	1440.00	21.10	15.30	363.00	22.20	9.30	5.5
ZK2	9.38	47.00	54.80	7.97	24.40	49.70	51.60	12.60	93.00	498.00	18.30	8.04	344.00	6.06	6.46	1.4
ZK3	8.56	70.50	44.60	8.97	28.10	23.00	65.90	11.10	78.60	1033.00	13.80	7.03	276.00	17.40	6.90	5.0
ZK4	11.30	67.40	66.30	12.60	31.80	17.50	65.30	15.30	105.00	256.00	23.00	7.56	412.00	14.00	10.20	2.4
ZK5	7.87	75.60	40.80	8.62	25.80	24.50	36.30	10.40	73.50	1353.00	12.40	8.07	236.00	10.60	7.37	6.9
ZK6	3.26	26.70	17.80	3.69	13.60	12.00	21.20	4.24	33.00	3393.00	6.07	3.41	265.00	5.00	3.14	2.5
ZK7	3.92	40.90	20.40	5.24	18.80	39.00	122.00	5.34	36.00	1803.00	6.52	3.51	152.00	8.20	4.04	5.9
ZK8	13.90	87.80	64.50	13.80	30.30	43.10	61.60	18.10	117.00	834.00	21.70	10.50	390.00	18.40	14.20	5.9
ZK9	9.21	47.20	48.80	9.21	25.60	16.80	43.60	12.30	94.20	948.00	16.80	7.23	383.00	9.17	8.91	2.0
ZK10	8.63	58.80	42.90	8.84	24.60	22.50	38.90	11.10	81.00	3345.00	13.20	7.26	416.00	12.60	7.03	3.5
ZK11	9.54	70.80	52.30	10.30	29.50	32.50	40.50	13.10	105.00	3798.00	17.30	12.00	542.00	9.56	8.11	4.5
ZK12	6.48	48.50	32.50	7.22	21.80	17.40	27.50	8.41	58.60	3414.00	12.50	5.95	437.00	13.50	5.95	5.0
ZK13	12.60	92.30	62.40	13.30	33.10	34.70	56.20	16.40	112.00	609.00	19.40	11.10	298.00	21.80	12.10	9.5
ZK14	10.80	61.20	57.50	10.10	26.10	29.60	78.30	14.20	111.00	446.00	21.40	7.82	466.00	9.59	9.19	2.7
ZK15	15.10	96.70	74.50	14.50	35.70	13.90	77.80	21.00	147.00	209.00	24.10	12.50	480.00	14.20	13.40	2.5
ZK16	16.40	90.50	96.10	16.30	42.20	25.80	85.20	22.50	195.00	280.00	24.10	32.00	411.00	14.20	14.60	3.4
ZK17	10.40	69.10	60.00	9.43	29.60	21.70	60.60	13.40	113.00	339.00	22.20	17.80	270.00	9.43	11.60	3.5
ZK18	5.59	58.70	31.40	7.08	24.10	20.30	38.90	7.34	55.00	3208.00	9.05	10.40	303.00	28.30	6.57	13
ZK19	15.20	89.00	78.70	13.00	35.20	29.10	88.60	20.80	163.00	165.00	24.90	19.90	414.00	7.53	14.00	3.5
ZK20	13.10	82.80	65.90	10.20	31.30	19.80	68.30	17.80	138.00	1012.00	20.10	18.10	379.00	6.77	10.80	2.0
ZK21	15.90	96.80	78.90	14.90	38.30	46.20	107.00	21.30	173.00	3874.00	21.90	30.30	431.00	13.30	11.20	5.5
ZK22	17.00	90.40	83.60	16.90	41.50	62.70	89.50	21.80	186.00	692.00	24.30	24.70	472.00	17.10	14.00	3.9
