PS Characteristics and Origin of Source Rocks in the Small Faulted Lacustrine Basin*

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Abstract

Compared to a large-scale lake basin, the small faulted lacustrine basin is characterized by a small area, shallow water, multi-and-near sources, oxidative sedimentary environment and high sedimentation rate. To recognize the origin of source rocks in a small faulted lacustrine basin, four basins (Aer, Wuli, Saihan, Naoer) in the Erlian Basin Group, one of the most petroliferous basins in northern China, have been analyzed to characterize source rock potential, to reveal environmental and ecological changes and construct source rocks depositional models. These basins have dissimilar boundary fault activities and sedimentation rates, which are consistent with changes in clastic influx input, productivity and redox conditions. With more active boundary faults and higher sedimentation rates, the terrigenous organic matter inputs to Aer and Wuli basins are higher than Naoer and Saihan basins, which can be confirmed by relative steranes abundances. The carbon isotopic composition of carbonates suggests that the productivity of Aer and Wuli basins is higher than that of Naoer and Saihan basins. Total reduced sulfur and Pr/Ph ratios show an oxidizing environment in Aer and Wuli basins, while a reducing environment was present in Naoer and Saihan basins.

Different tectonic conditions lead to variations in ecological communities and enable us to construct source rock deposition models. During source rock deposition in the small basin with active boundary faults and high sedimentation rates, the high influx of clastic sediments carrying high terrigenous organic matter and dissolved inorganic carbon and nitrate into the lake, might have sustained high productivity and oxidizing conditions. Due to high influx of clastic sediments and unstable water column stratification, the depositional environment is oxidizing. In the high productivity lake, there is still significant organic matter accumulation in the oxidized environment after oxidative degradation. High productivity is the dominant factor controlling the formation of organic-rich sediments and deposition of source rocks. During source rock deposition in the small basin with inactive boundary faults and low sedimentation rates, the depositional environment is reducing due to low influx of clastic sediments with low productivity. In the low productivity lake, a reducing sedimentary environment substitutes for productivity and becomes the predominant factor controlling the formation of source rocks.

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1. Geologic setting

Erlian Basin is an Early Cretaceous rift basin group developed on Hercynian folded basement and comprises more than 40 north-northeast trending small fault basins, with an area smaller than 5000 km2 (Fig. 1, Fig. 2).

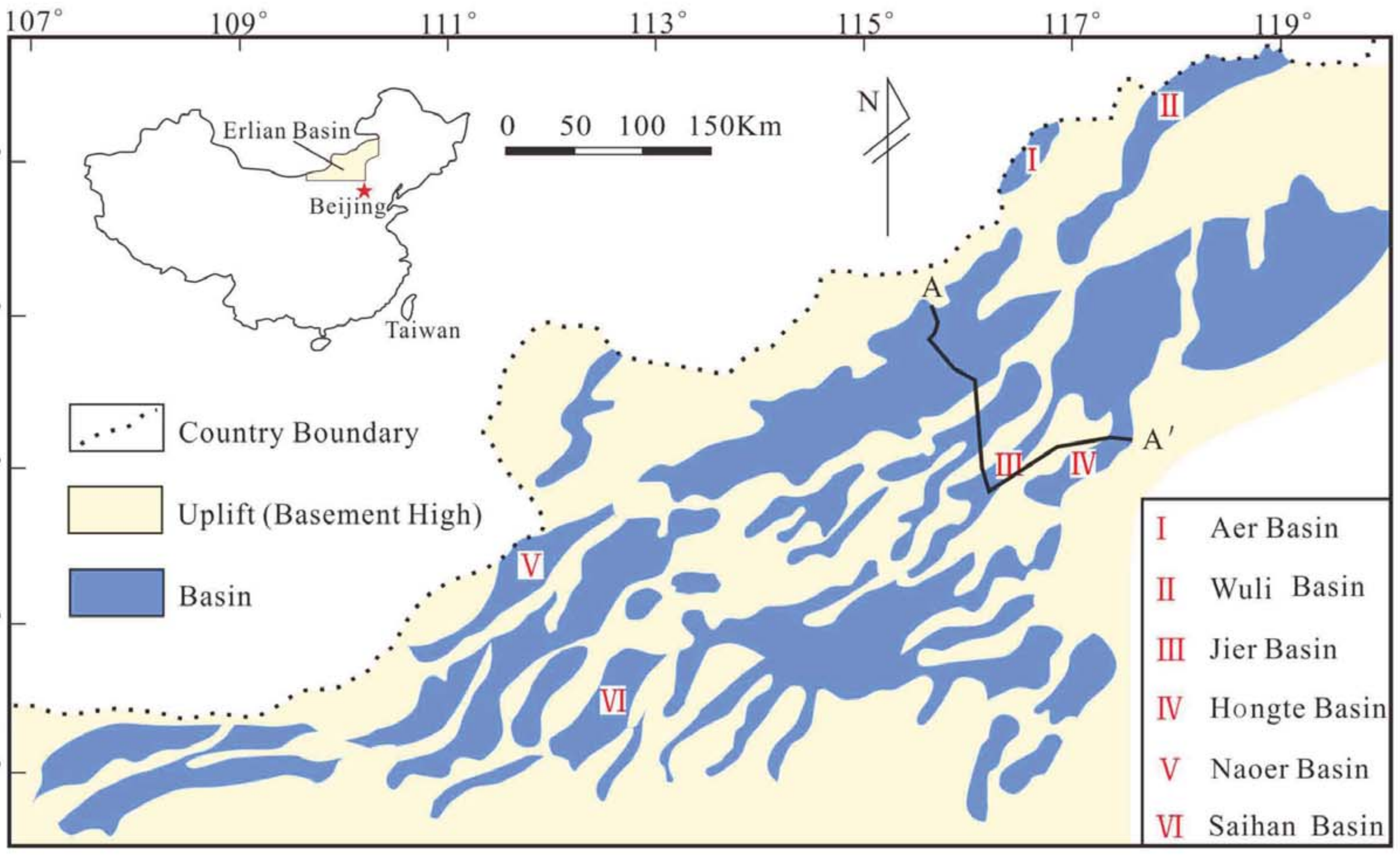


Fig. 1 Map of the Erlian Basin Group, showing location of each study small fault basin, Aer, Wuli, Jier, Hongte, Naoer, Saihan.

2. Characteristics of small faulted lacustrine basin

Compared to large-scale lake basin, small faulted lacustrine basin is characterized by small area, shallow water, multi-and-near sources, oxidative sedimentary environment and high sedimentary rate.

