# 关于南雄盆地 K/ T界线问题的讨论

## ——与 D.A.拉塞尔,D.E.拉塞尔,A.R.斯威特商榷[1)]

叶 捷

(中国科学院古脊椎动物与古人类研究所 北京 100044)

**摘要** 陆相山间盆地的沉积过程远比某些海相的沉积过程复杂。评述了当今流行的利用沉积速率来检验、甚至推断陆相磁性地层极性时序列方法的可靠性。南雄盆地地层及哺乳动物化石的分布研究表明,前人所定 K/T界线上下地层连续,并不象一些学者认为的在上湖组底部缺失了数百万年的沉积。

**关键词** 南雄盆地,K/T界线,地层

**中图法分类号** P534.53,61

1991 年赵资奎等在《古脊椎动物学报》发表了"广东南雄盆地白垩系—第三系交界恐龙绝灭问题"。两年后拉塞尔等 (Russell *et al.*, 1993)发表了对赵等在文章中所阐述的关于南雄盆地 K/T界线及恐龙绝灭等主要问题的全面评论。近年来笔者与同事们开展了建立新生代高精度高分辨率哺乳动物地层年表工作(院重点基金,KZ952—J1—410),为此重新研读了拉塞尔等的文章。拉塞尔等外国同行治学认真,十分关心中国同行研究工作的进展,笔者感到由衷的敬佩、赞赏。

拉塞尔等首先用沉积速率检验赵资奎等(1991)所建立的南雄盆地 K/T界线附近磁性地层的极性时序,并列表展示了他们对赵等的各极性时段地层沉积速率的计算结果(Russell *et al.*, 1993, Table 1)。拉塞尔等认为这些极性时间段沉积速率相差悬殊,其中的一些沉积速率明显高于北美的已知快速沉积,且为使各极性时段的沉积速率相对均匀建立了一个新的南雄盆地磁性地层极性时序列 (Russell *et al.*, 1993, Table 2)。该序列与赵资奎等(1991)所确定的序列明显不同,原近园圃组顶部的 31N 被更改为 32.2N,原定为 29R 段的地层在坪岭组的部分被改定为 31R,上湖组的部分被更改为 26R,两者之间至少存在着长达 6.37Ma[2)]的沉积间断。拉塞尔等根据前人提供的化石资料分析了上湖组哺乳动物群年代,从生物地层上论证上湖组底部缺失了数百万年的下古新统部分,作为新建的极性序列的依据 (Russell *et al.*, 1993, P.144)。由此可见拉塞尔等与赵资奎等对南雄 K/T界线附近的地层时序的认识存在着巨大的分歧。造成分歧的原因不仅是由于对南雄

1) 中国科学院"九五"重点项目(编号:KZ952—J1—410)资助。

2) 依Russell *et al.* (1993)表2数据计算。

收稿日期: 1999-03-19

盆地的最基本的生物地层资料的掌握不同,而且也是因为对一些有关地层的分析方法的认识与使用上的差异所致。为促进南雄盆地的地层研究工作,笔者愿以南雄盆地为例与拉塞尔等探讨下列问题:1)如何认识和利用地质历史时期的沉积速率;2)确定陆相沉积磁性地层极性时序的要素;3)K/T界线与铱异常的关系。

## 1 关于计算地质历史时期的沉积速率的原则及使用范围

近年来许多学者用沉积速率检验磁性地层的极性时序列。对此笔者并无异议,但认为这种检验必须有先决条件,即只能在接近匀速沉积的地层(例如海相沉积、大型湖盆中的沉积或某种持续的均一相的沉积)中进行有效检验。对于复杂相变的陆相地层,特别是某些山间小盆地的堆积,沉积速率的计算会受多种因素的影响而失真。导致这种方法检验失效的原因有三。首先,陆相沉积的过程相当复杂。笔者曾在秦岭山区见到一场暴雨后形成数米厚的堆积物,但此堆积物在被其后的堆积埋藏保存前会被逐渐剥蚀减薄。被保留的堆积物的厚度受到了各种非沉积因素的控制。因此地质历史时期的陆相堆积的厚度是各种地质作用的综合结果。所以复杂沉积过程的沉积速率的变化是难以把握的。南雄盆地是一个窄长的地堑型山间盆地,其中生代晚期以来的地质发展历史受到南、北两条边界断层运动的控制。盆地中沉积物的分布和厚度变化明显地受该断层当时的差异性活动的影响。南雄盆地中的堆积不仅相变复杂,相间突变也时常可见。拉塞尔等所认为沉积速率问题较大的坪岭组为河流相堆积。根据野外观察可知,该组岩层在沉积过程中河道摆动,洪水泛滥时有发生,切割与沉积交替不断。因此仅依据测量厚度推算出的平均沉积速率并非是纯沉积作用的速度,其值亦应是多变的。

