Deep-time Paleogeographic Reconstruction Based on Database: Taking the South China *T. approximatus* Biozone (Early Ordovician) as an Example

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Paleogeography is a discipline that studies spatial distribution and evolutionary characteristics of geographic objects in earth history (Feng, 2003; Feng et al., 2012). It focuses on the sediments, organisms and environmental proxies, most of which are preserved in the rocks. However, a large amount of this geological and biological information was no longer preserved after the geological process of burial, preservation and transformation. This loss caused great difficulties in producing paleogeographic reconstructions of high temporal precision and spatial resolution. With as much geological data as possible, and by using quantitative methods, the influence of incompleteness in geological records can be reduced. Here, we discuss the concepts and methods of paleogeographic reconstruction in the context of rapid developments in geochronology, geological big data and geographic information systems (GIS). We illustrate these procedures on data from the Early Ordovician Tetragraptusapproximatus Biozone of South China, creating the paleogeographic maps and analyzing their geological significance.

1 Concepts and methods in deep-time paleogeography

High temporal precision

Precise time frameworks provide the basis to understand the details of regional and global paleogeographic evolution. Through the rapid development of the various subdivisions of stratigraphy and geochronology (e.g., biostratigraphy and biochronology, cyclostratigraphy, astrochronology, magnetic stratigraphy, geomagnetic polarity studies, isotope stratigraphy, geochronology, statistical and quantitative stratigraphy, geochronology; Gradstein et al., 2012), the assessment of geological time can be improved, with ‘deep time’ becoming one of the most important concepts in geology (Sun and Wang, 2009; Wu, 2011). At present, 72 GSSPs, nearly 69.9% of the total GSSPs, have been designated (Fan et al., 2018). Thus, most geological stages have been established. In addition, precise refinements of the geologic timescale (to biozone level) was published for regions, such as South China, North America, Australia and Europe.

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High spatial resolution

Higher spatial resolutions and larger-scale paleogeographic maps can be used to pinpoint paleogeographic locations, boundaries, units and even evolutionary patterns of facies more accurately, which enhances the power of paleogeography. However, with the rapid accumulation of geological data, issues such as integration, management, sorting, verification and use of such huge amounts of geological information becomes a significant and inevitable problem. Digital databases represent an important way to resolve this problem (e.g., PBDB and GBDB; Fan et al., 2013, 2016). Through the assembly of digital databases with appropriate data structures (Table 1), users can store, organize, and use geological data more efficiently. Meanwhile, if all data are digitized and stored based on uniform standards, data entry, retrieval and update can be accomplished in an accurate and convenient manner. Ideally, all geological data need to be FAIR, i.e., Findable, Accessible, Interoperable, and Reusable.

From qualitative to quantitative

The pathway from qualitative to quantitative is an important indicator of the state of a discipline’s development. In terms of paleogeography, quantification brings at least two important advantages. First, quantitative paleogeography can make use of use numerical or digitized maps to express the distribution pattern of paleogeographic units more accurately. Second, since the data for paleogeographic research come mostly from rocks and fossils, it is difficult to avoid the influence of incompleteness of rock and fossil records. Quantitative paleogeography can help eliminate this kind of influence through mathematical data analysis and statistics, so as to reveal the actual state of observations as well as assisting with inferences and interpretations. For example, paleobiogeography usually represents the geographic distribution of a species by enclosing the set of localities where the fossils are found within a boundary. Inevitably this represents an underestimate of the true geographic range because of the incompleteness of fossil records. However, by using the known fossil occurrences and environmental data, a quantitative paleogeographic methods and can be used to construct a mathematical species distribution models (SDMs), that can then be applied to an entire study area.
in order to estimate a species’ potential distribution (Zhang et al., 2013).

From static to dynamic

Geography and environment are always in the process of continuous development and change. When we study paleogeography and paleoenvironment, we need to study not only their original states and changes through time, but also their variations due to subsequent denudation, structural destruction and metamorphism during the preservation. Therefore, special attention must be paid to systematic studies of paleogeographic dynamics, in order to reconstruct paleogeographic maps of multiple, successional time intervals and analyze the spatial evolution of geographic objects.

Multidisciplinary integration

With the development of geology, the objects and scope of paleogeography have also been expanded. In addition to traditional lithofacies paleogeography, fossil occurrences, stratigraphic data (e.g., stratigraphic thickness, lithology), geochemical parameters for oil and gas investigation (e.g., TOC, maturity of organic matter), and paleoenvironmental parameters (e.g., paleo-water depth, hydrodynamics) can all be used to recover and reconstruct the geographic and environment aspects of Earth history. In other words, almost all geologic data with spatial attributes can be included in the study of paleogeography. As a result, the integration of paleogeography with other disciplines is becoming more popular. For example, the combination of paleogeography and biodiversity research can help us to understand the macroevolutionary patterns of biotas in both time and space. The combination of paleogeography and sequence stratigraphy can also help us to study the developmental history of sedimentary basins.