ZK23	16.50	88.90	78.60	15.80	40.80	40.10	78.20	21.40	175.00	415.00	24.70	22.40	431.00	36.20	10.90	3.5
ZK24	13.40	79.40	72.60	15.00	38.60	29.90	78.20	17.20	168.00	1040.00	19.20	65.50	355.00	20.30	12.40	5.5
ZK25	17.80	114.00	94.80	21.90	45.00	31.00	96.00	22.60	203.00	303.00	23.90	30.80	499.00	17.00	14.70	3.0
ZK26	16.10	102.00	84.70	16.70	43.10	28.80	92.70	19.40	205.00	666.00	22.00	52.10	362.00	9.78	11.60	3.5
ZK27	9.02	55.20	49.50	10.10	26.20	17.80	58.70	11.10	104.00	11837.00	19.20	31.10	399.00	9.10	8.72	2.5
ZK28	16.70	103.00	86.70	18.20	42.90	26.40	98.90	21.60	204.00	272.00	25.80	39.50	361.00	14.30	13.10	2.8
ZK29	16.50	95.20	85.60	13.80	40.60	20.30	97.70	21.20	204.00	639.00	22.80	50.20	370.00	8.94	12.40	2.5
ZK30	16.90	114.00	86.30	15.40	39.50	34.50	107.00	21.60	198.00	1247.00	23.60	50.80	410.00	15.30	13.70	4.5
ZK31	17.30	102.00	90.10	15.70	41.70	36.20	111.00	21.80	200.00	673.00	26.00	40.00	427.00	17.60	14.30	3.5
ZK32	11.80	73.70	63.20	12.10	32.80	20.40	76.00	14.90	129.00	289.00	21.40	25.80	311.00	11.80	11.80	2.5
ZK33	17.90	114.00	93.90	16.60	41.70	30.60	105.00	23.10	219.00	502.00	25.80	45.90	439.00	14.90	15.30	3.5
ZK34	14.40	74.70	72.10	15.10	39.00	26.10	90.40	18.60	167.00	380.00	24.70	34.10	356.00	18.30	12.80	2.9
ZK35	17.20	102.00	68.00	14.10	37.50	25.00	102.00	22.00	194.00	212.00	25.70	39.60	411.00	14.50	14.10	2.9
ZK36	14.10	77.90	70.00	18.80	40.10	38.70	86.60	17.60	166.00	3076.00	22.20	58.60	406.00	20.70	11.80	4.4
ZK37	15.00	85.20	70.60	14.60	36.60	29.50	89.90	18.20	167.00	6262.00	23.00	53.60	393.00	13.10	12.10	8.0
ZK38	13.40	80.20	67.40	12.00	33.20	22.50	84.30	17.10	147.00	3030.00	23.00	34.60	414.00	16.20	12.70	3.7
ZK39	13.20	75.30	62.30	15.10	36.30	24.50	80.90	16.90	155.00	3024.00	20.30	54.50	370.00	24.10	11.70	2.0
ZK40	8.31	48.70	46.20	9.48	25.80	16.50	51.50	10.40	95.90	13868.00	14.90	25.10	656.00	9.14	8.54	3.5
ZK41	16.30	74.00	54.30	13.60	34.60	25.90	93.30	20.10	189.00	708.00	24.50	50.50	450.00	9.32	12.50	4.5
ZK42	11.70	69.50	55.80	12.20	29.20	20.80	75.90	14.40	114.00	323.00	25.80	22.30	357.00	16.30	11.50	2.8
ZK43	13.00	68.80	65.60	19.00	39.10	28.10	83.10	15.60	144.00	2288.00	23.60	39.90	356.00	20.10	12.30	3.5

