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甘肃灵台文王沟晚中新世—早更新世小哺乳动物[1)]

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摘要 根据大量小哺乳动物化石在地层中的分布,将文王沟剖面23层划分出5个生物地层带:Ⅰ带相当于榆社马会组;Ⅱ带与Ⅲ带相当于高庄组;Ⅳ带相当于麻则沟组;Ⅴ带为午城黄土底部。根据生物属种转换判定出4个主要生物事件发生时期,分别在5.8、3.6、3.0、2.4Ma左右。每一个生物事件集中发生的时期指示生态环境的一次显著向干冷方向变化。

关键词 甘肃灵台文王沟,晚新生代,小哺乳动物,生物地层,生物事件,环境变迁

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黄万波等1971~1972年及黄万波与Hideo Nakaya等1992~1993年在甘肃灵台雷家河村附近的野外考察中发现的含小哺乳动物化石地点主要有5个,即小石沟72074(1)、72074(3)、72074(4)及文王沟93001和93002地点(图1)。其中93001(包括93002)及72074(4)地点含化石层位多,产化石数量最为丰富,已进行了初步报道(Zheng, 1994)。但该报道存在的主要问题是没有逐层系统采集标本,因而在剖面上留下许多空白。为了提高生物地层学研究的精度,追寻哺乳动物各化石门类的进化规律和生物的发生、发展(或扩散)及绝灭事件及其反映的生态环境的变化,1997年9~11月间,笔者等再度赴灵台采集化石标本和孢粉样品。

采集标本的剖面集中在72074(4)和93001地点。采集方法是首先开挖出两地点的新鲜剖面,然后主要按旋回地层学方法将同一旋回地层划分为一层,每层再根据岩性变化分为不同的小层,并作好醒目的标记,最后逐层挖取岩样(平均每小层取土样约500kg)进行筛选。共获砂样约800kg。

经过室内选样和分类整理发现,几乎每一取过样的地层单元都有数量不等的小哺乳动物化石标本产出。在同一个剖面上包含如此丰富的生物信息在中国是绝无仅有的,在世界范围内也是罕见的。

本文集中报道93001地点的地层及小型哺乳动物化石在地层中的分布规律,也将93002地点(只1个化石层位)包括其中。小石沟3个地点的生物地层及其与文王沟生物地层的关系将在另文中研究发表。

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文中所用古地磁研究结果为魏兰英等(1993)所作，对比 Cande and Kent (1995)，依据 Berggren *et al.* (1995)的数据作了修订，并根据剖面存在着一个大的沉积间断作了新的年代解释。

剖面分层号为 WL，意为文王沟层序号。

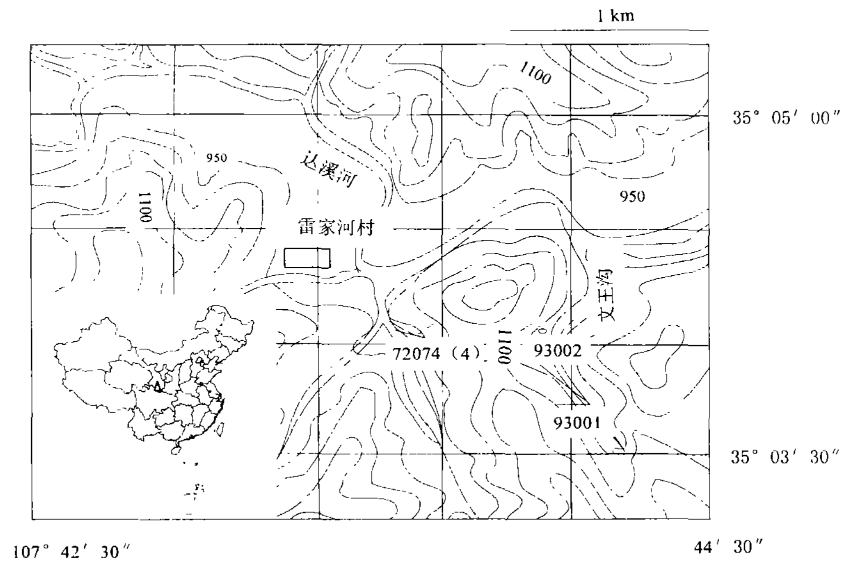

图1　甘肃灵台雷家河含小哺乳动物化石地点分布

Fig.1　Sketch map of the fossil micromammal localities near Leijiahe village, Lingtai, Gansu Province

