

Conodont evolution and stratotype sign of carboniferous Tournaisian-Visean boundary in South China

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Abstract A stratotype section, boundary point and conodont sign have been recommended for GSSP of the Tournaisian-Visean boundary, based on studies of sectional sedimentology, conodont facies and phylogenesis in South China. Two areas representing margin and inner of the Yangtzi Plate and three sections of different facies were chosen, i.e. the Longdianshan section of the platform facies in Liuzhou of Guangxi, the Yudong section of the ramp facies in Shidian of Yunnan and the Pengchong section of the basin facies in Liuzhou of Guangxi. Stratigraphic frameworks of two areas were set up by systematical studies of carbonate facies and cycles. Conodont facies-distribution and paleoecologic conditions were researched on statistics of fossil variation and richness, and a kind of planktonic conodont, gnathodids that were widespread, is chosen to select the sign-fossil from it. Seven conodont pedigrees were supplemented or erected by studies of statistics and transitional forms. Conodont evolution in the Early Carboniferous could be divided into three stages, i.e. the *Siphonodella* stage, the *Gnathodus typicus* stage and the *Gnathodus bilineatus* stage. The transform-surface between the later two stages could be put as the Tournaisian-Visean boundary. Finally, this paper proposes that the Pengchong section can be the stratotype candidate of the Tournaisian-Visean boundary, the boundary point be put at the bottom of bed 58 and the stratotype sign of conodont be the first occurrence of *Gnathodus prae bilineatus* of the *Gnathodus semiglaber* branch.

Keywords: Tournaisian-Visean boundary, global stratotype, conodont evolution.

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Sediment-successive strata of the Carboniferous Tournaisian-Visean period, i.e. Aikuanian-Datangian, are widespread in South China, where it is most possible to establish the GSSP of the TV boundary. Owing to a global drop of sea-level in the period, when the dropping-range could reach to 150 m^[1], sedimentary interruptions, sudden changes of facies and disjunctions of organic-evolutionary chains occurred commonly and cause sharp conflicts on division and correlation of the boundary. In the 6th International Con-

ference of Carboniferous, this boundary was put at the bottom of the first dark-limestone bed, the bed 141 in the Bastion section of the Dinan basin of Belgium. The boundary horizon coincides with the first appearances of conodont *Paragnathodus homopunctatus* and foraminifera *Eoparastaffera*. But studies later verified that the boundary is dia-chronous in the horizontal and the first occurrences of both mark-fossils are lower than the boundary in their evolutionary pedigrees^[2].

