

浙江和江西二叠/三叠系界线层上下的辐鳍鱼类化石与鱼类的绝灭、复苏和辐射¹⁾

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摘要: 记述了浙江长兴县煤山剖面、江西修水县四都乡东岭剖面和信丰县铁石口镇铁石口剖面二叠/三叠系界线层上下的辐鳍鱼类6个类别的微体化石,包含2新属2新种,它们是:赵氏浙江鱼(*Zhejiangichthys zhaoi* gen. et sp. nov.)和小齿葆青鱼(*Baoqingichthys microdontus* gen. et sp. nov.)。这是包括全球二叠/三叠系界线层型剖面和点位(GSSP)在内的全球二叠/三叠系界线层上下辐鳍鱼类微体化石序列的首次报道。

在总结煤山剖面已记述的鱼类大化石和微体化石资料的基础上,分析了长兴煤山剖面二叠纪末鱼类的集群绝灭。绝灭发生得很晚,持续的时间很短,规模也很大,绝灭率高达93%。

讨论了华南二叠/三叠系之交大绝灭后鱼类的复苏和辐射,认为鱼类和牙形类一样都是大绝灭后在三叠纪最早复苏的类别,最早复苏的鱼类为裂齿鱼类;鱼类从绝灭期到辐射期仅用了1.3 Ma到4 Ma,从地质时间考虑,大绝灭后鱼类的复苏和辐射是相当快的。华南早三叠世以裂齿鱼类的张氏鱼(*Zhangina*)和软骨鱼类的弓鲛(*Hybodus*)为代表的组合替代了晚二叠世以古鲟类的中华扁体鱼(*Sinoplatusmys*)和软骨鱼类的中华尖齿鲨(*Sinacrodus*)为代表的组合。

华南晚二叠世海相地层产出的辐鳍鱼类和软骨鱼类的一些土著属与产于特提斯区三叠纪的一些属非常相近,表明华南下扬子区很可能是后来繁盛于特提斯区的三叠纪鱼类的发源地。

关键词: 华南,二叠/三叠系界线层,辐鳍鱼类微体化石,集群绝灭,复苏,辐射

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1 前言

二叠/三叠系界线作为古生界与中生界的分界受到全球地质古生物界人士的关注,所以相关化石的研究也特别受到重视。与长兴煤山剖面和其周边地区二叠/三叠系界线层上下无脊椎动物化石的研究相比,界线层上下鱼类化石的研究更需要加强,因为它们剖面中脊椎动物的代表。

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以往对华南二叠 / 三叠系界线层上下鱼类化石的研究主要从三个方面展开,一是对晚二叠世长兴组煤山段底部鱼类大化石的研究(刘宪亭、张弥曼,1963;魏丰,1977;王念忠、刘宪亭,1981;刘宪亭、魏丰,1988;金幸生,1997)。二是对早三叠世鱼类化石的研究(刘宪亭,1964;苏德造,1981;苏德造、黎作骢,1983;钱迈平等,1997;刘冠邦等,2002;金帆等,2003;金帆,2006)。三是对华南二叠 / 三叠系界线上下鱼类微体化石的研究,仅有两篇报道,描述了广西田东早三叠世弓鲛类和多尖齿鲨类(王念忠等,2001)及浙江和江西二叠 / 三叠系界线以下的软骨鱼类(王念忠等,2007)。华南晚二叠世 / 早三叠世鱼类的分布见图 1。

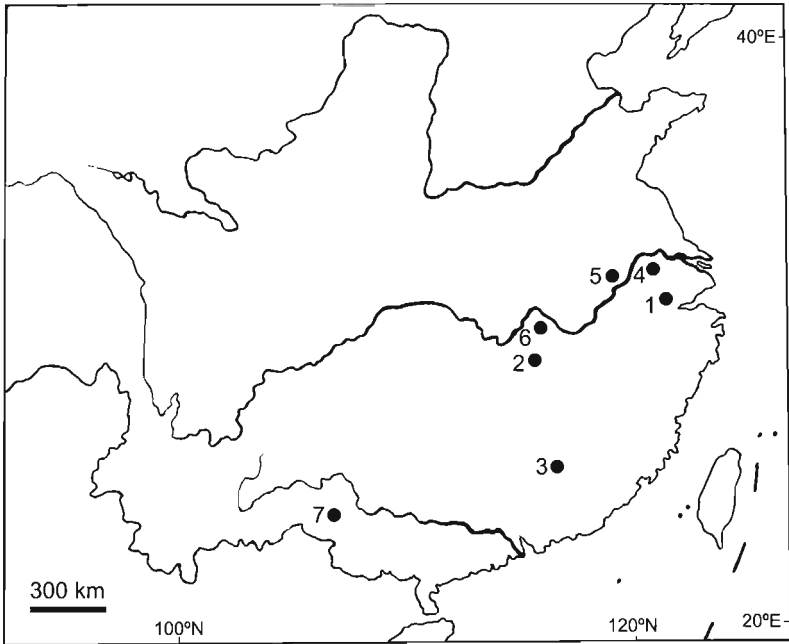


图 1 华南晚二叠世 / 早三叠世鱼类的分布

Fig. 1 Distribution of the fishes in Late Permian / Early Triassic of South China

1. 浙江长兴 Changxing, Zhejiang; 2. 江西修水 Xiushui, Jiangxi; 3. 江西信丰 Xingfeng, Jiangxi; 4. 江苏句容 Jurong, Jiangsu; 5. 安徽和县 Hexian, Anhui; 6. 湖北黄石 Huangshi, Hubei; 7. 广西田东 Tiandong, Guangxi

本文对浙江长兴煤山剖面(赵金科等,1981;杨遵仪等,1987;王成源,1995;张克信等,1995;Yin et al., 2001)、江西修水东岭剖面和信丰铁石口剖面(朱相水等,1998)等二叠 / 三叠系界线层上下的辐鳍鱼类微体化石进行记述,特别是煤山的 Z 剖面界线层 1、2 和 3 的化石。在此基础上结合已记述的软骨鱼类微体化石(王念忠等,2007)和煤山剖面煤山段的鱼类大化石,讨论煤山剖面二叠 / 三叠系之交鱼类的集群绝灭和绝灭后的复苏;并综合长兴煤山剖面晚二叠世已记述的鱼类化石和江苏、安徽、湖北和广西早三叠世鱼类化石资料讨论华南二叠 / 三叠系之交大绝灭后鱼类的复苏和辐射。

本文是华南二叠 / 三叠系界线上下鱼类序列研究之六。

2 标本记述

硬骨鱼纲 Osteichthyes Huxley, 1880

辐鳍鱼亚纲 Actinopterygii Woodward, 1891

葆青鱼属(新属) *Baoqingichthys* gen. nov.

属型种 *Baoqingichthys microdontus* gen. et sp. nov.。

特征 同属型种。

词源 Baoqing 来自化石产地一个村名, -ichthys 为希腊语后缀, 意为鱼。

小齿葆青鱼(新种) *Baoqingichthys microdontus* gen. et sp. nov.

(图 2, 3)

词源 micr 希腊语, 意为小; odontus 希腊语, 意为牙齿。

正型标本 一枚完整的牙齿, 中国科学院古脊椎动物与古人类研究所标本编号: IVPP V 14549. 1。

副型标本 一枚牙齿尖端质帽(acrodine cap)的纵向磨片, V 14551. 1。

归入标本 另外 2 枚完整的牙齿, V 14550. 1, V 14551. 2 以及 6 枚仅保存尖端质帽的牙齿 V 14549. 2-7。

产地与层位 V 14549. 1-7 产自浙江长兴煤山 Z 剖面, 层位号(从下到上)分别为: AEL877, AEL881(界线层 1), AEL882-2、AEL882-3 和 AEL882-4(界线层 2), AEL883(界线层 3), 长兴组上部 Act232。V 14550. 1 产自江西修水东岭剖面长兴组上段底部, 层位号: Xdfo-1。V 14551. 2 产自江西信丰铁石口剖面长兴阶殷坑组底部, 层位号: T26; V 14551. 1 产自江西信丰铁石口剖面长兴组, 层位号: T14。

特征 尖端质帽长, 呈扁尖锥形, 两侧具明显的侧棱, 侧棱的一侧呈扁平状, 另一侧略凸出, 从牙齿尖端向下尖端质帽凸度变得越来越明显, 相应地也由光滑逐渐变为具少数细的纵向脊纹; 牙齿下部几乎呈筒状, 具发育的纵向细脊纹; 尖端质帽长, 略短于牙齿下部。牙齿的古组织学构造: 尖端质和齿质的齿质管均细长且密集; 尖端质与齿质、齿质与闪光质交界均不规则。

描述 牙齿小, 由上下两部分构成; 牙齿上部为尖端质帽, 呈扁尖锥状, 两侧具明显的侧棱, 侧棱的一侧呈扁平状, 另一侧略凸出, 从牙齿尖端向下凸度变得越来越明显, 也由光滑变为具少数细的纵脊纹; 牙齿下部几乎呈筒状, 具发育的纵向细脊纹, 断面近圆形。尖端质帽略短于牙齿下部, 以 V 14550. 1 标本为例, 尖端质帽长 0.3 mm, 牙齿下部长 0.4 mm(详细测量见表 1)。V 14551. 1 为一枚牙齿的纵向磨片, 显示尖端质和齿质的齿质管均细长且密集; 尖端质与齿质之间和齿质与领部的闪光质之间的界线均不规则。

比较 这里记述的牙齿不同于煤山段已记述的古鳕鱼类的牙齿, 也不同于后面所记述的赵氏浙江鱼的牙齿, 特别是它的尖端质帽长, 具纵向细脊纹; 牙齿下部具发育的纵向细脊纹, 牙齿的古组织学构造也明显不同于赵氏浙江鱼。就牙齿的大致形状而言, 它与产自美国内华达州中三叠世的 *Birgeria* sp. (Rieppel et al., 1996) 和产自德国晚侏罗世的 *Ionoscopus*