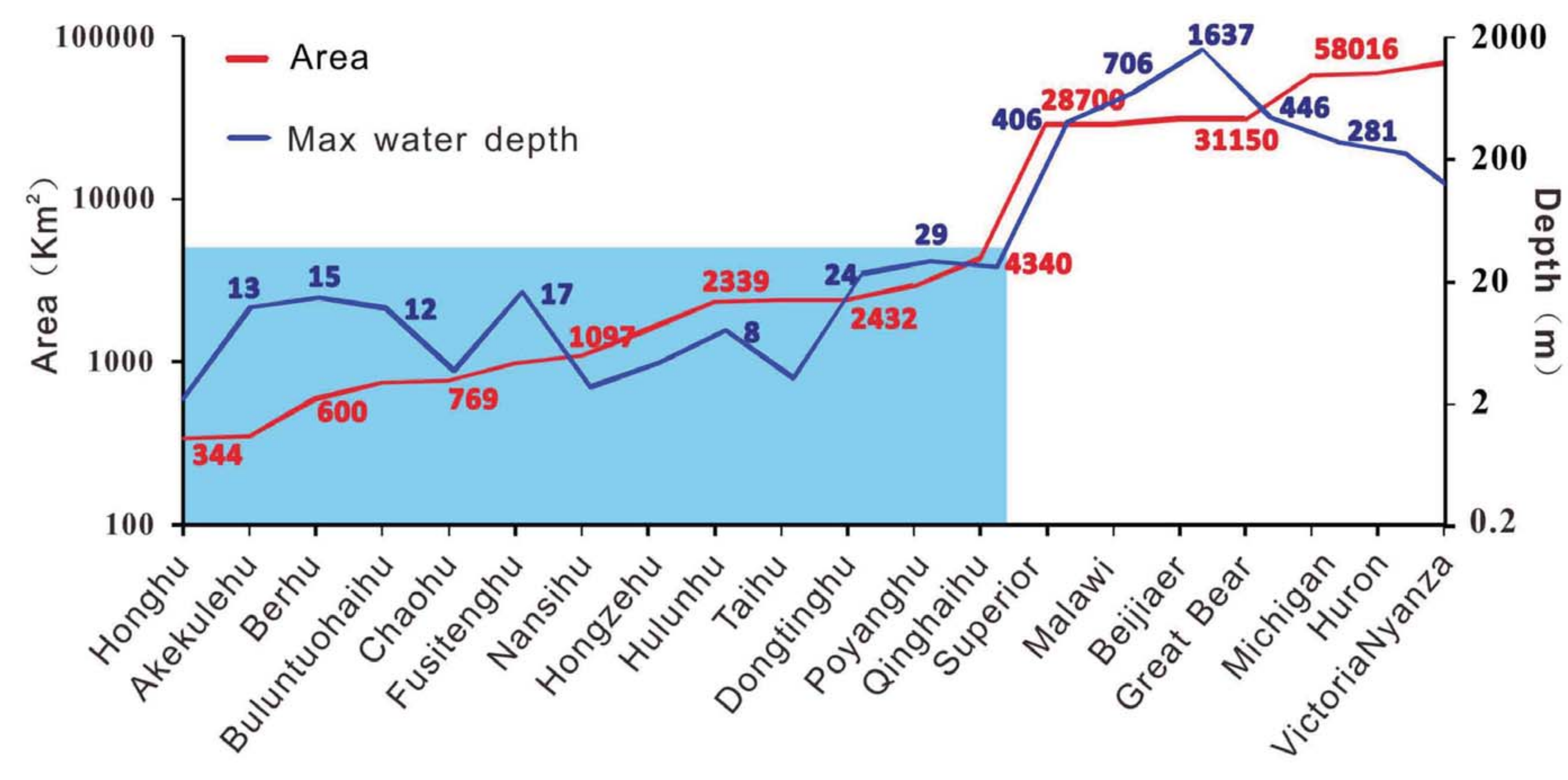


Fig. 4 The area and the maximum water depth of the modern lake. The Prsent is the key to the past. The max. water depth of small modern lake is usually smaller than 30m. The datas come from Wikipedia.

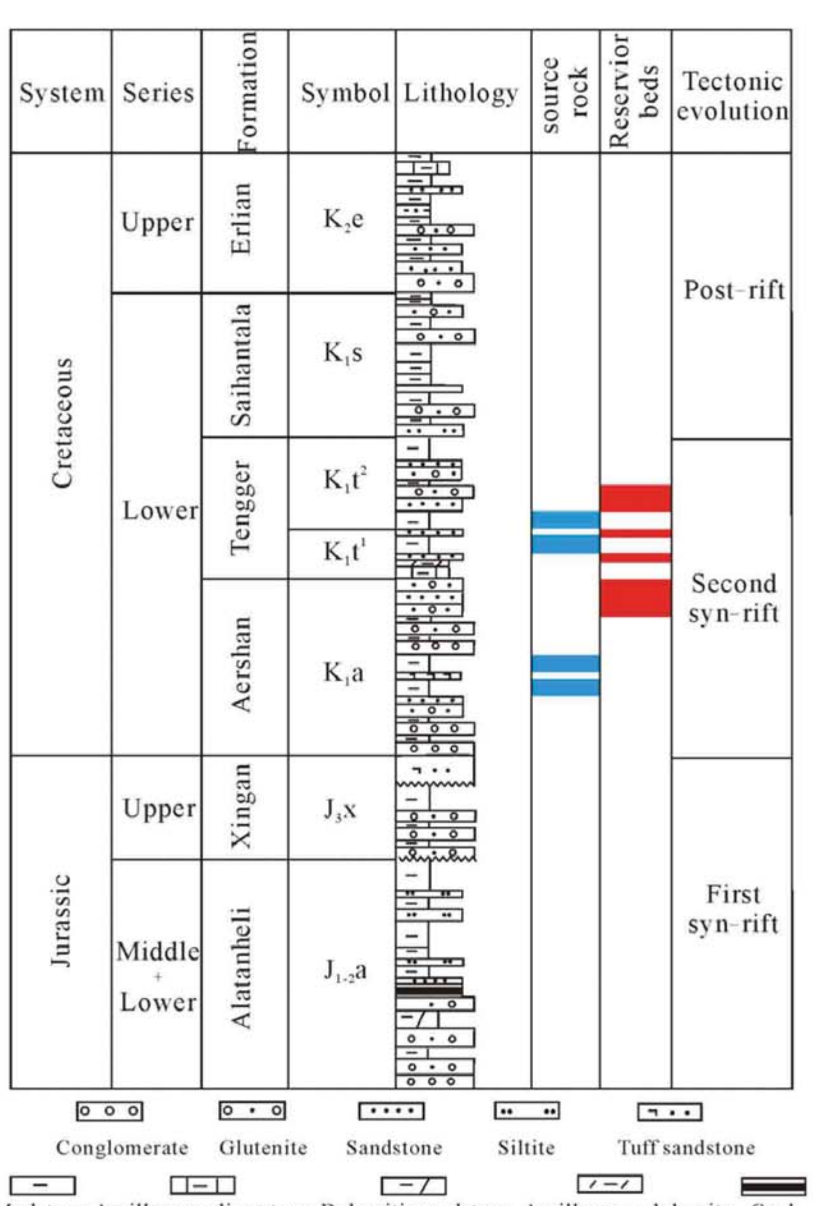


Fig. 3 Generalized stratigraphy of the Erlian Basin. Possible source rock and major reservoir intervals are marked.

The small fault basins are formed by extension during the Jurassic and Cretaceous and dominated by half-grabens or asymmetric grabens, and display similar tectonic evolution and clear basin boundary (Dou, 1998; Dou, 2003).

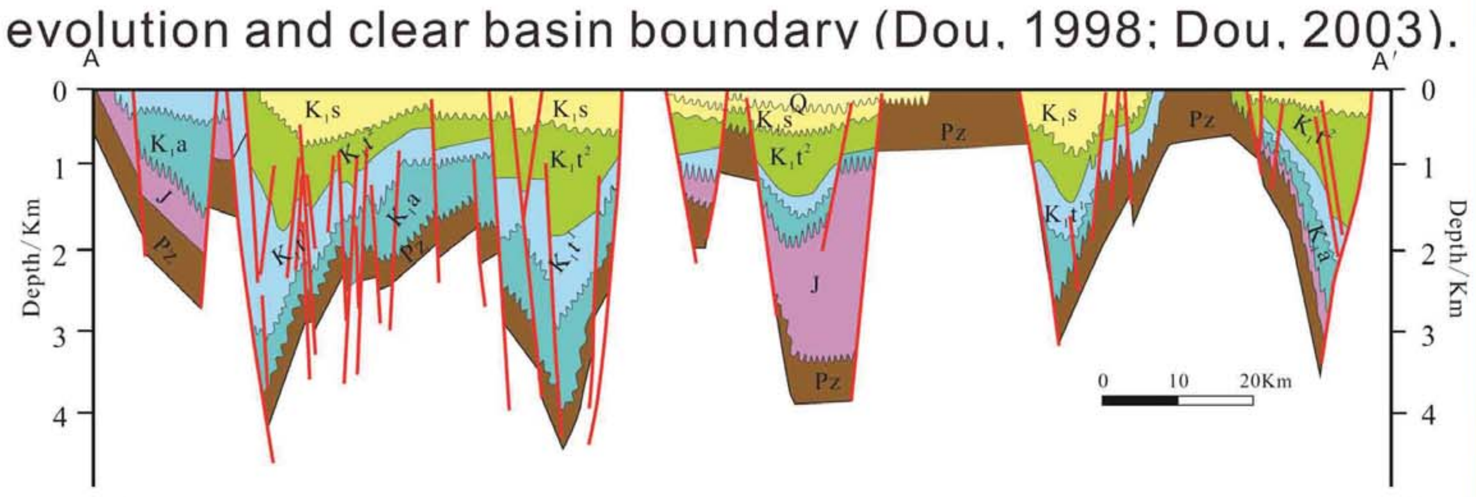


Fig. 2 Cross section shows the structural framework of these small fault basins. Note the thick Cretaceous sediments and strong faulting in the Erlian Basin Group. Section location is given in Fig. 1.

The Tengger Formation is made up of dark grey-black mudstones interbedded with sandstones and siltstones, with a thickness of 500-2100m, and can be further subdivided into the lower Tengger member (K_1t^1) and the upper Tengger member (K_1t^2). Possible source rock horizons exist mainly in the K_1a and K_1t^1 formations. The K_1t^2 formation is excluded as a possible source rock mainly due to its shallow burial depth and low maturity.