1　地层划分与剖面描述

文王沟 93001 地点剖面从午城黄土底部往上第三层古土壤层顶部起往下为：

1. 棕红色古土壤，含化石　0.9m
2. 黄土，含钙质结核，未取样　0.4m
3. 上部黄土与下部的棕红色古土壤，含化石　1.8m
4. 黄土，含钙质结核，未取样　0.6m
5. 黄土，下部有薄层古土壤，含化石　1.35m
6. 黄土，含大量的钙质结核，钙质结核大，且形状不规则，未取样，含化石　2.5m
7. 棕红色粉砂质泥岩与棕黄色泥岩互层，含极少量的钙质结核，顶部与黄土混杂，分上、中、下 3 层取样，含化石　6.0m
8. 棕黄色砂砾石层。砂砾成分为小的钙质结核，砾径 0.5～1cm，磨圆度好，泥质胶结，夹少量的泥岩透镜体，含大量化石　1.65m
9. 棕红色泥质粉砂岩，夹薄层砂砾石透镜体(钙质结核，含少量化石)　1.2m
10. 棕黄色砂砾石层与棕褐色泥岩互层。砂砾石组成以钙质结核为主，砾径均一，磨圆度好，松散胶结。按岩性变化共分为 11 个小层，每小层均含大量化石　2.65m
11. 棕黄色砂砾石层与棕褐色泥岩互层。砂砾石组成以钙质结核为主，砾径均一，磨圆度好，松散胶结。按岩性变化分为 8 个小层，其中第 7 与第 8 小层的岩相变化较快，厚度

也有明显的变化。该层与下伏第 12 层之间存在不整合面，每小层均含大量化石 2.85m

12. 棕黄色砂砾石与灰褐色古土壤层。上部古土壤层有机质含量较高，下部有一清楚的淀积层。分上、下 2 层取样，含化石 2.0m

13. 棕红色砂岩与粉砂岩。下部砂岩层胶结坚硬，地形上突出。分上、下 2 层取样，未发现化石 0.45m

14. 棕黄色粉砂岩、泥质粉砂岩、泥岩等，夹少量的细砂岩透镜体。共分 8 个层位取样，从上往下只第 1、2、6、7、8 层中发现化石 12.2m

15. 棕黄色粉砂岩，夹 3 层细砂岩及砾石透镜体。分 4 个层位取样，只第 2、3 层发现化石 4.7m

16. 厚层砾岩层，砾石成分以花岗岩、片麻岩、石英岩等为主；磨圆度好，分选中等，胶结坚硬，地形上成陡坎，未取样 4.6m

17. 灰褐色、灰绿色、棕黄色泥岩，上部富含植物遗迹，为灰黑色泥炭透镜体。93002 地点经过测量、对比，与该层顶部相当。下部砂砾石透镜体中含化石 4.2m

18. 灰褐色泥岩，底部为砂砾石。砂砾石成分以花岗岩、片麻岩为主；磨圆度好，松散胶结。底部含化石 1.2m

19. 棕黄色粉砂岩、粉砂质泥岩，底部有 5cm 厚的砂砾石层。砂砾石成分以花岗岩、片麻岩为主；磨圆度好，松散胶结。底部含化石 0.6m

20. 棕黄色粉砂岩、粉砂质泥岩，底部有 20cm 厚的砂砾石层。砂砾石成分以花岗岩、片麻岩为主；磨圆度好，松散胶结。底部含化石 0.9m

21. 棕黄色粉砂岩、粉砂质泥岩，底部有 35cm 厚的砂砾石层。砂砾石成分以花岗岩、片麻岩为主；磨圆度好，松散胶结。底部含化石 0.6m

22. 棕黄色粉砂岩、粉砂质泥岩，下部夹灰绿色泥岩透镜体，底部有 10cm 厚的砂砾石层。砂砾石成分以花岗岩、片麻岩为主；磨圆度好，松散胶结。底部含化石 0.7m