ZK44	12.20	79.20	60.50	12.50	36.10	47.50	142.00	15.30	153.00	2804.00	18.80	84.60	363.00	13.80	10.30	13.0
ZK45	17.40	61.60	77.90	16.40	41.10	25.80	101.00	21.20	216.00	161.00	26.00	61.90	389.00	14.50	15.00	3.4
ZK46	15.90	60.40	58.70	13.10	36.90	21.10	89.00	19.10	202.00	816.00	26.00	61.80	366.00	10.00	14.50	3.0
ZK47	16.20	72.90	64.50	13.80	34.80	25.60	89.40	20.40	178.00	165.00	27.90	42.20	456.00	13.30	13.00	3.5
ZK48	13.20	87.50	66.50	18.20	34.10	67.90	85.20	17.10	140.00	647.00	26.10	31.90	403.00	17.70	11.90	3.2
ZK49	12.00	58.90	58.50	16.50	44.40	25.80	66.70	14.40	144.00	857.00	19.10	56.10	268.00	43.50	10.70	4.9
ZK50	7.79	42.80	42.00	7.95	21.80	28.30	58.60	9.13	84.10	14887.00	18.40	27.50	298.00	7.02	8.06	2.8
ZK51	16.50	71.80	64.60	16.40	38.00	27.50	97.90	19.70	225.00	4382.00	24.60	78.50	411.00	19.20	14.60	5.2
ZK52	18.20	86.80	84.10	17.60	41.00	38.20	105.00	22.50	218.00	242.00	26.00	76.30	406.00	34.90	16.00	6.7
ZK53	11.10	61.20	58.30	11.40	33.40	40.60	156.00	12.80	132.00	287.00	23.80	27.60	306.00	15.30	11.70	2.7
ZK54	14.40	74.30	60.70	15.90	35.40	29.80	92.60	16.30	165.00	2949.00	21.30	48.40	454.00	17.60	12.20	5.6
ZK55	12.30	53.60	54.90	11.30	31.50	28.60	68.40	14.60	140.00	264.00	20.70	32.60	319.00	8.19	11.00	2.4