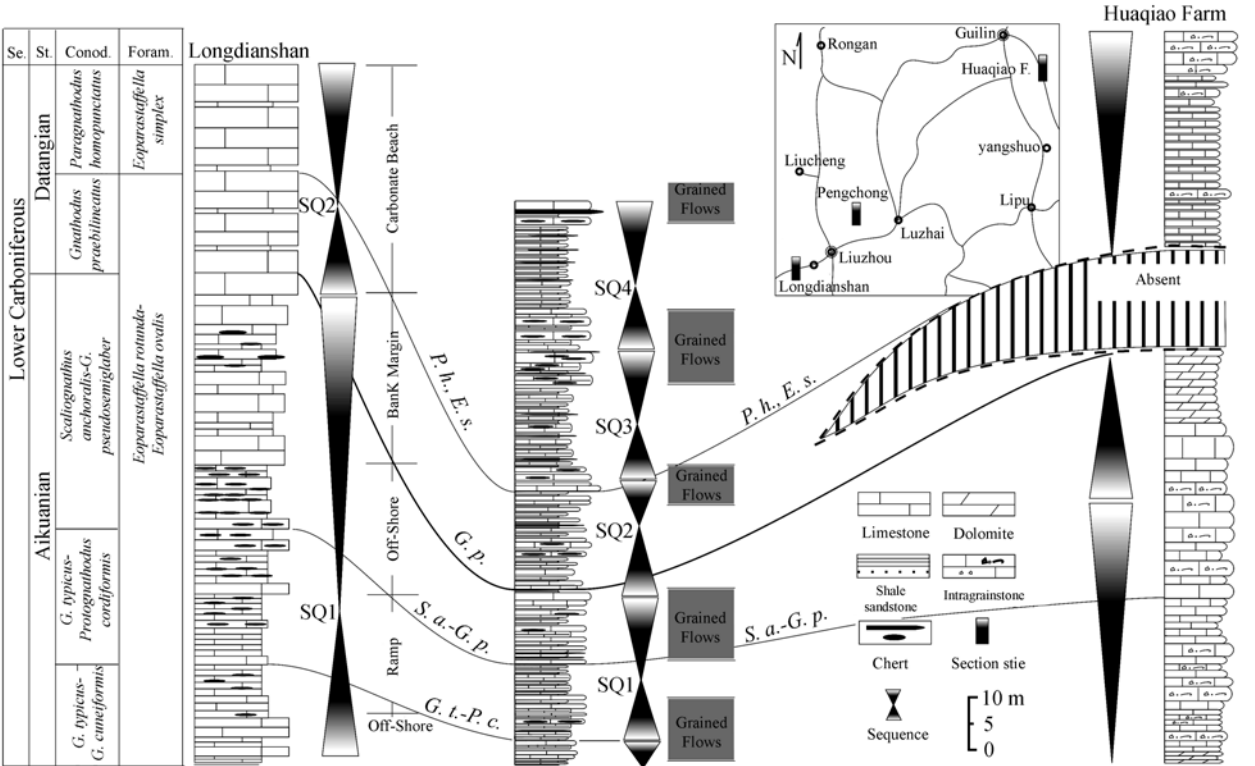


Fig. 1. A stratigraphic framework of the TVV boundary strata in the Guilin-Liuzhou area of Guangxi.

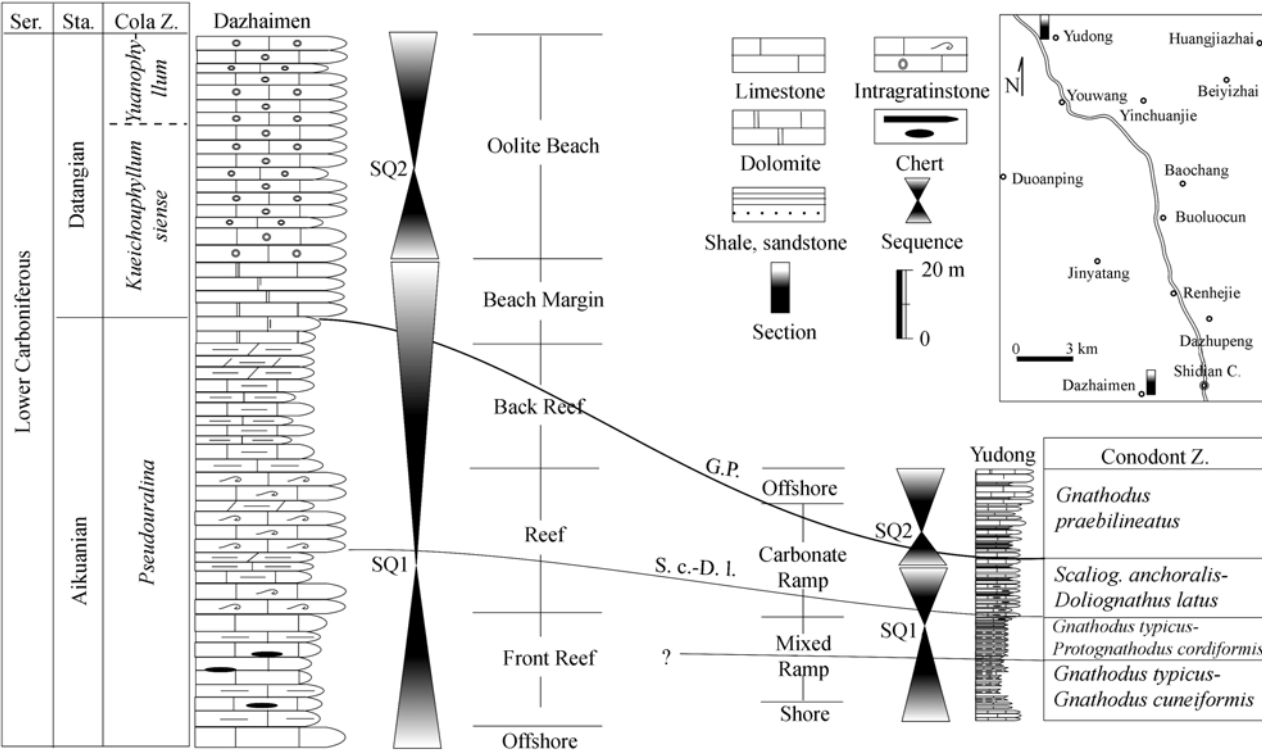


Fig. 2. A stratigraphic framework of the TVV boundary strata in the Baoshan area of Yunnan.

margin ramp facies and consists of dark-grey mid-thin bedded and inter-thick bedded grain-micritic limestone, with rich microfossils of conodonts and ostracoda, etc. Although the middle of the SQ1 belongs also to the off-shore shallow-water facies, but is characterized by rich siliceous belts and blocks, and composed of gray and dark-gray, mid- and inter-thick bedded grain-microlite limestone, with a large number of macro- and microfossils. Upper part of the SQ1 is to the bank-margin facies and consists of gray thick-block-bedded mid-fine grained limestone, and inter-thin-bedded limestone with siliceous belts and blocks. Features of the fossil assemblage indicate a shallow-water and active energy conditions, which includes fossils of unit corals, brachiopods, conodonts and stromatolites.

