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广东省南雄盆地白垩系—第三系交界恐龙绝灭问题

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关键词　广东南雄　K/T交界　恐龙绝灭　恐龙蛋

内　容　提　要

广东省南雄盆地中的红层可划分为三个群五个组，大致代表了晚白垩世—始新世的沉积。根据绝对年龄、古地磁测定结果和脊椎动物化石组合性质的综合分析，位于地磁极性带29R上部的坪岭组和上湖组之间的分界线被确定为K/T界线。

对晚白垩世恐龙蛋的研究表明，不同"种"的恐龙蛋是在地磁极性带29R的中、下部，也就是说在白垩系—第三系交界之前20～30万年期间绝迹的。而且在这一时期内，所有已发现的蛋壳中，绝大多数蛋壳的厚度和显微结构都显示出明显的病理特征，例如根据随机取样统计，*Macroolithus yaotunensis* 蛋壳异常结构的出现率，最高可达75%。

产生病态恐龙蛋壳的生理机制可以根据发生在现生鸟类的相同病理特征来解释。进一步分析恐龙蛋壳的微量元素和稳定同位素组成，结果显示，Pb, Cu, Mn等9种元素丰度变化在这一时期达到最大峰值，$\delta^{18}O$ 也出现正异常。在这一基础上提出，微量元素的污染和气候突然的变化妨碍了正常蛋壳结构的形成，导致了恐龙的绝灭。这一绝灭过程大约经历了20～30万年。

恐龙是中生代陆地上最大的爬行动物，可是它们在白垩纪末期发生的大绝灭事件中却全部灭绝了。这是脊椎动物演化史上最重大而又令人迷惑不解的一个问题。近10年来，碰撞理论的提出（Alvarez 等，1980; Hsü, 1980），在国际上受到了科学界和公众极大的关注，从而引起了一场空前的争论。然而，到目前为止，可以用来讨论这一问题的最好记录，主要来自北美西部内陆地区（Archibald, 1982,1987; Archibald 等,1982; Russell, 1982; Sloan 等,1986; Smit 等,1987; van Valen 等，1977），而来自其它地区，如欧洲地中海地区（Erben 等,1979; Erben, 1983），南美洲的秘鲁（Marshall 等,1983）及亚洲的中国(赵资奎,1978)等的资料则很少或不很完全。

1983 年以来，由中国和联邦德国的地质古生物学工作者联合组成的考察队（考察队**成员名单在后面列出）**系统地研究了我国广东省南雄盆地白垩系—第三系剖面和古生物**化石。现在对该**盆地的地质概况，白垩系—第三系交界地球磁极的变化，古地理沉积环境**和恐龙蛋壳结构**及其所含的微量元素和氧、碳稳定同位素的研究已经获得了重要的结果，为划定白垩系—第三系界线，探讨当时的全球性绝灭事件，特别是当前国际上关注的恐龙绝灭问题提供了新的资料。在详细的系统研究成果未发表之前，本文简要报道这一研究的结果。

一、南雄盆地的地层概况及白垩系—第三系界线的确定

南雄盆地位于广东省北部南雄县和始兴县境内，向东延伸至江西省信丰县西部，为一呈北东—南西向延伸的狭长盆地。

盆地内红层的时代和地层划分对比的研究，只是在 1960 年以后，才有了较大的进展，并且第一次在我国南部广大地区发现了晚白垩世恐龙蛋和古新世哺乳类化石（张玉萍、童永生，1963；杨钟健，1965；郑家坚等，1973；童永生等，1976；周明镇等，1977；王伴月，1978），因而使得南雄盆地成为讨论陆相 K/T 界线的理想地点。许多单位先后在南雄盆地工作，

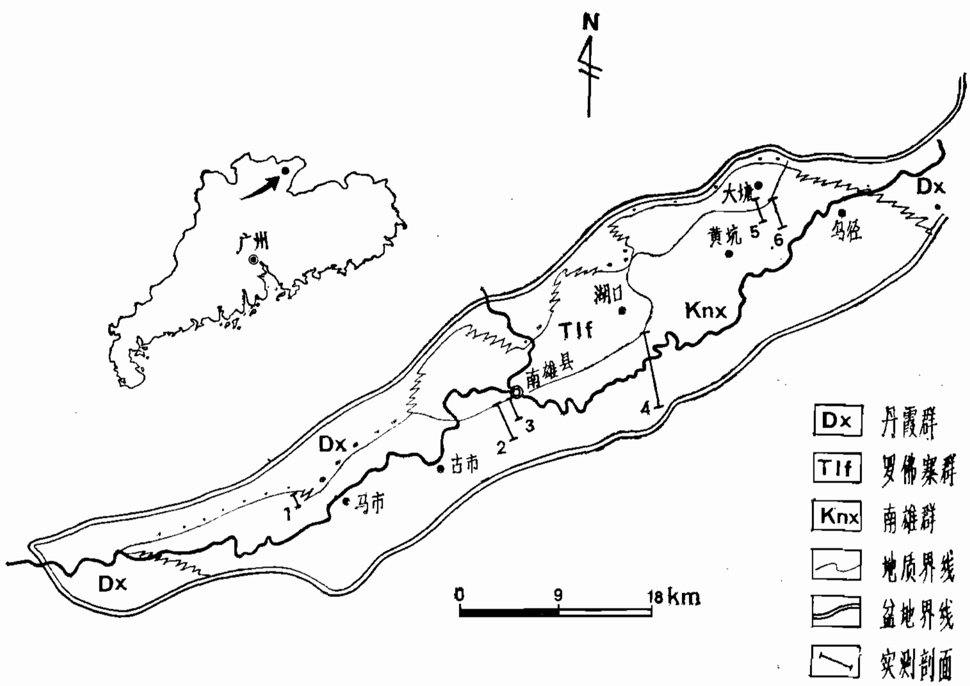

图 1　南雄盆地地质简图

Fig. 1　Sketch Geologic Map of Nanxiong Basin Showing Lithostratigraphy (Dx: Danxia Group; Tlf: Early Tertiary Luotuzhai Group; Knx: Late Cretaceous Nanxiong Group) and Stratigraphic Section (1. CGP; 2. CGT, CGF-I and CGF-II; 3. CGN; 4. CGQ, CGH, CGL and CGW; 5. CGY, CGY+, CGD and CGD'; 6. CGH')

对南雄盆地的岩石地层和生物地层做了大量工作，提出了不同的看法[1)]。

我们把工作的区域选择在含有丰富脊椎动物化石的盆地中部。西起 114°01′E，东至 114°33′E，面积近 700 平方公里。在 1983，1984 和 1986 年的三次野外工作中，先后共测制了 14 条地质剖面(图 1)。从江头—五台岗及大塘乡一带，出露的岩石地层大致可分为三个群、五个组。

园圃组是盆地中段最早期堆积，代表了从山麓洪积相逐渐过渡为湖相沉积的一个完整旋迴，和坪岭组(河流相)共同组成一套相对较粗的紫红色碎屑岩系，即南雄群。上湖组、浓山组及古城组共同组成一套粒度较细，颜色相对较暗的碎屑岩系，即罗佛寨群。在盆地两端和北缘分布的一套粗砂砾岩构成了丹霞群，与南雄群，罗佛寨群呈相变和超覆关系。