23. 棕红色粉砂质泥岩，下部被坡积物覆盖

2 生物地层带与年代范围

文王沟迄今所发现小哺乳动物化石总计约 60 余种，在地层中的分布见图 2。

根据岩石地层学和生物的进化，可以将文王沟剖面从下至上划分为五个生物地层带。

Ⅰ带 地层层位从 WL22～WL17 层。该带中鼠科化石比重最大(占 41%)，化石种类主要为我国北方中新世晚期常见的分子。与榆社的马会组及高庄组桃杨段动物化石组合(Tedford *et al.*, 1991; Wu *et al.*, 1992; Flynn *et al.*, 1997)可以对比的种类有：*Ochotona lagrelli*、*Prosiphneus* sp.、*Micromys tedfordi*、*Huaxiamys* n. sp.、*H. primitivus*、*Pseudomeriones abbreviatus* 等。其中 *Ochotona lagrelli*、*Micromys tedfordi*、*Huaxiamys primitivus*、*Pseudomeriones abbreviatus* 等种类在本剖面上延续时间较榆社的长。*Huaxiamys* n. sp. 显示出较 *H. primitivus* 原始的特征，在本剖面的产出层位也较低，*Prosiphneus* sp. 可能和榆社的 *P. murinus* 相当。与二登图动物群(Fahlbusch *et al.*, 1983; Qiu, 1987; Storch, 1987; Wu, 1991)可对比的种类有 *Ochotona lagrelli*、*Pseudomeriones abbreviatus*、*Paralactaga*、*Occitanomys* n. sp.、"*Karnimata*" *hipparionum*、*Nannocricetus* *mongolicus*、*Prosiphneus* 等。与榆社马会组动物群一样，文王沟剖面上也未出现二登图动物群的特征分子 *Microtoscoptes* 和 *Microtodon*，这似乎表明它们所处的生物地理区系像马会组一样有所不同(Flynn *et al.*, 1997)。I 带在动物群的成分上似乎表明当时的动物地理区系更接近山西榆社，而较少内蒙古二登图的色彩。通过古地磁测试结果对比，第 1 生物地层带中包含了 3 个正向期及 2 个很短的反向期，与 GPTS 对比，可能分别相当于 C3A 与 C3Br. ln，因此本剖面的底部年龄可能与灵台任家坡红粘土剖面的底部相当，约 7Ma(Sun *et al.*, 1998)；而该带上部年龄约为 5.8Ma。这与榆社盆地马会组上部古地磁测试结果(Tedford *et al.*, 1991; Flynn *et al.*, 1995)相吻合。综合以上动物群对比与古地磁测定结果，可以初步认为该哺乳动物化石带的年龄与山西榆社马会组动物群相当，为中新世晚期，约 7～5.8Ma，二登图动物群的时代也与其相当，并可能早于中、上新世界线(Flynn *et al.*, 1995; Flynn, 1997)。

II 带　地层层位为 WL16 层。该层为厚度较大的砾岩层，在本地区分布面积较大，大石沟部分地段及文王沟的右岸口处直接覆盖在白垩系泥岩之上。尽管没有化石发现，但可能指示了一个相当长的地质时期。

III 带　地层层位从 WL15～WL13 层。该带化石发现较少，与其层位相对应的小石沟剖面上发现的化石可作为重要的补充(将另文发表)。除继续生存的 *Pseudomeriones abbreviatus*、*Micromys tedfordi*、*Huaxiamys primitivus*、*Chardinomys yusheensis* 等外，还出现 *Chardina sinensis*、*Micromys* cf. *M. chalceus* 等新种类。此带仍然以鼠科种类占优势为典型特点。*Chardina sinensis* 的高冠程度显著大于中新世晚期种类(郑绍华，1997)，*Micromys* cf. *M. chalceus* 主要发现于 Turolian 期至 Ruscinian 期(Storch, 1987)，*Huaxiamys primitivus* 在榆社盆地仅发现于马会组上部与高庄组下部，*Chardinomys yusheensis* 则发现于高庄组上部(Wu et Flynn, 1992)。根据以上动物化石组合，该带应当相当于高庄组。古地磁极性对比结果显示该带相当于吉尔伯特反向期，为上新世早期，但只包含了三个正向期，这可能是与 WL16 层为一个侵蚀间断有关。