The SQ2 belongs entirely to the high-energy bank facies and its small-cycles are distinguished by appearances of those internal thin- and mid-layers. The SQ2 is constituted by pale-gray and gray-white, thick-block bedded, mid-crude grained limestone and contains the shallow-water fossils, like unit corals, brachiopods, crinoids, bryozoa, etc. which are poorly preserved. A few of conodonts are selected from those internal thin- and mid-layers.

1.2 Pengchong section of Liuzhou, Guangxi

The section is located at Pengchong Village and 14 km southeast from Liuzhou City. The boundary strata are composed of dark-gray and gray-black, mid-thin bedded, siliceous belt- and block-bearing, grain-micritic or micritic limestone, and they appear features of a typical plateau-basin facies. Some pieces of the section are constituted by inter-bedded with gray thick-bedded grain-limestone or grain-micritic limestone from intermittent grain-flows. These grain-flow beds supply reliable evidence for dividing sedimentary cycles or sequences. Their occurrences commonly indicate that fall-down ages of the sea level and the water-dynamics could remove a lot of grains into the basin. These basins were only low-lying areas in the plateau and ramps around the basins were much gent. The gravitation-collapses did not occur, thus these thick-bedded limestone layers are not turbidites or mixture accumulations. Ecologic analyses of conodont

assemblages also prove that conodonts were preserved in place. Boundary strata of this section are constituted by 4 sequences and contain abundant fossils of conodonts, foraminifera, ostracoda, etc.

1.3 Yudong section of Shidian, Yunnan

The section exposes by a highway, 20 km northwest from the Shidian, Baoshan of Yunnan Province. Strata of the TV boundary are mainly of the plateau-margin ramp facies and constituted by 2 sequences. The facies series are, from lower to upper, the near-shore facies—the mixed ramp facies—the carbonate ramp facies—the off-shore facies. Strata of the near-shore facies are constituted by gray or brown-yellow silty mudstone, interbedded with dark-gray and yellow-gray, thin-mid-bedded sandy marble, dolomitic limestone and limestone. Fossils include conodonts, small-body corals, brachiopods, etc. Among fossils, conodonts are rich and the mixture appears. This part of strata indicates exactly a muddy tidal-infratidal environment.

Environment of the lower part is the muddy and dolomite mixed ramp. This piece of strata is composed by alternations of brown-yellow, thin-bedded silty mudstone-muddy siltstone and yellow-gray, thin-bedded marl-muddy limestone. Small-body corals and conodont gnathodids are abundant in it. Environment of the middle part changed to the carbonate ramp, which is characterized by gray and dark-gray, thin-mid-bedded micritic limestone, inter-bedded with abundant siliceous belts and blocks. Conodonts are rich and variable. Upper part of the section belongs to the off-shore shallow-water facies. Its rocky composition is gray and dark-gray, mid-thick bedded power-fine grained limestone. It contains some corals and brachiopods, but conodonts are monotonous and poor.

1.4 Conodont facies distribution and boundary marks

Conodont facies and ecologic patterns of the Early Carboniferous have been discussed by many people^[11–13]. Most consider that conodont animals were pelagic and stratified in the ocean-surface. But

authors of this paper think that they could have variable ecologic modes. According to statistics of conodonts yielded in different facies, some kinds were strictly controlled by local conditions and might be limited in a near-shore shallow-water.

(i) Group gnathodids. This conodont group includes 3 genera, *Protognathodus*, *Gnathodus* and *Paragnathodus*. They might live in the ocean-surface by pelagic pattern and so called the group spreading everywhere. They were dominant clearly in the basin. The unit number accounts for 70%–90% of the total and the species variety for 50%. In the shallow-beach, the unit number occupied 40%–60% and the species variety 40%. Even in muddy water and the muddy-dolomite mixed ramp, the unit number can reach to 40%–50% and the species variety to 60%.

(ii) Genus *Siphonodella*. The genus was much thriving in the earlier-middle Tournaisian. But till to the later, this genus remained a few units that their oral surfaces ornament with longitudinal ridges, *Siphonodella* sp. These remains were discovered in the shallow-plateau facies and the carbonate ramp facies at the Longdianshan section, Guangxi and the Yudong section, Yunnan. They might be alive by swimming.

(iii) Genera *Scaliognathus* and *Doliognathus*. Both genera are widespread all over the world. In South China, they have been obtained from facies of the plateau-marginal ramp, the carbonate ramp, the mixed ramp and the shallow-water plateau. One or two units can also be found in facies of the high-energy beach or the basin. They might be pelagic in the ocean-surface same as gnathodids and only the number is too poor. Genus *Doliognathus* is only collected from the Yudong section, the platform-margin facies, and might be not suitable to live in a limited sea on the inner-platform.