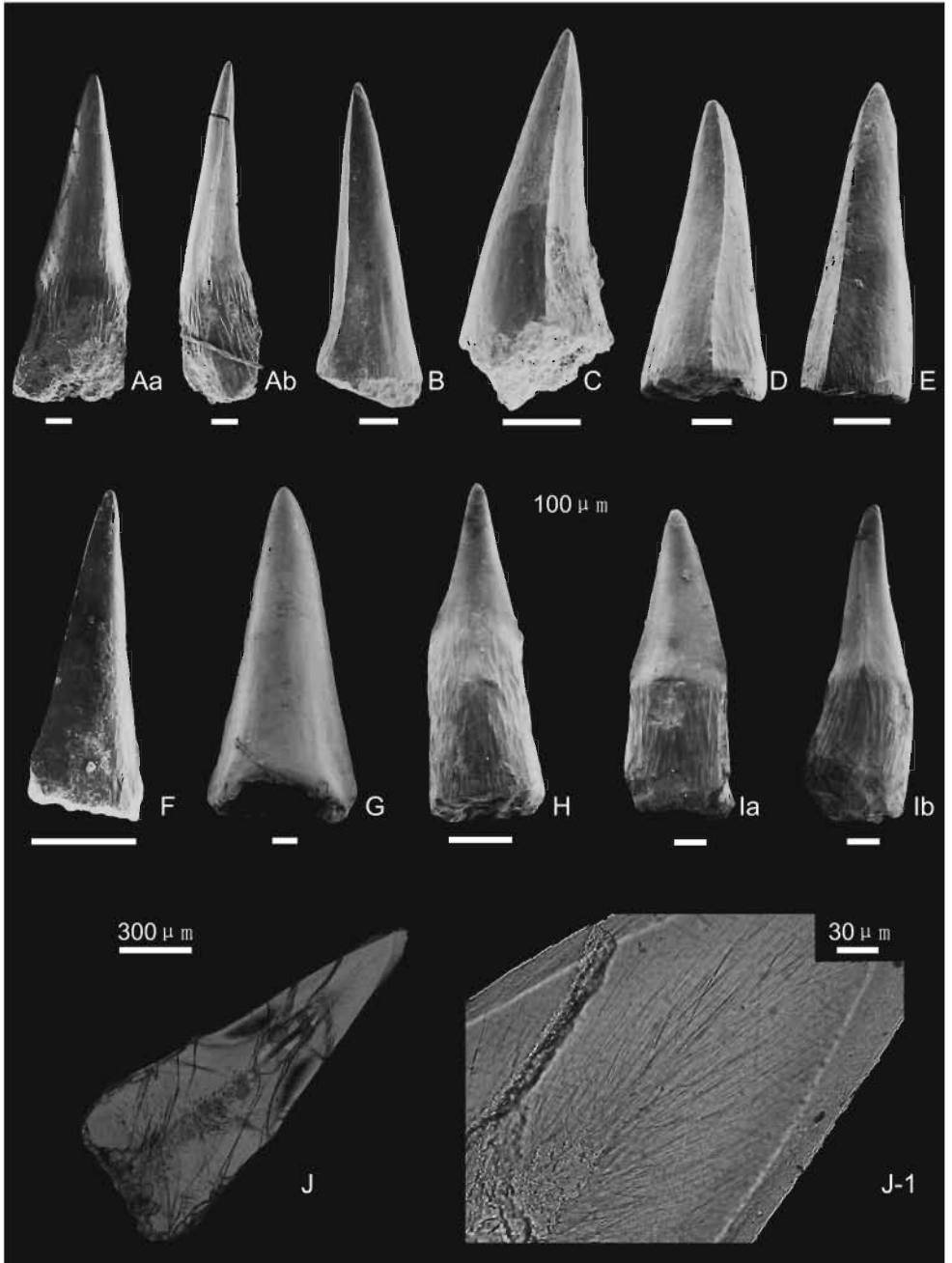


图2 小齿葆青鱼(新属、新种)的牙齿

Fig.2 Teeth of *Baoqingichthys microdontus* gen. et sp. nov.

A. V 14549. 1 (正型标本 holotype), Aa. 侧视 in lateral view, Ab. 尖端质帽及其侧棱 acrodine cap with lateral flange; B-C. V 14549. 2-7, 尖端质帽 acrodine caps; H. V 14550. 1, 侧视 in lateral view; I. V 14551. 2, Ia. 侧视 in lateral view, Ib. 尖端质帽及其侧棱 acrodine cap with lateral flange; J. V 14551. 1 牙齿纵切面 longitudinal section, J-1. 局部放大 detail

的牙齿(Thies and Mudroch, 1996)有某些相似,比如尖端质帽长,具明显的侧棱和纵向脊纹等。但华南标本明显不同于前者的是,尖端质帽呈扁尖锥状,一侧呈扁平状,另一侧则凸出,纵向脊纹稀等。不同于后者的是,牙齿下部的脊纹稀但发育。基于以上比较,笔者在此将描述的标本作为一新属种,小齿葆青鱼(*Baoqingichthys microdontus* gen. et sp. nov.)。

表 1 小齿葆青鱼(新属、新种)牙齿测量

Table 1 Measurements of the teeth of *Baoqingichthys microdontus* gen. et sp. nov. (mm)

标本 Specimen	牙齿长 Length of tooth	尖端质帽长 Length of acrodine cap
V 14549.1	>1.4	0.9
V 14550.1	0.7	0.3
V 14550.2	1.0	0.6

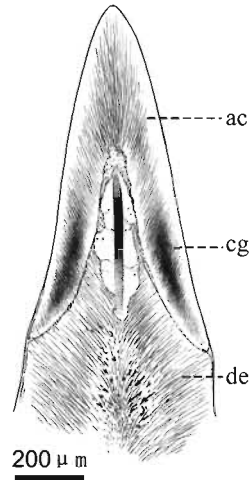


图 3 小齿葆青鱼(新属、新种)的牙齿纵切面复原, V 14551.1, 示组织学构造

Fig. 3 Restoration of a tooth longitudinal section of *Baoqingichthys microdontus* gen. et sp. nov., V 14551.1, showing histological structure
ac. acrodine 尖端质; cg. collar ganoine 颌部硬鳞质; de. dentine 齿质

葆青鱼(未定种) *Baoqingichthys* sp.

(图 4)

标本 2 枚牙齿的尖端质帽, V 14552.1 和 V 14552.2。

产地与层位 浙江长兴煤山 Z 剖面界线层 2, 层位号: AEL882-1 和 AEL882-2。

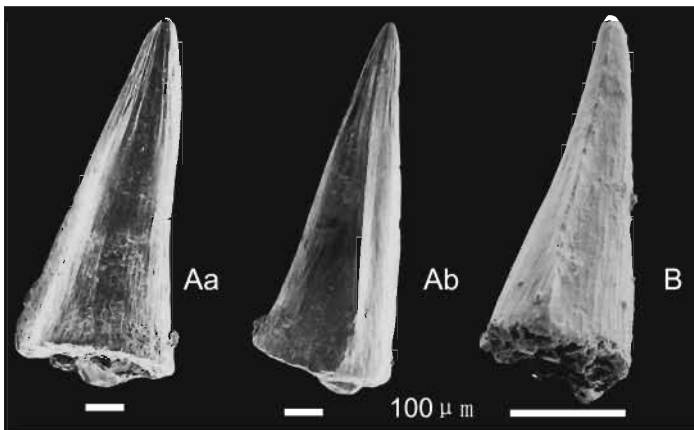


图 4 葆青鱼(未定种)的牙齿

Fig. 4 Teeth of *Baoqingichthys* sp.

A. V 14552.1, Aa. 尖端质帽, 侧视 acrodine cap, in lateral view, Ab. 尖端质帽及其侧棱 acrodine cap with lateral flange; B. V 14552.2, 尖端质帽及其侧棱 acrodine cap with lateral flange

描述 这里记述的牙齿仅为辐鳍鱼类牙齿的尖端质帽部分, V 14552. 1 标本长 1.0 mm, 呈长扁锥形, 边缘具侧棱, 侧棱一侧略凸出, 另一侧明显凸出, 具发育的细脊纹(包括尖端质帽)。

比较 这里描述牙齿的尖端质帽部分与小齿葆青鱼的相应部分比较相近, 比如高的尖端质帽, 侧棱的两侧突出, 但此处标本侧棱一侧略凸出, 另一侧明显凸出, 尖端质帽的细脊纹发育等性状不同于小齿葆青鱼, 所以我们将它作为葆青鱼(未定种)(*Baoqingichthys* sp.)。

辐鳍鱼牙齿类型 1 Actinopterygian tooth type-1

(图 5)

标本 一枚完整的牙齿 V 14553。

产地与层位 江西修水东岭剖面长兴组上段底部, 层位号: Xdfo-2。



描述 一枚完整的辐鳍鱼类牙齿, 在牙齿尖端质帽与其后部分存在一个明显向内凹入的环, 牙齿长 0.7 mm, 尖端质帽长 0.3 mm, 牙齿光滑无任何纹饰。

比较 该牙齿明显属于辐鳍鱼类, 但牙齿尖端质帽部分之下有一明显的收缩而不同于上面记述的几种鱼类牙齿。虽然仅有 1 枚牙齿, 但有代表性, 所以此处将它作为辐鳍鱼牙齿类型 1。

古鳕鱼目 Palaeonisciformes Goodrich, 1909

古鳕鱼亚目 Palaeoniscoidei Berg, 1955

科不定 (Family incertae sedis)

浙江鱼属(新属) *Zhejiangichthys* gen. nov.

属型种 *Zhejiangichthys zhaoi* gen. et sp. nov.。

特征 同属型种。

词源 Zhejiang 为化石产出的省名, -ichthys 为希腊语后缀, 意为鱼。

赵氏浙江鱼(新种) *Zhejiangichthys zhaoi* gen. et sp. nov.

