

Research Advances

Molecular Biomarker Characteristics of the Linxi Formation Source Rocks in the Middle-Western Region of Inner Mongolia: New evidence for late-stage tectonic evolution of the Paleo-Asian Ocean

ZHANG Yongsheng¹, PENG Yuan^{1,*}, SHI Lizhi¹, XING Enyuan¹, GUI Baolin¹ and LI Kai²

¹ MLR Key Laboratory of Saline Lake Resources and Environments, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China

² School of Earth Sciences and Resources, China University of Geosciences (Beijing), Beijing 100083, China

Objective

Two important geological issues have long been controversial in the Xing–Meng area of North China. The first concerns the final closure of Paleo-Asian Ocean in Xing–Meng area, and the other concerns the folding and lifting of the Xing–Meng Trough. The focus of these issues is the Late Permian sedimentary environment, which is generally considered to be either an exclusively continental environment or from the closed inland sea environment in the Early to Middle stage to continental lacustrine environment in the late stage. In recent years, we have successively discovered abundant typical marine fossils (e.g., bryozoans and calcareous algae) in the Upper Permian thick limestone layer from Linxi County and Ar Horqin Banner in eastern region of Inner Mongolia and Jiutain County in Jilin Province. These significant findings have attracted the attention from fellow academics. The thesis selected the Guandi–Zhaijiagou section of Linxi County where marine fossils were first found as the breakthrough point to conduct research. This work discussed the molecular biomarker characteristics of source rocks in Linxi Formation for further exploring the Late Permian palaeogeographical environment in the Xing–Meng area. It will provide new evidence for major geological problems about the final closure of the Paleo-Asian Ocean.

Methods

Based on field geological survey, we collected shale samples in the fourth and fifth members of Linxi Formation from Guandi–Zhaijiagou section in Linxi County to analyze the characteristics of Late Permian marine sediments in the Xing–Meng area through comprehensive analysis of molecular biomarkers. All the tests on the shale molecular biomarkers were done at the Key Laboratory of the Ministry of education, Yangtze University.

* Corresponding author. E-mail: cugb_pengyuan@126.com

Results

Defined as "molecular fossils", the biomarker compounds, such as *n*-alkanes, isoprenoid alkanes, terpenes and steranes, are molecular markers in source rocks and crude oil that derives from organism. During the geological evolution, the molecular markers with almost unchanged carbon skeleton can reflect geological information of the sedimentary environment, source input and maturity.

N-alkanes exist extensively in bacterias, algae and higher plants, and it can thus be used to trace organic matter source input and maturity. Acyclic isoprenoid alkanes can also be used in indicating the source of organic matter and oxidation-reduction environment. The curves of saturated hydrocarbon gas chromatogram in shale samples are unimodal with *n*C₁₈ or *n*C₁₉ as the dominant peak. The carbon predominance index (CPI) value is usually used to estimate whether *n*-alkanes have odd even predominance. The CPI values of shale samples are very high (1.19–1.68), showing strong odd-over-even carbon number predominance. The values of $\sum nC_{21}^- / \sum nC_{21}^+$, $(nC_{21}+nC_{22})/(nC_{28}+nC_{29})$, Pr/nC_{17} and Pr/nC_{18} are 0.61–1.79, 1.41–21.83, 0.83–2.74, and 1.23–1.79, respectively. These shale samples are also characterized by low pristane/phytane (Pr/Ph) ratios (0.04–0.26), which suggest obvious phytane advantage. These above parameters indicate that the parent materials were derived from lower aquatic organisms and algae, and formed in a strong-reduced and high-salinity depositional environment (such as saline lakes or marine environment).

The distribution of long chain tricyclic terpanes in the shale samples from Linxi Formation ranges from C₁₉ to C₃₀ with C₂₃ as the dominant peak, which may be indicative of the source input from lower aquatic organisms. The pentacyclic triterpanes series have relative high abundance in these samples. The distribution of the pentacyclic triterpanes is similar in most samples and mainly consists of

Table 1 Organic geochemical parameters of source rocks from the Linxi Formation

Sample No.	Main Peak	$\Sigma nC_{21}/\Sigma nC_{21}^+$	$(nC_{21}+nC_{22})/(nC_{28}+nC_{29})$	Pr/ nC_{17}	Ph/ nC_{18}	Pr/Ph	CPI	Gammacerane/ C_{30} hopane	C_{27}/C_{29}
14-LG-15-1	C ₁₈	0.92	2.63	0.92	1.44	0.19	1.35	0.16	1.41
14-LG-29-1	C ₁₉	0.61	1.41	1.03	1.74	0.15	1.53	0.15	1.30
14-LG-29-3	C ₁₉	0.72	1.66	0.83	1.79	0.04	1.65	0.14	1.48
14-LG-30-1	C ₁₉	0.61	1.56	0.93	1.79	0.04	1.68	0.13	1.51
14-LG-34-1	C ₁₈	1.20	3.11	0.99	1.42	0.22	1.19	0.12	1.44
14-LG-D-1-1	C ₁₉	0.93	2.74	2.74	1.67	0.26	1.28	0.13	1.53
14-LG-D-4	C ₁₈	1.79	21.83	0.96	1.23	0.25	1.19	0.14	1.54

C₂₇ trisnorhopane to C₃₅ trishomohopane with 17 α (H) and 21 β (H)-C₃₀ hopanes as the major compound. In addition, the abundance of C₃₁ hopane to C₃₅ hopane gradually decreases. As a kind of C₃₀ triterpane, The gammacerane is commonly used to identify marine depositional environment. High abundance of gammacerane and high gammacerane/C₃₀ hopanoic ratio are usually typical features of strong reducing condition in a saline Lake environment. The abundance of gammacerane in marine environment is high, but the gammacerane/C₃₀ hopane ratio is relatively low and usually closer to 0.1–0.2. The gammacerane/C₃₀ hopane ratios of shale samples from Linxi Formation are 0.12 to 0.16 with the average value of 0.14, which are consistent with the characteristic of marine source rocks. The above characteristics imply the shales in Linxi Formation were deposited in a high salinity and strong reduced marine environment.

Steranes often reflect the contribution from eucaryon such as algae, phytoplankton and higher plants. The carbon number distribution of steranes reflect organic matter input, which is effective parameter of provenance. Huang and Meinschein put forward that relative content of C₂₇-C₂₈-C₂₉ normal regular steranes can be used to induce organic matter sedimentary source. The C₂₇ steranes

originate from lower aquatic organism and C₂₉ steranes originate from higher plant. The distribution of C₂₇, C₂₈, and C₂₉ regular steranes of shale samples from Linxi Formation show “V” patterns, and the C₂₇/C₂₉ ratios are 1.30–1.54, C₂₇ steranes have higher abundance. Thus, these parameters indicate that the parent materials mainly come from lower aquatic organisms.

Conclusion

Based on the biomarkers analysis of shales in the fourth and fifth members of Linxi Formation from Guandi–Zhaijiagou section, we conclude that Linxi Formation was deposited in a high salinity and strong reduced marine environment. It further confirms the Paleo-Asian Ocean was still incompletely closed in Late Permian.

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