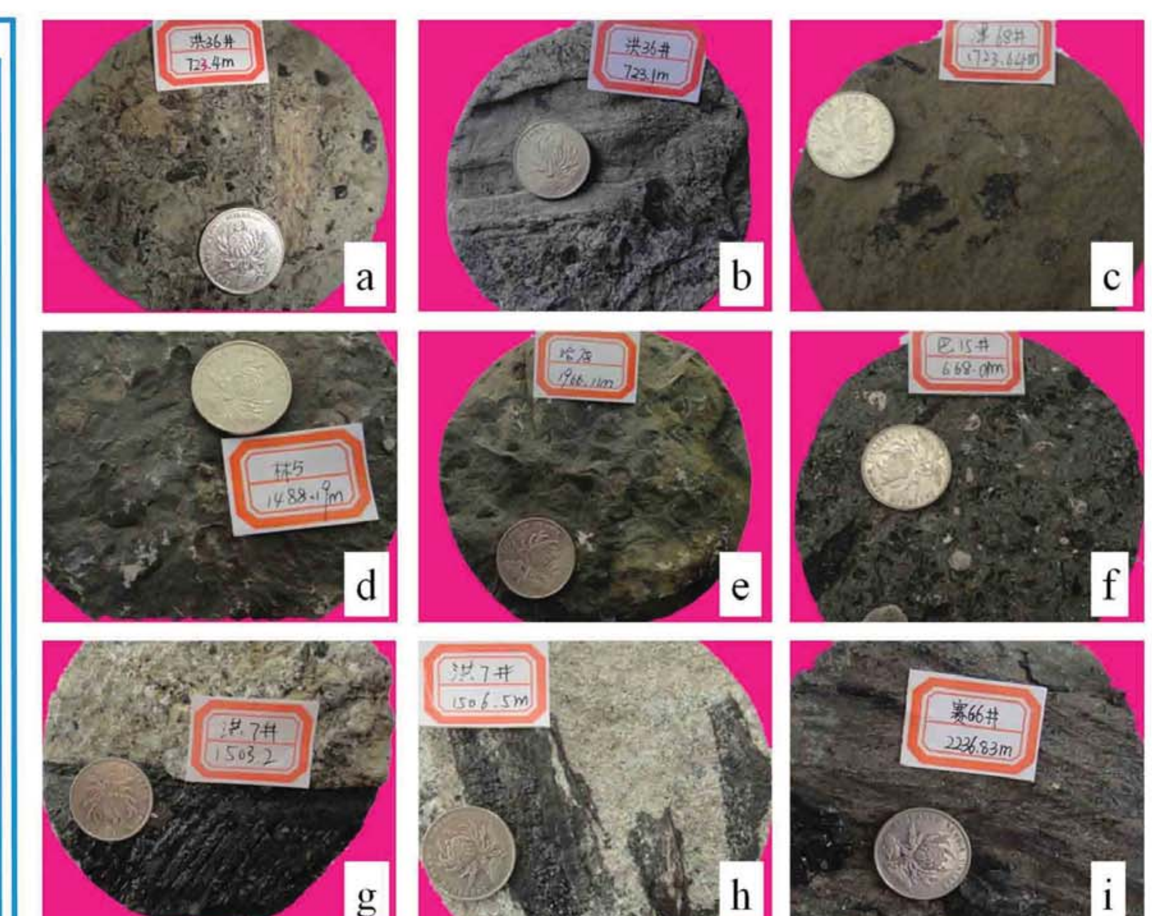


Fig. 5 The photograph of cores in small faulted laustrine basin, Erlian Basin Group.

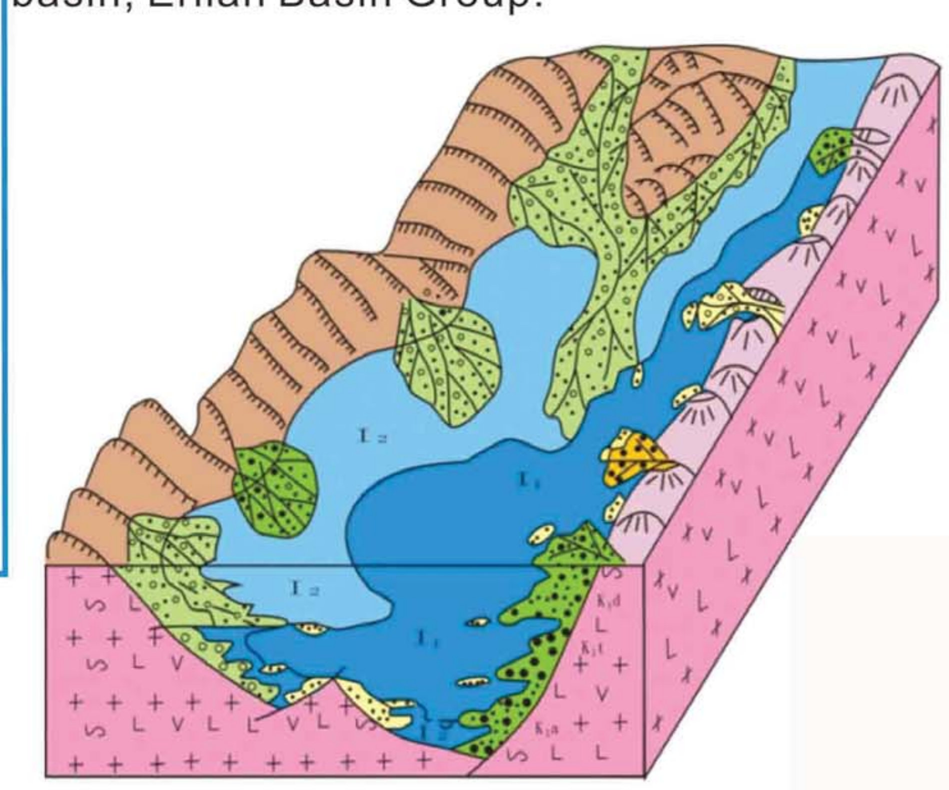
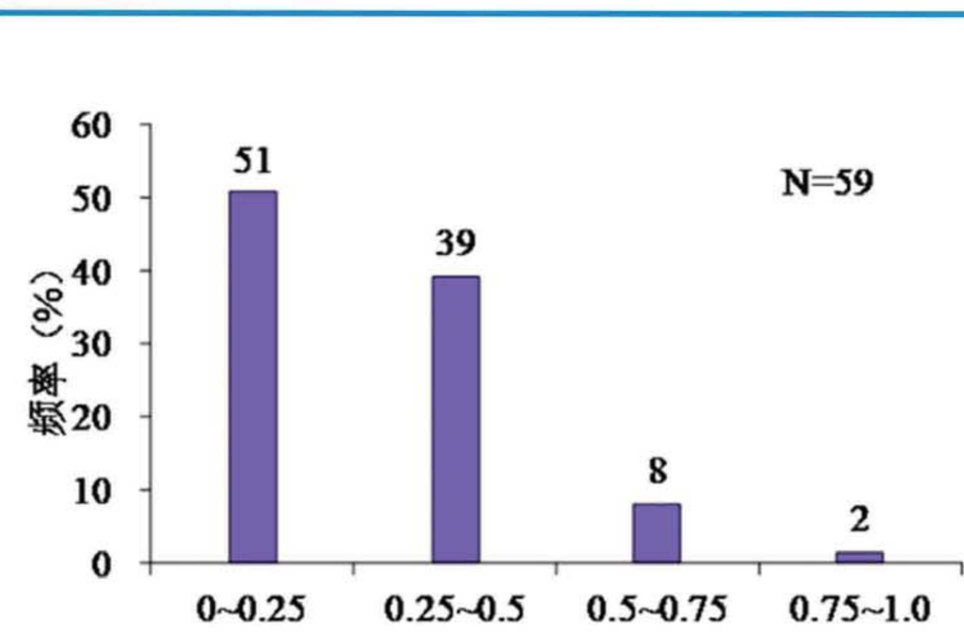
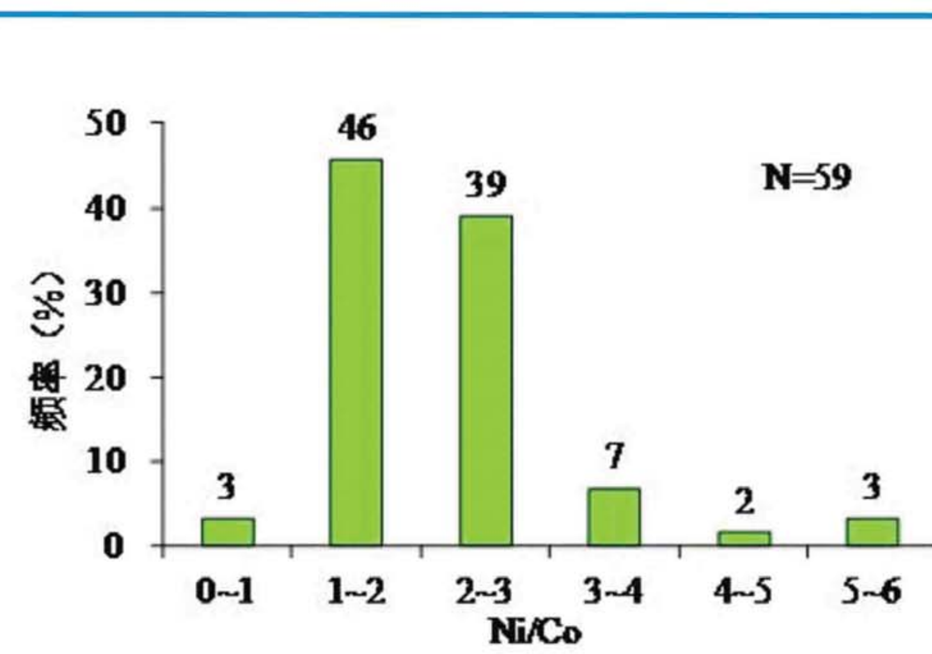