(图 6, 7)

词源 种名赠于著名的古生物学家赵金科先生, 他对长兴二叠 / 三叠系界线的研究有开创性的贡献。

正型标本 一枚完整的牙齿, V 14554. 1。

副型标本 一枚牙齿的纵切面, V 14556. 1。

归入标本 另外 3 枚完整的牙齿, V 14554. 2 和 V 14554. 3, V 14555. 1。

产地与层位 V 14554. 1 和 V 14554. 2 产自浙江长兴煤山 Z 剖面长兴组顶部, 层位号 AEL874 和 AEL879; V 14554. 3 产自长兴组下部, 层位号: Act126。V 14555. 1 产自江西修水剖面, 长兴组上段底部, 层位号: Xdfo-1; V 14556. 1 产自江西信丰长兴组上段近底部, 层位号: JP5。

表 2 赵氏浙江鱼(新属、新种)牙齿测量

Table 2 Measurements of the teeth of *Zhejiangichthys zhaoi* gen. et sp. nov. (mm)

标本 Specimen	牙齿长 Length of tooth	尖端质帽长 Length of acrodine cap
V 14554.1	1.1	0.10
V 14554.2	0.6	0.10
V 14554.3	0.9	0.15
V 14555.1	0.9	0.15

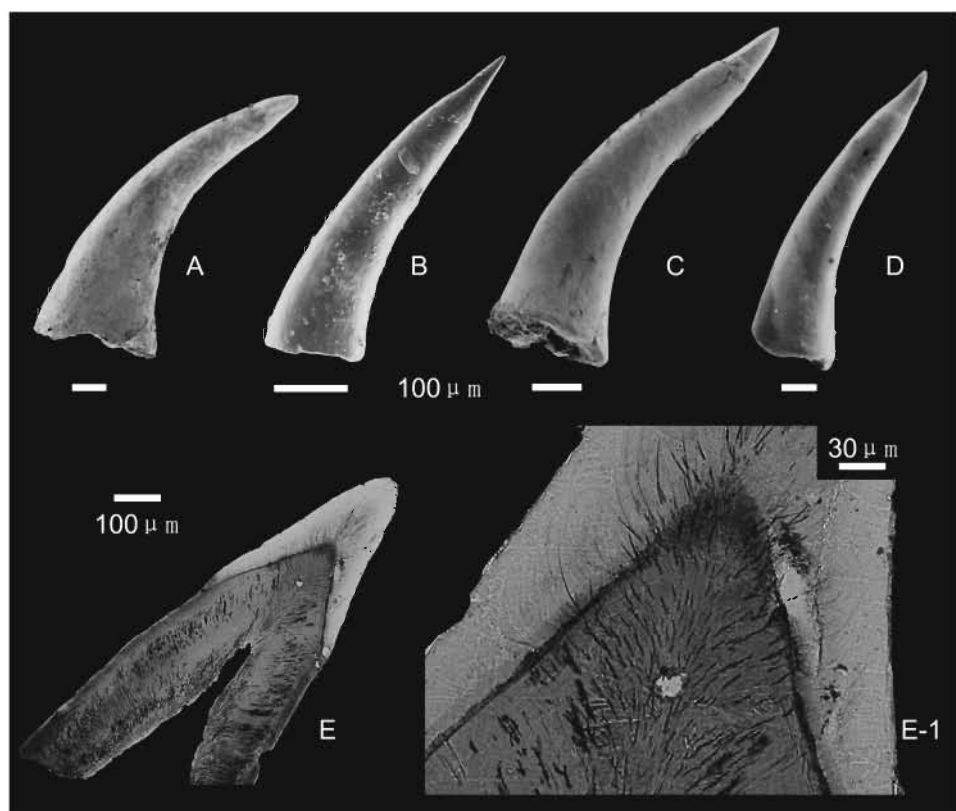


图 6 赵氏浙江鱼(新属、新种)的牙齿

Fig. 6 Teeth of *Zhejiangichthys zhaoi* gen. et sp. nov.

A. V 14554.1 (holotype), B. V 14554.2, C. V 14554.3, D. V 14555.1, A-D. 侧视 in lateral view; E. V 14556.1 纵切面 longitudinal section, E-1. 局部放大, 显示组织学构造 its detail, showing histological structure

特征 牙齿细小, 呈尖锥状, 略弯曲, 光滑无纹饰; 尖端质帽小而半透明, 具侧棱; 颌部不太发育。镜齿质 (vitrodentine) 的齿质管短粗、分布稀, 不分枝或顶端二分叉; 正齿质 (orthodentine) 的齿质管具分枝; 尖端质与齿质分界和齿质与闪光质分界均规则。

描述 牙齿细小, 呈尖锥状, 略弯曲, 光滑无纹饰; 尖端质帽小, 像笔帽状套在齿质部分之上, 呈半透明状, 具侧棱。颌部不太发育。副型标本为一枚完整牙齿的纵切面, 显示牙齿的古组织学构造, 尖端质中的镜齿质的齿质管短粗、分布稀、不分枝或顶端二分叉; 齿

质中的正齿质的齿质管具分枝。牙齿测量见表 2。

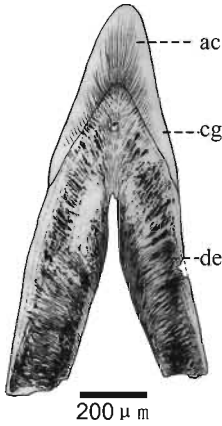


图 7 赵氏浙江鱼(新属、新种)的牙齿纵切面复原(V 14556.1),示组织学构造

Fig. 7 Restoration of a tooth longitudinal section of *Zhejiangichthys zhaoi* gen. et sp. nov. (V 14556.1), showing histological structure (缩写见图 3 for abbreviations see Fig. 3)

组织学构造特征为:镜齿质的齿质管短粗,分布稀,不分枝或顶端二分叉;正齿质的齿质管具分枝;尖端质与齿质,齿质与闪光质之间分界均规则。因此我们将这里论述的标本命名为一新属种,赵氏浙江鱼(*Zhejiangichthys zhaoi* gen. et sp. nov.)。由于仅有牙齿的特征,所以科的归属难以确定。

裂齿鱼目 Perleidiformes Berg, 1940

裂齿鱼科 Perleididae Brough, 1931

裂齿鱼科(属、种不定) Perleididae gen. et sp. indet.

(图 8)

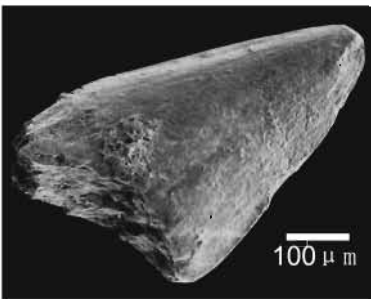


图 8 裂齿鱼科(属、种不定)一枚牙齿(V 14557)

Fig. 8 A tooth of Perleididae gen. et sp. indet. (V 14557)

比较 古鳕鱼类是全球石炭纪和二叠纪非常繁盛的一个类群(Janvier, 1996; Poplin et al., 1997; 王念忠等, 2004),但从鱼类微体化石研究的角度考虑却涉及甚少。浙江长兴晚二叠世长兴组煤山段底部具丰富的鱼类大化石,但至今只有一种古鳕鱼类化石被记述(魏丰, 1977)。经过对比,这里记述的牙齿特别细长,尖端质帽相对比较小,不同于煤山段已论述过的这类化石。其牙齿比较发育且细长也不同于始龙鱼(*Eosaurichthys*)的牙齿(刘宪亭、魏丰, 1988)。从牙齿的形态考虑,这里记述的化石与产自法国 Codère 盆地早二叠世 Autunian(奥顿阶)的 *Usclasicthys maerodens* (Heyler, 1977, fig. 8b)有些相近,比如牙齿细长,具小的尖端质帽等。但我们的标本与 Codère 盆地的标本存在的主要区别在于尖端质帽更小,其上具侧棱;这里记述的标本的古

标本 一枚不完整的牙齿, V 14557。

产地与层位 浙江长兴煤山 Z 剖面界线层 2, 层位号: AEL882-3。

描述 一枚不完整的牙齿, 尖端呈宽椎状, 具不太明显的侧棱, 侧棱两侧对称凸出, 具不明显的极细长脊纹。

比较 这枚不完整的牙齿的产出层位相当重要, 所以我们把它介绍出来。牙齿尖端呈宽锥形, 侧棱两端对称凸出, 具极细的长脊纹, 明显不同于上面记述的牙齿类型。它与

早三叠世裂齿鱼类的牙齿比较相近(Lehman, 1953; 苏德造, 1981; Selezneva and Lozovskiy, 1986; 钱迈平等, 1997; 刘冠邦等, 2002; 金帆等, 2003)。但由于牙齿保存不全, 加之数量又少, 确切对比十分困难, 所以此处作为裂齿鱼科(属、种不定)(Perleididae gen. et sp. indet.)。

弓鳍鱼目 Amiiformes Nelson, 1994

卡吐鲁科 Caturidae Koken, 1911

卡吐鲁属 *Caturus* Agassiz, 1834

卡吐鲁属(近似属) cf. *Caturus*

(图9)

标本 一枚完整的牙齿 V 14558。

产地与层位 江西信丰铁石口剖面, 长兴组顶部, 层位号: T5。

描述 一枚完整的鱼类牙齿, 明显区分为两部分: 尖端质帽及其下部分, 牙齿长 0.9 mm, 尖端质帽长 0.45 mm, 侧面具明显突出的侧棱, 侧棱两边牙齿的凸度相近, 光滑无纹饰, 其下端明显粗于牙齿的下部; 牙齿下部无脊纹但具不少大小不等的长形浅凹坑。

比较 该牙齿大致形状类似于小齿葆青鱼和葆青鱼(未定种), 但它尖端质帽光滑, 具明显的侧棱, 尖端质帽下端明显粗于牙齿的下部, 牙齿下部无脊纹但具长短不等、很浅的长形凹坑等明显不同于葆青鱼。这里记述的牙齿与产自德国晚侏罗世的 *Caturus* (Thies and Mudroch, 1996, pl. 2, figs. 9–10) 的牙齿比较相近, 特别是尖端质帽侧棱的形状和光滑的尖端质帽, 但牙齿下部具许多不规则浅凹坑, 明显不同于后者。虽然仅一枚牙齿, 但具代表性, 所以将它作为 *Caturus* 的近似属。 *Caturus* 属分布在晚三叠世到晚白垩世的地层中。



图9 卡吐鲁属(近似属)一枚牙齿(V 14558)

Fig.9 A tooth of cf. *Caturus* (V 14558)

A. 示牙齿形状 showing tooth form;

B. 示冠部侧棱 showing lateral flange

3 讨论

3.1 浙江长兴、江西修水和信丰二叠/三叠系界线上下鱼类微体化石化石由硬骨鱼纲的辐鳍鱼亚纲和软骨鱼纲的板鳃鲨亚纲构成:

硬骨鱼纲 Osteichthyes Huxley, 1880

辐鳍鱼亚纲 Actinopterygii Woodward, 1891

小齿葆青鱼(新属、新种) *Baoqingichthys microdontus* gen. et sp. nov.