(iv) Genus *Polygnathus*. Same as gnathodids, this genus is widespread and might be alive by pelagic. The unit number in the basin facies, contrasted with gnathodids, is smaller and accounts for 20%–30% of the total. Three species of the genus have been found in working sections. In the high-energy beach facies,

the unit number can occupy 30%–50% of the total and only one species is found. Units in turbid water, the muddy-dolomite mixed ramp, make up 20%–30% and two species are found. Many specimens have also been collected in strata of the other facies.

(v) Genus *Pseudopolygnathus*. Units of this genus are mainly discovered in facies of the carbonate ramp and the shallow plateau. The unit number can reach to 30%. Some units can also be found in facies of the high-energy beach. But from strata of the mixed ramp and the basin, units of this genus are rarely obtained. Only one unit was collected from the Pengchong section. It is separated from thick-bedded grain-limestone that was generated by the grain-flow. According to the data, this genus might be alive by swimming and possess a stronger activity.

(vi) Genera *Finognathodus* and *Dollymae*. Both genera have the same facies-distribution. They are obtained mainly from facies of the high-energy beach and the shallow-water plateau. Especially in facies of the beach-margin, the unit number can reach to 30%–50% of the total. The conodont animals might be alive by benthonic swimming and possess a poor activity.

A fossil-sign of the GSSP must possess characters of widespreading, richness and strict features. Then it could have common representation. Based on analyses of carbonate facies and conodont distribution above, conodont-sign of the Carboniferous TV boundary could be selected in the group gnathodids. The group might be alive by pelagic in ocean-surface and their distribution could not be limited by local conditions, so they can be used for dividing and correlating strata most widely.

2 Conodont evolution in the TV boundary period

2.1 Conodont pedigrees

Based on statistics of conodont richness^[6] and similarities, more than 7 pedigrees have been erected in South China. Conodont evolution in the TV boundary period has been deeply studied before and many pedigrees set up^[3,14–16] already. But most of these pedigrees were not erected on the data of suc-

cessive sections, varied facies. So they caused many controversies on the first appearances, distinct horizons, evolutionary relationships, etc. Some controversies are discussed based on the data of South China as follows.

(i) Gnathodid pedigree. The pedigree includes 3 genera, *Protognathodus*, *Gnathodus* and *Paragnathodus*. Among them, *Protognathodus* has a much close relationship with *Gnathodus*. The former was differentiated from *Spathognathodus stabilis* at the end of Devonian. Its variety and richness were lower in the early-middle Tournaisian and contained only 4 species, i.e. *Protognathodus meischeri*, *P. collinsoni*, *P. kockli* and *P. kuehni*. At the end of middle Tournaisian or in the lower *crenulata* zone, *Protognathodus praedelicatus* was derived from *P. kockli*. Then *P. praedelicatus* in the upper *crenulata* zone radiated out 3 species of *Gnathodus*, i.e. *Gnathodus delicatus*, *G. typicus* and *G. punctatus*. Genus *Gnathodus* occurred. According to

data of South China, *Gnathodus cuneiformis* was diverged from *P. praedelicatus* really at the bottom of the *typicus-cuneiformis* zone. The occurrence of this species provides evidence for defining beginning of the *Gnathodus typicus* stage (Fig. 3).

Species *Gnathodus semiglaber* differentiated from *Gnathodus punctatus* at near bottom of the *typicus-cuneiformis* zone, and marked occurrence of the *G. semiglaber* branch. Evolutionary trends of the branch are adding nodes or node-rows gradually on the broad outer-platform. In this branch, the first appearances of *G. pseudosemiglaber* and *G. praebilineatus* not only sign two bottom boundaries of zones, but also perform transformations to the *G. bilineatus* stage. So *G. praebilineatus* could be taken as the strato-type-mark of TV boundary.

Genus *Paragnathodus* clearly has a different origination contrasting to *Protognathodus* and *Gnathodus*. Its specimens possess bilaterally symmetric and ellip-