IV 带　地层层位从 WL12～WL7 层。该带化石种类、数量最为丰富(共 43 种)。其中鼠科种类所占比例(20%)下降，鼢鼠大量出现(占 23%)，仓鼠、松鼠、鼠兔、鼯科等也占有相当比例。该带层位可与魏兰英等(1993)的高斯期(约 3.6～2.6Ma)对比。在 WL8 层(约 3.1～3.2Ma)，发现于我国北方第四纪早期化石地点，如周口店第十八地点(Teilhard, 1940)、山东淄博 A 动物群(郑绍华等，1997)的 *Alilepus brachypus* 开始出现，上新世种类如 *Ochotona* cf. *O. lagrelli*、*Mesosiphneus*、*Paralactaga*、*Protozapus*、*Chardinomys louisi* 等为最后的出现。该带化石组合中 *Chardinomys louisi*、*Micromys tedfordi*、*Allocricetus bursae*、*A. ehiki*、*Ochotonoides complicidens* 等与榆社盆地麻则沟组产出化石可直接对比。*Chardinomys louisi* 和原始的 *Borsodia* 等则可与山西静乐动物群(周晓元，1988)相对比。通过 *Chardinomys louisi* 和最进步的 *Mesosiphneus* 等在时代上可与稻地动物群(蔡保全，1987；蔡保全、邱铸鼎，1993)对比。古地磁测定结果为高斯正向期(魏兰英等，1993)，年龄约为 3.6～2.6Ma。其时代应相当于上新世晚期。

V 带　地层层位从 WL7～WL1 层。该带化石种类大量减少。我国北方第四纪早期的 *Yangia* cf. *Y. trassaerti*、*Allophaiomys* 开始出现。被认为是最原始的 *Allophaiomys* 种 *A.*

terrae-rubrea (Repenning *et al.*, 1990)曾在周口店第十八地点(Teilhard, 1940)、山东淄博孙家山(郑绍华等,1997)及北京黄坎(黄万波等,1983)等地点发现过。*Yangia* cf. *Y. trassaerti* 在榆社盆地延续的时间可能在2.5～1.8Ma之间(郑绍华,1997)。动物化石组合的面貌基本上显示出早更新世的特征。化石层位对应的古地磁极性期为松山负极性期早期,相当于更新世最早期。

综上所述,除II带可能代表了一段侵蚀期外,文王沟剖面基本上代表了从中新世晚期至早更新世早期的地质历史时期。

3 属种转换与生物事件

1) 3.6～3.0Ma时期:纵观文王沟剖面,化石最密集的时段在3.6～3.0Ma间,代表了上新世晚期华北地区小哺乳动物化石最丰富的地点,其种类(46种)远比榆社麻则沟组(19种)(Flynn *et al.*, 1997)、静乐小红凹(8种)(周晓元,1988)、泥河湾稻地组(21种)(蔡保全,1987,1989;蔡保全、邱铸鼎,1993)等同一时期动物群丰富。由于剖面连续,所产化石上下层位的时间限定清楚,因而记录了许多生物事件(包括属种转换、上新世时期种类的最后绝灭、第四纪属种的最早出现)等信息。

在这一时段,记录了鼠兔科中的 *Ochotonoides complicidens*,鼢鼠科中的 *Yangia omegodon*, *Eospalax* 和 *Allosiphneus teilhardi*,鼾科中的 *Cromeromys gansunicus* 和 *Borsodia*,仓鼠科中的 *Bahomys*,沙鼠科中的 *Pseudomeriones complicidens* 以及鼠科中的 *Chardinomys louisi* 的最早出现,同时记录了兔科中的 *Trischizolagus dumitrescuae*,鼢鼠科中的 *Chardina truncatus*、*Mesosiphneus praetingi*、*M. intermedius*,仓鼠科中的 *Cricetinus mesolophidus* (吴文裕等,待刊),沙鼠科中的 *Pseudomeriones abbreviatus*,松鼠科中的 *Atlantoxerus*,鼠科中的 *Huaxiamys downsi*, *Micromys tedfordi* 和 *Chardinomys yusheensis* 的最后绝灭。在这些最后绝灭和最早出现之间孕育了明显的属种转换事件。

在鼢鼠类中,根据臼齿特别是m1的形态区分出的凹枕型和凸枕型鼢鼠(郑绍华,1997)构成了这一时期生物转换事件的主体。最进步的高冠的、臼齿带根的凹枕型鼢鼠 *Mesosiphneus intermedius* 大约在3.5Ma前后从 *M. praetingi* 中分化出来,而其自身又在大约3.45Ma进化出臼齿无根的 *Yangia* n. sp. 和 *Y. omegodon*;最进步的高冠的臼齿带根的凸枕型鼢鼠 *Pliosiphneus* n. sp. 2可能在大约3.5Ma时孕育了最原始的臼齿无根的 *Eospalax* n. sp., 后在大约3.3Ma可能又孕育出一类特殊的臼齿无根的鼢鼠 *Allosiphneus teilhardi*。尽管剖面中记录的最原始的臼齿无根的凸枕型鼢鼠 *Eospalax* 早于最进步的臼齿带根的 *Pliosiphneus* n. sp. 2,但这种判断似乎合乎情理。