Fig. 6 The depositinal model of small faulted laustrine basin, Erlian Basin Group (Huabei oilfield, CNPC).





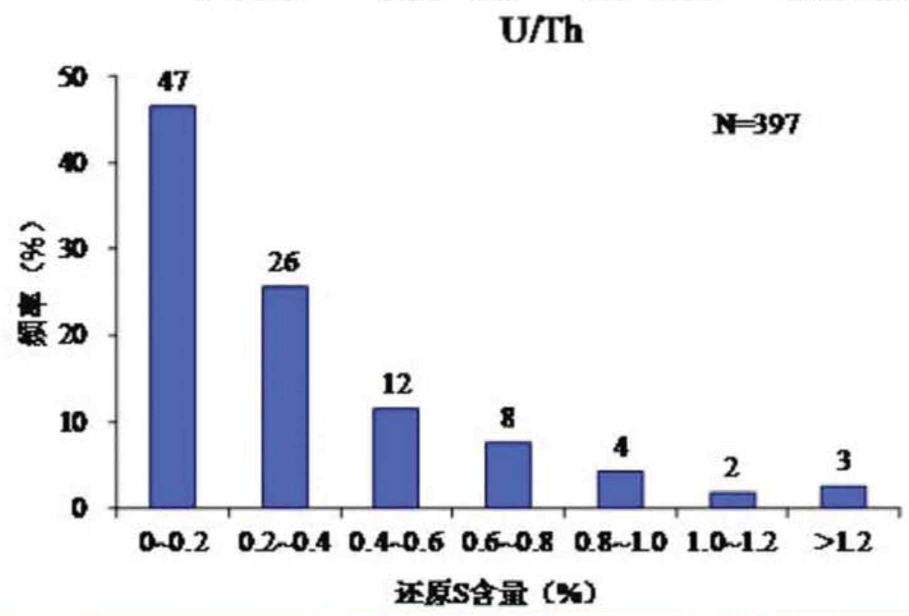


Fig. 7 Histogram of U/Th, Ni/Co values and reducing S content in source rocks, Erlian Basin. A relatively oxic, suboxic and anoxic depositional environment of small fault basin are indicated. The trace elements data and ratios reveal the depositional environment during sedimentation of source rocks (Harris et al., 2004; Fu et al., 2011). Total reduced sulphur contents in sediments may provide insight into the depositional environment and microbial sulphate reduction (Mulier, 2002; Kao et al., 2004).

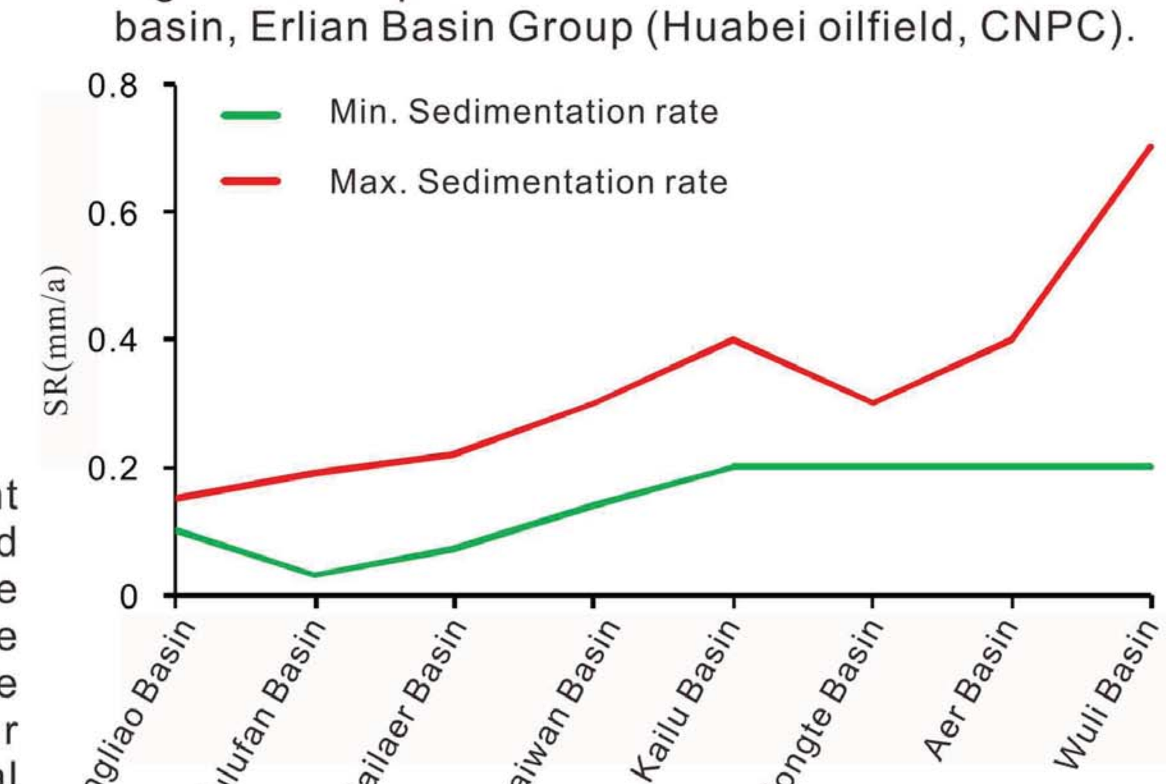


Fig. 8 Max. and Min. values of sedimentation rate in Mesozoic-Cenozoic basin of China.

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3.Source rocks characteristics

In the Erlian Basin, the source rocks in the eastern Basins have higher TOC than the western. For instance, the TOC contents of mudstone samples in the Aer Basin range from 0.36% to 4.87%, while in the Naoer Basin TOC ranges from 0.07% to 2.63%.