由于在南雄盆地白垩系—第三系沉积层序中以前没有进行过磁性地层学研究，因此，我们选择了沉积相对连续，露头清楚的大塘乡以南杨梅坑—逆龙坑的 CGY—CGD 剖面以及盆地西段铺背附近含有喷发玄武岩的 CGP 剖面(属园圃组上段)系统采集古地磁样品，共布采集点 342 个，钻取岩心 1009 个。这批样品由本文作者之一(李华梅)分别在联邦德国科隆大学地质研究所和中国科学院地球化学研究所的实验室中进行分析。结果表明，在 CGY—CGD 剖面中反向磁化样品占绝对优势，仅有四处以正向磁化样品为主，可以把它们划分为四个正向磁极性带。它们从下到上依次位于 CGY109—172 米处(园圃组上段)，CGD 0—33 米处(坪岭组)，CGD 236—259 米处(上湖组)和 CGD 390—415 米处(上湖组上部)。夹有玄武岩的 CGP 剖面的样品均为反向磁化。铺背附近玄武岩产出层位大致可对应于东部 CGY 剖面起点附近，相当于园圃组上段的上部。从田心北部的钻孔中采集到的样品可能是该地区晚白垩世最后一次火山喷发的玄武岩。根据中国科学院地球化学研究所王慧芬提供的钾氩法测定的年龄值为 67.04±2.31Ma 和 67.37±1.49 Ma。这样，再结合脊椎动物化石组合的性质以及考虑到未发现有大的地层缺失和间断，上述 CGY—CGD 剖面中由下到上的四个正向极性带应相当于 31N—28N (图 2)。因此，CGD 33—236 米的反向极性带应为 29R。它可与美国圣胡安盆地陆相白垩系—第三系剖面中的 β 反向极性带 (Butler 等，1985)以及意大利的古比奥海相白垩系—第三系剖面中的G反向极性带 (Alvarez 等，1977)对比。

目前国际公认的白垩系—第三系界线的年龄值是 6,500 万年。在磁性地层年代表中应位于 29 正向极性时 (29N) 之下的 29 负向极性时(29R)的上部。在南雄盆地 CGD 剖面中，29R 的底界位于 CGD33 米处，顶界位于 CGD236 米处，也就是说，它包括了坪岭组的上部和上湖组的底部。如果我们假定 CGD 剖面 29R 间隔中的地层是匀速堆积的，那么，利用 29R 的上下时界线年龄值差分求得的 6,500 万年年龄的参考位置应位于坪岭组和上湖组交界线之上 20 米处。但是，从上湖组所含哺乳动物化石的进化水平来看，以该参考点位置作为白垩系—第三系界线显然偏高。上湖组底部基本上接近于古新世最早期。而且，由于南雄盆地是一规模不大的窄长断陷盆地，其中的堆积物明显地受边界断层差异活动的控制，沉积速率多变，难以掌握，要精确标定 6,500 万年的位置比较困难。因

1) 有关这一问题的讨论，可参考《华南中、新生代红层——广东南雄"华南白垩纪—早第三纪红层现场会议"论文集》，科学出版社，1979年。

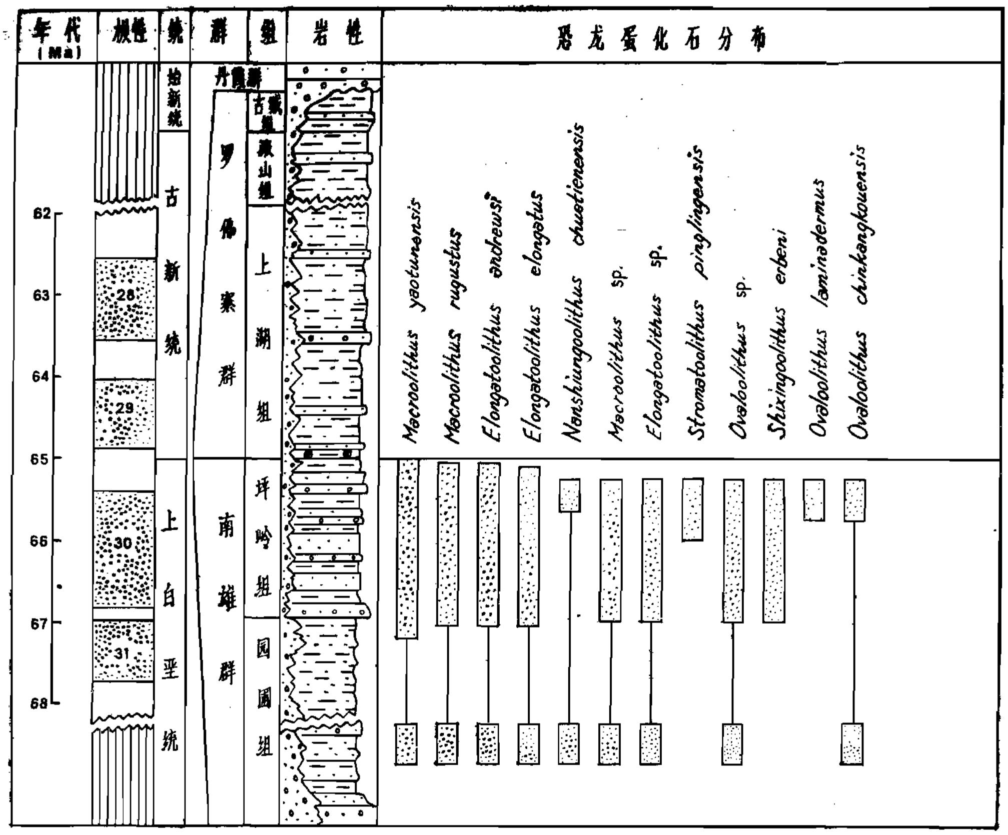

图 2　南雄盆地恐龙蛋类群的地层分布

Fig. 2　Diagram Showing Stratigraphic Occurrence of the Eggshell ot Different Types at Nanxiong Basin

此，在 29R 极性带的上部选择一条明显而稳定的，显然接近于 6,500 万年的界线作为白垩系一第三系交界可能是比较明智的。

坪岭组与上湖组之间的界限位于 CGD 161 米处，显然位于 29R 极性带的上部。该界线在泥质粉砂岩之中，无任何明显的间断现象。但是这条界线却十分明显：(1)界线之下的粉砂岩为紫红色，界线之上的粉砂岩呈棕红色，颜色变暗。(2) 界线之下的粉砂岩中含有小的钙质结核，界线之上则含大的钙质结核，且形状不规则，内部具空洞。(3)界线之下含有恐龙蛋和恐龙化石，界线之上的地层中则从未发现过恐龙蛋或恐龙的化石，但古新世哺乳类化石特别丰富。这条界线东起恐村，西至枫门凹，几乎在盆地中部的所有界线观察点上都可见到。可以说，它是位于 29R 极性带上部地层中非常清楚、稳定的岩石地层界线。因此，我们选定它作为白垩系一第三系界线。

