Are There Any Links between Biodiversity and Paleogeographic Differentiation in the Ordovician?

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Two significant biological and geological events happened during the Ordovician, i.e., the great Ordovician biodiversification event (GOBE; Webby et al., 2004) and the end-Ordovician mass extinction (Sheehan, 2001). The two events were remarkably well recorded in South China and manifested by the diversity history of major marine fossil groups (e.g., Chen et al., 2004; Rong and Zhan, 2004; Rong et al., 2007). Along with the biodiversity change, there were dramatic paleogeographic differentiations in South China through the Ordovician. In the Early and Middle Ordovician, South China can be divided into three parts, the Yangtze Platform, the Jiangnan Slope and the Zhuijiang Basin from the northwest to the southeast (Mu, 1983). Near the end of Ordovician, the South China was geographically typified by only one platform and two depressions, and the Yangtze Sea was surrounded by several land areas (Zhang et al., 2016). It has been well-known that the development of biota is critically controlled or affected by environmental factors, including geographic background. But there have been few studies focusing on the relationships between the biodiversity and paleogeographic evolution through the Ordovician. Recently we reconstructed successive quantitative paleogeographic maps of South China in the Ordovician, which provided the necessary data to depict the paleogeographic change, while the previous studies on Ordovician marine organisms provide enough data for biodiversity dynamics. Based on this work, herein we present our latest studies on possible links between biodiversity and paleogeographic differentiation.

1 Study materials and methods

Based on the time slices designed by Webby et al. (2004) and the graptolite biozones recognized in South China (Zhang and Chen, 2003; Chen et al., 2006), we divide the Floian to Hirnantian (Ordovician) into fifteen time intervals for the estimation of biodiversity (D1-D15 in Fig. 1), which correspond to seven time intervals for paleogeographic reconstruction (P1-P7 in Fig. 1). The Tremadocian was not included in the present analysis due to the scarcity of fossil records and poor biostratigraphical constraint.

During the past half century, a lot of research work on systematic paleontology and biostratigraphy has been done on the Ordovician major fossil groups in South China, which provides plentiful data for the present diversity estimation. Seven fossil groups were chosen to estimate the biodiversity based on the data available in the literature (graptolites from Chen et al., 2004, Zhang et al., 2010; conodonts from Wu et al., 2012; chitinozoans from Chen et al., 2009, Liang and Tang, 2016; acritarchs from Li et al., 2008; brachiopods from Rong and Zhan, 2004; echinoderms from Zhang et al., 2010; and trilobites from Chen et al., 2003).

Fig. 1. Chronostratigraphic subdivisions and graptolite biozones of the Ordovician in South China, and the time slices for biodiversity estimation (D1-D15) and paleogeographic reconstruction (P1-P7).

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two ecological groups were also utilized, the pelagic group including graptolites, conodonts, chitinozoans and acritarchs, and the benthic group including brachiopods, trilobites and bivalves. The diversities of the graptolites, conodonts and chitinozoans were calculated at the species level, while the diversities of the acritarchs, brachiopods, trilobites, bivalves, and the pelagic, benthic groups as well as total diversities were all calculated at the genus level.

The Ordovician strata in South China were deposited continuously and are well exposed. Through the GBDB database (http://www.geobiiodiversity.com; Fan et al., 2013), hundreds of Ordovician stratigraphic sections were compiled and well organized for paleogeographic research. Seven litho-paleogeographic maps were reconstructed over intervals from Floian to Hirnantian, and each of them was based on more than 300 sections so that their paleogeographic boundaries could be precisely located. In the present study, we employ the TIN Polygon method in ArcGIS software to calculate the distribution area of each lithofacies (Fig. 2). Firstly, we draw a polygon around each locality (section) and make sure that the distance from each point in this polygon to this locality is shorter than that to any other locality. Secondly, all the polygons of the same facies are added up to get the total distribution area of this facies.