Table 3. Contents of rare elements from Well ZK0303, Jiangnan Basin (unit in ppm).

No.	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
ZK1	33.80	61.90	7.13	27.10	4.85	0.98	4.44	0.72	4.19	0.70	2.15	0.35	2.11	0.32
ZK2	25.60	49.60	5.80	22.10	3.67	0.81	3.67	0.62	3.21	0.53	1.90	0.32	1.87	0.25
ZK3	23.10	44.40	5.26	18.30	3.22	0.62	3.02	0.53	2.71	0.44	1.56	0.23	1.41	0.21
ZK4	33.90	60.10	7.74	28.50	5.01	1.16	4.81	0.88	4.30	0.77	2.67	0.38	2.16	0.35
ZK5	20.40	37.50	4.54	16.30	2.97	0.62	2.56	0.46	2.24	0.42	1.25	0.21	1.17	0.21
ZK6	9.40	17.50	2.10	8.04	1.33	0.30	1.25	0.24	1.16	0.20	0.59	0.11	0.61	0.09
ZK7	10.90	19.40	2.53	9.53	1.61	0.34	1.37	0.26	1.40	0.24	0.72	0.12	0.73	0.11
ZK8	39.50	68.10	8.32	31.80	5.16	1.20	4.77	0.85	4.53	0.78	2.37	0.39	2.41	0.36
ZK9	24.40	46.10	5.56	21.00	3.74	0.84	3.22	0.58	3.34	0.62	1.81	0.29	1.76	0.26
ZK10	21.40	40.70	4.68	17.50	2.80	0.69	2.57	0.50	2.53	0.47	1.43	0.24	1.53	0.22
ZK11	23.40	44.50	5.40	20.30	3.55	0.83	3.06	0.58	3.01	0.55	1.57	0.27	1.75	0.26
ZK12	20.10	37.60	4.44	17.60	3.00	0.65	2.50	0.45	2.51	0.42	1.29	0.21	1.34	0.20
ZK13	33.80	59.20	7.22	27.10	4.52	1.11	4.03	0.71	3.60	0.67	2.12	0.37	2.04	0.29
ZK14	31.00	57.30	7.20	27.90	4.52	1.04	4.18	0.76	3.83	0.72	2.33	0.38	2.29	0.37
ZK15	35.00	65.00	7.93	32.40	5.44	1.26	4.76	0.92	4.84	0.86	2.90	0.47	3.08	0.46
ZK16	42.00	73.60	8.94	33.50	5.16	1.38	5.04	0.82	5.14	0.89	2.83	0.47	2.97	0.46
ZK17	33.30	59.50	7.47	29.90	4.96	1.23	4.53	0.80	4.49	0.79	2.47	0.40	2.63	0.36
ZK18	15.00	26.90	3.47	14.00	2.23	0.45	1.98	0.35	1.93	0.34	0.96	0.16	1.07	0.16
ZK19	39.40	70.20	8.71	35.20	6.31	1.47	5.23	0.91	5.27	0.90	2.91	0.47	2.96	0.45
ZK20	33.30	61.60	7.58	29.30	4.80	1.01	4.60	0.76	4.12	0.73	2.16	0.35	2.46	0.36
ZK21	46.90	88.00	11.10	40.00	5.23	1.10	5.19	0.76	4.07	0.75	2.50	0.38	2.21	0.36
ZK22	40.20	63.40	8.28	32.60	5.39	1.16	5.09	0.83	4.70	0.93	2.66	0.45	2.80	0.37
ZK23	35.60	64.10	8.06	31.00	5.14	1.02	4.79	0.85	4.64	0.89	2.70	0.41	2.71	0.45
ZK24	39.50	71.10	8.52	33.10	4.82	0.96	4.57	0.72	3.92	0.69	2.27	0.34	2.11	0.34
ZK25	74.70	133.00	15.70	61.40	7.83	1.57	7.33	1.08	5.40	0.91	2.97	0.47	2.70	0.42
ZK26	37.60	62.90	7.98	31.60	5.06	0.92	4.42	0.77	3.99	0.77	2.49	0.39	2.42	0.37
ZK27	28.10	50.90	6.36	25.60	4.33	0.96	3.95	0.62	3.65	0.71	2.12	0.35	2.02	0.28
ZK28	42.30	71.70	8.87	34.30	5.40	1.06	5.20	0.91	4.87	0.93	2.70	0.42	2.94	0.42
ZK29	39.40	67.90	7.71	31.20	4.89	0.96	4.44	0.78	4.24	0.76	2.38	0.39	2.50	0.38
ZK30	39.40	68.90	8.31	33.00	5.53	1.17	4.90	0.87	4.75	0.82	2.62	0.44	2.53	0.43
ZK31	41.70	72.40	8.91	35.00	5.97	1.27	5.42	0.91	5.03	0.95	2.91	0.46	2.85	0.43
ZK32	33.60	58.40	7.32	29.10	5.07	1.13	4.30	0.77	4.14	0.79	2.42	0.39	2.51	0.38
ZK33	46.50	76.70	9.62	36.20	6.23	1.30	5.57	0.93	5.01	0.95	3.00	0.44	2.93	0.45
ZK34	38.10	68.40	8.44	33.10	5.97	1.23	5.12	0.88	5.00	0.88	2.76	0.42	2.57	0.42
ZK35	41.60	73.40	9.10	35.70	6.31	1.25	5.35	0.90	5.28	0.92	2.87	0.46	2.82	0.43
ZK36	34.30	60.60	7.54	28.00	4.98	1.02	4.56	0.78	4.59	0.76	2.49	0.37	2.35	0.39
ZK37	36.80	62.10	8.00	29.80	5.41	1.06	4.73	0.82	4.53	0.79	2.44	0.39	2.51	0.40
ZK38	37.80	65.60	8.60	31.80	5.58	1.20	4.99	0.82	4.74	0.84	2.72	0.40	2.38	0.39
ZK39	31.50	58.90	7.18	26.30	4.63	0.95	4.22	0.72	4.09	0.74	2.35	0.38	2.31	0.36
ZK40	29.80	53.90	6.90	24.10	4.25	0.83	3.57	0.59	3.02	0.56	1.85	0.26	1.60	0.27
ZK41	35.90	66.00	8.43	29.00	5.57	1.20	4.85	0.81	4.59	0.86	2.73	0.45	2.75	0.41
ZK42	41.30	76.20	10.00	35.60	6.00	1.21	5.72	1.00	5.15	0.90	2.88	0.44	2.70	0.40
ZK43	36.00	64.50	8.56	30.60	5.30	1.17	4.95	0.83	4.68	0.81	2.81	0.38	2.38	0.39