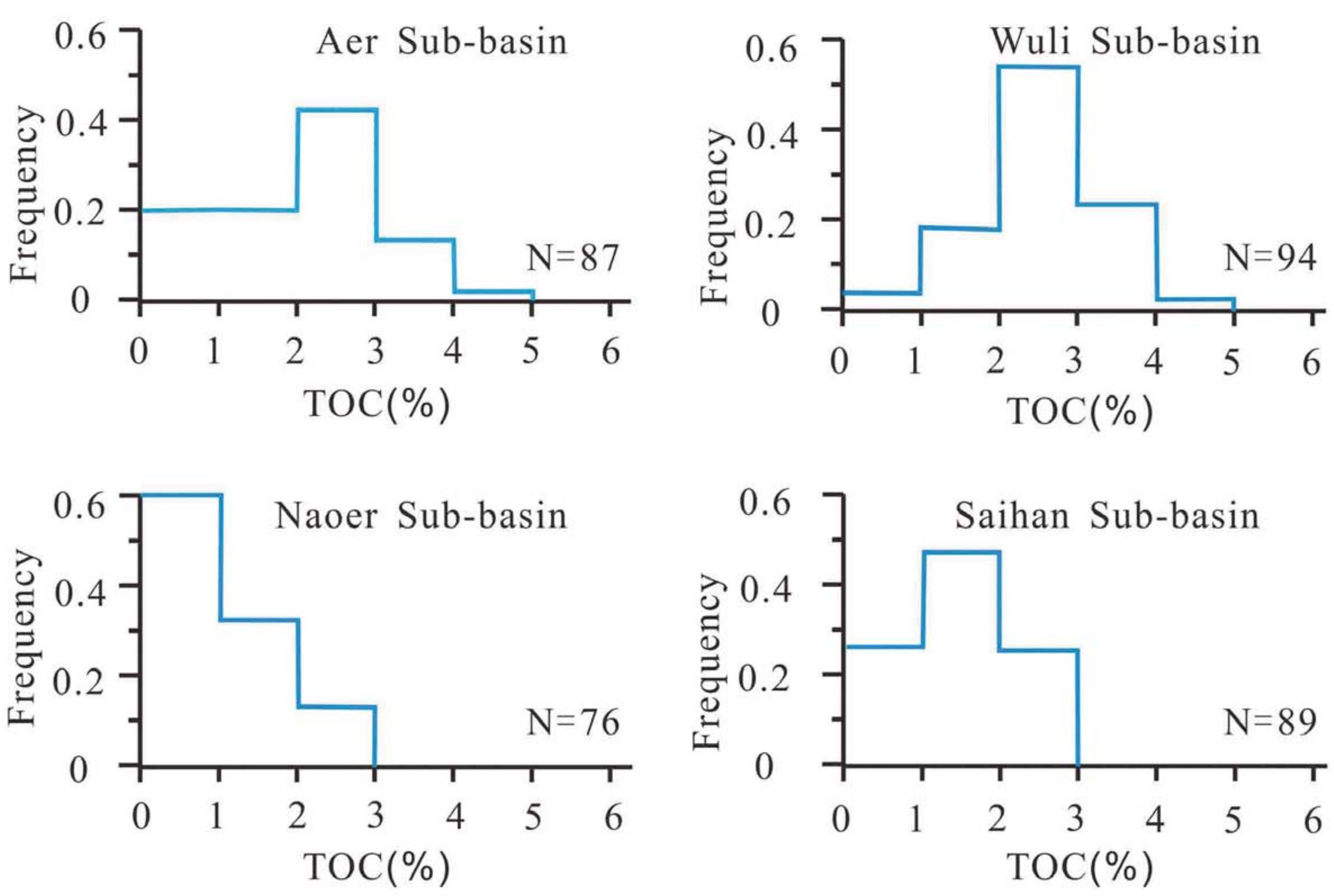

Fig. 9 Total organic carbon content histograms of source rocks in K_1t^1 of Aer, Wuli, Naoer and Saihan Basins in the Erlian Basin Group.

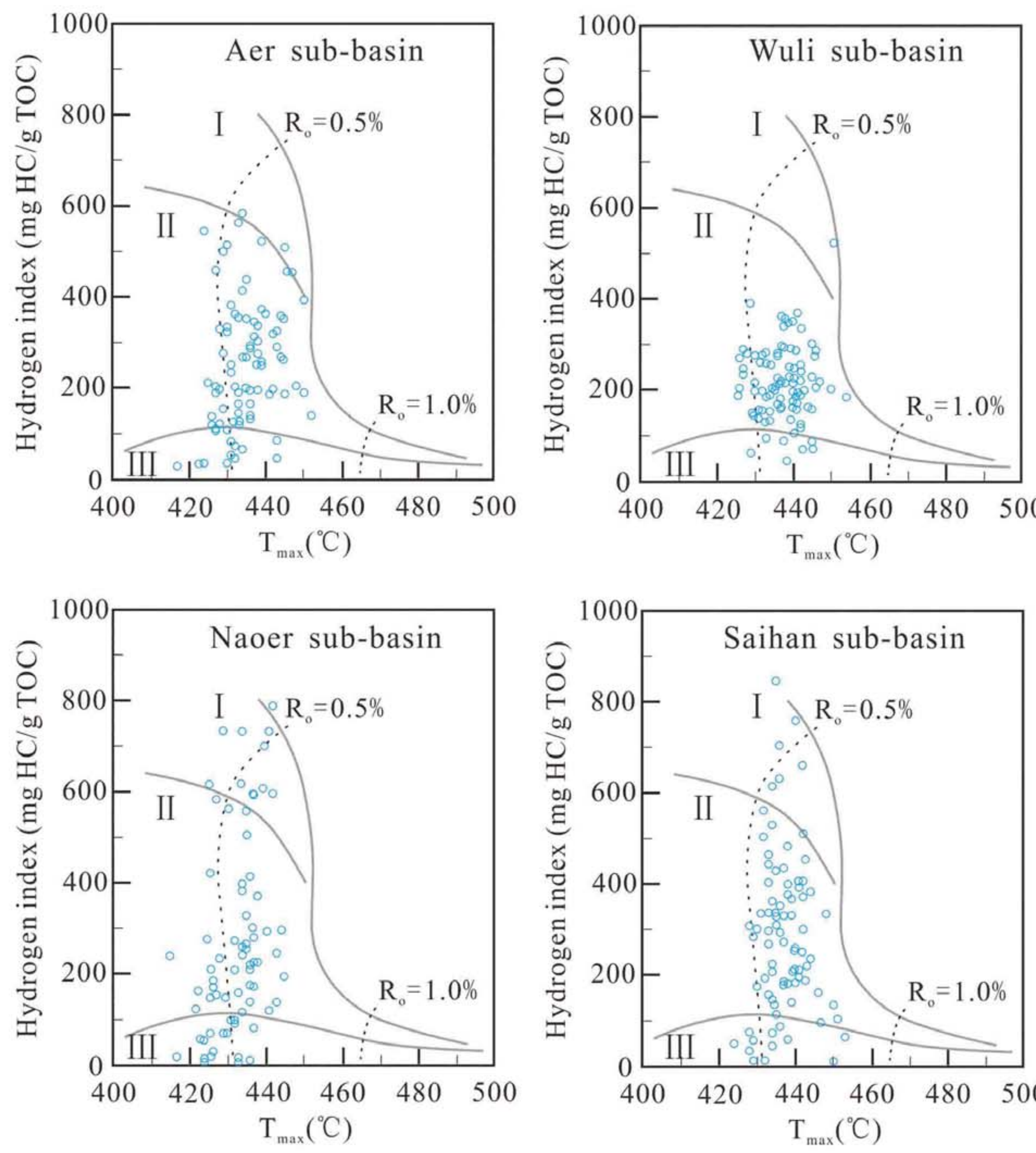

Fig. 10 Plot of Hydrogen Index versus T_{max} outlining the kerogen type of Aer, Wuli, Naoer and Saihan Basins in the Erlian Basin Group.

Rock-Eval pyrolysis is a commonly-used technique to classify organic matter types and assess hydrocarbon generating potentials (Peters, 1986). In Aer and Wuli Basins, the source rocks have relatively low hydrogen index, indicative of mixed type II and III kerogen. While in Naoer and Saihan Basin, kerogen composition ranges from type I to type III, with bacterial, algal and higher plant remains all making important but variable contributions.

4.Depositional environment

According to reduced sulphur/organic carbon ratio, biomarker characteristics and trace elements distribution, a fresh to brackish water conditions and a relatively oxic, suboxic and anoxic depositional environment of small fault basin are indicated.