二、南雄盆地晚白垩世恐龙蛋

从 1962 年以来，在南雄盆地晚白垩世地层中，除发现了一些恐龙化石和龟化石外，还先后发现了大量的蛋化石。据不完全统计，一共有 24 个蛋窝，计 305 枚比较完整的化石

蛋及将近 2 万片的碎蛋壳。另外，我们联合考察队在 1983、1984 及 1986 年的三次野外工作中，又逐层采集了约 2 万余片的碎蛋壳，并且首次在盆地中发现了两种恐龙脚印。

蛋化石地点主要分布在南雄县城西南、武台岗、坪岭和乌径及始兴县的马市等地区。从这些蛋化石的地层分布来看，它们主要分布在园圃组中段上部和上段上部以及整个坪岭组中。其中尤以坪岭组的蛋化石在种类及数量上最为丰富。

根据我们的观察，这批蛋化石除少量属于龟类及鳄类的外，其余的可以说都是恐龙蛋。由于现在还无法知道它们的形态结构和恐龙骨化石之间的关系，因此，除了某些含有胚胎骨骼化石的蛋外，要指出某一种蛋化石是某一种恐龙的蛋，的确是一个很棘手的问题。然而，根据其形态结构的特征，却可以把它们划分为不同等级的分类单元。根据赵资奎（1975，1979）提出的恐龙蛋分类的处理原则，可以把这些蛋化石划分为 6 个属，12 个种。其分类系统如下：

Elongatoolithidae

Macroolithus yaotunensis; *Macroolithus rugustus*;
Macroolithus sp. nov.; *Elongatoolithus andrewsi*;
Elongatoolithus elongatus; *Elongatoolithus* sp. nov.;
Nanshiungoolithus chuetienensis

Spheroolithidae

Ovaloolithus cf. *chinkangkouensis*; *Ovaloolithus* sp. nov.;
Ovaloolithus cf. *laminadermus*

此外，还有两种蛋化石尚未描述。由于正式研究报告的发表尚有一段时间，为了便于在有关问题的研究中应用和讨论，在此对这两种蛋的属和种的定义摘要描述如下：

Spheroolithidae Zhao 1979
***Shixingoolithus* gen. nov.**
***Shixingoolithus erbeni* sp. nov.**

正型标本　有34枚蛋化石一窝（No. 901）。

地点层位　广东始兴陆源；南雄群坪岭组。

属与种的特征　近乎圆形，长径为 125—105 毫米；短径为 123—99 毫米。蛋壳厚度为 2.3—2.6 毫米。锥体层厚度约占蛋壳厚度的 1/4。柱状层中方解石微晶的菱形解理特别发育。

上述特征与目前已知的 *Spheroolithus*, *Paraspheroolithus* 和 *Ovaloolithus* 有明显不同，应代表一新属新种——*Shixingoolithus erbeni*. 种名 erbeni 献给 H.K. Erben 教授，表彰他在推进中一德两国古生物学家间的合作和在本项目中所作的贡献。

Fam. indet.
***Stromatoolithus* gen. nov.**
***Stromatoolithus pinglingensis* sp. nov.**

正型标本　碎蛋壳 224 片（CGD 063）。

地点层位 广东南雄坪岭；南雄群坪岭组。

属与种的特征 蛋壳外表面具不很明显的蠕虫状纹饰。由锥体和柱状体构成的蛋壳基本结构单位，一般都是以 2—3 个相互联结一起，其中有机基质纤维呈叠重状排列。气孔道很发育。

上述 12 种恐龙蛋化石在地层中的分布似乎有上、下差别，*Shixingoolithus erbeni*, *Stromatoolithus pinglingensis* 和 *Ovaloolithus* cf. *laminadermus* 只发现于坪岭组中，其余的种类在上、下地层中都有分布。从目前的材料看，仍应认为属同一化石组合较为合理，其时代为晚白垩世晚期(马斯特里赫期)。

然而，上述的恐龙蛋类型在地层中分布的另一个值得注意的现象是，在园圃组中大约有 9 个类型的恐龙蛋，到了坪岭组中部，恐龙蛋的种类更加多样，共计有 12 个类型，而且数量也很丰富。但是，到了坪岭组的上部，恐龙蛋种类和标本数量急剧下降。最后，只有一个类型的恐龙蛋，*Macroolithus yaotunensis* 一直到白垩系—第三系交界才绝迹。根据上述的磁性地层学标准，它们正好是在 29R 极性带的中、下部不同层位中消失的(图 2)。这就表明，生活在我国南部白垩纪末期的恐龙是在白垩系—第三系交界之前 20—30 万年开始绝灭的，然后持续至交界，最后一类恐龙蛋绝迹。

三、恐龙蛋壳的病理结构特征

在南雄盆地发现的各类恐龙蛋壳中，出乎意料的是有大量的蛋壳显示出病理结构特征。它们明显地表现在两个方面：

1. 蛋壳厚度异常

在南雄盆地发现的 12 个类型恐龙蛋中，除少数类型外，绝大多数类群的蛋壳厚度一般都显示出有较大的变异范围。在园圃组中发现的蛋壳，一般都显得厚一些，变异范围也小一些；在坪岭组中发现的蛋壳，其变异范围则相对的显得大一些。然而，这些类型的蛋壳从下到上连续分布，数量很多，可以作为统计和对比的只有 *Macroolithus yaotunensis*, *Macroolithus rugustus*, *Elongatoolithus andrewsi* 和 *Elongatoolithus elongatus* 等四个类群。我们测量了在园圃组 CGH 剖面和坪岭组的 CGY—CGD、CGY^+、CGL—CGW、CGN 和 CGT—CGF-I 等 9 个剖面中逐层采集到的这四个类群的蛋壳碎片共 15435 块。图 3 是表示坪岭组 CGD 剖面各个层位中这四个类群蛋壳平均厚度的变化曲线。可以看出，各类蛋壳的平均厚度变异范围比较大，特别是在 CGD40—100 米范围内，蛋壳厚度表现出有更大的异常。坪岭组其它剖面，如 CGY^+、CGL—CGW、CGN 以及 CGT—CGF-I 等发现的这四类蛋壳的厚度也具有相同的变异现象。