2 Study material and methods

Recent achievements in the regional and global stratigraphy of Ordovician, based on a large number of sections have provided a more refined and reliable spatial and temporal framework, in which to place new observations for paleogeographic study. At the same time, the emergence of new techniques and approaches, such as digital databases, GIS, and quantitative paleogeographic methods, provides important sources of technical support for high-resolution, quantitative paleogeographic reconstruction.

The Tetragraptus approximatus Biozone in the early Floian of the Early Ordovician was chosen as the time interval for the present study. This is the first graptolite biozone in Floian, the basal boundary of which is marked by the first appearance of the graptolite Tetragraptus approximatus and the top boundary of which coincides with the base of the Acrograptus filiformis Biozone. This biozone is widely developed on the Jiangnan Slope of the Zhuijiang Basin (Chen & Wang, 1993), and can be found in the lower member of Tonggao Fm. in Sandu, Guizhou Province; Yenxi Fm. in Taqiang, Anhui Province and Yiyang, Hunan Province; the base of Ningkou Fm. in Chongyi, Jiangxi Province; the base of Huangai Fm. in Pingnan and Guiping, Guangxi Province; the base of Ningkou Fm. in Yushan, Jiangxi Province. The Tetragraptus approximatus Biozone can also be correlated with the widespread Hunghuayuan Fm. in the Yangtze platform (Zhang et al., 2005). In the present study, 16 lithostratigraphic units from South China were used for paleogeographic reconstruction, 529 sections for the lithofacies paleogeographic map, and 382 sections for the thickness isopach map (Table 2).

ArcGIS, a GIS product launched by ESRI, was used here to perform the geographic mapping and spatial interpolation.

3 Results and analysis

First, the ranges of sea and land in this study interval were accurately delineated based on data from a large number of sections. In this interval, South China was covered mainly by the Yangtze Sea, and the lands distributed mainly along its western margin. From north to south, a series of lands can be recognized, including the Hannan Land, Central Sichuan Land, Xichang Land and Central Yunnan Land (Fig. 1). There was also a

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<td>Reference</td>
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<th>Table 2 Stratigraphic units used in the paleogeographic reconstruction of South China in the T. approximatus Biozone</th>
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<td>Hunghuayuan Fm.</td>
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<td>Shapianxian Fm.</td>
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<td>Lower member of Jingshan Fm.</td>
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<td>Upper member of Yunzhu Fm.</td>
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<td>Tanjiqiao Fm.</td>
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<td>Lower member of Quaotingzi Fm.</td>
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<td>Lower member of Qixiling Fm.</td>
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<td>Lower member of Xiahuangkeng Fm.</td>
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<td>Gap</td>
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Central Guizhou Uplift situated in the northeast of the Central Yunnan Land. A small area exhibiting a sedimentary hiatus can also be recognized in the western Zhejiang. This is named provisionally as Western Zhejiang Land.

The sedimentary area of South China in the early Florian can be summarized as a ‘platform–slope–basin’ succession from northwest to southeast (Fig. 1). The Yangtze Platform was mainly deposited in shallow-water as black carbonaceous and siliceous shales. There was a narrow, transitional slope (Jiangnan Slope) from northeast to southwest, which spanned through northeastern Zhejiang, southern Anhui, northern Jiangxi, northern Hunan to southeastern Guizhou, which received clastic sediments interbedded with limestones.

Based on precisely located sections and stratigraphic data, we can accurately outline the boundaries of lands and the sea at this time, and thus recognize even the narrow straits between emergent land areas. The Luding Strait was identified between the Central Sichuan Land and the Xichang Land (Mu et al.,
1981); a new strait was recognized between the north and south parts of the Xichang Lands, and named as the Yanyuan Strait here; another new strait between the Xichang and Central Yunnan lands, named here as the Yongren Strait.

Meanwhile, the isopach map of the T. approximatus Biozone in South China was created using the natural neighbor interpolation method in ArcGIS. Stratigraphic thicknesses in the Yangtze Platform and the Zhujiang Basin are both less than 100 meters. The areas with large sediment thickness are located mainly along the southwestern margin of the Upper Yangtze Platform (northeastern part of Yunnan Province), the southwestern part of the Jiangnan slope (southeastern part of Guizhou Province), the border between southern margin of the Lower Yangtze region and northeastern part of the Jiangnan Slope (Fig. 2). All these areas are close to the emergent uplands, which demonstrates a coupling relationship between them. In the peripheral areas around the Central Sichuan and Hannan lands in the northwestern part of South China, stratigraphic thicknesses are very small, which indicates less clastic input from adjacent upland areas during this interval.

4 Conclusion

With the rapid increase of geological data and the development of GIS technique, paleogeographic study is facing new opportunities and challenges, as well as developing rapidly in the direction of higher temporal precisions and higher spatial resolution, quantification, and cross-disciplinary analysis. In an example investigation, we took the South China of the Early Ordovician Tetragnostus approximatus Biozone, and reconstructed its high-precision lithofacies paleogeographic map and isopach map of stratigraphic thickness. The boundaries between the Yangtze Sea, lands and different lithofacies were outlined as precisely as modern data allow and some undiscovered straits among those lands in the west were newly recognized.

Key words: paleogeography, deep-time, GIS, database

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References


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