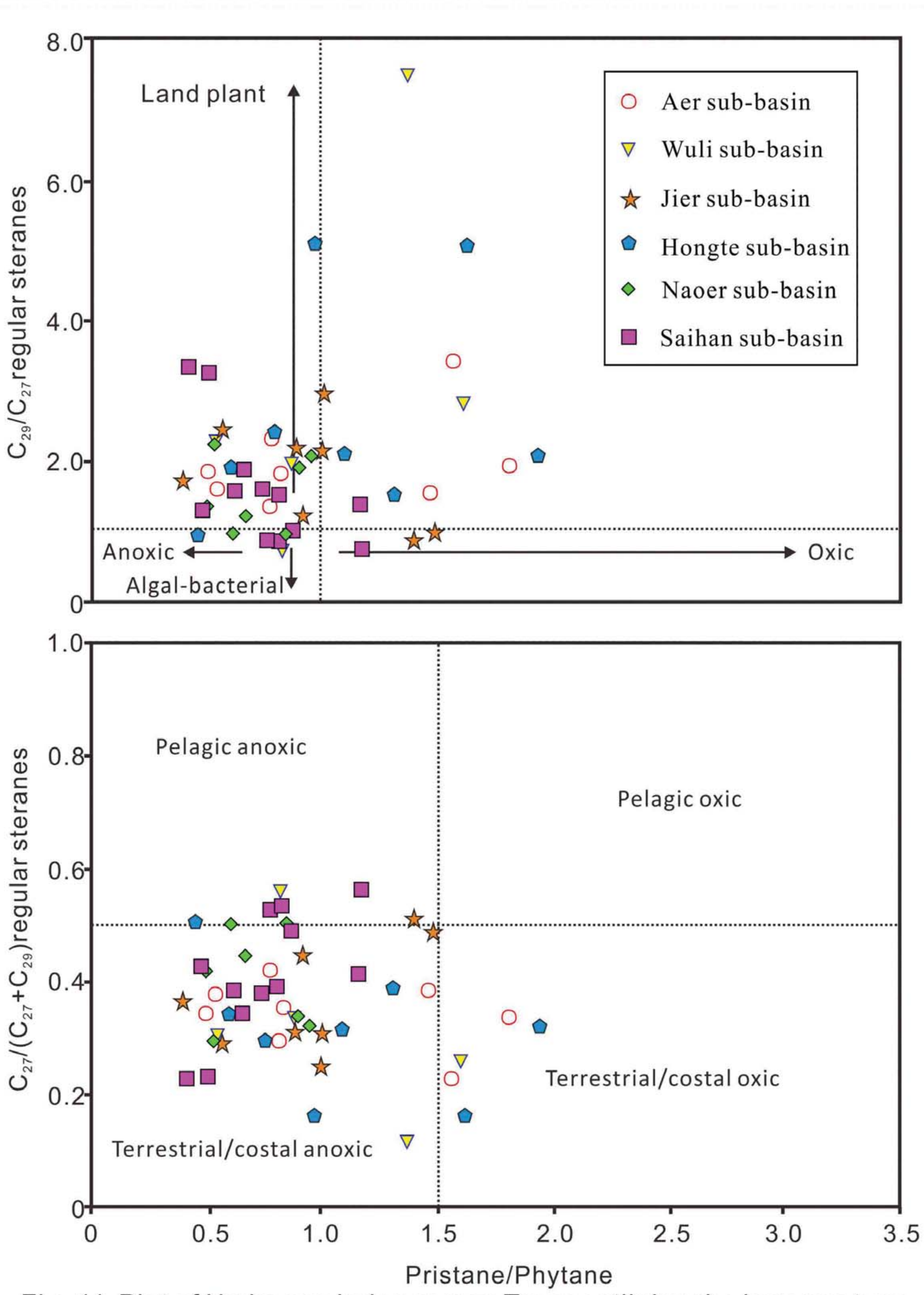

Fig. 11 Plot of Hydrogen Index versus Tmax outlining the kerogen type of Aer, Wuli, Naoer and Saihan Basins in the Erlian Basin Group.

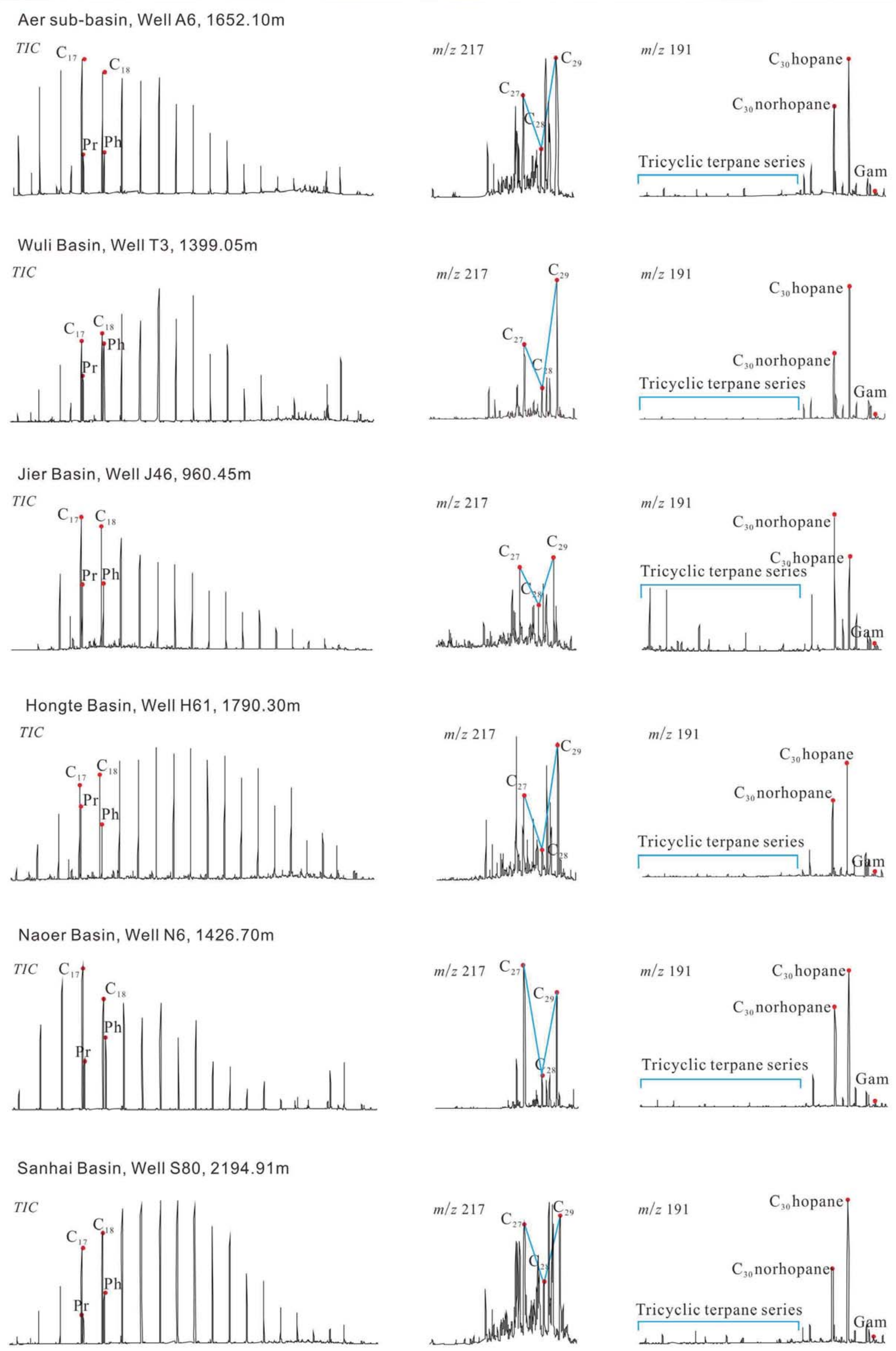

Fig. 12 Biomarker distribution of mudstone samples of small faulted basins in the Erlian Basin. Showed in sequence of TIC, sterane (m/z 217) and terpane (m/z 191) distribution. Pr = pristine; Ph = phytane; C_{27}, C_{28} and C_{29} represent C_{27} sterane 20R, C_{28} sterane 20R and C_{29} sterane 20R, respectively; Gam. = gammacerane.

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5.Controlling factors on organic matter accumulation

The carbon isotopic composition of carbonate is a key indicator of productivity in ancient lacustrine sediments (Isozaki et al., 2007). In Aer and Wuli Basins, productivity is the dominant factor controlling the formation of organic rich sediments. In Naoer and Saihan Basins, the respective R^2 is 0.31 and 0.27, which indicates no such control on the TOC of sediments.The correlation between TRS and TOC suggests that reducing conditions exerted a control on source rock development in Naoer and Saihan but not in Aer and Wuli Basins.