其二,任何野外剖面的测制都是追索露头进行的。一方面是在纵向上进行厚度累积,另一方面常常还必须在横向上位移(有时这种横向上的位移的距离相当大)。因此在复杂相变或厚度变化较大的地层所测得的结果有可能为测区该时段的各层厚度叠加的最大值或最小值,或是其间的一个数值。因此推算出的沉积速率因测制剖面的路线不同而发生变化。

第三,被计算出的沉积速率的含义会因所选择的时间单位的不同而发生变化。笔者认为拉塞尔等在计算南雄盆地K/T界线附近的地磁极性时段的地层沉积速率时对时间单位的选择考虑欠周。在赵资奎等的极性时序列中(Russell *et al.*, 1993, Table 1),各极性时段的时间跨度的差别较大,且以时间跨度小于1Ma的极性时段为主(占所讨论的极性时段的6/7),其中有3个极性时段的持续时间小于0.5Ma。我们知道,在以百万年做时间单位计算平均速率时,对于大于1Ma的时段是在用除法求均值,而对于小于0.5Ma的时段实则是用乘法(扩大倍数)求均值。两种算法的数学意义是相同的,但物理意义相差甚远。前者是某一时段的速率的平均,后者则是以某一特定小时段速率来替代大时段(1Ma)的速率。因此在表1中凡小于0.5Ma的时段的平均速率以百万年计均大于$10^2$。即使在被拉塞尔建立的、被认为更接近匀速沉积的极性时序列中(见Russell *et al.*, 1993, Table 2),小于0.5Ma的极性时段(32.1N)的沉积速率也(十分突出地)大于$10^2$。换言之,时间跨度愈短,其平均速率受到时段内特殊沉积事件的影响愈大。在此举一个极端的例子。笔者曾在

王府井东方广场实测一条沉积时间跨度为2万年的第四纪堆积剖面，其厚度达12m。如果不加条件限定地与北美纽瓦可群的沉积速率(Russell *et al.*, 1993, P.142)直接比较，则北京地区的沉积速率应是北美快速沉积的速率的2.4倍。因此必须谨慎地计算地质时期中的沉积速率，认真地理解计算结果的真实含义。

## 2　确定陆相沉积磁性地层极性时序的要素

上述分析表明，简单地用沉积速率否定赵资奎等(1991)建立的极性时序列的理由并不充分。但笔者并不坚持认为赵等建立极性时序列的理由足够充分。虽然地球磁性倒转是全球同步事件，但地磁倒转做为一种物理现象是可重复事件。因而在岩性多变的陆相地层中仅依靠磁性地层自身特点难以确定各极性时在标准磁性地层年表中的序号。人们还必须利用沉积记录中的其他时间信息载体帮助分析推断各极性时段的序号。

在南雄盆地中可供利用的时间记录是：1)在始兴地区近园圃组顶部所夹喷发型玄武岩的钾氩法测年数据是67.04±2.31Ma和67.37±1.49Ma。含该年龄值的地层段可与杨梅坑剖面的C.G.Y.109～172m段地层对比。因此可以确定该段磁性地层的极性时为31N。但拉塞尔等为使沉积速率相对均匀而忽略了该年龄值，将该段地层置于32.2N中。笔者认为尽管可以怀疑测年数据的准确性，但解决的办法是重新到不同的实验室测定。在无充分理由否定已知数据时，最好的办法还是参考这些数据。

2) 化石做为一种地质时期的时间载体可以帮助分析和确定含化石的磁性地层的极性时序号。拉塞尔等利用前人报道的南雄盆地中古新世哺乳动物和孢粉化石资料分析推断了上湖组中的两个正向极性时的序号。拉塞尔等的分析方法是正确的，但因前人提供的化石分布层位欠精确而影响了他们的分析结果。有关南雄哺乳动物化石的分布层位笔者将在下一段落讨论。在此仅想说明一点，南雄盆地中上湖组与坪岭组界线附近的地层中断层较发育，水田分布颇多，前人有关文献难以与笔者测制的剖面做精确对比。故笔者在此对非脊椎动物化石的分布不敢妄加评论，在下文中仅讨论已经笔者核实过的哺乳动物化石分布。

