The Llandovery (Silurian) conodont species diversity on the Upper Yangtze Platform, South China

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Abstract. Conodonts are one of the stratigraphically most important fossil groups in the Silurian Period. We examine the regional diversity dynamics of the Llandovery condonts on the Upper Yangtze Platform. The data set of 41 species from seven sections is compiled from the Geobiodiversity Database. Four measures of taxonomic richness based on zonal counting are used to demonstrate the conodont diversity change. The CONOP (Constrained optimization) program is used to build up a more precise composite sequence, which provides the data for comparative analysis of diversity change. Conodont richness keeps growing from the *Ozarkodina* aff. *hassi* Zone through the *Ozarkodina obesa* Zone to the *Ozarkodina guizhouensis* Zone and reaches a peak at the fourth zone, the *Pterospathodus eopennatus* Zone. This significant growth was followed by a rapid decrease, which probably represents an extinction in the mid-Telychian. This extinction event can also be observed in other fossil groups such as graptolites and chitinozoans based on recent studies.

Key words: conodont, Llandovery (Silurian), Upper Yangtze Platform, South China, diversity, CONOP.

INTRODUCTION

The Llandovery conodont-bearing strata are widely distributed on the Upper Yangtze Platform, South China. The conodont fauna and the biozonation of the rocks were first studied by Zhou et al. (1981) based on the material from the Leijiatun section in the Guizhou Province. Since then, a series of papers on the Silurian conodonts on the Upper Yangtze Platform have been published. However, few publications applied the multi-element concepts in conodonts until Wang & Aldridge (1998) revised the taxonomy of the Silurian conodont genera of China. Several conodont-bearing sections on the Upper Yangtze Platform were studied in 2009 and 2010, by Chengyuan Wang & Richard J. Aldridge (Wang et al. 2009, 2010; Wang & Aldridge 2010). Seven of those sections were studied in more detail and became the data source of the present paper.

The regional conodont diversity change in South China during the Llandovery Epoch has never been studied before. Conodont animals were swimming in the ocean (Briggs et al. 1983). Their diversity change may be used to infer the changes in sea level, water temperature and chemical environment (Sweet 1988; Wu et al. 2008). Here we first use the traditional 'binned' richness curve to reveal the zonal change in the richness of conodonts. Four different measurements are employed to reduce some of the effect of sampling bias. However, the 'binned' richness curve can only provide an estimation of zonal resolution. We used the Constrained optimization (CONOP) method to construct a more precise range history of conodonts during the studying interval and generated the species richness curve for comparative analysis of conodont diversity.

DATA

The conodont data set for the present study includes the occurrence records of 15 genera and 41 species from seven well-studied conodont-bearing sections on the Upper Yangtze Platform. Among them, the Leijiatun Section in the Guizhou Province, the Yushitan Section in the Shaanxi Province and the Xuanhe Section in the Sichuan Province were described by Wang & Aldridge (2010); the Xiushan and Qianjiang sections in the Chongqing City, the Zhangjiajie Section in the Hunan Province and the Yanglin Section in the Hubei Province were recorded by Wang et al. (2010) (Fig. 1). Those sections cover a stratigraphic range from the Rhuddanian

Fig. 1. Locations of the studied sections. Black triangles indicate the positions of the studied sections.

Stage to the Telychian Stage, which is presently subdivided into five regional conodont zones, the *Ozarkodina* aff. *hassi*, *Ozarkodina obesa*, *Ozarkodina guizhouensis*, *Pterospathodus eopennatus* and *Pterospathodus celloni* zones in ascending order (Fig. 2). The 'unzoned interval' was recognized in only one section. Therefore, in the present study, we combine the 'unzoned interval' and the underlying *Ozarkodina obesa* Zone as one unit. The conodont species from those sections were studied by Wang & Aldridge (2010), and their identification is followed herein to avoid inconsistency in taxonomy.

The stratigraphic and taxonomic data were first compiled through the Geobiodiversity Database (GBDB, http://www.geobiodiversity.com; Fan et al. 2013a). Then they were standardized and exported as a CONOP-format file through the online CONOP function in the GBDB platform.