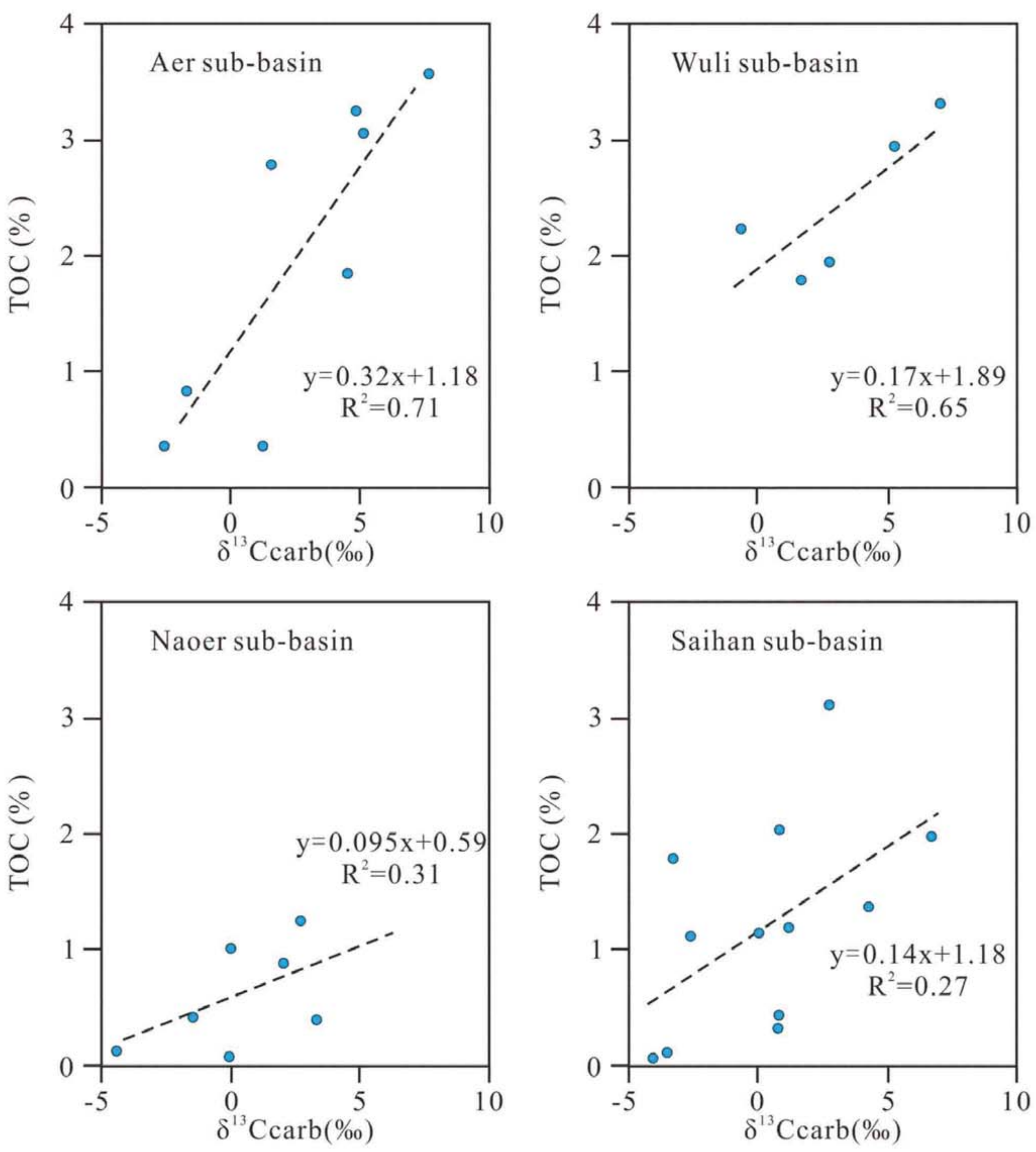

Fig. 13 Cross-plots of the carbon isotopic composition of carbonate (δ^{13}Ccarb) vs. total organic carbon content (TOC) of Aer, Wuli, Naoer and Saihan Basins in the Erlian Basin. δ^{13}Ccarb shows a significant correlation with %TOC in Aer and Wuli BasinS, indicating the productivity control on organic matter deposition. The lack of significant correlation in Naoer and Saihan Basins samples indicates no such control on organic matter accumulation.

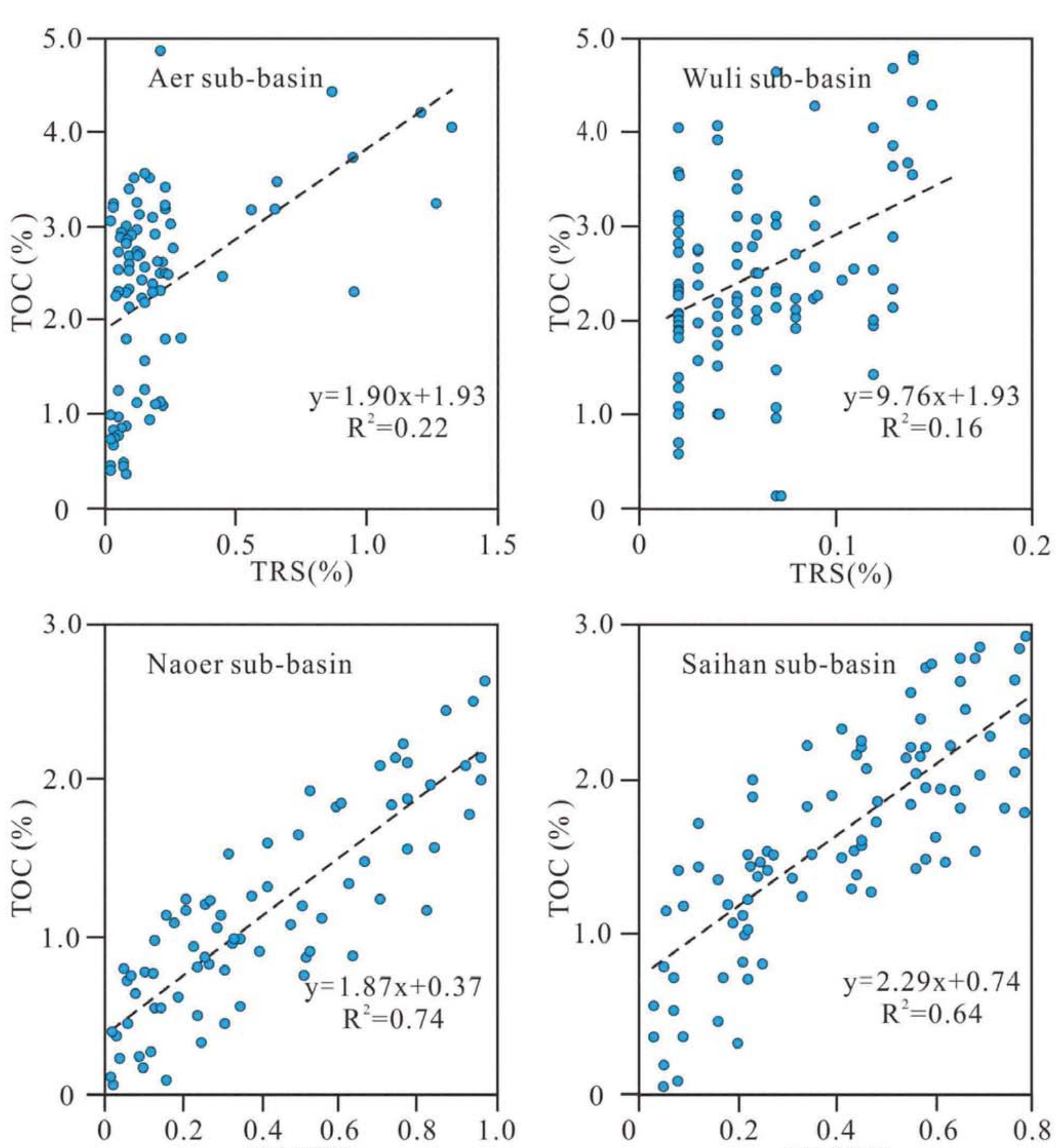

Fig. 14 Cross-plots of the total reduced sulfur (TRS) vs. total organic carbon content (TOC) for Aer, Wuli, Naoer and Saihan Basins in the Erlian Basin Group. TRS shows a significant correlation with %TOC in Naoer and Saihan sub-basin, indicating the control of anoxic conditions on organic matter deposition. The lack of significant correlation in Aer and Wuli sub-basins samples indicates no such control on organic matter deposition.

6.Models for source rock deposition

The differences in tectonic settings among these sub-basins caused variations in sedimentation rate, terrigenous organic matter inputs, productivity and redox conditions. The synergetic evolution of environments and organisms in the lake systems accounted for the deposition of the source rocks with distinct characteristics.