葆青鱼(未定种) *Baoqingichthys* sp.

- 辐鳍鱼牙齿类型 1 Actinopterygian tooth type-1
- 古鳕鱼目 Palaeonisciformes Goodrich, 1909
- 古鳕鱼亚目 Palaeoniscoidei Berg, 1955
- 赵氏浙江鱼(新属、新种) *Zhejiangichthys zhaoi* gen. et sp. nov.
- 裂齿鱼目 Perleidiformes Berg, 1940
- 裂齿鱼科 Perleididae Brough, 1931
- 裂齿鱼科(属、种不定) Perleididae gen. et sp. indet.
- 弓鳍鱼目 Amiiformes Nelson, 1994
- 卡吐鲁科 Caturidae Koken, 1911
- 卡吐鲁属(近似属) cf. *Caturus*
- 软骨鱼纲 Chondrichthyes Huxley, 1880
- 板鳃鲨亚纲 Elasmobranchii Bonaparte, 1838
- 目和科不定 Order and Family incertae sedis
- 刘氏煤山鲨 *Meishanselache liui* Wang et al., 2007
- 王氏长兴鲨 *Changxingselache wangi* Wang et al., 2007
- 真鲨类 Euselachii Hay, 1902
- 栉棘鲨超科 Ctenacanthoidea Zangerl, 1981
- 栉棘鲨科 Ctenacanthidae Dean, 1909
- 栉棘鲨科(属、种不定) Ctenacanthidae gen. et sp. indet.
- 弓鲛超科 Hybodontoida Zangerl, 1981
- 弓鲛超科鳞片类型 1 Hybodontoid scale type-1
- 弓鲛科 Hybodontidae Owen, 1846
- 弓鲛科(属、种不定) Hybodontidae gen. et sp. indet.
- 尖齿鲨科 Acrodontidae Casier, 1959
- 中华尖齿鲨 *Sinacrodus* Wang et al., 2007
- 东岭中华尖齿鲨 *Sinacrodus donglingensis* Wang et al., 2007
- 多尖齿鲨科 Polyacrodontidae Glückman, 1964
- 滑齿鲨 *Lissodus* Brough, 1935
- 修水滑齿鲨 *Lissodus xiushuiensis* Wang et al., 2007
- 多尖齿鲨 *Polyacrodus* Jackel, 1889
- 江西多尖齿鲨 *Polyacrodus jiangxiensis* Wang et al., 2007
- 新鲨类 Neoselachii Compagno, 1977
- 新鲨类鳞片类型 1 Neoselachian scale type-1
- 新鲨类牙齿类型 1 Neoselachian tooth type-1

本文记述了辐鳍鱼类 2 个新属种:赵氏浙江鱼和小齿葆青鱼,以及葆青鱼(未定种),辐鳍鱼牙齿类型 1,裂齿鱼科(属、种不定)和卡吐鲁属(近似属)化石。在本文的姊妹篇(王念忠等,2007)中记述了软骨鱼类 3 新属,5 新种,及栉棘鲨科(属、种不定),弓鲛超科鳞片类型 1,弓鲛科(属、种不定),新鲨类鳞片类型 1 和新鲨类牙齿类型 1 化石。所以两篇文章共记述了 16 个类别的鱼类微体化石。

3.2 浙江长兴煤山剖面二叠纪末鱼类的集群绝灭

3.2.1 浙江长兴煤山 Z 剖面和 D 剖面的关系

浙江长兴煤山是一座小山,其南翼从西向东分布着 A、B、C、D、E 和 Z 共 6 个二叠/三叠系界线剖面,几个剖面之间距离很近。2001 年国际地科联批准其中的 D 剖面作为全球二叠/三叠系界线层型剖面和点位(GSSP),剖面中 27c 以首次出现牙形类微小欣德尔刺(*Hindeodus parvus*)作为三叠纪的开始。Z 剖面称为忠心大队剖面,距 D 剖面很近。两剖面的分层完全可以比对,特别是界线层 2,Z 剖面的 AEL882-1、2、3 和 4 层分别相当于 D 剖面的 27 层 a、b、c 和 d 层(王成源,1995;王念忠、王士涛,2003)。Z 剖面和 D 剖面的鱼类微体化石与牙形类化石一起产出。

值得一提的是,长兴煤山剖面二叠/三叠系界线层生物搅动的研究表明,界线层没有受到垂直生物搅动的影响(Bottjer et al., 1998),包括鱼类微体化石在内的所有微体化石都是原地沉积,为开展厘米级生物地层的系统研究和绝灭—复苏的研究奠定了很好的基础(戎嘉余等,1996;王成源,1998)。

3.2.2 长兴煤山 Z 剖面鱼类化石在界线层的绝灭情况

赵氏浙江鱼在长兴组顶部(AEL879 = 24 层顶部)即在事件地层界线下绝灭。

小齿葆青鱼从长兴组上部(AEL877 层 = 24 层底)向上延伸穿越事件地层界线和生物地层界线达界线层 3(AEL883 = 28 层),进入早三叠世格里斯巴赫阶(Griesbachian)。

葆青鱼(未定种)仅发现于殷坑组底部(AEL882-1 = 27a, AEL882-2 = 27b),即长兴阶最晚期,该类鱼在生物地层界线下绝灭。

新鲨类鳞片类型 1 仅发现于长兴组葆青段顶部。

弓鲛科(属、种不定)最早发现于葆青段顶部向上延伸达长兴组顶部(AEL879 = 24 层顶部),在事件地层界线下绝灭。

裂齿鱼科(属、种不定)则发现于生物地层界线之上(AEL882-3 = 27c),为一新生者(debutant)(图 10)。

3.2.3 浙江长兴煤山二叠纪末鱼类集群绝灭的特点

1) 绝灭率高。在长兴煤山剖面长兴组煤山段已论述了 6 种鱼类大化石,其中包含辐鳍鱼类 2 种:赵氏始龙鱼(刘宪亭、魏丰,1988),煤山中华扁体鱼(魏丰,1977);肉鳍鱼类 3 种:新槐杨氏鱼(王念忠、刘宪亭,1981)、秀丽长兴鱼(王念忠、刘宪亭,1981)、魏氏长兴鱼(金幸生,1997)和软骨鱼类一种:长兴中华旋齿鲨(刘宪亭、张弥曼,1963)。本文和前文(王念忠等,2007)记述了 9 种鱼类微体化石,其中包含辐鳍鱼类 3 种:赵氏浙江鱼(新属、新种)、小齿葆青鱼(新属、新种)和葆青鱼(未定种);软骨鱼类化石 6 种:刘氏煤山鲨、王氏长兴鲨、东岭中华尖齿鲨、栉棘鲨科(属、种不定)、弓鲛超科鳞片类型 -1 和弓鲛科(属、种不定)。不难看出,浙江长兴煤山剖面长兴阶已记述鱼类微体和大化石共 15 种,其中仅有 1 种化石穿越二叠/三叠系界线层达到早三叠世。其他 14 种鱼化石中,有 2 种鱼化石绝灭于事件地层之下,另一种绝灭于生物地层界线之下。其余 11 种鱼化石的微体化石虽然未被发现于界线层,但它们很可能同样绝灭于界线层这一时段,所以如此判断,是因为

Fishes	PTB	Section Z	Bed Thickness (cm)	Boundary Beds	Fm	Stage	System	Section D	
Bao Per Bsp Zhe Hyb	↓ Biostratigraphic boundary ↓ Eventostratigraphic boundary	884	13	Boundary Bed 3	Yinkeng Formation	Griesbachian Stage	TRIASSIC	29	
		883	2					28	
		882-4							27d
		882-3	16	H. parvus				27c	
		882-2						27b	
		882-1						27a	
		881	4	Boundary Bed 1				26	
		880	3	Boundary clay				25	
		879	5					24	
		878	5						
877	2								
876	5		23 ?						
875	9								
874	10								

图 10 浙江长兴煤山 Z 剖面 P/T 界线层上下的鱼类

Fig. 10 Fishes in the Permian-Triassic boundary beds in the section Z at Meishan, Changxing County, Zhejiang Province, China (After Wang 1995, with some modification)

Bao. *Baoqingichthys microdonotus* gen. et sp. nov. ; Bsp. *Baoqingichthys* sp. ; Fm. Formation; Hyb. Hybodontidae gen. et sp. indet. ; Per. Perleididae gen. et sp. indet. ; PTB. Permian-Triassic Boundary; Zhe. *Zhejiangichthys zhaoi* gen. et sp. nov.