METHOD

The conodont occurrence records from each conodont zone were classified into four different categories:

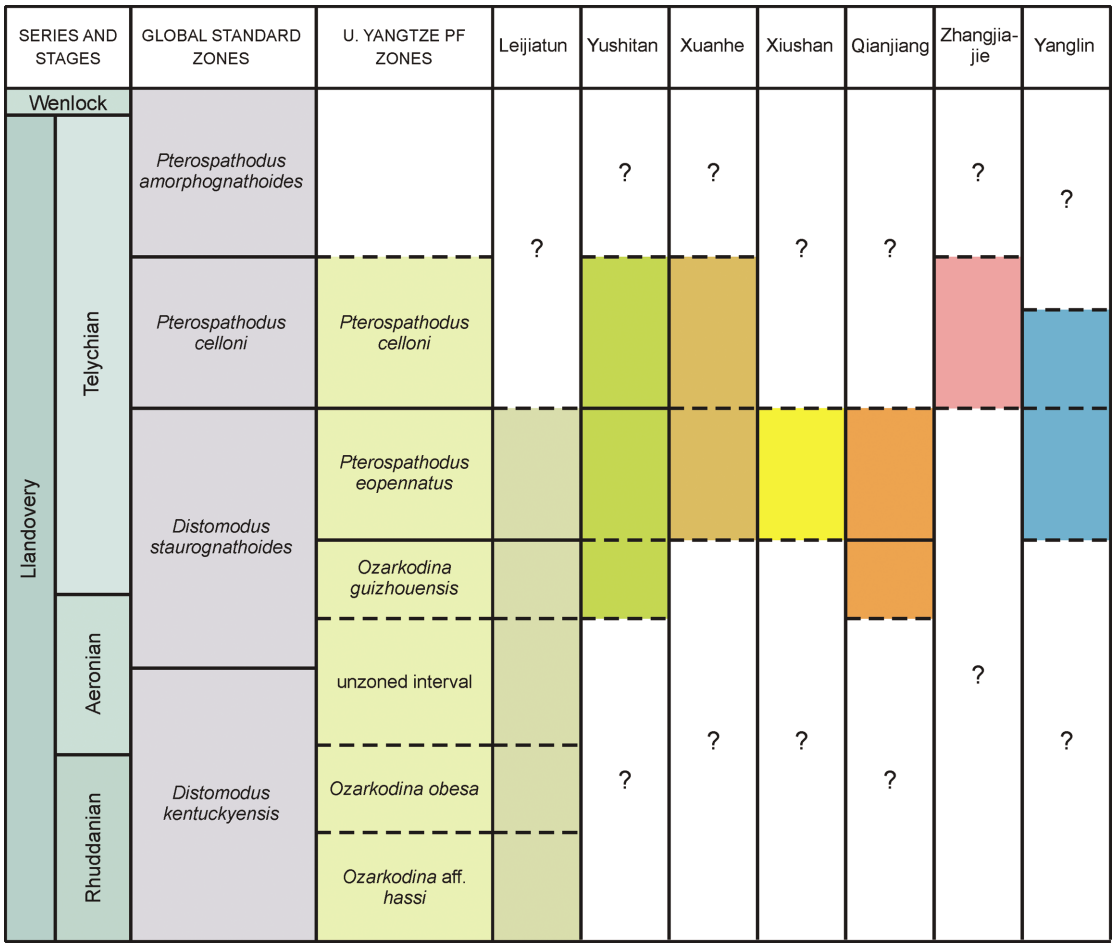

Fig. 2. Conodont biozonation for the Llandovery Series. The Global Standard biozonation comes from Aldridge & Schönlaub (1989). The conodont biozonation of the Upper Yangtze Platform (U. Yangtze PF) comes from Wang & Aldridge (2010).

(1) FL, i.e., taxa whose first and last appearance are both within the zone; (2) Ft, i.e., taxa that make their first appearance during the zone and cross the top boundary; (3) bL, i.e., taxa that cross the bottom boundary and make their last appearance during the zone; (4) bt, i.e., taxa that range through the entire zone, crossing both the top and bottom boundaries (Foote 2000). Different methods of calculating the diversity depend on different opinions on the contributions of those four types. For instance, in the method of normalized diversity, singletons (i.e., FL) are included but calculated as half the value, while in that of estimated mean standing diversity, singletons are omitted. The species richness of each category were denoted as N_{FL}, N_{Ft}, N_{bL}, N_{bt}, and the following four measures of species richness were used in the present study (Foote 2000; Cooper 2004):

Total diversity: $N_{tot} = N_{FL} + N_{Ft} + N_{bL} + N_{bt}$

Total diversity minus singletons: $N_{tot-} = N_{Ft} + N_{bL} + N_{bt}$

Estimated mean standing diversity: $N_{emsd} = 1/2 (N_{Ft} + N_{bL}) + N_{bt}$

Normalized diversity: $N_{norm} = 1/2 (N_{FL} + N_{Ft} + N_{bL}) + N_{bt}$

Only the tendencies shown in all the curves were thought to be significant and discussed further. In addition to the 'binned' richness estimations, the same data set was used to generate an 'unbinned' richness curve by using the quantitative stratigraphic method.