3) 如果在南雄盆地所建立的磁性地层剖面基本连续，则在确立了31N之后其余的极性时段的序号可依此建立。但拉塞尔等认为在上湖组与坪岭组间存在着一个较大的沉积间断。通常沉积间断是通过野外实地观察沉积地层间接触关系，并利用生物化石的分布规律判定是否有年代缺失而确定的。根据笔者的野外研究，在南雄盆地的中新生代堆积中相对显著的沉积间断应位于园圃组与坪岭组间。园圃组第3段为一套岩性较细的以粉砂质为主的湖相堆积，近其顶部的一些地方(如杨梅坑等)层面出现泥裂，并有恐龙行走留下的足印，反映出水体较浅，堆积物时常暴露在水面之上。坪岭组底部为一套厚约5m的砂砾岩层，在一些地段可明显看到其中有园圃组3段的粉砂岩角砾。虽然该间断清楚，但并无持续时间较长的证据，恐龙蛋化石在其上下并无变化，表明上下地层间仅有短暂的沉积间隙。过去一些地质工作者认为在南雄盆地中生代与新生代间应为不整合接触，坪岭组与上湖组间存在间断。为此笔者等认真地观察了两组间的接触关系。坪岭组顶部为一套紫红色泥质粉砂岩，含小钙质结核，产成窝恐龙蛋化石。上湖组底部为一套棕红色泥质

粉砂岩，内含个体较大、形状不规则的中空钙质结核。两套泥质粉砂岩界线平整清楚，找不到任何沉积间断线索。

拉塞尔等(1993)根据前人提供的哺乳动物化石资料分析认为上湖组下部无下古新统地层存在。但是根据新的哺乳动物化石分布情况，下古新统地层是否存在，还值得商讨。目前已知南雄盆地古新统地层厚达800m余，共发现有7个哺乳动物化石层位。两个层位在浓山组，所含化石与下伏上湖组中者差别较大，但并不如拉塞尔所言化石组分中有 *Coryphodon* 和 *Prodinoceras* (Wang *et al.*, 1998)。其余的5个层位分布在厚约500m的上湖组中。周明镇等(1977)报道了其中的4个层位：顶部、上部、中部和下部产化石层位，并认为上、中、下3个层位的化石共同组成了中古新世上湖哺乳动物群。笔者对周明镇等的下部产化石层位进行了实地核查，发现所谓下部产化石的层位的最低位置经实测距上湖组底56m(厚度)。1991年笔者与同事在距上湖组底2m处又新发现了一个化石层位，因化石保存不好不能鉴定到属种。但所发现化石显然与其上4个层位者不同，有关专家认为可能是一种小型的原始踝节类。遗憾的是目前对中国的早古新世哺乳动物群的认识分歧颇大，王元青等(1998)认为上湖组哺乳动物化石的时代相当于北美 Puercan 至 Torrejonian 中期，而丁素因(1998，p.141)虽在表中把“上湖期”与北美 Torrejonian 期相当，但与 Puercan 的对比，文中也是持待定态度的。因之，无论如何，上湖组底部均不应缺失数百万年的早古新世堆积。目前当务之急是结合中国其他地区不同层位的古新世哺乳动物化石，对上湖组的5个层位分别产出的化石进行深入研究，确定每一层位的化石的时代，或许有可能帮助确定在上湖组底部是否有最早古新统地层存在。

## 3 K/T界线与铱异常

拉塞尔等在讨论 K/T界限上下地层是否连续时曾强调了铱异常是否存在的问题(Russell *et al.*, 1993，P.143)。对此笔者尚不能理解其准确的含意：是认为铱异常是 K/T 界线的标志，还是做为 K/T界线上下地层连续的判定标准？笔者认为，恐龙绝灭的原因仍在探讨争论之中，尽管“碰撞”假说有一定道理，但仍因证据不足而不能成为科学定论。故对白垩纪末的铱异常事件的性质和波及范围尚不能完全肯定，将铱异常做为全球的 K/T 界线的唯一标志仍需慎重。此外，铱通常是以微粒形式保存于地层之中，因此在流水环境中铱能否沉积值得考虑。因而根据铱异常的不存在来否定 K/T界限上下地层连续的理由并不充分。但笔者始终认为铱异常事件对于 K/T界线的位置的确定具有极其重要的参考作用，在南雄盆地的堆积中寻找铱异常事件的工作将是十分有意义的。