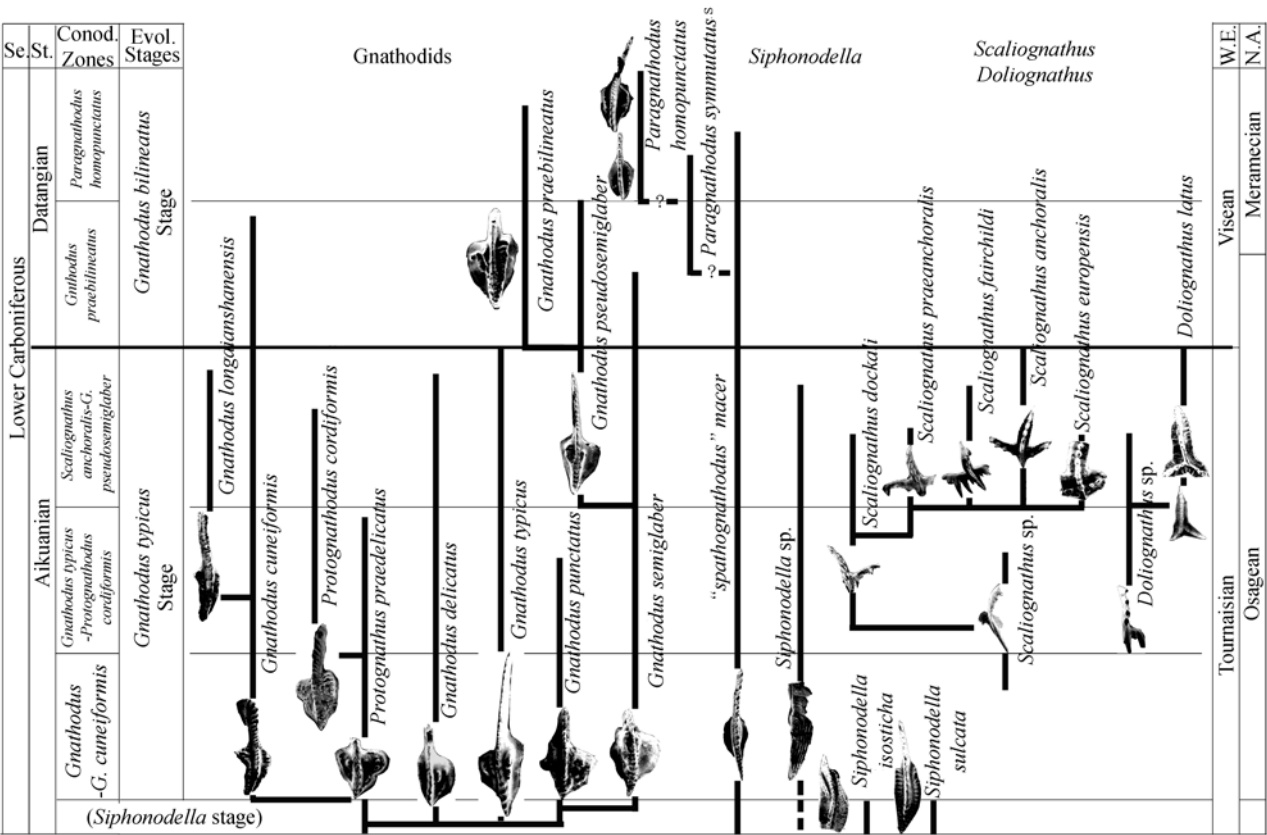


Fig. 3. Conodont evolutions in the transition period of Carboniferous TV boundary.

