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**Research Advances**

# A Marine or Continental Nature of the Deltas in the Early Cretaceous Lingshandao Formation—Evidences from Trace Elements

YANG Renchao[1, 2, *], FAN Aiping[1], HAN Zuozhen[1] and A.J. (Tom) VAN LOON[3]

1 *College of Earth Science and Engineering, Shandong University of Science and Technology, Qingdao 266590, Shandong, China*

2 *Laboratory for Marine Mineral Resources, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266071, China*

3 *Geocom Consultants, Valle del Portet 17, 03726 Benitachell, Spain*

## Objective

A succession with well-developed soft-sediment deformation structures and well-exposed gravity-flow deposits in the Early Cretaceous Lingshandao Formation has caused considerable controversy on whether the non-disputed deltaic environment was marine or continental. This dispute cannot be solved by mere sedimentological analysis and, moreover, too few fossils are present to be decisive. The main objective of the present contribution is to shed light on this problem on the basis of trace-element analysis.

## Methods

Field work was carried out for collecting samples of dark shales from both the middle and the upper Lingshandao Fm., in the western Yellow Sea. Six of the samples were used for Analysis of 16 trace elements. The trace-elements analysis was performed by means of inductively coupled plasma mass spectrometry (ICP-MS). The sedimentary environment during the Early Cretaceous was determined on the basis of the trace-element analysis in combination with the ratios of some specific elements and plant fragments. The paleosalinity (Sp) of the Lingshandao Fm. was calculated from the boron (B) concentration following Adamas Formula (Sp=0.0977*B−7.043).

## Results and Analysis

The ratios of the 16 trace elements from the six samples are provided in Table 1. These data can be used for analysis of main sedimentary environments, such as marine vs. continental facies, but also for determining the paleosalinity and oxidation-reduction potential.

The boron can be used to distinguish deposits with a marine facies (usually 80–125 ppm) from those with a continental facies (usually less than 60 ppm). The boron (B) concentration in the Lingshandao Fm. varies from 82.734 to 174.672 ppm, thus being always higher than 80 ppm. The paleosalinity (Sp), calculated by using Adamas Formula, ranges from 1.040‰ to 10.022‰, which indicates a brackish-water environment. The high concentration of strontium (Sr) in the six samples is high, varying from 229.197 to 408.056 ppm, thus pointing at a marine environment (>160 ppm) rather than a continental one (usually < 90 ppm). The concentration of vanadium (V), ranging from 78.165 to 115.089 ppm is intermediate between the values known for marine (<86 ppm) and continental sediments (>110 ppm). The gallium (Ga) content in the Lingshandao Fm., however, seems to point consistently to a continental environment (15–23 ppm), rather than to a marine environment (<15 ppm).

Although the concentrations of some trace elements may be indicative of a marine or continental environment, the ratio of some particular elements is more reliably conclusive. The B/Ga ratio varies from 4.347 to 7.732, which points to a marine facies (>4.2), rather than a continental facies (<3.3). The Sr/Ba ratio ranges from 0.296 to 0.709, mostly being higher than 0.35, indicating a marine environment (>0.35), rather than a continental one (<0.2). The Rb/Sr ratio, ranging from 0.299 to 0.663 also infers a marine environment, as well as a humid paleoclimate.

The Cu/Zn, V/Cr, Ni/Co, U/Th, and V/(V+Ni) ratios are indicative of the oxidation-reduction potential. The Cu/Zn ratio in the Lingshandao Fm. ranges from 0.235 to 0.390, thus indicating a slightly reducing environment. The V/(V+Ni) ratios vary between 0.724 and 0.800, equally implying a slightly reducing environment, as well as a stratified flow of seawater. However, the ratios of V/Cr (<2), Ni/Co (<5) and U/Th (<0.75) imply a slightly