长兴 P/T 界线层附近之下并未发生明显的绝灭事件。因此长兴剖面长兴阶已记述的 15 种鱼化石中有 14 种可能都绝灭于二叠纪末，绝灭率高达 93%。这与中国南方二叠纪末期 7 个海生无脊椎动物门的绝灭率为 95% - 100% (Yin et al., 1988) 的论断非常接近，进一步证明了二叠纪末期发生的集群绝灭是显生宙以来所发生的 5 次集群绝灭事件中规模最大的一次这一论断 (Raup and Sepkoski, 1982)。

2) 鱼类的集群绝灭在界线层很短的地质时间内是逐步发生的，表明在同一水域不同鱼类对环境变化的耐受力是不同的，对环境变化越是敏感的种类，绝灭得越早。事件地层界线使一些鱼类绝灭，如赵氏浙江鱼和弓鲛科 (属、种不定) 化石，表明这些鱼类对铀的高峰值和氧 ($\delta^{18}O$) 碳 ($\delta^{13}C$) 同位素的剧烈变化的耐受力低于小齿藻青鱼和藻青鱼 (未定

种)。这一界线和 P/T 生物地层界线不是对所有晚二叠世的鱼类都是一条死亡线,小齿葆青鱼就穿越了这条界线而成为幸存者。

3.3 华南早三叠世鱼类的复苏和辐射

裂齿鱼科(属、种不定)化石发现于长兴煤山 Z 剖面二叠 / 三叠系生物地层界线之上(Z 剖面 AEL882-3 = D 剖面 27c),为三叠纪的新生者。它与牙形类微小欣德尔刺(*Hindeodus parvus*)位于同一层位,而后的首次出现被作为早三叠世的开始。因此,在未发现微小欣德尔刺的情况下,若最初出现裂齿鱼科(属、种不定)化石也可作为早三叠世的开始。

华南早三叠世鱼类主要发现于浙江、江苏、安徽、湖北和广西。江苏句容东昌镇的化石产自早三叠世青龙组早期(钱迈平等,1997)或下青龙组上部(刘冠邦等,2002),两种说法实指一套地层,产出鱼化石的层位大致相当于殷坑组上部,产出的鱼化石有裂齿鱼类江苏张氏鱼(*Zhangina jiangsuensis*)和一些属种有待进一步确定的副半椎鱼类(钱迈平等,1997;刘冠邦等,2002;金帆等,2003)。安徽和县驷马山产出的鱼化石为裂齿鱼类的扬子张氏鱼(*Zhangina yangtzensis*)(苏德造,1981;金帆等,2003;童金南等,2004;金帆,2006),产出的层位与江苏相近。湖北黄石的化石产自大冶组第 4 段,大致相当于 Olenekian 阶晚期,含有大冶似裂齿鱼(*Plesioperleidus dayeensis*)(苏德造、黎作骢,1983)。广西早三叠世鱼化石的产出层位确切,产自广西田东早三叠世罗楼组,属于 Olenekian 阶 Spathian 期早期,含有软骨鱼类化石作登弓鲛(*Hybodus zuodengensis*)、乐氏弓鲛(*Hybodus yohi*)和田东多尖齿鲨(*Polyacrodus tiandongensis*)(王念忠等,2001)以及产自广西凤山早三叠世罗楼组的空棘鱼类凤山中华空棘鱼(*Sinocoelacanthus fengshanensis*)(刘宪亭,1964)(图 11)。总之,华南早三叠世产出的鱼类包括辐鳍鱼类的裂齿鱼类和副半椎鱼类;软骨鱼类的弓鲛类、多尖齿鲨类和肉鳍鱼类的空棘鱼类,其中最具有代表性的为裂齿鱼类和弓鲛类。裂齿鱼类属于以往惯称的“亚全骨类”,现在称其为“高等辐鳍鱼类”,如张氏鱼;而古生代繁盛的辐鳍鱼类则是属于“软骨硬鳞类”,现在称其为“低等辐鳍鱼类”(Agassiz, 1833; Stensjö, 1921, 1932; Brough, 1939; Lehman, 1952, 1953, 1966; Beltan, 1996; Moy-Thomas and Miles, 1971; Patterson, 1982; Selezneva and Lozovskiy, 1986; Janvier, 1996),如赵氏浙江鱼(新属、新种)和中华扁体鱼。弓鲛类的弓鲛属为典型的中生代鲨类,最早被发现于早三叠世,而中华尖齿鲨类则发现于华南晚二叠世。不难看出,华南早三叠世以张氏鱼(裂齿鱼类)—弓鲛(弓鲛类)为代表的组合完全替代了以中华扁体鱼(古鳕类)—中华尖齿鲨(软骨鱼类)为代表的晚二叠世组合。

更值得注意的是,华南早三叠世已出现了中生代最常见的三大类别的鱼类即辐鳍鱼类、肉鳍鱼类和软骨鱼类;在三大类别鱼类已记述的 7 个属中,就有 4 个土著属,即葆青鱼、张氏鱼、似裂齿鱼和中华空棘鱼;而已记述的 8 个种全部为土著种,它们为小齿葆青鱼、江苏张氏鱼、扬子张氏鱼、大冶似裂齿鱼、乐氏弓鲛、作登弓鲛、田东多尖齿鲨、凤山中华空棘鱼。这些土著的属种广布在华南 6 个省早三叠世海相地层中,这表明华南早三叠世海相地层中的鱼类不论丰度和分异度均已达到相当高的水平,已进入辐射期。

从二叠纪末鱼类集群绝灭(251 Ma)到早三叠世印度阶晚期(殷坑组上部)(约为 249.7 Ma)或到 Spathian(罗楼组,大约为 247 Ma)鱼类辐射,华南鱼类从集群绝灭到复苏

Macro-, micro-fossils of fishes	Changhsingian stage		Induan stage	Olenekian stage	Localities
	Changxing Fm.				
	Baoqing Mb.	Meishan Mb.	Nanlinghu Fm. Helongshan Fm.		
<i>Eosaurichthys chaoi</i>		•			Changxing, Zhejiang
<i>Sinoplatysomys meishanensis</i>		•			
<i>Youngichthys xinhuaensis</i>		•			
<i>Changxingia aspratilis</i>		•			
<i>Changxingia weii</i>		•			
<i>Sinohelicoprion changhsingensis</i>		•			
<i>Meishanselache liui</i>		•			
<i>Changxingselache wangi</i>	•	•			
<i>Sinacrodus donglingensis</i>		•			
<i>Zhejiangichthys zhaoi</i> g. sp. n.	•	•	•		
<i>Baoqingichthys micrododus</i> g. sp. n.		•	•	•	
<i>Baoqingichthys</i> sp.			•	•	
Perleididae g. sp. indet.			•		
Ctenacanthidae g. sp. indet.	•				
Neoselachian scale type-1	•				
Hybodontidae g. sp. indet.	•	•			
<i>Zhejiangichthys zhaoi</i> g. sp. n.		•			Xiushui, Jiangxi
<i>Baoqingichthys micrododus</i> g. sp. n.		•			
Actinopterygian tooth type-1		•			
<i>Sinacrodus donglingensis</i>		•			
<i>Lissodus xiushuiensis</i>		•			
<i>Polyacrodus jiangxiensis</i>		•			
Neoselachian tooth type-1		•			
<i>Zhejiangichthys zhaoi</i> g. sp. n.			•		Xinfeng, Jiangxi
<i>Baoqingichthys micrododus</i> g. sp. n.		•	•		
cf. <i>Caturus</i>		•	•		
Hybodontoid scale type-1		•	•		
Hybodontoid scale type-2		•			
<i>Sinacrodus donglingensis</i>		•			
<i>Lissodus xiushuiensis</i>		•	•		
<i>Hybodus zuodengensis</i>				•	Tiandong, Guangxi
<i>Hybodus yohi</i>				•	
<i>Polyacrodus tiandongensis</i>				•	
<i>Sinocoelacanthus fengshanensis</i>				•	
<i>Zhangina jiangsuensis</i>			•		Jurong, Jiangsu
Parasemionotidae g. sp. indet.			•		
<i>Zhangina yangtzensis</i>				•	Huangshi, Hubei
<i>Plesioperleleodus dayeensis</i>				•	
<i>Saurichthys</i> sp.				•	

图 11 浙江长兴和周边地区晚二叠世、二叠/三叠系界线层和早三叠世鱼类的分布
 Fig. 11 Distribution of fish fossils in the Late Permian, Permian-Triassic boundary beds and Early Triassic from Changxing, Zhejiang Province and other localities of South China
 Fm. Formation; H. A. Hexian, Anhui Province; Mb. Member

和辐射期大约仅用了 1.3 Ma 到 4 Ma;从地质时间考虑,华南二叠 / 三叠纪之交鱼类大绝灭后到早三叠世鱼类的复苏和辐射是相当快的。关于我国二叠纪末发生的无脊椎动物集群绝灭和之后的复苏和辐射国内外已有许多重要报道 (Pitrat, 1973; Schaeffer, 1973; Raup and Sepkoski, 1982; 李子舜等, 1986; Erwin, 1994, 1996; 戎嘉余等, 1996; Bottjer et al., 1998; 王成源, 1998, 2004; 方宗杰, 2004; 沈树忠等, 2005)。但对鱼类在二叠纪末的集群绝灭,以及在早三叠世的复苏和辐射则报道不多 (Pitrat, 1973; Schaeffer, 1973; Poplin et al., 1997; 王念忠, 2006)。本文是全球二叠 / 三叠系界线层型剖面 and 点位 (GSSP) 辐鳍鱼类的首篇报道。

还有一点需要特别指出,华南晚二叠世海相地层产出的辐鳍鱼类和软骨鱼类的一些土著属,比如始龙鱼 (*Eosaurichthys*)、中华扁体鱼 (*Sinoplatysomus*)、中华旋齿鲨 (*Sinohelicoprurus*)、中华尖齿鲨 (*Sinacroodus*) 等与产于特提斯区三叠纪的一些属,比如龙鱼 (*Saurichthys*)、扁体鱼 (*Platysomys*)、旋齿鲨 (*Helicoprurus*)、尖齿鲨 (*Acroodus*) 等非常相近,这表明华南下扬子区很可能是后来繁盛于特提斯区的三叠纪鱼类的发源地。