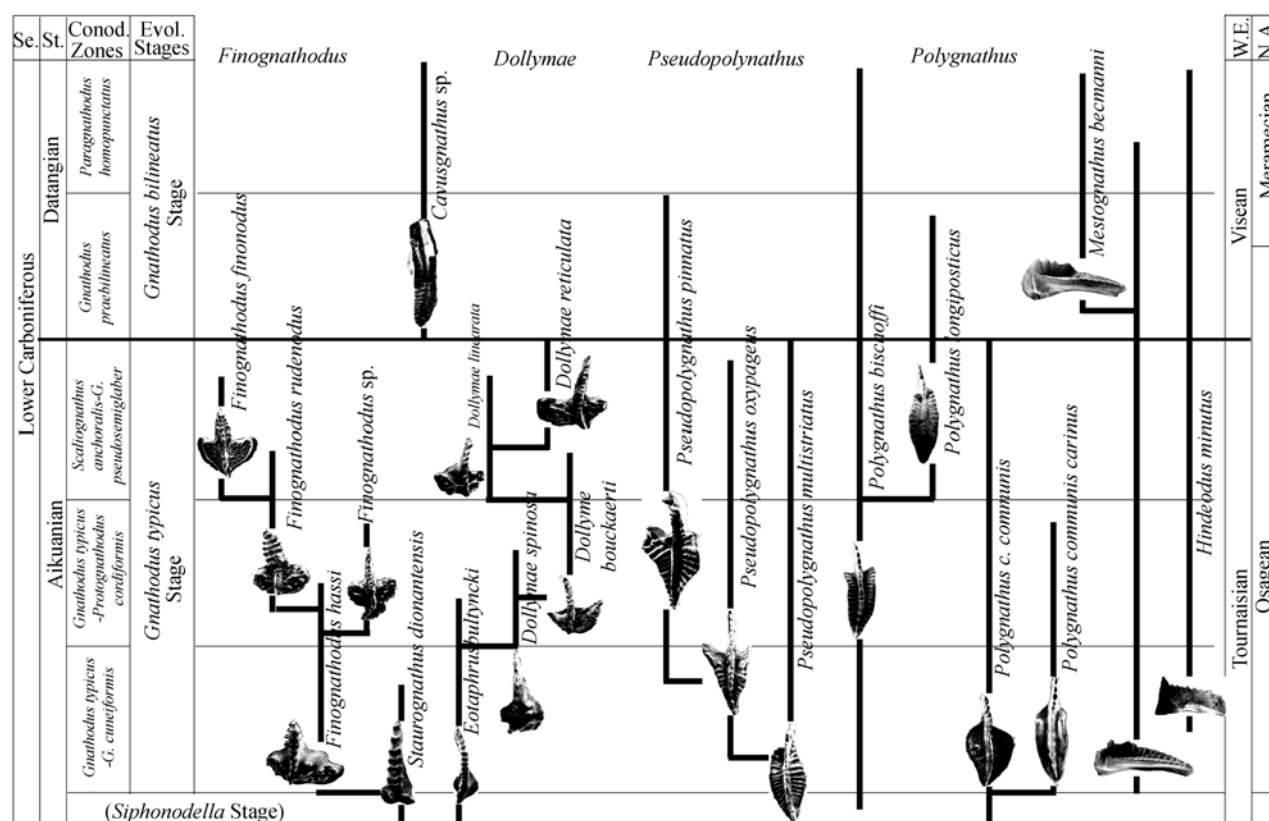


Fig. 4. Conodont evolutions in the transition period of Carboniferous TV boundary.

tical platforms. But the latter two genera have bilaterally asymmetrical platforms. *Paragnathodus* might be straightly derived from *Spathognathodus*, e.g. “*Spathognathodus*” *macer*. Firstly by expanding basal cavities and contracting carinas to platforms, “*S.*” *macer* transformed to *Paragnathodus symmutatus*. Then by increasing nodes on bilateral platforms, to *Paragnathodus homopunctatus*. Only *P. symmutatus* has not been found in South China and its first appearance cannot be determined so far.

(ii) *Scaliognathus* pedigree. Lane & Ziegler^[11] erected the *Scaliognathus* pedigree by summing up evolutionary data comprehensively. This study in South China verifies that the first appearance of *S. anchoralis* occurred at bottom of the *anchoralis-pseudosemiglaber* zone and 3 species of the genus, *S. anchoralis*, *S. fairhildi* and *S. europensis*, were radiated out from *S. praeanchoralis* simultaneously. The data also prove that all species of the genus did not range out of top-line of the *anchoralis-pseudo-*

semiglaber zone.

(iii) *Finognathodus* pedigree. The pedigree is newly erected in this paper (Fig. 4). Genus *Finognathodus* are diagnosed by an expanded platform ornamented strikingly with radiated- or concentric-ranged nodes and short ridges, and a short-wide anterior bar or para-platform with two rows of nodes or short ridges which are on both sides of the carina. Evolutionary trends of the genus are that nodes and ridges on the platform varied, i.e. concentrating on the posterior part — scattering over the surface — turning to fine and crowded, and anterior bars changed from nodes on the lateral margins to short ridges on the para-platform. According to ridges on the anterior bar and un-striking nodes of carina, genus *Finognathodus* might derive from species *Staurognathus dionantensis*. Firstly by expanding basal cavity strongly, *Staurognathus dionantensis* differentiated out of *Finognathodus hassi* (= *Dollymae hassi*) at the bottom of the *typicus-cuneiformis* zone. Then nodes and short ridges

scattered over the platform, three lists of nodes and short ridges (*F. rudenodus*) or only one list of nodes (*Finognathodus* sp.) developed on the anterior bar or para-platform, during period of the *typicus-cordiformis* zone. Up to bottom of the *anchoralis-pseudosemiglaber* zone, *F. finonodus* was derived out by a para-platform ornamented with fine and concentrated nodes and ridges. According to data in South China so far, any species of the genus does not range over top-line of the *anchoralis-pseudosemiglaber* zone.

(iv) *Dollymae* pedigree. Specimens of genus *Dollymae* were reported poorly from many places, i.e. North America, Germany^[17], Belgium^[18], England^[20,21], etc.^[19] But in South China, abundant specimens have been collected from facies of the shallow-water plateaus. The *Dollymae* pedigree is erected in this paper. Evolutionary trends of *Dollymae* are mainly that ornaments on platforms are varied along node spines—nodes and ridges—threadlike ridges—netlike ridges. And their platform outlines changed along circular—elliptical—extended wing-like. This paper agrees with Austin & Grossens^[22] that *Dollymae* originated from *Eotaphrus bultincki*. At the bottom of the *typicus-cordiformis* zone, *E. bultincki* evolved to *Dollymae spinosa* by developing crude node-spines on the circular platform and contracting end of carina anterior-wards to the biggest node-spine. According to the data reported from places above, *Dollymae bouckaerti* occurred at the middle of *typicus-cordiformis* zone. Till to bottom of the *anchoralis-pseudosemiglaber* zone, *Dollymae lineartus* appeared and possessed branched linear ornament on the platform. And at the middle of *anchoralis-pseudosemiglaber* zone, appearance of *Dollymae reticulata* with net ornament represents evolutionary top of the genus. Any unit of the genus has not been found in overlying *praebilineatus* zone in South China.