ZK44	31.30	56.20	6.95	25.30	4.51	0.81	3.80	0.68	3.72	0.66	2.15	0.31	1.96	0.30
ZK45	43.10	74.20	9.63	34.10	6.04	1.20	5.31	0.94	5.00	0.93	2.94	0.44	2.54	0.43
ZK46	41.80	73.50	9.48	33.30	6.00	1.16	5.30	0.90	4.88	0.88	2.96	0.43	2.61	0.44
ZK47	38.40	67.20	8.93	32.10	6.09	1.27	5.39	0.95	5.23	1.00	3.10	0.49	2.84	0.48
ZK48	35.40	62.50	7.94	29.50	5.65	1.11	4.80	0.84	4.91	0.89	2.85	0.41	2.70	0.42
ZK49	29.90	58.30	6.89	25.80	4.63	0.83	3.82	0.65	3.77	0.70	2.17	0.31	1.91	0.32
ZK50	26.50	47.00	6.15	22.20	4.14	0.86	3.69	0.64	3.57	0.64	1.89	0.30	1.90	0.30
ZK51	41.70	70.50	8.78	31.80	5.86	1.27	4.97	0.87	4.82	0.88	2.73	0.42	2.69	0.40
ZK52	42.40	72.70	9.33	35.10	6.01	1.14	5.14	0.89	4.91	0.92	2.94	0.44	2.80	0.47
ZK53	34.80	63.30	7.93	29.50	5.59	1.24	4.77	0.87	4.82	0.82	2.60	0.38	2.45	0.37
ZK54	43.60	77.60	9.69	35.00	5.57	1.11	4.98	0.78	4.41	0.79	2.45	0.37	2.40	0.38
ZK55	32.90	61.30	7.80	28.50	5.36	1.08	4.52	0.76	4.13	0.75	2.40	0.34	2.28	0.34