3.4 关于鲨类化石的译名

建议 *Elasmobranchii* 译名由板鳃亚纲改为板鳃鲨亚纲。

另外,凡是属这一亚纲的属名不论是否含有 -selach 后缀都加一个鲨字,比如本文涉及的几个属 *Meishanselache* (煤山鲨) 和 *Changxingselache* (长兴鲨) 含有后缀 -selach (鲨); 而 *Sinacroodus* (中华尖齿鲨)、*Lissodus* (滑齿鲨) 和 *Polyacroodus* (多尖齿鲨) 则不含后缀 -selach, 但在译属名时也加鲨字。这种译法我们已在 2004 年的文章中试用 (王念忠等, 2004)。目的在于突出“鲨类”这一认知,有别于广义的“鱼类”。

致谢 王成源、王志浩研究员赠送第一作者长兴煤山剖面部分鱼类微体化石,徐自强先生陪我们到煤山剖面界线层采取处理鱼类微体化石的岩样,金幸生先生协助观察浙江自然博物馆馆藏的长兴县长兴组煤山段已研究的和部分未研究的辐鳍鱼类大化石;于小波先生修改英文摘要;2003 年 9 月在拉脱维亚和爱沙尼亚举行的第二届格罗斯鱼类国际研讨会期间 G. Johnson 和 A. Ivanov 博士与第一作者讨论了本文涉及的部分化石;张文定、周会先生摄制扫描电镜照片和扩印古组织学磨片的照片;沈文龙先生绘制精美的牙齿纵切面插图,作者在此致以衷心的感谢。

ACTINOPTERYGIAN FISHES FROM THE PERMIAN-TRIASSIC BOUNDARY BEDS IN ZHEJIANG AND JIANGXI PROVINCES, SOUTH CHINA AND FISH MASS EXTINCTION, RECOVERY AND RADIATION

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Key words South China, Permian-Triassic boundary beds, Actinopterygian microremains, mass extinction, recovery, radiation

Summary

The actinopterygian microfossils dealt with in this paper were collected from the Permian-Triassic boundary beds in Meishan section, Changxing County, Zhejiang Province; Dongling section, Xiushui County and Tieshikou section, Xinfeng County, Jiangxi Province, South China. This is the first report of actinopterygian microfossils at the Meishan section where the GSSP of Permian-Triassic boundary is defined. The fish microfossils comprise actinopterygian tooth type-1, *Zhejiangichthys zhaoi* gen. et sp. nov., *Baoqingichthys microdontus* gen. et sp. nov., *Baoqingichthys* sp., Perleididae gen. et sp. indet. and cf. *Caturus*.

This is the sixth report on the fish sequence study near the Permian-Triassic boundary in South China.

The material described herein is housed in the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Sciences.

1 Systematics

Osteichthyes Huxley, 1880

Actinopterygii Woodward, 1891

Baoqingichthys gen. nov.

Type species *Baoqingichthys microdontus* gen. et sp. nov.

Diagnosis As that of the type and only species, *Baoqingichthys microdontus* gen. et sp. nov.

Distribution So far know only from Late Permian in China.

Etymology The genus name derives Baoqing village near the Meishan section; -ichthys, a Greek suffix meaning fish.

Baoqingichthys microdontus gen. et sp. nov.

(Figs. 2, 3; Table 1)

Etymology The species name derives micr- (G.) meaning small and -odontus (G.) meaning tooth.

Holotype A complete tooth, IVPP V 14549. 1.

Paratype A longitudinal section of a tooth acrodine cap, V 14551. 1.

Material Other two complete teeth, V 14550. 1, V 14551. 2 and six tooth acrodine caps, V 14549. 2-7.

Locality and horizon V 14549. 1-6, Permian-Triassic boundary beds of the Meishan section Z, horizon number: AEL877, AEL881 (Boundary bed 1), AEL882-2, 3 and 4 (Boundary bed 2), AEL883 (Boundary bed 3) and V 14549. 7, upper member of the Changxing Fm., horizon number: Act232, Changxing County, Zhejiang Province; V 14550. 1, lower part of upper member of the Changxing Fm., Xiushui County, horizon number: Xdfo-1; V 14551. 2, lower part of the Yinkeng Fm. (Changhsingian stage), horizon number: T26 and V 14551. 1, upper member of the Changxing Fm., Xinfeng County, horizon number: T14, Jiangxi Province, China.

Diagnosis Acrodine cap high, near one half of tooth length, cone-shaped with anterior and posterior flanges, one side of the flanges flat and the other convex, ornamented with some fine and sparse longitudinal ridges; lower part of tooth conical with developed fine ridges. Dentine tubules in both acrodine and dentine fine, long and dense; boundary between acrodine and dentine or between dentine and collar ganoine being irregular.

Remarks The teeth described herein differ much from those of both *Sinoplatysomus* (Wei, 1977) and *Eosaurichthys* (Liu and Wei, 1988) in tooth shapes and also from those of

Zhejiangichthys zhaoi gen. et sp. nov. in both morphological and histological features. But they are similar in some aspects to those of *Birgeria* sp. (Rieppel et al., 1996) from Middle Triassic of Nevada and *Ionoscopus* (Thies and Mudroch, 1996) from Late Jurassic of Germany, such as high acrodine cap with anterior and posterior flanges and ornamented with fine longitudinal ridges. However, they are different from the teeth of Nevada in having a cone-shaped acrodine cap, one side of tooth flanges being flat and the other side being convex and ornamented with sparse longitudinal ridges. They are different from the tooth of Germany in having a few but developed ridges at base of the teeth. Therefore, the teeth described herein are named as a new genus and species *Baoqingichthys microdontus* based on both morphological and histological characters.

***Baoqingichthys* sp.**

(Fig. 4)

Material Two acrodine caps, V 14552.1 and V 14552.2.

Locality and horizon Permian-Triassic boundary bed 2, in the Meishan section Z, Changxing County, Zhejiang Province, horizon number: AEL882-1 and AEL882-2.

Remarks Acrodine caps described herein are similar in shape to those of *Baoqingichthys microdontus* gen. et sp. nov., such as high acrodine cap with anterior and posterior flanges, but they differ from those of *B. microdontus* gen. et sp. nov. in having more convex flanges and developed ridges. Therefore the teeth dealt with herein are regarded as *Baoqingichthys* sp.

Actinopterygian tooth type-1

(Fig. 5)

Material A complete tooth, V 14553.

Locality and horizon Lower part of upper member of the Changxing Formation, Xiushui County, Jiangxi Province, horizon number: Xafo-2.

Remarks The tooth described herein has a clear contraction between tooth acrodine cap and lower part. It differs much from other teeth described in this paper and similar teeth are not discovered in other localities. Therefore it is regarded as actinopterygian tooth type-1.

Palaeonisciformes Goodrich, 1909

Palaeoniscoidei Berg, 1955

Family incertae sedis

***Zhejiangichthys* gen. nov.**

Type species *Zhejiangichthys zhaoi* gen. et sp. nov.

Diagnosis As that of the type and only species, *Zhejiangichthys zhaoi* gen. et sp. nov.

Distribution So far know only from Late Permian in China.

Etymology The genus name derives Zhejiang Province and ichthys, a Greek suffix meaning fish.

***Zhejiangichthys zhaoi* gen. et sp. nov.**

(Figs. 6, 7; Table 2)

Etymology The species is named after the late Professor Zhao Jin-ke, a famous paleontologist, who had a creative dedicate for the study of the P/T Meishan section of Changxing County.

Holotype A complete tooth, V 14554.1.

Paratype A longitudinal section of a tooth, V 14556.1.

Material Other three complete teeth, V 14554.2,3 and V 14555.1.

Locality and horizon Top of the Meishan Member (horizon number: AEL874 and

AEL879) of the Changxing Formation in the Meishan section Z (V 14554. 1 and 2), lower part of the Changxing Fm. (V 14554. 3, horizon number: Act126), Changxing County, Zhejiang Province; Lower part of upper member of the Changxing Fm. both in Xiushui County (V 14555. 1, horizon number: Xdfo-1) and Xinfeng County (V 14556. 1, horizon number: JP5), Jiangxi Province, China.

Diagnosis Teeth small, slender, smooth, cone-shaped and slightly curved; acrodine cap very small and translucent with anterior and posterior flanges; acrodine composed of vitrodentine with tubules sparse, without branch or with bifurcation in the top of some tubule; dentine tubules branched; boundary between acrodine and dentine or between dentine and collar ganoine being regular.

Remarks The teeth dealt with herein differ much in tooth shape from those of *Sinoplatus* from Meishan section in having slender tooth with a very small acrodine cap (Wei, 1977) and *Eosaurichthys* also from Meishan in having developed and slender tooth (Liu and Wei, 1988); but they are similar in tooth shape to those of *Uslasichthys* coming from Autunian of Coderè (Heyler, 1977) such as slender tooth with a small acrodine cap, but they are different from the specimens of Coderè in having a very small acrodine cap with anterior and posterior flanges. Therefore the teeth described herein are named as a new genus and species — *Zhejiangichthys zhaoi* based on both morphological and histological characters of the teeth.

Perleidiformes Berg, 1940
Perleididae Brough, 1931
Perleididae gen. et sp. indet.
 (Fig. 8)

Material An incomplete tooth, V 14557.

Locality and horizon Permian-Triassic boundary bed 2 (Early Triassic) in the Meishan section Z, Changxing County, Zhejiang Province, horizon number: AEL882-3.

Remarks Tooth dealt with herein differs very much from those of other actinopterygian forms described in this paper but is similar in tooth shape to those of Perleididae such as the tooth has broad cone-shaped and double convex tip carrying fine ridges, therefore it is regarded as Perleididae gen. et sp. indet.

Amiiformes Nelson, 1994
Caturidae Koken, 1911
Caturus Agassiz, 1834
cf. Caturus
 (Fig. 9)

Material A complete tooth, V 14558.

Locality and horizon Top of the Changxing Formation, Xinfeng County, Jiangxi Province, horizon number: T5.

Remarks Tooth described herein is similar in tooth shape to that of *Caturus* from Late Jurassic of Germany, such as a smooth acrodine cap with expanded lower end, but it differs from the latter in having many small pits at lower part of the tooth, therefore the tooth dealt with herein is regarded as cf. *Caturus*.