(v) *Pseudopolygnathus* pedigree. The pedigree was called the *Pseudopolygnathus multistriatus* group by Lane et al.^[3] This study verified the horizons of first appearances and disappearances for many species. According to the data in South China, both *P. pinnatus* and *P. oxypageus* appeared in the *typicus-cuneiformis*

zone that is equal to the Lower *typicus* zone. *P. pinnatus* occurring at the upper and *P. oxypageus* at the lower. *P. pinnatus* might range to the *praebilineatus* zone.

(vi) *Polygnathus* pedigree. The first appear- and the disappear-horizons of *Polygnathus longiposticus* are important for stratigraphic division in South China. This species appeared firstly at the bottom of the *anchoralis-pseudosemiglaber* zone, and disappeared in the upper of the *praebilineatus* zone.

2.2 Evolutionary stages in the TVV boundary period

(i) *Siphonodella* stage. During the early-middle Tournaisian, genus *Siphonodella* widespread and was dominant in both quantity and variety. At least 9 evolutionary branches were radiated out and more than 30 species and morph-types have been distinguished (Lane & Ziegler, 1983). Conodont 6 zones are erected based on the evolutionary pedigrees. But in the upper Tournaisian, most species of *Siphonodella* had disappeared at bottom of the *typicus-cordiformis* zone, and only some units, *Siphonodella* sp., ranged into top of overlying *typicus-pseudosemiglaber* zone.

(ii) *Gnathodus typicus* stage. Conodont gnathodids begun to thrive at the bottom of the *typicus-cordiformis* zone. According to the data of South China, the species number of gnathodids occupies 1/4 of the total from the *typicus-cordiformis* zone to the *anchoralis-pseudosemiglaber* zone. The unit quantity is about 50% in every facies. Among these species, *Gnathodus typicus* was most dominant in the later Tournaisian. During this period, many genera and group occurred and thrived also, i.e. *Scaliognathus*, *Doliognathus*, *Finognathodus*, *Dollymae*, *Pseudopolygnathus multistriatus* group, *Mestognathus*, *Hindeodus*, etc. All genera and groups above made up a distinctive assemblage of conodonts.

(iii) *Gnathodus bilineatus* stage. Getting into the period of *praebilineatus* zone, conodont assemblage changed clearly again and marked the beginning of the *Gnathodus bilineatus* stage. According to the data obtained^[22–24], gnathodids were dominant also, the later stage was characterized by thriving of *Gnathodus*

bilineatus. *Gnathodus* and *Paragnathodus* include 7—12 species which occupy about 50% of the total. The unit quantity is over 60%. Associated genera in the stage are *Cavusgnathus*, *Adetognathus*, *Mestognathus*, *Spathognathodus*, *Hindeodus*, etc.

3 Conodont sign and the TVV boundary stratotype

From Figs. 3 and 4, it can be seen that the bottom of *praebilineatus* zone is the change surface of two evolutionary stages. The conodont assemblage below is represented by *Gnathodus typicus* and characterized by thriving of *Gnathodus*, *Protognathodus*, *Scaliognathus*, *Doliognathus*, *Finognathodus*, *Dollymae*, *Pseudopolygnathus*, *Polygnathus*, etc. More than 29 species of these genera, about 70% of the total, disappeared in this stage, which did not range upto the surface. So this change surface can be chosen as the boundary of the Tournaisian-Visean.

The assemblage above belongs to the *Gnathodus bilineatus* fauna. The assemblage in the *praebilineatus* zone has sprouting colors clearly. The unit quantity

was poor and the variety monotonous. Only a few species and 2 genera, i.e. *Gnathodus praebilineatus*, *Paragnathodus* and *Cavusgnathus*, occurred newly in both the *praebilineatus* and *homopunctatus* zones. About associate 9 species ranged up from the underlying stage. Species *Gnathodus praebilineatus* is the pioneer of *Gnathodus bilineatus* and its appearance indicates the evolutionary beginning of the *Gnathodus bilineatus* fauna. Owing to the widespread of *G. praebilineatus*, striking feature and clear origination, the species is suited to be a stratotype sign of the TV boundary.