2. 蛋壳的病理组织特征

根据光学显微镜及扫描电镜的观察，南雄盆地发现的蛋壳病理组织特征主要表现如下：

(1) 锥体层和柱状层厚度比例异常。在正常的情况下，每类恐龙蛋壳的锥体层和柱

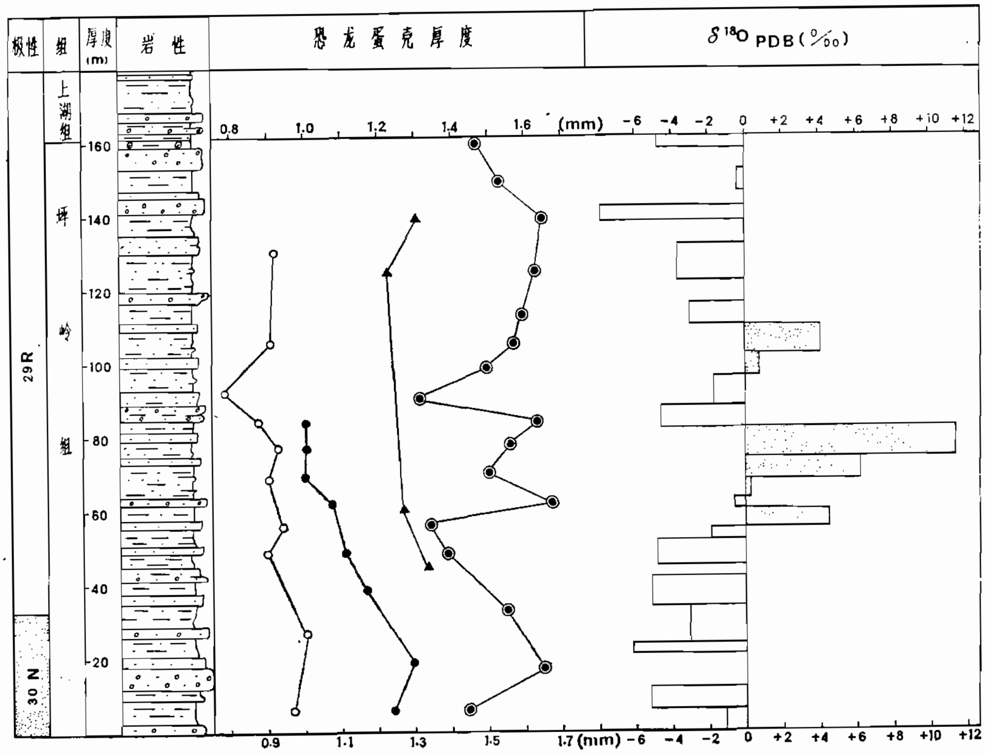

图 3　南雄盆地坪岭组 CGD 剖面不同类群蛋壳厚度变异及氧－18 分布

Fig. 3　Diagram Showing Variations in the Thickness of the Four Types of the Dinosaur Eggshell and the Oxygen-18 Record at CGD Section. ○ = *Elongatoolithus elongatus*; ● = *Elongatoolithus andrewsi*; ▲ = *Macroolithus rugustus*; ⊙ = *Macroolithus yaotunensis*

状层的厚度是有一定比例的。例如 *Macroolithus yaotunensis* 的锥体层和柱状层厚度之比约为 1:3。但是在异常的情况下，这两层的厚度之比，大约为 1:1，有的为 1:5。这种厚度比例的异常现象可能是在蛋壳形成过程中，由于卵在输卵管中蠕动的速度发生异常的结果。

（2）双层锥体及多层锥体。这种异常结构的特征是在锥体层和柱状层之间，局部地夹有一层或两层以上重叠的锥体。它们大都发现于 *Macroolithus yaotunensis*、*Macroolithus rugustus* 和 *Macroolithus* sp. 等三个类型中。

（3）具有不规则形或圆形的腔隙。这种异常结构一般在 *Elongatoolithus andrewsi*、*Elongatoolithus elongatus* 和 *Macroolithus* 中见到。它们往往出现在锥体之间以及靠近外表面的柱状层中。

（4）柱状层中有局部的不规则排列的方解石晶体。这种情况主要见于 *Elongatoolithus andrewsi* 中。

具有病态结构的恐龙蛋壳在坪岭组中比较常见。根据随机取样的统计，从 CGD 剖面发现的 *Macroolithus yaotunensis* 来看，CGD 40 米以下发现的蛋壳，具有病态结构的样品约占 20%；在 CGD 40—110 米范围内的样品，有异常结构的约占 75%；在 CGD

110 米以上的蛋壳样品，有异常结构的则占 35%。这一结果与上述蛋壳厚度异常出现的层位是很一致的。

爬行类和鸟类的卵是雌性动物的生殖器官协调作用下产生的。如果生殖系统的生理活动发生暂时的或永久性的障碍，都可能形成病态的蛋壳。根据对鸟蛋壳形成的实验观察，在蛋壳钙化过程中，有机基质起着重要的作用。从化学组成来看，这种有机基质是一种由氨基酸组成的类似于软骨的糖蛋白。由它们组成的锥体生长中心（也称乳突生长中心）是最初形成结晶的部位。它们的分布、显微结构和染色特性在那些薄的和脆弱的蛋壳中是很不正常的。有证据证明，一些微量元素如 Mn, Zn, Sr 等的不足或过多，对蛋壳有机基质和碳酸钙的形成都有影响，从而形成异常结构的蛋壳（Meuller and Leach, 1974)。例如母鸡在产卵期间，如果其饲料中锶（Sr）的含量超过常量的 30%，结果就会形成很脆弱的薄蛋壳。因此，似乎有理由认为，上述的病态结构的恐龙蛋壳，也可能与微量元素的作用有关。这一假设可以从下述的恐龙蛋壳微量元素分析的结果得到证实。

四、恐龙蛋微量元素及氧、碳同位素异常

我们分析了 CGY—CGD 剖面发现的 *Macroolithus yaotunensis* 30 个蛋壳样品的微量元素含量。图 4 所示的是 CGD 剖面的蛋壳样品微量元素丰度变化曲线。可以看出，在所有被分析的微量元素中，除锶（Sr）的最大峰值出现在 CGD 40 米以下的地层中外，其余 8 种元素基本上都在 CGD40—100 米范围内不同程度地出现最大的丰度变化。那么是什么原因导致了恐龙蛋中微量元素的富集？

从鸟蛋的情况来看，在正常的情况下，一个完整的鸡蛋大约含有 20 余种微量元素，总量约为 7 毫克，其中钙质蛋壳约含 0.1 毫克。（Romanoff and Romanoff, 1949)。最近，Ferguson (1982) 报告美洲密河鳄（*Alligator mississippiensis*）的蛋壳也含有极微量的 Cu, Mn, Zn 等多种元素。根据实验观察，鸟蛋所含微量元素的多少主要取决于母体动物饲料中的矿物组成。例如在母鸡的饲料中加入大剂量的 Mn，它所产的卵，Mn 的含量便大量增加；根据放射性同位素追踪研究，母鸡摄入的放射性锶（Sr）同位素，主要都沉积在其产的钙质蛋壳中（Romanoff and Romanoff, 1949)。因此，可以认为，上述恐龙蛋壳所含的微量元素同样是通过食物而进入到恐龙体内，然后又沉积到它们产的这些蛋壳中的。这就进一步表明，恐龙蛋壳中微量元素的异常可能与当时的环境因素有关。

恐龙蛋壳的氧、碳稳定同位素的分析是在中国国家地震局地质研究所的实验室和联邦德国格廷根大学地球化学研究所的实验室中分别进行的。中方分析了园圃组 CGH 剖面和坪岭组 CGY—CGD、CGL—CGW、CGN 及 CGT—CGF 等剖面发现的蛋壳共 167 个样品；德方分析了 96 个样品。此外，我们又从 CGY—CGD 剖面各层位中采集的 *Macroolithus yaotunensis* 中，随机抽取 22 个样品，由本文作者之一(赵振华)在格廷根的实验室中再次进行分析。虽然双方所得的数值有的差异比较大，但是，总的说来，它们在地层中由下到上的变化趋势却是比较一致的。