Constrained optimization (CONOP) is a model for optimizing the procedure of stratigraphic graphic correlation (Kemple et al. 1989, 1995). In the present study, we used the CONOP.net version 1.0 to create the best-fit composite standard sequence which provides the highest possible stratigraphic resolution and is used to generate the 'unbinned' richness curve. This new version was programmed in the C# language by Junxuan Fan, Xudong Hou and Peter M. Sadler in 2013.

LLANDOVERY CONODONT DIVERSITY

The four 'binned' richness curves based on zonal countings (Fig. 3) and the 'unbinned' richness curve based on CONOP9 (Fig. 4) show apparently similar changes. Firstly, species richness increased gradually in the first three conodont zones, i.e., the *Ozarkodina* aff. *hassi*, *Ozarkodina obesa* and *Ozarkodina guizhouensis* zones. This increase may represent the recovery and radiation of the conodont fauna after the Late Ordovician mass extinction. Chen et al. (2000) reported the occurrence of only one conodont species, *Amorphognathus ordovicicus* from the *Normalograptus extraordinarius* Zone at the Wangjiawan North section. This is the only record of the conodont fauna during the mass extinction in South China. The relatively lower but gradually increased conodont richness in the *Ozarkodina* aff. *hassi* and *Ozarkodina obesa* zones probably indicates the recovery stage of the conodont fauna after the Late Ordovician mass extinction. Conodont richness increased considerably from the *Ozarkodina guizhouensis* Zone to the *Pterospathodus eopennatus* Zone and reached the peak of the radiation of the conodont fauna in the

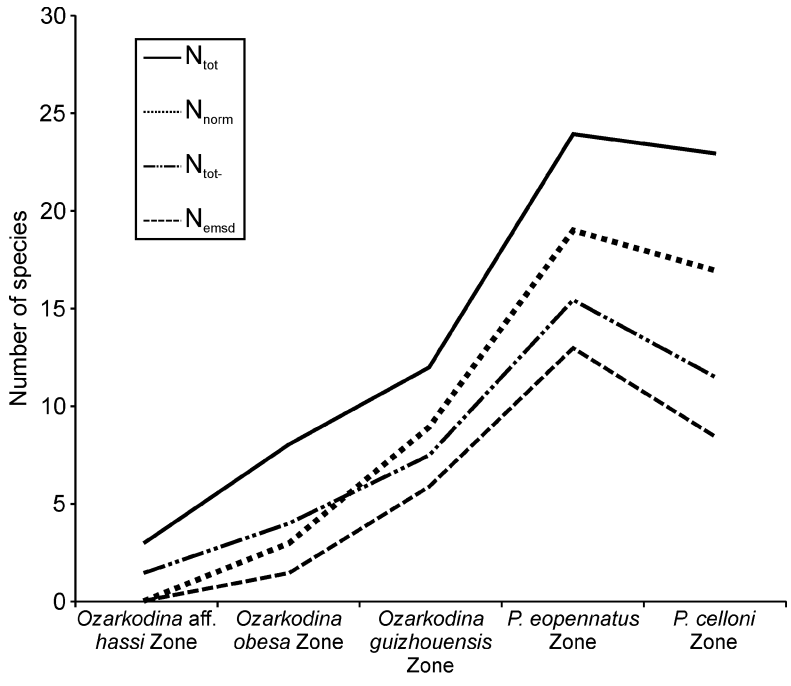

Fig. 3. Species richness curve of the Llandovery conodonts of the Upper Yangtze Platform. *P.*, *Pterospathodus*.