在此应该提到的是曾经和我们一起在南雄盆地工作的德国波恩大学的同行阿尔本等(H. K. Erben *et al.*)于1995年发表了一本关于南雄盆地 K/T界线研究成果的专著。他们认为界限附近地层连续，未发现任何沉积间断。并提出南雄盆地的沉积速率约为40cm/ka(400m/Ma)。阿尔本等根据孢粉分析结果，从 C.G.D.57m 起松科植物开始大量出现，热带型植物消失，认为 C.G.D.57～78m 气候变冷，与世界其他地区的 K/T界线处的气候变冷相一致。又依据该段地层中恐龙蛋壳中稳定同位素及微量元素出现异常等现象，确认该段21m厚的地层为南雄盆地的 K/T界线。这一界线从赵资奎等(1991)所定界线向下移

动了 40m，因此恐龙蛋化石也越过 K/T界线 40m。在此笔者不打算评价阿尔本 1995 年的 K/T界线。但笔者认为生物地层学者们对于如今流行的地层年代的确定与划分方法的理解与使用上仍存在着颇大的差距，因而很有必要加强这方面的交流与讨论。

**致谢**　在成文过程中，笔者曾与李传夔、翟人杰、吴文裕、王元青等研究员进行过有关问题的讨论，张永红曾协助整理有关资料，特在此对他们表示感谢。

## DISCUSSION ON THE PROBLEMS OF K/T BOUNDARY IN THE NANXIONG BASIN

YE Jie

(*Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences* Beijing 100044)

**Key words**　Nanxiong Basin, K/T boundary, stratigraphy

**Summary**

Eight years ago Zhao and his colleagues' paper (1991) "Extinction of the dinosaurs across the Cretaceous–Tertiary boundary in Nanxiong Basin, Guangdong Province" appeared in Vertebrata PalAsiatica. Two years later (1993) D. A. Russell *et al.* made comments on Zhao's paper.

Russell *et al.* examined the sequence of the polarity chron established by Zhao *et al.* by calculating the depositional rates (Russell *et al.* 1993, table 1). In their opinion the variation in sedimentation rates of the different polarity chron is quite great. The depositional rates of the upper part of the Pingling Formation are extremely high, even higher than those in the rapidly subsiding Trassic–Jurassic rift valleys of Newark Group in eastern North America. Therefore Russell *et al.* modified the sequence of the polarity chrons for reducing the apparent variation in sedimentation rates (Russell *et al.*, 1993, table 2). The new chrons are very different from older one: the original chron 31N near the top of the Yuanpu Formation was changed into 32.2N in New sequence and, original chron 29R was substituted by two chrons: chron 31R for the upper part of the Pingling Formation and chron 26R for the lower Part of the Shanghu Formation. Hence a hiatus of ca. 6.37Ma occurs between the Shanghu Formation and the Pingling Formation. Russell *et al.* analysed the shanghu local mammal fauna based on the previous data and came to the conclusions: "…and it is unlikely that the chrons identified by Zhao *et al.* (1991) near the middle of the formation as 29N and 28N are older than 26N and 25N (see table 2)". The mention above indicates big divergence between Russell *et al.* and Zhao *et al.* in the

chronological framework of Nanxiong sections. It is not only because of the different basic biostratigraphic data they possessed from ours but also because of the differences in understanding and using of the methods of stratigraphy. In order to promote the study of the stratigraphy in Nanxiong Basin, I would discuss the following problems with Russell *et al.* 1) How to understand the depositional rate during geological time. 2) How to identify polarity chrons in continental section. 3) Interrelation between K/T boundary and iridium anomaly.