根据中方分析的结果，从园圃组CGH剖面来的蛋壳样品，$\delta^{13}C$ 的变异范围为 $-7.79‰$ 至 $-11.05‰$；$\delta^{18}O$ 为 $+8.57‰$ 至 $-2.79‰$。从坪岭组 CGD 剖面来的蛋壳样品，$\delta^{13}C$ 的

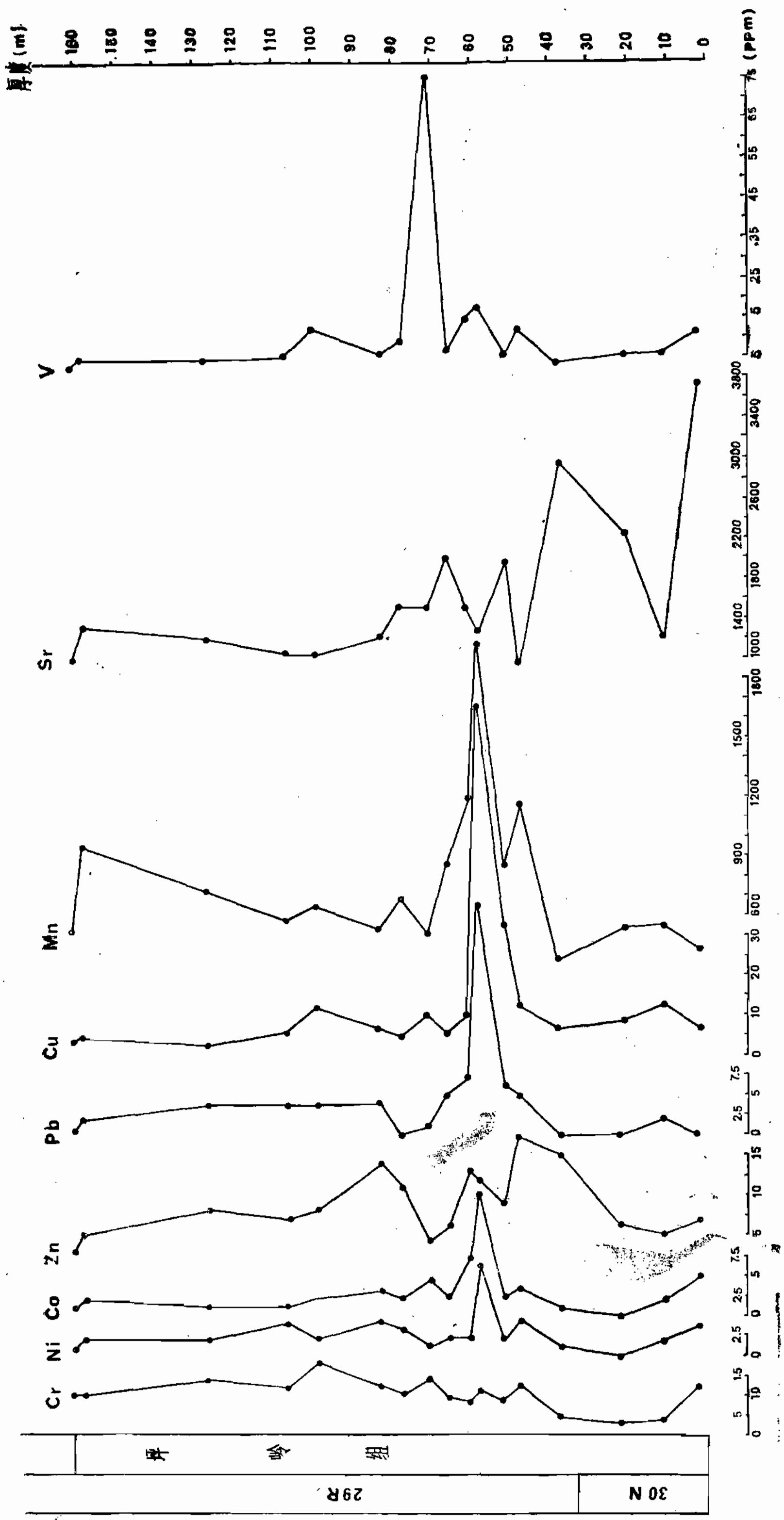

图 4　南雄盆地坪岭组 CGD 剖面 *Macroolithus yaotunensis* 蛋壳微量元素丰度变化

Fig. 4　Abundance Variations of Trace Elements Contained in the Eggshells, *Macroolithus yaotunensis*, at CGD Section

变异范围为−9.20‰至−11.94‰；$\delta^{18}O$为+11.43‰至−6.14‰。表明在这两个剖面中，$\delta^{13}C$比率变化较小，而$\delta^{18}O$的变化较大，尤其是CGD剖面的样品更为明显。

根据扫描电镜的观察，这些蛋壳样品的晶体形态是典型的原生方解石，几乎没有重结晶现象。另一方面，从上述蛋壳的氧、碳同位素组成的分析结果也可看出，它们与那些受过成岩作用的白垩纪淡水灰岩的方解石所含的氧、碳同位素组成的平均值：$\delta^{13}C=-4.3‰$，$\delta^{18}O=-10.2‰$ (Keith and Weber, 1964)，差别非常之大。因此，可以认为，我们分析的这些蛋壳样品是不大可能发生过成岩蚀变的。

碳酸盐蛋壳中的碳 (C) 和氧 (O) 来自产卵动物所吃的食物、水和呼吸的空气。其中$^{13}C/^{12}C$和$^{18}O/^{16}O$比值的范围和变化可以说明碳和氧的来源。Folinsbee 等 (1970) 以及 Hoefs 和 Wedpohl (见 Erben 等，1979)都证实了水的氧同位素和碳酸盐蛋壳中氧同位素之间的线性关系。然而由于陆地上水源多变，湖.河等的大小也受到一定的限制，同时，雨水中的氧同位素组成不仅受气温的控制，而且也受当地蒸发过程、与海岸的距离和纬度的高低等因素的控制，特别是蒸发作用可能使淡水氧同位素组成逐步接近"海水"的数值，因此，要具体地估计这些可变因素对于淡水环境古温度测定的影响，目前仍存在着一定困难。

从上述列举的南雄盆地恐龙蛋壳氧同位素组成的数值可以看出，坪岭组 CGD 剖面的样品比园圃组 CGH 剖面的蛋壳样品有更大的变异范围。尤其值得注意的是在 CGD 剖面中，氧同位素组成显示出两个明显的异常 (图 3)，即 CGD60—80 米的 4 个蛋壳样品，$\delta^{18}O$分别为+0.27‰，+4.22‰，+6.37‰和+11.43‰；CGD100—110 米的 2 个样品，$\delta^{18}O$各为+0.87‰和+4.10‰。说明当时的气候环境可能发生过显著的变化。现代非洲鸵鸟生活在年平均气温 30℃以上，自然环境非常干燥的低纬度地区，其蛋壳所含的$\delta^{18}O=+7.1‰$，$\delta^{13}C=-8.3‰$ (见 Erben 等，1979)。由于有关的资料很少，对于南雄盆地白垩纪末期的水温和气温的变化还不可能获得可靠的结论性意见。但是，从另一方面来看，CGD 剖面中蛋壳$\delta^{18}O$的突然增加也许是受另一个参量的影响，即上面已经提到的，蒸发作用可以改变淡水体氧同位素组成。那么，似乎有理由认为，上述的蛋壳氧同位素的异常增加，可能表示当时曾出现过相当严重的干燥气候。