2 Discussion

2.1 Permian-Triassic fishes in the Meishan section and their end-Permian extinction

There are sixteen forms of Permian and Triassic fishes (both macro- and micro-fossils) described in both the Meishan sections D and Z of Changxing County, Zhejiang Province, China.

They include actinopterygians: *Sinoplatsyomus meishanensis* (Wei, 1977), *Eosaurichthys chaoi* (Liu and Wei, 1988), *Zhejiangichthys zhaoi* gen. et sp. nov., *Baoqingichthys microdontus* gen. et sp. nov., *Baoqingichthys* sp. and Perleididae gen. et sp. indet.; sarcopterygians: *Youngichthys xinhuaensis* (Wang and Liu, 1981), *Changxingia aspratilis* (Wang and Liu, 1981) and *Changxingia weii* (Jin, 1997), and chondrichthyans: *Sinohelicoprion changhsingensis* (Liu and Chang, 1963), *Changxingselache wangi*, *Sinacrodus donglingensis*, *Meishan-selache liui*, Ctenacanthidae gen. et sp. indet., Hybodontidae gen. et sp. indet. and Neoselachian scale type-1 published in a companion article of this paper (Wang et al., 2007). Among them *Zhejiangichthys zhaoi*, Hybodontidae gen. et sp. indet., *Baoqingichthys microdontus*, *Baoqingichthys* sp. and Perleididae gen. et sp. indet. have been found from the Permian-Triassic boundary beds 1, 2 and 3 of the Meishan section Z.

We must point out that the global stratotype section and point (GSSP) of the Permian-Triassic boundary was defined at the base of bed 27c, Meishan section D, Changxing County. In fact, the Meishan sections, taken from south of the Meishan Hills, have six sections: A, B, C, D, E and Z from west to east. The sections are nearby and can be compared with each other, particularly for the Permian-Triassic boundary beds, such as bed 27c of the Meishan section D being equal to bed 882-3 of the Meishan section Z. The other correlate beds are showed in figure 10.

The ranges of fishes are clear in the Permian-Triassic boundary beds of the Meishan section Z.

1) *Zhejiangichthys zhaoi* gen. et sp. nov. and Hybodontidae gen. et sp. indet. were extinct at the top of the Changxing Formation or under the P/T eventostratigraphic boundary.

2) *Baoqingichthys* sp. was extinct under the P/T biostratigraphic boundary.

3) *Baoqingichthys microdontus* gen. et sp. nov. was extending-up across the P/T biostratigraphic boundary and passed into the Lower Triassic Griesbachian stage and was becoming a survivor.

4) Perleididae gen. et sp. indet. made its first appearance at the beginning of the Griesbachian stage.

In such circumstances there is reason to establish the following points:

1) There were fifteen forms of both micro- and macro-fish fossils appearing in the Changhsingian stage of the Meishan section but only *Baoqingichthys microdontus* gen. et sp. nov. was extending-up across both the P/T eventostratigraphic and biostratigraphic boundaries, got into Early Triassic Griesbachian stage and became a survivor. Other fourteen fishes were extinct under the P/T eventostratigraphic boundary such as *Zhejiangichthys zhaoi* gen. et sp. nov. and Hybodontidae gen. et sp. indet. or under the P/T biostratigraphic boundary such as *Baoqingichthys* sp. Though microfossils of other eleven kinds of fishes were not found in the P/T boundary beds of the Meishan section, they were probably extinct during the period of the P/T boundary beds, because there were not any obvious events before the period of the P/T boundary bed in the Changhsingian stage. Therefore the extinct rate of the fishes was 93% in the end-Permian period of the Meishan section. The rate is similar to 95%–100% extinct rate obtained from 7 phyla of marine invertebrates at the end-Permian period of South China (Yin et al., 1988).

2) The fish mass extinction in the Meishan section demonstrates a stepwise character and the fish was the earliest to recover from the P/T mass extinction indicating by the appearance of Perleididae with conodont *Hindeodus parvus* (Wang, 1998) in the beginning of the Griesbachian stage.

3) *Baoqingichthys microdontus* gen. et sp. nov. showed a higher prolong than the other fish fossils in the Changhsingian stage on oceanic anoxia both in the P/T eventostratigraphic and biostratigraphic boundaries of the Meishan section Z.

2.2 Fish recovery and radiation after the end-Permian extinction in South China

There are five provinces with reports of Early Triassic fishes in South China: Zhejiang, Jiangsu, Anhui, Hubei and Guangxi. Perleididae gen. et sp. indet. was found at the beginning of the Griesbachian stage of Changxing County, Zhejiang Province. Perleidid *Zhangina jiangsuensis* and some semionotid fishes were found from the Qinglong Formation (corresponding to upper part of the Yinkeng Formation, about 249.7 Ma) of Jurong County, Jiangsu Province (Qian et al., 1997; Liu et al., 2002; Jin et al., 2003). *Zhangina yangtzensis* was found from Early Triassic of Hexian, Anhui Province (Su, 1981; Jin et al., 2003). *Plesioperleidus dayeensis* was found from the fourth member of the Daye Formation (corresponding to early Olenekian) of Huangshi, Hubei Province (Su and Li, 1983). Hybotontoidea fossils *Hybodus zuodengensis*, *Hybodus yohi*, *Polyacrodus tiandongensis* were found from the Luolou Formation (early Spathian of Olenekian stage, about 247 Ma) of Tiandong County (Wang et al., 2001) and coelacanthid *Sinocoelacanthus fengshanensis* was found from the Luolou Formation of Fengshan County, both Guangxi Province, China (Fig. 11).

These findings lead to the following conclusions:

1) There are 7 genera and 8 species of actinopterygian, sarcopterygian and chondrichthyan fossils discovered in Early Triassic of South China in which 4 endemic genera (*Baoqingichthys*, *Zhangina*, *Plesioperleidus* and *Sinocoelacanthus*) and all 8 endemic species (*Baoqingichthys microdontus*, *Zhangina jiangsuensis*, *Z. yangtzeensis*, *Plesioperleidus dayeensis*, *Hybodus zuodengensis*, *H. yohi*, *Polyacrodus tiandongensis* and *Sinocoelacanthus fengshanensis*) are included. Therefore, the faunas in Early Triassic of South China got into radiation after the end-Permian extinction.

2) Fish recovery and radiation in Early Triassic of South China occurred in a short geologic time interval: from 1.3 Ma to 4 Ma, viz. from the end-Permian extinction (251 Ma) to Induan (249.7 Ma) or Spathian (247 Ma).

3) Early Triassic *Zhangina* and *Hybodus* took the place of Late Permian *Sinoplatysomus* and *Sinacrodus* since *Zhangina* and *Hybodus* were typical representatives of Early Triassic fishes, and *Sinoplatysomus* and *Sinacrodus* were typical representatives of Late Permian fishes in South China.

4) The Lower Yangtze region of South China is probably the cradle of some Triassic fish genera (*Saurichthys*, *Platysomys*, *Helicoprus* and *Acrodus*) subsequently flourishing in the Tethyan realm, because similar genera (*Eosaurichthys*, *Sinoplatysomus*, *Sinohelicoprion* and *Sinacrodus*) are discovered in Late Permian of South China.

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References

- Agassiz L, 1833–1844. Recherches sur les poisson fossils. Tome II, Pt 2. Neuchâtel: Imprimerie de Petipierre. 1–336
- Beltan L, 1996. Overview of systematics, paleobiology and paleoecology of Triassic fishes of northwestern Madagascar. In: Arratia G, Viohl G eds. Mesozoic Fishes-Systematics and Paleoecology. München: Verlag Dr. Friedrich Pfeil. 479–500
- Bertin L, 1958. Denticules cutanés et dents. In: Grassé P ed. Traité de Zoologie. Paris: Masson et Cie. 505–531