## 1 The understanding and employment of the continental sedimentation rate during geological time

Recently the sedimentation rate has usually been used to check up the polarity chrons identified. The method is feasible when the strata to deal with were accumulated at relatively uniform rates (for example, marine and /or huge lacustrine deposits and the sediments with uniform facies). For the continental deposits with multiple facies, especially those in the small intermountain basins, the calculating of sedimentation rate conld be interfered by various factors. At first the continental sedimentations are usually complicated. The auther once witnessed the rapid clastic accumulation during a rainstorm in Qinling Mountains to a thickness of several metres which, however must had been partly worn away before it was covered by later deposits. The thickness of remainder depends on the various nondepositional factors. It is therefore very difficult to restore the real depositional rate of the continental sediments. Nanxiong Basin is an intermountain basin about 80km long, 20km wide, a typical graben basin bounded by two faults, which have been controlling the geological history of the basin since late Mesozoic era. The distribution and thickness of sediments in the basin varies, resulting from differential activities of the faults. The change of facies here is complicated and even abrupt change can be found in the sediments. Russell *et al.* have doubts about the depositional rate of the Pingling Formation, which is of fluviatile deposits. According to my study in the field the river changed the course and overflowed often and thus cutting and filling took place alternatively during the sedimentation. So the average depositional rate calculated by means of the measured thickness is not the real rate and is variable.

Second, the measuring of any stratigraphical section has to be done by tracing outcrops. During accumulating the thickness in the ordinate the measuring position has to be often moved in the abscissas. Therefore the thickness of the layer obtained could be the maximum, minimum value or a value between them in measured area, which depends on measured position.

Third, the implication of the depositional rate obtained is different when the time units chosen for calculating are different. Regretfully Russell *et al.* did not choose the proper time unit carefully for calculating the depositional rate of polarity chrons near the K/T boundary of Nanxiong Basin. In table 1 of Russell *et al.* there are 7 chrons identified by Zhao *et al.*, of which 6 chrons are of duration less than 1Ma and 3 chrons are of duration less than 0.5Ma. Give 1Ma as time unit for calculating, the depositional rate is calculated with division when the duration is longer than 1Ma, and when the duration shorter than 0.5Ma the average depositional rate is calculated with multiplication. Both calculations have the same mathematical meaning but different physical meaning. The former presents an average depositional rate in a relatively long time, while the latter gives actually an average depositional rate in a rather short duration less than 0.5Ma. On other words the depositional rate of the short duration ( $< 0.5$Ma) is used instead of the depositional rate of long duration (1Ma). Therefore when 1Ma is chosen as time unit under the latter condition the average depositional rate is always higher than $10^2$ (see Russell *et al.* 1993, table 1 & table 2).

## 2 How to identify the polarity chrons in continental sediment sequence

Geomagnetic polarity reversal is global synchronous and repeated event during the whole history of the Earth. Hence, it is difficult to identify the paleomagnetion chrons of the strata according to only the magnetopolarity records. We have to use other time carriers kept in the sediment to calibrate the identified magnetic chrons.

In Nanxiong Basin the following time records can be used: 1) The basaltic lava near the top of Yuanpu Formation was dated 67.4Ma on an average (Zhao *et al.* 1991, pp.3, 14), indicating late Mastrichtian age and approximating the end of polarity chorn 31N, comparable with 109～172m of C. G. Y. section (an interval of normal polarity near the top of Yuanpu Formation). However, Russell *et al.* changed the magnetic polarity of C.G.Y. 109～172m into chron 32.2N without any new data in order to reduce the apparent variation in sedimentation rate (Russell *et al.* 1993, table 2, P.142).

2) Fossil record as one of time carriers is helpful for magnetostratigraphic analysis. Russell *et al.* identified two normal polarity intervals in Shanghu Formation based on the published data of fossil mammals and pollens. However the biostratigraphic information they utilized of the fossils was not certain. Some mammal-bearing beds in Nanxiong Basin will be discussed below. Near the bottom of Shanghu Formation often exist faults and paddy fields, so it is difficult to check up these beds described by predecessors (invertebrate paleontology). Instead of invertebrate and pollens will here discuss the distribution of mammal fossils.

3) If the stratigraphic sequence established by Zhao *et al.* (1991) is successive, the polarity chrons of the rock can be deduced after the 31N chron is identified.

However Russell *et al.* considered that a big hiatus existed between Pingling Formation and Shanghu Formation. It has also been considered by the Chinese geologists that an unconformity should be exist between Mesozoic and Cenozoic rocks in Nanxiong Basin–a hiatus occurred between Pingling Formation and Shanghu Formation. According to the careful observation of the present author in the field, the top part of Pingling Formation consists of purplish red muddy siltstone with small calcareous concretions, yielding nests of Dinosaur eggs; the bottom part of Shanghu Formation consists of brownish red muddy siltstone with larger irregular–shaped hollow calcareous concretions. The contact surface of these two formations is clear and flat with no trace of hiatus in between. The relatively apparent hiatus should occur in the Mesozoic between Yuanpu and Pingling formations. The third member of Yuanpu Formation consists of lacustrine deposit, and mudpacks and footprints of dinosaurs have been found on the surface of the rocks near the top of the member, indicating the environment of shallow water where the sediments exposed often to the air. The bottom part of Pingling Formation consists of sandy conglomerates of 5m thick, scattered with breccias of siltstone coming from the third member of the Yuangpu Formation. The haitus between Yuanpu and Pingling formations is therefore obvious. However the haitus is short for the dinosaur eggs from above and below the boundary are consistent.