五、恐龙最后绝灭的原因

根据上述的研究资料，南雄盆地各类恐龙蛋在坪岭组中、上部地层中的绝迹几乎是与那些病态蛋壳大量出现、微量元素异常以及氧同位素异常同时发生的。它们都出现在 29R 极性带的中、下部的层位中。这就说明我国华南地区白垩纪末期恐龙的绝灭开始发生在白垩系—第三系交界之前 20—30 万年，而绝灭的原因可能和当时环境的变化，特别是与微量元素的富集有关。因此，这种情况可以不必从地球以外去寻找原因，它与目前流行的"碰撞理论"也很不一致。

我们可以假定，在白垩系—第三系交界之前 20—30 万年，我国华南地区可能在受到了微量元素污染的同时又出现了相当严重的干燥气候，而过度的蒸发作用又使土壤和水中所含的微量元素更加富集起来。通过食物链环的运转，这些微量元素过多地聚集到恐

龙体内，从而破坏了恐龙体内生理活动过程中微量元素的平衡，结果影响了恐龙的生殖过程，形成了病态结构的蛋壳。它们易碎而无法保证胚胎的正常发育。另一方面，由于这些微量元素过多地积聚在蛋内的营养物质(如蛋黄和蛋白)中，也会大大地降低恐龙蛋的孵化率，使恐龙无法正常繁殖后代而逐渐绝灭。这一过程大约持续 20～30 万年。

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EXTINCTION OF THE DINOSAURS ACROSS THE CRETACEOUS-TERTIARY BOUNDARY IN NANXIONG BASIN, GUANGDONG PROVINCE

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Key words　Nanxiong, Guangdong; K/T boundary; Dinosaur extinction; Dinosaur egg

Summary

Dinosaurs were giant reptiles on land during the Mesozoic era, but they all vanished from the earth in the global events of terminal Cretaceous turnover. This is a significant and perplexed question in the history of vertebrate evolution. During the past ten years the impact theory proposed by Alvarez and others (1980) and by Hsü (1980) has drawn considerably scientific and public interest, thus evoked a heated dispute. The extinction of the dinosaurs appears to be a global phenomenon. However, the best record so far we can use to discuss this issue comes from the West Interior of North America (Archibald, 1982, 1987; Archibald et al., 1982; Russell, 1982; Sloan et al., 1986; Smit et al., 1987; van Valen et al., 1977), and the available information from other regions such as European Mediterranean (Erben et al., 1979; Erben, 1983), Peru (Marshall et al., 1983) or China (Zhao, 1978) are very little or incomplete.

Interdisciplinary investigations on the redbed facies of Late Cretaceous to Early Tertiary passage beds in Nanxiong Basin, Guangdong Province have been continued by a Sino-German team (members mentioned in the acknowledgements) since 1983. Important results have been made on the general geology, magnetostratigraphy, isotopes, trace elements and microstructure of dinosaur eggshells. These will provide new evidence for defining the Cretaceous-Tertiary boundary at Nanxiong Basin and for exploring the global events occurring at that time, especially the dinosaur extinction problem that is currently being debated. As the final publication of the systematic study by both the Chinese and German authors may probably be delayed for some time, a brief report on the work by the present authors is given here.

I. The Stratigraphy and the Cretaceous-Tertiary Boundary at the Nanxiong Basin

The Nanxiong Basin situated chiefly in northern Guangdong Province embodies Nanxiong and Shixing counties and the western part of Xinfeng county of Jiangxi Province. It is an elongated basin with its long axis oriented NE-SW. The study on the division of the red beds in the basin has gained some rapid since 1960. It is from here that Cretaceous dinosaur eggshells and Paleocene mammals were found in South China for the first time (Zhang et al., 1963; Young, 1965; Zheng et al., 1973; Tong et al., 1976; Zhou et al., 1977; Wang, 1978).

The middle part of the basin is rich in vertebrate fossils, so it was selected for investigation. It is limited between 114°01'EL to 114°33' EL, covering an area of about 700 Km^2, where 14 geological sections were measured in 1983, 1984 and 1986. In the middle part of the basin the strata exposed can be divided into three groups and five formations (Fig. 1).

The Nanxiong Group consists of the Yuanpu and Pingling Formations. The Yuanpu Formation comprises from bottom to top deposits of fanglomerate facies, fluviolacustrine facies and lacustrine facies, forming a sedimentary cycle. The Pingling Formation is of fluvial deposits. The Luofuzhai Group which is darker and finer than the Nanxiong Group contains Shanghu Formation, Nongshan Formation and Gucheng Formation. The Danxia Group is a suite of coarse sandy conglomerate in the north margin and at both ends of the basin. This unit overlaps or intertongues with the Nanxiong and Luofuzhai Groups.

Continuous Late Cretaceous to Early Tertiary deposits are generally well-exposed south of Datang, from Yangmeikeng to Nilongkeng. So, closely-spaced paleomagnetic samples were collected from CGY Section (near Yangmeikeng), CGD Section (near Nilongkeng), and CGP Section (near Pubei) which contains extrusive basalts. 1009 samples were collected from 342 sampling horizons. These samples were measured at the laboratories in Köln, Bundesrepublik Deutschland and in Guiyang, China by one of us (Li Huamei).

In the CGY and CGD sections the primary remnant magnetization of the samples showed 4 intervals of normal polarity, i.e. CGY 109—172m (upper member of Yuanpu Formation), CGD 0—33m (Pingling Formation), CGD 236—259m (Shanghu Formation) and CGD 390—415m (upper part of Shanghu Formation). All the samples from CGP Section show a reversed polarity situation. Some basaltic samples from the borehole in Tianxin area were collected and they were dated as 67.04±2.34 my and 67.7±1.49my with K-Ar method at the laboratory in Guiyang. These samples represent the last extrusion flow known so far, which is near to the top of the Yuanpu Formation.

Based on the age of the uppermost basalt and the results of study on vertebrate fossils from the lower part of the Shanghu Formation, the 4 intervals of normal polarity in CGY and CGD sections should be correlated to magnetic chron 31N, 30N, 29N and 28N respectively (Fig. 2). Therefore, CGD 33—236m should correspond to magnetic anomaly 29 and correlate with magnetic anomaly β in San Juan Busin (Butler et al., 1985), North America and magnetic anomaly G at the Gubbio section in Italy (Alvarez et al., 1977).

According to the current geologic time scale the Cretaceous-Tertiary boundary is put at 65my at the midpoint (39/53) of magnetic anomaly 29. Assuming a constant rate of accumulation at the span of chron 29R in CGD Section, the positon of the Cretaceous-Tertiary boundary should be CGD 182.3m by linear interpolation, i.e. 20m above the base of the Shanghu Formation. But mammal fossils show that the lower part of the Shanghu Formation seems to be very close to the beginning of Paleocene, and the boundary by such interpolation is higher than the true one in the CGD Section. As the Nanxiong Basin is a small narrow downfaulted basin, sediments evidently were controlled by the different movements of the boundary faults and the rate of sedimentation is changeable. So, it is difficult to define the precise position of

65my in the CGD Section. It is better to select the lithologic boundary, which is clear, stable and very close to 65my, as the Cretaceous-Tertiary boundary.