Table 4. Selected element ratios from Well ZK0303, Jiangnan Basin

No.	SiO ₂ /Al ₂ O ₃	K ₂ O/Al ₂ O ₃	K ₂ O /Na ₂ O	C- value	Ni/Co	V/Cr	V/(V+Ni)	Sr/Cu	Ga/Rb	La/Sc	Co/Th	La/Th	δCe	LREE/HREE
ZK1	3.03	0.23	2.83	0.31	2.34	1.19	0.71	40.00	0.13	2.36	1.69	3.63	0.91	9.06
ZK2	5.77	0.23	1.22	0.25	3.06	0.86	0.66	10.02	0.14	2.73	1.23	3.96	0.93	8.70
ZK3	3.20	0.27	1.12	0.12	3.13	1.58	0.72	44.91	0.14	2.70	1.30	3.35	0.93	7.70
ZK4	4.42	0.21	1.10	0.25	2.52	1.02	0.68	14.63	0.15	3.00	1.24	3.32	0.85	8.36
ZK5	3.18	0.25	0.50	0.10	2.99	1.85	0.75	55.22	0.14	2.59	1.17	2.77	0.89	9.68
ZK6	3.78	0.27	0.08	0.05	3.69	1.50	0.66	282.75	0.13	2.88	1.18	2.99	0.90	9.10
ZK7	3.78	0.26	0.09	0.06	3.59	2.00	0.69	46.23	0.15	2.78	1.30	2.70	0.84	8.95
ZK8	3.25	0.25	0.90	0.29	2.20	1.36	0.74	19.35	0.15	2.84	0.97	2.78	0.86	9.36
ZK9	3.84	0.27	0.62	0.16	2.78	0.97	0.65	56.43	0.13	2.65	1.03	2.74	0.90	8.55
ZK10	3.19	0.26	0.36	0.13	2.78	1.37	0.71	148.67	0.14	2.48	1.26	3.04	0.93	9.26
ZK11	3.71	0.26	1.05	0.15	2.86	1.35	0.71	116.86	0.12	2.45	1.27	2.89	0.90	8.87
ZK12	3.63	0.23	0.35	0.10	3.02	1.49	0.69	196.21	0.14	3.10	1.21	3.38	0.91	9.35
ZK13	3.39	0.23	0.83	0.24	2.49	1.48	0.74	17.55	0.15	2.68	1.10	2.79	0.87	9.61
ZK14	4.74	0.24	1.44	0.28	2.58	1.06	0.70	15.07	0.13	2.87	1.10	3.37	0.88	8.68
ZK15	3.18	0.25	1.83	0.46	2.46	1.30	0.73	15.04	0.14	2.32	1.08	2.61	0.89	8.04
ZK16	2.94	0.29	2.65	0.42	2.59	0.94	0.68	10.85	0.12	2.56	1.12	2.88	0.87	8.84
ZK17	4.55	0.24	1.31	0.25	3.14	1.15	0.70	15.62	0.12	3.20	0.81	2.87	0.86	8.29
ZK18	3.64	0.26	0.76	0.07	3.40	1.87	0.71	158.03	0.13	2.68	1.08	2.28	0.87	8.44
ZK19	2.97	0.26	2.56	0.44	2.71	1.13	0.72	5.67	0.13	2.59	0.93	2.81	0.89	8.86
ZK20	3.04	0.27	2.56	0.31	3.07	1.26	0.73	51.11	0.13	2.54	0.94	3.08	0.86	8.40
ZK21	2.74	0.26	2.65	0.31	2.57	1.23	0.72	83.85	0.12	2.95	1.33	4.19	0.85	8.33
ZK22	2.77	0.28	3.41	0.41	2.46	1.08	0.69	11.04	0.12	2.36	1.21	2.87	0.92	8.35
ZK23	2.90	0.25	2.16	0.40	2.58	1.13	0.69	10.35	0.12	2.16	1.45	3.27	0.88	11.86
ZK24	3.00	0.27	3.10	0.26	2.57	1.09	0.67	34.78	0.10	2.95	1.21	3.19	0.79	8.47
ZK25	2.78	0.25	3.68	0.41	2.05	1.20	0.72	9.77	0.11	4.20	1.49	5.08	0.86	8.31
ZK26	2.88	0.27	3.12	0.38	2.58	1.20	0.70	23.13	0.09	2.34	1.44	3.24	0.89	13.83
ZK27	4.95	0.26	1.62	0.21	2.59	1.12	0.68	665.00	0.11	3.12	1.16	3.22	0.83	9.35
ZK28	2.91	0.22	4.00	0.46	2.36	1.19	0.71	10.30	0.11	2.53	1.39	3.23	0.87	8.48
ZK29	2.95	0.26	4.17	0.37	2.94	1.11	0.70	31.48	0.10	2.39	1.11	3.18	0.85	8.90
ZK30	2.71	0.26	3.98	0.44	2.56	1.32	0.74	36.14	0.11	2.33	1.12	2.88	0.89	9.58
ZK31	2.83	0.25	4.04	0.43	2.66	1.13	0.71	18.59	0.11	2.41	1.10	2.92	0.87	9.00
ZK32	4.12	0.24	2.48	0.27	2.71	1.17	0.69	14.17	0.12	2.85	1.03	2.85	0.85	8.58
ZK33	2.75	0.27	4.80	0.49	2.51	1.21	0.73	16.41	0.11	2.60	1.08	3.04	0.83	9.16
ZK34	3.27	0.26	3.62	0.35	2.58	1.04	0.66	14.56	0.11	2.65	1.18	2.98	0.87	8.60
ZK35	2.96	0.26	3.82	0.39	2.66	1.50	0.73	8.48	0.11	2.42	1.00	2.95	0.86	8.80
ZK36	2.94	0.24	3.43	0.25	2.13	1.11	0.66	79.48	0.11	2.43	1.59	2.91	0.86	8.37
ZK37	2.84	0.23	3.14	0.32	2.51	1.21	0.70	212.27	0.11	2.45	1.21	3.04	0.83	8.62
ZK38	3.54	0.24	2.87	0.35	2.77	1.19	0.71	134.67	0.12	2.82	0.94	2.98	0.83	8.71
ZK39	2.97	0.25	3.66	0.27	2.40	1.21	0.67	123.43	0.11	2.39	1.29	2.69	0.90	8.54
ZK40	4.03	0.23	2.33	0.15	2.72	1.05	0.65	840.48	0.11	3.59	1.11	3.49	0.86	10.23
ZK41	2.96	0.24	3.75	0.39	2.54	1.36	0.68	27.34	0.11	2.20	1.09	2.87	0.87	8.37
ZK42	4.48	0.22	1.55	0.28	2.39	1.25	0.70	15.53	0.13	3.53	1.06	3.59	0.86	8.88