* Corresponding author. E-mail: yang100808@126.com

**Table 1 Trace elements and ratios of some specific elements in the Lingshandao Fm.**

| Element/Ratio | Blank (ppb) | ZC1 (ppm) | ZC2 (ppm) | ZC3 (ppm) | DT1 (ppm) | DT2 (ppm) | DT3 (ppm) |
|---|---|---|---|---|---|---|---|
| Sc | 0.078 | 11.041 | 11.717 | 14.514 | 11.057 | 12.781 | 12.516 |
| V | 0.013 | 78.165 | 95.167 | 115.089 | 82.243 | 96.383 | 93.760 |
| Cr | 0.633 | 66.046 | 54.105 | 65.194 | 58.537 | 59.101 | 68.918 |
| Co | 0.031 | 7.597 | 13.176 | 13.287 | 5.120 | 12.133 | 7.084 |
| Ni | 0.350 | 29.861 | 25.360 | 30.801 | 21.549 | 27.349 | 23.473 |
| Cu | 0.065 | 15.805 | 29.119 | 29.363 | 17.342 | 28.185 | 17.288 |
| Zn | 0.289 | 41.061 | 74.668 | 81.207 | 73.518 | 72.997 | 73.649 |
| Ga | 0.004 | 18.148 | 18.201 | 22.591 | 18.949 | 20.252 | 19.031 |
| Rb | 0.125 | 118.515 | 122.213 | 184.621 | 126.721 | 154.172 | 128.414 |
| Sr | 0.015 | 251.878 | 408.056 | 278.553 | 313.242 | 282.225 | 229.197 |
| Ba | 0.084 | 729.813 | 575.561 | 638.569 | 738.532 | 700.540 | 773.345 |
| La | 0.003 | 45.792 | 41.865 | 45.999 | 35.359 | 44.047 | 34.576 |
| Pb | 0.087 | 12.632 | 25.587 | 23.095 | 8.865 | 23.654 | 9.556 |
| Th | 0.003 | 12.893 | 13.210 | 16.546 | 12.873 | 14.358 | 14.005 |
| U | 0.001 | 3.286 | 4.074 | 3.155 | 3.189 | 3.450 | 3.356 |
| B | / | 119.946 | 97.313 | 174.672 | 103.977 | 107.395 | 82.734 |
| Sp(‰) | / | 4.676 | 2.464 | 10.022 | 3.116 | 3.449 | 1.040 |
| B/Ga | / | 6.609 | 5.347 | 7.732 | 5.487 | 5.303 | 4.347 |
| Sr/Ba | / | 0.345 | 0.709 | 0.436 | 0.424 | 0.403 | 0.296 |
| Rb/Sr | / | 0.471 | 0.299 | 0.663 | 0.405 | 0.546 | 0.560 |
| Cu/Zn | | 0.385 | 0.390 | 0.362 | 0.236 | 0.386 | 0.235 |
| V/Cr | / | 1.183 | 1.759 | 1.765 | 1.405 | 1.631 | 1.360 |
| Ni/Co | / | 3.931 | 1.925 | 2.318 | 4.209 | 2.254 | 3.314 |
| U/Th | / | 0.255 | 0.308 | 0.191 | 0.248 | 0.240 | 0.240 |
| V/(V+Ni) | / | 0.724 | 0.790 | 0.789 | 0.792 | 0.779 | 0.800 |

*Analyses were performed at the State Key Laboratory of Continental Dynamics, Northwest University, Xi'an, China.

oxidizing environment.

Field observations provide additional clues regarding the sedimentary environment of the Lingshandao Fm.. Numerous remains of carbonized plant fragments found on top of sandy debrites in the formation suggest that the sediments originated from the continent. This may explain the apparently inconsistent conclusions drawn on the basis of the trace elements: the salinity of the sea water was periodically lowered by the input of fresh-water floods from the nearby continent.

## Conclusion

The Early Cretaceous Lingshandao Fm. was deposited in a deep sea instead of marine or continental deltas. The salinity of the sea water was lower than normal because of the inflow of fresh-water floods from the nearby continent. The oxidation-reduction potential in the depositional environment varied from slightly reducing to slightly oxidizing-flow events and fresh-water input. A humid climate is indicated by both the trace elements and the abundance of plant fragments.

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