CGD 161m is the boundary betwen the Pingling Formation and the Shanghu Formation. This boundary is in argillaceous siltstone. Although the contact is structurally conformable, the boundary is lithologically very clear: (1) The colour changes through the boundary. Below it the siltstone is purplish red, but above it the siltstone becomes dark red; (2) Different calcareous concretions are observed above and below the boundary, they become small below but big ones above, with irregular shapes and hollow-center; (3) Above the boundary dinosaur eggshells disappear and they are replaced by a rich Paleocene mammal fauna. This boundary is so clear that it can be observed all th way from east Kongcun to west Fengmenao. Therefore, the boundary between the Pingling Formation and the Shanghu Fomation is selected as the Cretaceous-Tertiary boundary.

II. Late Cretaceous Dinosaur Eggs from Nanxiong Basin

From the Upper Cretaceous Nanxiong Group unusually rich specimens of fossil eggs besides some dinosaurian and chelonian remains have been successively discovered since 1962. Our collection consists of about twenty thousand eggshell fragments and about 305 more or less completely preserved eggs including 24 nearly complete or partly preserved nests. In adddition, more than twenty thousand eggshell fragments were collected bed-by-bed by the Sino-German team during the field seasons of 1983, 1984 and 1986.

Geographically, the fossil eggs are chiefly located in the southwestern part of the county city of Nanxiong, and at Wutaigang, Pingling and Wujing areas as well as at Mashi area of Shixing County. According to our observations, the fossil eggs seem to be restricted to the uppermost and middle parts of the Yuanpu Formation, and in sedimentary sequence of the Pingling Formation there occur the definitely autochthonous eggshell fragments and a large number of complete eggs.

Examination of the eggshells by polarizing light microscopy and scanning electron microscopy shows that all these fossil eggs probably belong to dinosaurian, except a few eggshells which may be attributed to crocodilian and chelonian. The eggshells are independent of dinosaurian skeletons——never structurally connected with the skeletons, so it is difficult to assign a certain egg to a certain dinosaur taxon, except in the case of eggs containing embryonic skeletons. However, the dinosaur eggs from Nanxiong may artificially be classified into a hierarchy of taxa based on similarities or differences of their micro morphological structure. According to Zhao's taxonomical terminology (Zhao, 1975, 1979), they can be divided into 12 "species" belonging to 6 "genera" as follows:

Elongatoolithidea

Macroolithus yaotunensis; *Macroolithus rugustus*;
Macroolithus sp. nov.; *Elongatoolithus andrewsi*;
Elongatoolithus elongatus; *Elongatoolithus* sp. nov.;
Nanshiungoolithus chuetienensis

Spheroolithidae

Ovaloolithus cf. *chinkangkouensis*; *Ovaloolithus* sp. nov.; *Ovaloolithus* cf. *laminadermus*; *Shixingoolithus erbeni* gen. et sp. nov.

Fam. indet.

Stromatoolithus pinglingensis gen et sp. nov.

Judging from the stratigraphical distribution of the 12 "species" of the dinosaur eggshell mentioned above, *Ovaloolithus* cf. *laminadermus, Shixingoolithus erbeni* and *Stromatoolithus pinglingensis* seem to be restricted to the Pingling Formation, but they are absent in the Yuanpu Formation. The other "species" are distributed in both formations. Of the two the latter is somewhat distinct from the former, but at the present stage of our knowledge the "species" of the dinosaur eggshell in both formations are considered as representing a single assemblage, which indicates clearly Maastrichtian in age.

However, a highly interesting fact is that within the Pingling Formation there is a progressive reduction of taxa of the dinosaur eggshell during the last 200,000—300,000 years of the Cretaceous, The number of "species" of eggshell catalogued at fourteen sections in both the Yuanpu and Pingling formations was compared. The combined record shows that there are 9 "species" of the dinosaur eggshells in the Yuanpu Formation, then in the middle part of the Pingling Formation diversity is further increased to 12 "species". In the upper part of the formation the number of "species" reduces rapidly. Finally, only one "species", *Macroolithus yaotunensis* ranges up to the Cretaceous-Tertiary boundary, where it becomes extinct. This event occurred exactly within the early-middle span of chron 29R magnetostratigrphy mentioned above (Fig. 2). Hence, according to the above-mentioned data the dinosaur extinction in South China took place during the 200,000 to 300,000 years before the Cretaceous-Tertiary boundary.

III. Pathologic Dinosaur Eggshells from Nanxiong Basin

Generally speaking, normal eggshells of different types have each structural pattern and a normal range of shell thickness. However, it is remarkable that of the different types of the dinosaur eggshells found in Nanxiong Basin, many of them exhibit abnomalities. Two types of the pathological development are classified here according to the morphological structures of the eggshells.

1. Anomaly of eggshell thickness

Among 12 "species" of the dinosaur eggshells mentioned above, most of them, except a few "species", have eggshells varying considerably in thickness. In the Yuanpu Formation the eggshell thickness of different types represents the variations in normal range, whereas in the Pingling Formation the eggshell thickness obviously varies. It would appear from these records that a temporary tendency towards a reducton in thickness is revealed from the Yuanpu Formation to the Pingling Formation. However, only the samples of four "species" of the dinosaur eggshells, *Macroolithus yaotunensis, Macroolithus rugustus, Elongatoolithus andrewsi* and *Elongatoolithus elongatus* are large enough for statistically significant evaluations. Measurements of thickness involve about 15435 eggshell fragments of the four "species" from successive horizons of CGH Section of the Yuanpu Formation and from successive horizons of CGY—CGD, CGY$^+$, CGL—CGW, CGN and CGT—CGF-I sections of the Pingling Formation. The data of the eggshell thickness are presented in Fig. 3 with sample depth plotted on a scale in order to show the frequency of thickness in the four "species" from successive horizons of CGD Section near the Cretaceous-Tertiary boundary. It can be seen that within the horizons of CGD Section of the Pingling Formation mean values of eggshell thickness of each "species" distinctly vary, especially in those from levels of 40 to 100 meters of CGD Section. On the other hand, the same situation exists also in other sections of the Pingling Formation such as in the horizons of CGY+, CGL-CGW, CGN and CGT-CGF-I etc., without any exception.

2. Histopathological pattern of the eggshells

An examination of the defective eggshell texture with the polarizing light microscope and the scanning electron microscope shows as follows:

(1) The eggshell with abnormally proportional thickness between cone layer and columnar one

This pathological pattern has been observed in *Macroolithus*. Under normal circumstances, the thickness of the cone layer of each "species" of the eggshell is proportional to that of the columnar one. For example, the thickness between cone layer and columnar one is in the proportion of one to three in *Macroolithus yaotunensis*. However, the ratio of both is about 1:1, or 1:5 in the pathological eggshells. It is reasonable to assume that the abnormal structure could be caused by paristaltic movements in the oviduct during eggshell calcification.