- Bottjer D J, Droser M L, Wang C Y, 1998. Fine-scale resolution of mass extinction events; trace fossil evidence from the Permian-Triassic boundary in South China. *Geol Soc Am, Abstracts with Programs*, **20**: A106
- Brough J, 1939. The Triassic fishes of Besano, Lombardy. London: British Museum (Natural History). 1-117
- Erwin D H, 1994. The Permo-Triassic extinction. *Nature*, **367**: 231-236
- Erwin D H, 1996. Permian global bio-events. In: Walliser O H ed. *Global Events and Event Stratigraphy*. Heidelberg: Springer-Verlag. 251-264
- Fang Z J (方宗杰), 2004. The Permian-Triassic boundary crisis; patterns of extinction, collapse of various ecosystems, and their causes. In: Rong J Y, Fang Z J eds. *Mass Extinction and Recovery*. Hefei: University of Science and Technology of China Press. 785-928 (in Chinese with English summary)
- Heyler D, 1977. Les vertébrés Permien du Bassin de Lodève (Hérault); Bilan. *Bull Soc Hist Nat Autun*, **157**: 5-28
- Janvier P, 1996. *Early Vertebrates*. Oxford: Clarendon Press. 1-393
- Jin F (金帆), 2006. An overview of Triassic fishes from China. *Vert PalAsiat (古脊椎动物学报)*, **44**(1): 28-42
- Jin F (金帆), Wang N Z (王念忠), Cai Z Q (蔡正全), 2003. A revision on the perleiid fishes from the Lower Yangtze region of South China, second report on the fish sequence study near the Permian-Triassic boundary in South China. *Vert PalAsiat (古脊椎动物学报)*, **41**(3): 169-184 (in Chinese with English summary)
- Jin X S (金幸生), 1997. New species of coelacanth from Changxing Formation of Zhejiang. *Sci Tech Bull (Zhejiang) (科技通报)*, **13**(3): 143-147 (in Chinese with English summary)
- Lehman J-P, 1952. Etude complémentaire des poissons de l'Eotrias de Madagascar. *K Svenska VetAkad Handl, Sér 4*, **2**(6): 1-201
- Lehman J-P, 1953. Etude d'un *Perleidus* du Trias de Madagascar. *Ann Paleontol*, **39**: 1-7
- Lehman J-P, 1966. Actinopterygii. In: Piveteau J ed. *Traité de Paléontologie*. Tome IV, Vol 3. Paris: Masson. 1-242
- Li Z S (李子舜), Zhan L P (詹立培), Zhu X F (朱秀芳) et al., 1986. Mass extinction and geological events between Palaeozoic and Mesozoic era. *Acta Geol Sin (地质学报)*, **60**(1): 1-15 (in Chinese with English summary)
- Liu G B (刘冠邦), Feng H Z (冯洪真), Wang J X (王菊香) et al., 2002. Early Triassic fishes from Jurong, Jiangsu. *Acta Palaeont Sin (古生物学报)*, **41**(1): 27-52 (in Chinese with English summary)
- Liu H T (刘宪亭), 1964. A new coelacanth from the marine Lower Triassic of N W Kwangsi, China. *Vert PalAsiat (古脊椎动物学报)*, **8**(2): 211-214 (in Chinese with English summary)
- Liu H T (刘宪亭), Chang M M (张弥曼), 1963. Discovery of helicoprionid fossil in China. *Vert PalAsiat (古脊椎动物学报)*, **7**(2): 123-129 (in Chinese with Russian summary)
- Liu H T (刘宪亭), Wei F (魏丰), 1988. A new saurichthyid from Upper Permian of Zhejiang, China. *Vert PalAsiat (古脊椎动物学报)*, **26**(2): 77-89 (in Chinese with English summary)
- Moy-Thomas J A, Miles R S, 1971. *Palaeozoic Fishes*. London: Chapman and Hall. 1-259
- Ørvig T, 1967. Phylogeny of tooth tissues; evolution of some calcified tissue in early vertebrates. In: Miles A E W ed. *Structural and Chemical Organization of Teeth*, Vol 1. New York: Academic Press. 45-110
- Patterson C, 1982. Morphology and interrelationships of primitive actinopterygian fishes. *Am Zool*, **22**: 241-259
- Pitrat C W, 1973. Vertebrates and the Permo-Triassic extinction. *Palaeogeogr, Palaeoclimatol, Palaeoecol*, **14**: 249-264
- Poplin C, Blicke A, Cloutier R et al., 1997. Paléontologie des vertébrés inférieurs - renouveau et développements. *Geobios, M S*, **20**: 437-446
- Qian M P (钱迈平), Zhu S P (朱士鹏), Zhao F M (赵凤鸣) et al., 1997. Discovery of Early Triassic fish fossils and its significances in Jurong, Jiangsu Province. *Jiangsu Geol (江苏地质)*, **21**(2): 65-71 (in Chinese with English abstract)
- Raup D M, Sepkoski J J, 1982. Mass extinction in the marine fossil record. *Science*, **215**: 1501-1503
- Reif W E, 1982. Evolution of dermal skeleton and dentition in vertebrates; the odontode regulation theory. *Evol Biol*, **15**: 287-368
- Richter M, Smith M M, 1995. A microstructure study of the ganoine tissue of selected lower vertebrates. *Zool J Linn Soc*, **144**: 173-212

- Rieppel O, Kindlimann R, Bucher H, 1996. A new fossil fish fauna from the Middle Triassic (Anisian) of North-Western Nevada. In: Arratia G, Viohl G eds. Mesozoic Fishes-Systematics and Paleocology. München: Verlag Dr. Friedrich Pfeil. 501-512
- Rong J Y (戎嘉余), Fang Z J (方宗杰), Chen X (陈旭) et al., 1996. Biotic recovery-first episode of evolution after mass extinction. Acta Palaeont Sin (古生物学报), **35**(3): 259-271 (in Chinese with English summary)
- Schaeffer B, 1973. Fishes and the Permian-Triassic boundary. In: Logan A, Hills L V eds. The Permian and Triassic Systems and Their Mutual Boundary. Mem Can Soc Petrol Geol, **2**: 493-497
- Selezneva A A, Lozovskiy V R, 1986. The first find of Perleididae in the Lower Triassic of the east European platform. Paleont Zh, **1986**(2): 113-116 (in Russian)
- Shen S Z (沈树忠), Wang Y (王玥), Jin Y G (金玉珩), 2005. Progress report on the global stratotype sections and points (GSSP) of the Permian System. J Stratigr (地层学杂志), **29**(2): 138-146 (in Chinese with English summary)
- Stensiö E A, 1921. Triassic fishes from Spitzbergen, Part I. Vienna: Adolf Holzhausen. 1-307
- Stensiö E A, 1932. Triassic fishes from East Greenland. Medd Grønl Geosci, **83**(3): 1-305
- Su D Z (苏德造), 1981. A new species of *Perleidus* from Anhui. Vert PalAsiat (古脊椎动物学报), **19**(2): 107-112 (in Chinese with English summary)
- Su D Z (苏德造), Li Z C (黎作聪), 1983. A new Triassic perleidid fish from Hubei, China. Vert PalAsiat (古脊椎动物学报), **21**(1): 9-16 (in Chinese with English summary)
- Thies D, Mudroch A, 1996. Actinopterygian teeth from the Late Jurassic of N Germany. In: Arratia G, Viohl G eds. Mesozoic Fishes-Systematics and Paleocology. München: Verlag Dr. Friedrich Pfeil. 105-114
- Tong J N (童金南), Zuo J X (左景勋), Zhao L S (赵来时) et al., 2004. Study on the Lower Triassic of Chaohu, Anhui Province. Prof Pap Stratigr Paleont (地层古生物论文集), (28): 147-163 (in Chinese with English abstract)
- Wang C Y (王成源), 1995. Conodonts of Permian-Triassic boundary beds and biostratigraphic boundary. Acta Palaeont Sin (古生物学报), **34**(2): 129-151 (in Chinese with English summary)
- Wang C Y (王成源), 1998. Conodont mass extinction and recovery from Permian-Triassic boundary beds. In: Department of Geology, Peking University ed. Collected Works of International Symposium on Geological Science Held at Peking University. Beijing: Seismologic Press. 379-389 (in Chinese with English abstract)
- Wang C Y (王成源), 2004. A comparative study of conodont mass extinction and recovery from the Permian-Triassic and Frasnian-Famennian boundary beds in South China. In: Rong J Y, Fang Z J eds. Mass Extinction and Recovery. Hefei: University of Science and Technology of China Press. 731-748 (in Chinese with English summary)
- Wang N Z (王念忠), 2006. Scientific achievements of 20 years of the studies of Palaeozoic vertebrate microfossils from China. J Stratigr (地层学杂志), **30**(1): 311-320 (in Chinese with English summary)
- Wang N Z (王念忠), Jin F (金帆), Wang W (王炜), 2004. Early Carboniferous fishes (Acanthodian, Actinopterygians and Chondrichthyes) from the east sector of North Qilian Mountain, China-Carboniferous fish sequence from the east sector of North Qilian Mountain (1). Vert PalAsiat (古脊椎动物学报), **42**(2): 89-110 (in Chinese with English summary)
- Wang N Z (王念忠), Liu H T (刘宪亭), 1981. Coelacanth fishes from the marine Permian of Zhejiang, South China. Vert PalAsiat (古脊椎动物学报), **19**(4): 305-312 (in Chinese with English summary)
- Wang N Z (王念忠), Wang S T (王士涛), 2003. IGCP-328: Paleozoic microvertebrates. In: China National Committee for International Geological Correlation Programme ed. IGCP 30 Years in China. Beijing: Geological Publishing House. 134-136 (in Chinese with English summary)
- Wang N Z (王念忠), Yang S R (杨守仁), Jin F (金帆) et al., 2001. Early Triassic Hybodontoida from Tiandong of Guangxi, China-First report on the fish sequence study near the Permian-Triassic boundary in South China. Vert PalAsiat (古脊椎动物学报), **39**(4): 237-250 (in Chinese with English summary)
- Wang N Z (王念忠), Zhu X S (朱相水), Jin F (金帆) et al., 2007. Chondrichthyan microremains under Permian-Triassic boundary in both Zhejiang and Jiangxi provinces, China-Fifth report on the fish sequence study near the Permian-Triassic boundary in South China. Vert PalAsiat (古脊椎动物学报), **45**(1): 13-36 (in Chinese with English summary)

- Wei F (魏丰), 1977. On the occurrence of platysomid in the Changhsing (Changxing) limestone of Zhejiang. *Acta Palaeont Sin* (古生物学报), **16**(2): 293-296 (in Chinese with English summary)
- Yang Z Y (杨遵仪), Yin H F (殷鸿福), Wu S B (吴顺宝) et al., 1987. Permian-Triassic boundary stratigraphy and fauna of South China. *Geological Memoirs, Series 2, Number 6*. Beijing: Geological Publishing House. 1-379 (in Chinese with English abstract)
- Yin H F, Yang F Q, Zhang K X et al., 1988. A proposal to the biostratigraphic criterion of Permian-Triassic boundary. *Mem Soc Geol Ital*, **34**: 329-344
- Yin H F, Zhang K X, Tong J N et al., 2001. The global stratotype section and point (GSSP) of the Permian-Triassic boundary. *Episodes*, **24**(2): 102-114
- Zhang K X (张克信), Lai X L (赖旭龙), Ding M H (丁梅华) et al., 1995. Conodont sequences and its global correlation of Permian-Triassic boundary in Meishan section, Changxing, Zhejiang Province. *Earth Sci-J China Univ Geosci* (地球科学—中国地质大学学报), **20**(6): 669-676 (in Chinese with English abstract)
- Zhao J K (赵金科), Sheng J Z (盛金章), Yao Z Q (姚兆奇) et al., 1981. The Changhsingian and Permian-Triassic boundary of South China. *Bull Nanjing Inst Geol Paleont* (南京地质古生物研究所集刊), **2**: 1-85 (in Chinese with English summary)
- Zhu X S (朱相水), Zhang D F (章定富), Zhang Y X (钟亚喜) et al., 1998. Profile correlation of Permian-Triassic boundaries between Xishui-Leping area of Jiangxi and Changxing area of Zhejiang, China. *Jiangxi Geol* (江西地质), **12**(3): 209-212 (in Chinese with English summary)