ZK43	3.59	0.24	3.30	0.30	2.06	1.05	0.64	81.42	0.11	2.77	1.54	2.93	0.84	8.48
ZK44	2.85	0.25	2.49	0.18	2.89	1.31	0.69	59.03	0.10	2.57	1.21	3.04	0.87	9.21
ZK45	2.95	0.27	5.25	0.48	2.51	0.79	0.60	6.24	0.10	2.48	1.09	2.87	0.83	9.08
ZK46	3.19	0.26	4.21	0.36	2.82	1.03	0.62	38.67	0.09	2.63	0.90	2.88	0.84	8.98
ZK47	3.17	0.25	3.46	0.47	2.52	1.13	0.68	6.45	0.11	2.37	1.06	2.95	0.83	7.91
ZK48	3.94	0.23	2.47	0.34	1.87	1.32	0.72	9.53	0.12	2.68	1.53	2.97	0.85	7.97
ZK49	3.25	0.25	2.87	0.20	2.69	1.01	0.57	33.22	0.10	2.49	1.54	2.79	0.82	8.34
ZK50	5.67	0.21	1.66	0.18	2.74	1.02	0.66	526.04	0.11	3.40	0.99	3.29	0.84	8.27
ZK51	2.83	0.27	4.68	0.35	2.32	1.11	0.65	159.35	0.09	2.53	1.12	2.86	0.84	8.99
ZK52	2.80	0.26	4.71	0.51	2.33	1.03	0.68	6.34	0.10	2.33	1.10	2.65	0.84	9.00
ZK53	4.31	0.25	2.64	0.27	2.93	1.05	0.65	7.07	0.10	3.14	0.97	2.97	0.87	8.33
ZK54	3.26	0.25	3.56	0.32	2.23	1.22	0.68	98.96	0.10	3.03	1.30	3.57	0.86	10.42
ZK55	4.53	0.25	2.41	0.31	2.79	0.98	0.63	9.23	0.10	2.67	1.03	2.99	0.87	8.83

Table 5. Geochemical proxies of redox environment.

Palec-oxygenation Facies	Oxygen Content (mL/L)	V/Cr	Ni/Co	V/(V+Ni)
Anaerobic, extremely dysaerobic	<0.20	>4.25	>7.00	>0.77
Dysaerobic, secondary aerobic	0.20-2.00	2.00-4.25	5.00-7.00	0.60-0.77
Aerobic	>2.00	<2.00	<5.00	<0.60

Figures

Figure 1

Geologic and tectonic sketch maps of the Jiangnan Basin region. (A) modified after Chen et al.27.