(2) The eggshell with double-layered or multilayered cone

This abnormal structure is usually examined in *Macroolithus yaotunensis, Macroolithus rugustus* and *Macroolithus* sp. It can be observed in radial sections that the eggshell is locally composed of two or more layered cones caused by repetitive cone formation and a columnar layer.

(3) The eggshell with irregular or dendritic spaces

In the radial section this abnormal structure is in the cone layer or in the columnar layer near the outer surface of the eggshell. It can usually be seen in *Elongatoolithus andrewsi, Elongatoolithus elongatus* and *Macroolithus.*

(4) The eggshell with disorderly arranged crystalline calcite of columnar layer. It is mainly seen in *Elongatoolithus andrewsi.*

The pathological dinosaur eggshells occur with an appreciable frequency in the Pingling Formation, especially in the levels of the middle part of this formation. By a random sampling in *Macroolithus yaotunensis* found in CGD Section, the pathological eggshell of this type is in about 20% of the eggshells in levels below CGD 40 m, in the levels of 40 to 110 m of CGD Section the frequency of the eggshell with pathological structure increases to about 75% of the eggshgells, and in the levels about CGD 110m, it decreases in about 35% of the eggshells. This agrees rather well with the horizons yielding abnormal thickness of the eggshells in CGD Section mentioned above.

The reptilian or avian egg is the product of the coordinated function of reproductive organs in female animal. Any temporary or permanent disturbance in the efficiency of the reproductive system may result in abnormal eggshell. Experiments have indicated that organic matrix is playing a key role in the eggshell calcification. Biochemically, the organic matrix is a glycoprotein with an amino-acid composition similar to that of cartilage. It constitutes the nuclei of the cone (mammilla) which is the first nucleation site of the calcium carbonate crystallites. In those thin and fragile eggshells, the distribution, microstructure and staining traits of these nucleation sites are abnormal. There is some evidence that deficiency or excess of some trace elements, such as Mn, Zn, Sr, etc., may greatly affect the synthesis of the eggshell matrix and calcium carbonate deposition, and cause the formation of the abnormal eggshell (Meuller and Leach, 1974). For example, levels of strontium above 3% in the diet of egg-laysystematic, and those of oxgen isotopes are distinctly different. The $\delta^{18}O$ values on samples from CGD Section are plotted in Fig. 3.

Examination of the samples with a scanning electron microscope indicates that it is typical for a primary calcitic growth structure of eggshells with almost no recrystallization. On the other hand, it can be seen that the above-mentioned isotopic data on the dinosaur eggshells measured by us are far from those of diagenetically altered freshwater limestones of the Cretaceous. The latter has an average calcite with the following isotopic composition: $\delta^{13}C = -4.3‰$; $\delta^{18}O = -10.2‰$ (PDB) (Keith and Weber, 1964). Therefore, it can be considered that our samples from Nanxiong Basin should not be altered diagenetically.

Oxygen and carbon in calcium carbonate of eggshells can derive from food, water or air which the egg-laying animals consumed. Specific ranges and changes of the ratio of ^{13}C to ^{12}C or ^{18}O to ^{16}O from these potential sources could show the source of oxygen and carbon contributions. Folinsbee et al. (1970) and Hoefs and Wedepohl (see Erben et al., 1979) established an almost linear correlation between oxygen from water and that from the eggshell canbonate. It has been indicated, however, that isotopic temperature of freshwater carbonates may be related to the changeable sources of continental waters, and to the restricted varying sizes of rivers and lakes. And the oxygen isotopic composition of rain-waters is not only controlled by air temperature but also by evaporation processes, by distance from the shore and by altitude. Especially, evaporation may shift the oxygen isotopic composition of freshwater towards "marine" values. Therefore, it is difficult to estimate the influence of these changeable factors on a paleotemperature related to freshwater environments.

Based on the foregoing oxygen isotopic composition of the dinosaur eggshells from Nanxiong Basin, the values of CGH Section are somewhat different from those of CGY-CGD Section. The latter seems to have more variations than the former. It is of interest that two remarkable oxygen-18 anomalies are seen in CGD Secion (Fig. 3). One is four samples from the levels of 60 to 80 meters of CGD Section and contains: $\delta^{18}O = +0.27‰$, $+4.22‰$, $+6.37‰$ and $+11.43‰$ respectively; the other is two samples from the levels of 100 to 110 meters of CGD Section and have $\delta^{18}O = +0.87‰$ and $+4.10‰$. It indicates that a remarkable change of climatic environment occurred at that time. According to Hoefs and Wedepohl (see Erben et al., 1979), extant ostrich in Africa must live on highly evaporated water at low latitude and at mean annual air temperature of the environment above 30°C. Their eggshells have an isotopic composition of $\delta^{18}O = +7.1‰$, $\delta^{13}C = -8.3‰$. Because relevant data are scarce, the changes on temperatures concerning the terminal Cretaceous of Nanxiong Basin can not conclusively be determined. From another point of view, however, the sudden increase of $\delta^{18}O$ from the eggshells in CGD Section can be due to a parameter other than temperature. As stated above, difference in evaporation is very effective in changing the oxygen isotopic composition of freshwater bodies. It seems reasonable to consider that the two unusual increases of heavy oxygen in the eggshells from CGD Section could reflect one, if not two, drastic changes of very dry climate.

V. Cause of the Last Dinosaur Extinction

As has been shown above, the different "species" of the dinosaur eggshell disappeared within the upper-middle part of the Pingling Formation. This almost coincides with the horizons yielding a great number of pathological eggshells and anomalous content in trace elesystematic, and those of oxgen isotopes are distinctly different. The $\delta^{18}O$ values on samples from CGD Section are plotted in Fig. 3.

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As has been shown above, the different "species" of the dinosaur eggshell disappeared within the upper-middle part of the Pingling Formation. This almost coincides with the horizons yielding a great number of pathological eggshells and anomalous content in trace elements and in oxygen isotope. They exactly fall within the early—middle span of chron 29R. These indicate that the dinosaur extinction in South China took place during the 200,000 to 300,000 years before the Cretaceous-Tertiary boundary. Good evidences show that the dinosaur extinction was related to the environmental changes, especially to the enrichment of trace elements. Therefore, such a condition requires no extraterrestrial explanation. It contradicts the fashionable impact theory.

Our scenario postulates that during the 200,000 to 300,000 years before the Cretaceous-Tertiary boundary, there was pollution by trace elements in South China area, and the extremely dry climate occurred at the same time. With excessive evaporation the trace elements contained in soil and in water were more enriched. Through the food chains, these trace elements were excessively taken into the dinosaurian body, thus causing imbalances of the trace element levels. As a result it affects dinosaur's reproduction, leading to the formation of pathologic eggshells. The eggshells became so bristle that they failed to protect the developing embryos. On the other hand, the trace elements, in spite of their presence in small amounts in the egg, may play an important role in the normal biological processes of the embryo. But the excess of trace elements transmitted to the egg from the dinosaur's food also causes abnormal embryonic development and considerably reduces hatchability. In consequence, the number of progeny reduced until finally the last population collapsed completely. This entire process of an extinction was, in terms of geological time, rather short, for our magnetostratigraphic evidence shows that it continued for only 200,000 to 300,000 years.

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