Thirdly, the first and second steps were repeated for each time interval, to obtain dynamic paleogeographic differentiation over time. To describe the paleogeographic characteristics, four parameters were adopted: (1) the number of facies types, (2) the evenness of distribution areas of different facies, (3) the percentage of distribution areas of carbonate rocks, and (4) the percentage of distribution areas with clastic rocks. The second parameter, which is a little more complicated than the other three, comes from the concept of Shannon evenness index in modern ecology. It is a formula connecting the number of facies and the percentage of distribution area with different types of facies. If the evenness is large, it means most of the facies have similar distribution area; otherwise, one facies may have much larger distribution area than the others.

2 Results and Discussions

Most of the resulting biodiversity curves show similar patterns: they increased from the Early Ordovician to the Middle Ordovician, reflecting the effect of the Ordovician biotic radiation, although different groups reached the peaks in different time intervals (Fig. 3). For example, conodonts, acritarchs, brachiopods and bivalves reached their diversity peaks earlier than graptolites and chitinozoans. Trilobites reached their diversity peak in late Katian, much later than the other fossil groups. All the fossil groups showed diversity troughs in the Hirnantian except the bivalves, which have few fossil records in South China since middle Katian.

In respects of the paleogeographic parameters, it is obvious that both the type and evenness of lithofacies were high from the early Floian to the early Darrwilian, and then decrease gradually. Only the evenness of facies became extraordinarily high in the middle Katian, which seems coincident with the diversity curve of benthic fauna (Fig. 3). The percentage of elastic rocks showed a similar pattern with those of the type and evenness of lithofacies during the Ordovician radiation. From the middle Floian to the early Darrwilian, and from the late Katian to the early Hirnantian, elastic rocks dominate the deposits, whereas carbonate rocks dominate in the other time intervals.

In order to understand the relationship between those paleogeographic parameters and the biodiversity curves, we use PAST software to calculate the linear correlation index (Table 1). It is difficult to find the relationship between the paleogeographic parameters and the diversities of each individual fossil group. Meanwhile, the percentages of carbonate or elastic rocks also show almost no correlation with the pelagic, benthic or total diversities. However, there is apparent correlation between the first two paleogeographic parameters and the pelagic, benthic and total diversities. The types of lithofacies are highly correlated with the pelagic and total diversities, while the evenness of lithofacies is strongly correlated with the benthic and total diversities. Accordingly, it seems possible that the increasing number of lithofacies in the Ordovician may suggest the diversification of hydrodynamic and hydrochemical conditions, which consequently creates more pelagic habitats for higher biodiversity. On the other hand, the higher evenness of lithofacies indicates more diversified living and sedimentary environments, which may facilitate the living and burial of marine benthic organisms.

Table 1 Correlation between paleogeographic parameters and biodiversity

<table>
<thead>
<tr>
<th></th>
<th>Graptolite</th>
<th>Conodont</th>
<th>Chitinozoan</th>
<th>Acritarch</th>
<th>Brachiopod</th>
<th>Trilobite</th>
<th>Bivalve</th>
<th>Pelagic</th>
<th>Benthic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of lithofacies</td>
<td>0.09</td>
<td>0.58</td>
<td>0.46</td>
<td>0.82</td>
<td>0</td>
<td>-0.41</td>
<td>0.70</td>
<td>0.87</td>
<td>0.33</td>
<td>0.85</td>
</tr>
<tr>
<td>Evenness of lithofacies</td>
<td>0.16</td>
<td>0.31</td>
<td>0.54</td>
<td>0.41</td>
<td>0.55</td>
<td>0.06</td>
<td>0.75</td>
<td>-0.35</td>
<td>0.78</td>
<td>0.67</td>
</tr>
<tr>
<td>Percentage of carbonate</td>
<td>0.24</td>
<td>0.04</td>
<td>0.67</td>
<td>-0.42</td>
<td>0.23</td>
<td>0.34</td>
<td>0.62</td>
<td>-0.30</td>
<td>0.34</td>
<td>0.03</td>
</tr>
<tr>
<td>Percentage of elastic</td>
<td>-0.24</td>
<td>-0.04</td>
<td>-0.67</td>
<td>0.42</td>
<td>-0.23</td>
<td>-0.54</td>
<td>0.62</td>
<td>0.30</td>
<td>-0.34</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Fig. 3. Lithofacies differentiation and biodiversity changes during the Ordovician in South China.

Key words: correlation analysis, lithofacies, bioevent, TIN polygon, Ordovician

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References

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