Figure 2

Tectonic map of the Jiangling depression (modified after Teng et al.22), and Stratigraphic column of the Shashi Formation in ZK0303.

Figure 3

(A) PAAS-normalized major element diagram of samples in Well ZK0303, Data of the PAAS are from McLennan39; (B) UC-normalized trace-element diagram of samples in Well ZK0303, Data of the UC are from Taylor & McLennan40; (C) Chondrite-normalized rare element diagram of samples in Well ZK0303, Data of the Chondrite are from Boynton et al.41.

Figure 4

Geochemical classification diagram (Herron42) of $\log (\text{SiO}_2/\text{Al}_2\text{O}_3)$ plotted against $\log (\text{Fe}_2\text{O}_3/\text{K}_2\text{O})$ for the samples of the Shashi Formation.

Figure 5

Discrimination diagrams illustrating sedimentary provenance. (A) Discrimination function diagram using major element ratios (after Roser & Korsch46), $F1 = -1.773TiO_2 + 0.607Al_2O_3 + 0.76Fe_2O_3 - 1.5MgO + 0.616CaO + 0.509Na_2O - 1.224K_2O - 9.09$, $F2 = 0.445TiO_2 + 0.07Al_2O_3 + 0.25Fe_2O_3 - 1.142MgO + 0.438CaO + 1.475Na_2O + 1.426K_2O - 6.861$; (B) TiO_2 (%) versus Al_2O_3 (%) bivariate diagram (after Hayashi et al.47); (C) TiO_2 (%) versus Zr (ppm) bivariate diagram (after Hayashi et al.47); (D) La/Th versus Hf (ppm) bivariate diagram (after Floyd & Leveridge48); (E) Co/Th versus Zr/Sc bivariate diagram (after McLennan et al.49); (F) Th/Sc versus Zr/Sc bivariate diagram (after McLennan et al.49).

Figure 6

Diagrams showing influence of weathering, sorting processes. (A) Al_2O_3 -($\text{CaO}^* + \text{Na}_2\text{O}$)- K_2O (A-CN-K) ternary diagram (after Nesbitt & Young60); (B) Al_2O_3 -Zr-TiO₂ ternary diagram (after McLennan et al.49).

Figure 7

Tectonic discrimination diagrams of samples in ZK0303. (A) Th-Co-Zr/10 ternary diagram (after Bhatia & Crook53); (B) La-Th-Sc ternary diagram (after Bhatia & Crook53); (C) $\text{SiO}_2/\text{Al}_2\text{O}_3$ versus $\text{K}_2\text{O}/\text{Na}_2\text{O}$ bivariate diagram (after Roser & Korsch43). OA: oceanic island arc, CIA: continental island arc, ACM: active continental margin, and PM: passive margin.

ZJRS: Zhijiang river system; YARS: Yuan'an river system;
NJRS: Nanjing river system.

Figure 8

Paleocene sedimentary facies of the Jiangling depression (modified after Teng et al.22).

Figure 9
 Discrimination diagrams for climatic conditions of samples in ZK0303. (A) SiO₂ (%) versus Al₂O₃+K₂O+Na₂O (%) bivariate diagram (after Suttner & Dutta77); (B) Sr/Cu versus C-value bivariate diagram (after Zhao et al.68; Cao et al.69); (C) Ga/Rb versus Sr/Cu bivariate diagram (after Sarki Yandoka et al.78).

Figure 10
 Discrimination diagrams for redox conditions of samples in ZK0303. (A) V/Cr versus Ni/Co bivariate diagram (after Jones & Manning83); (B) V/(V+Ni) versus Ni/Co bivariate diagram (after Hatch & Leventhal88).