Among genera new-occurred, units of *Cavusgnathus* are considered as dividing marks in the Meramecian and the Chesterian^[24]. In North America, they appeared firstly at the upper Meramecian above the *homopunctatus* zone, and reached quickly to a large varieties and quantities. But on the Pengchong section of South China, *Cavusgnathus* co-occurred with *Gnathodus praebilineatus* at the bottom of the *praebi-*

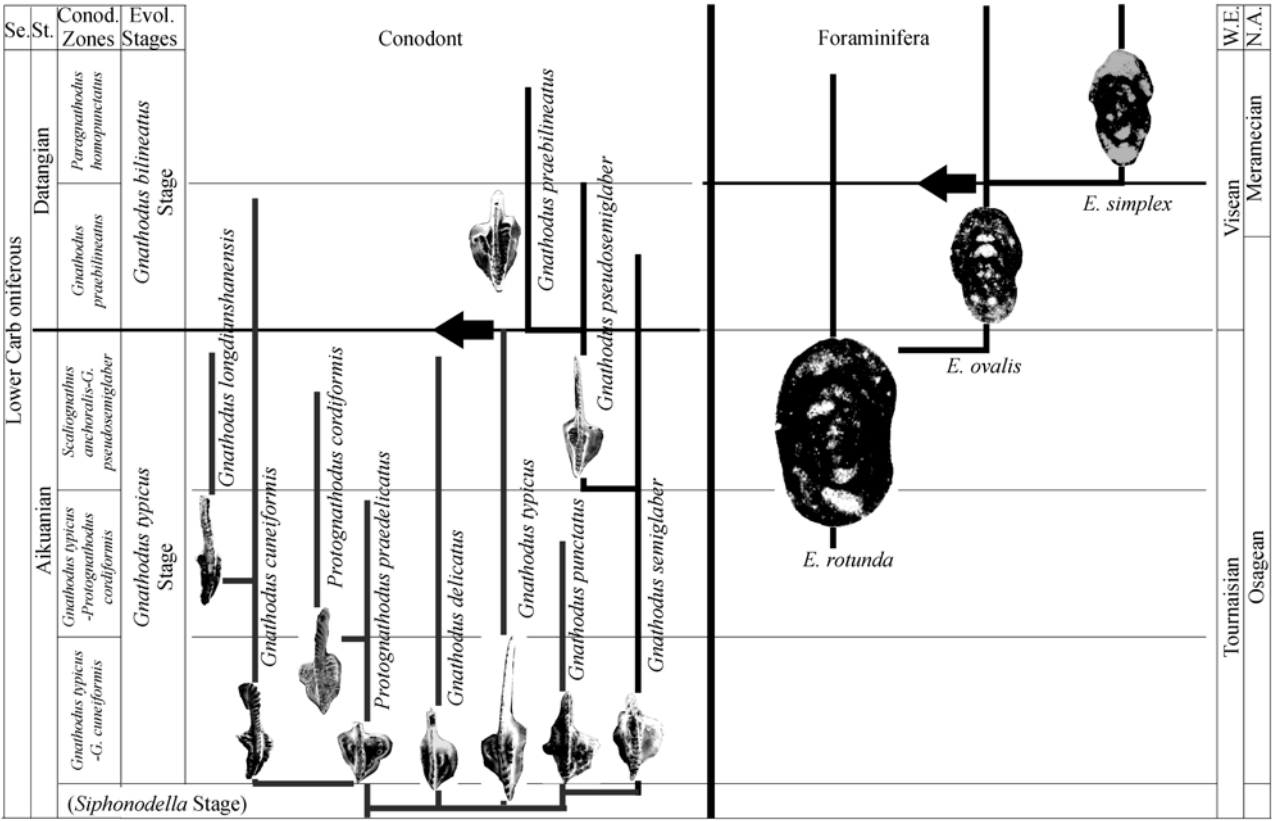


Fig. 5. Stratotypical bio-signs of the Carboniferous TVV boundary.

lineatus zone. Only it could not be determined whether the bottom is its first-occurred horizon owing to fewer units obtained. Lane et al.^[3] erected the *Gnathodus texanus* zone and took the first appearance of *G. texanus* as a sign of the TV boundary. But units with strict characters were not found in South China. Most of people think that its characters are not defined well, diagnosed difficultly and the origination disputed largely. So species *G. texanus* could not be taken as the boundary sign.

The appear-horizon of *Paragnathodus homopunctatus* coincides with the TV boundary determined by the 6th International Carboniferous Conference, and also corresponds roughly to the horizon of foraminifera *Eoparastaffella simplex*^[5]. But origination of *P. homopunctatus* is not clear and its first appear-horizon could not be defined so far. Some^[22] think that *Paragnathodus symmutatus* is the pioneer of *P. homopunctatus*. But it has not been found in South China and its appear-horizon is higher above the bottom of the *G. bilineatus* stage. So this paper proposes that the appear-horizon of *P. homopunctatus* could not be taken as the boundary of Turnaisian-Visean.

According to the data above in South China, the Pengchong section of the plateau-basin facies is recommend as the TV stratotype candidate. The boundary point is put at the bottom of bed 58 and the stratotype sign is taken as the first appearance of *Gnathodus prae bilineatus* in the *G. semiglaber* branch. This boundary point is lower than that defined by foraminifera *Eoparastaffella simplex* (Fig. 5).

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