Furthermore, based on the previously published data on the fossil mammals, Russell *et al.* considered that there are no lower Paleocene sediments in the lower part of Shanghu Formation. The updated information shows that the Paleocene sediment is of 800m thick in which 7 mammal fossiliferous layers have been found. Two layers locate in Nongshan Formation, whose yielded fossil mammals are quite different from those of Shanghu Formation and with no *Coryphodon* and *Prodinoceras* (Wang *et al.* 1998) as Russell *et al.* predicated. The other 5 layers are in Shanghu Formation of about 500m thick, of which Chow *et al.* (1977) reported 4 mammal fossiliferous layers: top, upper, middle and lower layers formed the middle Paleocene Shanghu mammal fauna. The present author has checked the lower fossiliferous layer in the field and confirmed that it was 56m above the bottom of Shanghu Formation. It should be mentioned that another fossiliferous layer 2m above the bottom of Shanghu Formation has been found by the present author and his colleagues. Although the fossils were ill–preserved and could not be identified exactly, they were obviously different from those from the four layers above. According to Zhai (oral communication) they could belong to one of the small primitive condylarths. Wang *et al.* (1998) dated the Shanghu Fauna to be equal to Puercan–middle Torrejonian of North American mammal Age, and Ting (1998) considered the Shanghuan to be equal to Torrejonian. It is therefore impossible that "several millions of years of the earliest part of Paleocene record is absent" in Nanxiong basin.

## 3 K/T boundary and iridium anomaly

When Russell *et al.* discussed whether deposits of the Cretaceous and Tertiary in the Nanxiong Basin were continuous they stressed iridium anomaly record (Russell *et al.* 1993, P. 143). The present author could not understand the reason why they stressed: Did they mean that iridium anomaly marked the K / T boundary or iridium anomaly is a criterion of continuous deposition. In my opinion, the reason of the last dinosaur extinction has been being a problem is dispute. Although impact theory is reasonable, it is not yet mature scientific conclusion because of insufficient evidences. The nature and the influenced area of iridium anomaly event has not been cleared. It should be careful to consider the iridium anomaly the only criterion of K/T boundary. In addition, it is worth considering the problem whether iridium could be deposited in running water, because iridium kept in stratum is form of particle. It is unreasonable to deny the deposit continuation at Cretaceous-Tertiary boundary based only on the absence of iridium anomaly although the iridium anomaly is very important for deciding where the K/T boundary lies.

### References


Chow M C (周明镇), Chang Y P (张玉萍), Wang B Y (王伴月) *et al.*, 1977. Mammalian fauna from the Paleocene of Nanxiong Basin, Guangdong. Pal Sin (中国古生物志) New Ser C, (20): 1～100 (in Chinese with English summary)

Erben H K, Ashraf A R, Bohm H *et al.* 1995. Die kreide/Tertiar-Grenze im Nanxiong-Becken (Kontinentalfazies, Sudostchina). Erdwissenschaftliche Forschung, **32**: 1～245

Russell D A, Russell D F, Sweet A R, 1993. The end of the dinosaurian era in Nanxiong Basin. Vert PalAsiat (古脊椎动物学报), **31**(2): 139～145

Ting S Y, 1998. Paleocene and early Eocene land mammal ages of Asia. Bull Carnegie Mus Nat Hist, **34**: 124～147

Wang Y Q, Hu Y M, Chow M C *et al.*, 1998. Chinese Paleocene mammal faunas and their correlation. Bull Carnegie Mus Nat Hist, **34**: 89～123

Zhao Z K (赵资奎), Ye J (叶捷), Li H M (李华梅) *et al.*, 1991. Extinction of the dinosaurs across the Cretaceous-Tertiary boundary in Nanxiong Basin, Guangdong Province. Vert PalAsiat (古脊椎动物学报), **29**(1): 1～20 (in Chinese with English summary)