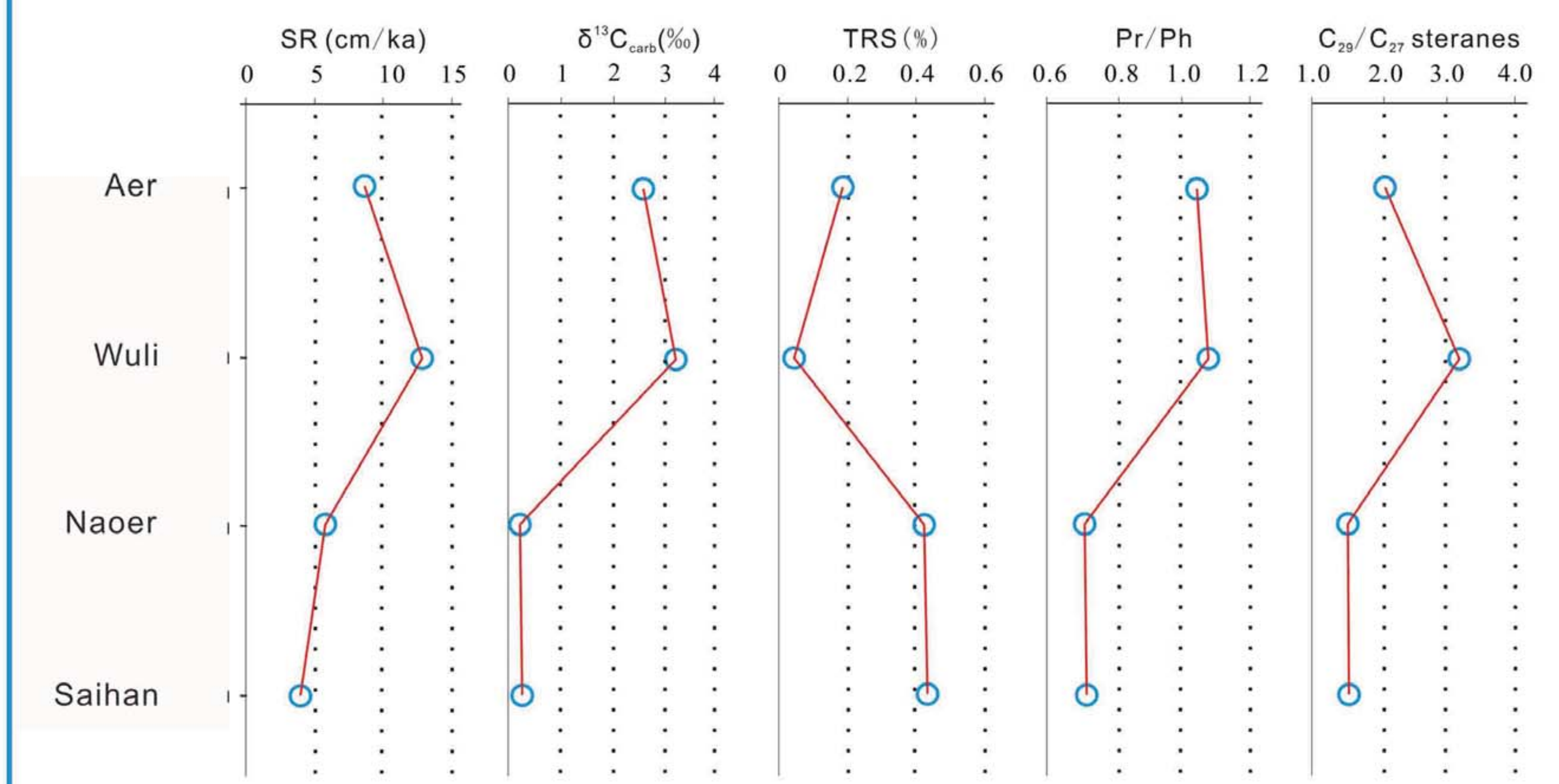

Fig. 15 The average values of sedimentation rate (SR, cm/ka), δ^{13}Ccarb (‰), total reduced sulfate (TRS, %), Pr/Ph, C_{29}/C_{27} steranes of Aer, Wuli, Naoer and Saihan Basins in the Erlian Basin Group.

During source rock deposition in Aer and Wuli Basins, the high influx of clastic sediments, which carried high terrigenous organic matter and dissolved inorganic carbon and nitrate, might have sustained high productivity. With high influx of clastic sediments and unstable water column stratification, the depositional environment was oxidizing. In a high productivity lake, there is significant organic matter accumulation in oxidized environment after oxidative degradation. The high productivity is the dominant factor controlling the formation of organic rich sediments and accounts for the formation of source rocks. During source rock deposition in Naoer and Saihan Basins, with low influx of clastic sediments, the depositional environment was reducing. Therefore, redox condition is the controlling factor of origin of source rock in Naoer and Saihan Basins.

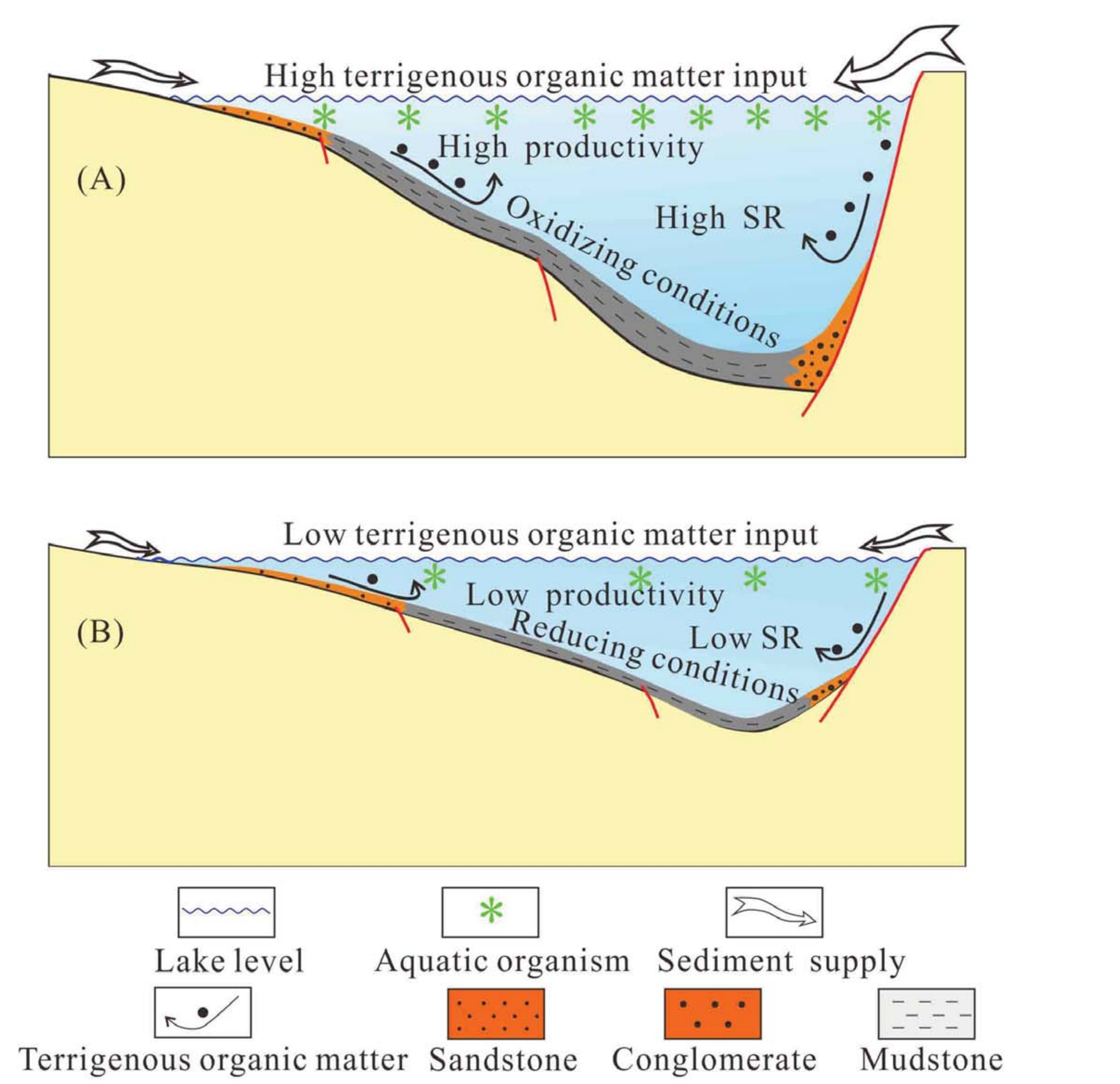

Fig. 16 Depositional models for lacustrine source rocks in the Erlian Basin, showing the productivity and redox condition of depositional environments induced by changes in tectonic settings and their controls on source rock formation. A: Aer and Wuli Basins; B: Naoer and Saihan Basins.