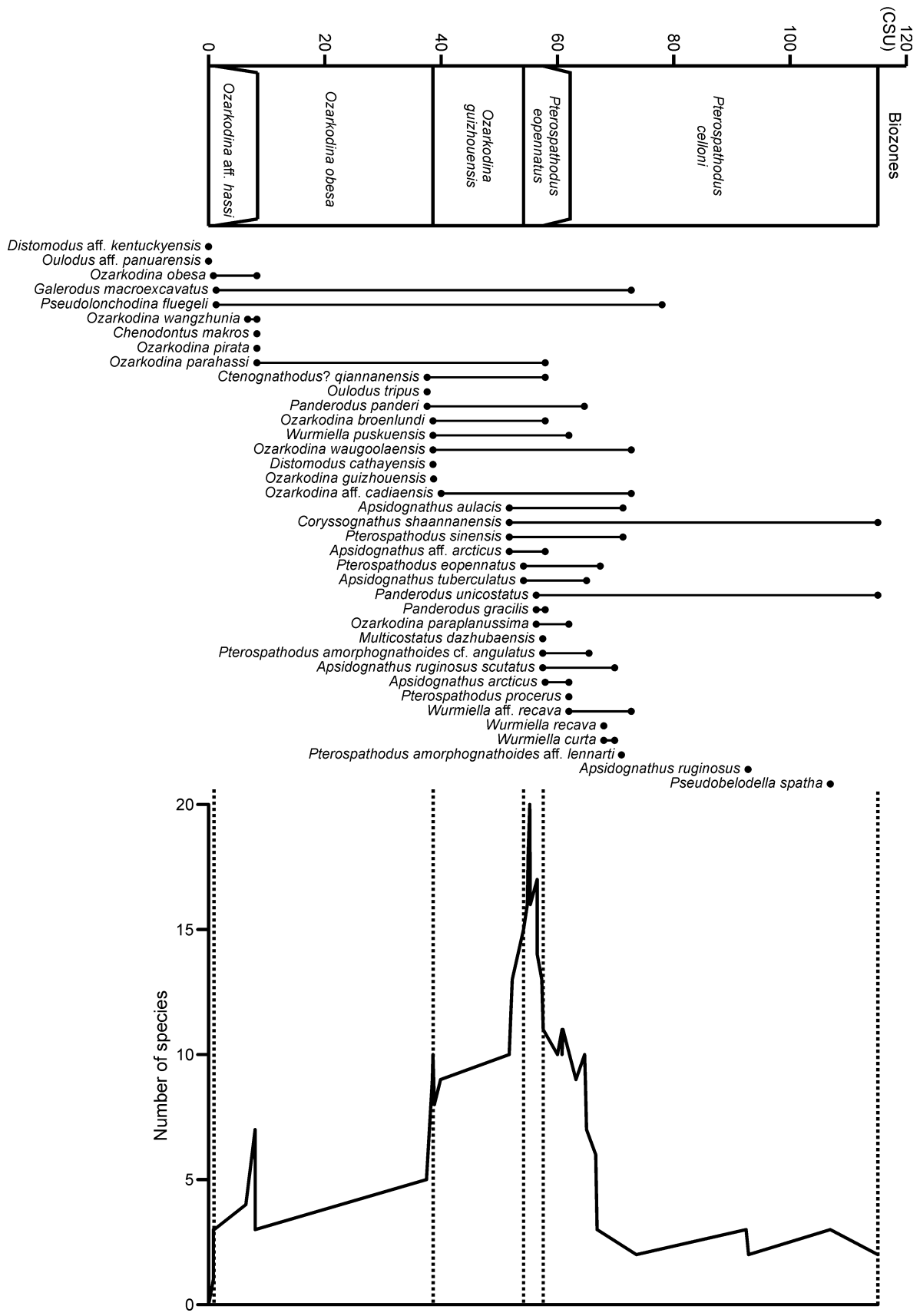

Fig. 4. Llandovery conodont species diversity of the Upper Yangtze Platform based on the conodont composite sequence.

middle of the *Pterospathodus eopennatus* Zone in the Llandovery Epoch. However, after that, species richness decreased rapidly from the upper part of the *Pterospathodus eopennatus* Zone to the *Pterospathodus celloni* Zone. Such a dramatic change is more prominent in the 'unbinned' richness curve (Fig. 4). It probably represents a new mass extinction of the conodont fauna in the middle Telychian.

DISCUSSION

After the Ordovician mass extinction, many fossil groups, such as graptolites, brachiopods, trilobites and chitinozoans, recovered and diversified in the Llandovery Epoch. Sadler et al. (2011) and Fan et al. (2013b) both found a gradual graptolite recovery and radiation during the early Rhuddanian. Sadler et al. (2011) and Cooper et al. (2014) also noticed a long-term and significant graptolite mass extinction during the middle and late Telychian Age. Paluveer et al. (2014) studied the chitinozoan diversity in the East Baltic region. They also recognized a rapid and significant drop in chitinozoan richness in the middle and late Telychian Age. Those studies, together with the present study, probably indicate a global, significant mass extinction event in both planktonic and swimming forms.

CONCLUSIONS

The Llandovery conodont species diversity of the Upper Yangtze Platform exhibited an increase from the *Ozarkodina* aff. *hassi* Zone to the middle of the *Pterospathodus eopennatus* Zone, which may represent the recovery and radiation of the conodont fauna after the Late Ordovician mass extinction. The species richness of conodonts then decreased rapidly from the upper part of the *Pterospathodus eopennatus* Zone to the *Pterospathodus celloni* Zone. It probably indicates a significant mass extinction of the conodont fauna in the middle Telychian. This extinction event has also been recognized in the studies of other fossil groups such as graptolites and chitinozoans based on a similar quantitative method.

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