最进步的臼齿带根的鼢鼠与最原始的臼齿无根的鼢鼠在同一时期共存表明早先关于鼢鼠类的线系进化模式(Teilhard et Young, 1931; Zheng, 1994, 1997)将会被修订。

在仓鼠类中,大型的 *Bahomys* 有可能在3.4Ma前后从大型的 *Cricetinus mesolophidus* 中演化形成,齿冠形态发生了很大变化。

沙鼠类中 *Pseudomeriones complicidens* 大约在3.5Ma前后从 *P. abbreviatus* 中发展而来,前者的个体相对较小,但齿冠形态相对更为复杂(张兆群,1999)。

在鼠科中最明显的是 *Chardinomys louisi* 在大约3.5Ma时从 *C. yusheensis* 分化出来,

其个体显著变小，M1 齿根数目从 4 个增加至 5 个，齿冠构造相对简单。

2) 2.4Ma 前后，鼾科中出现了时代最早的 *Allophaiomys terrae-rubrae* (Zheng et Li, 1990; Repenning *et al.*, 1990)。这种最早的臼齿无根、齿褶内带有丰富白垩质的田鼠有可能直接从最早出现于文王沟剖面一直延续到泥河湾时期(郑绍华，1976；Zheng et Li, 1990; Flynn *et al.*, 1997)的 *Cromeromys gansunicus* 中分化出来。鼢鼠科中的 *Yangia trassaerti* 有可能从 *Yangia* n. sp.中产生。

3) 5.8Ma 前后，93002 地点记录了 2 个重要的生物事件。一是 *Chardinomys yusheensis* 和? *Occitanomys* n. sp.共生。前者齿尖脊形化的 M1 和 m1 构造可能是从后者的锥形齿尖进化而来，因为两者具有相同的齿尖构造和排列方式，只是前者 M1 具 4 个、后者具 3 个齿根；二是出现了 *Micromys tedfordi* 的最早记录，尽管它和 *Micromys* cf. *M. chalceus* 没有在这一时期共生，但从后者在剖面中的分布的时间判断，它们之间似乎也存在着一种前者向后者的进化关系。

剖面中从 5.8～3.6Ma 之间产出化石较少，没有明显的生物事件反映出来，但邻近的小石沟剖面产出的丰富小哺乳动物化石可以填补这一时期的空白。我们将在另一篇文章中将文王沟与小石沟剖面有机地联系起来阐述。在描述属种的特征时将进一步讨论每一属种之间的进化关系。

4　生物事件与环境变迁

从文王沟剖面记录的小哺乳动物化石分析，大约 7.0Ma 以来，几乎所有种类都是华北地区的地方类型。一些种类如鼩鼱科中的 *Beremendia*、兔科中的 *Trischizolagus*、鼾科中的 *Cromeromys* 及 *Borsodia*、仓鼠科中的 *Kowalskia* 及 *Allocricetus*、沙鼠科中的 *Pseudomeriones*、林跳鼠科中的 *Protozapus*、松鼠科中的 *Atlantoxerus*、鼠科中的 *Occitanomys* 等的原始种类可能是外来者或是在中国发现的记录较晚，但从 7.0Ma 以来已完全地方化，从而落地生根，繁衍后代。在繁衍过程中为适应环境的变化不断改变自身的结构，从而发生属种的转换事件。一些种类适应能力较强，相对长寿；另一些种类适应能力较弱，则相对短命。

华北地区晚新生代以来环境变化既受全球气候波动也受青藏高原的不断抬升导致的东亚季风气候的控制。文王沟剖面上反映出 4 个大的气候事件分别发生在大约 5.8、3.6、3.0 和 2.4Ma BP。

约 7Ma，中国黄土高原地区的风尘沉积开始(孙东怀等，1997，1998；安芷生等，1999)，标志着东亚环境系统发生了很大的分异，作为风尘搬运动力的冬季风系统开始建立。从本剖面的底部开始，代表干旱气候条件的 *Pseudomeriones* 已从西亚进入中国，生活在草原环境的 *Ochotona*、*Prosiphneus* 等已普遍存在，但大量鼠科种类的存在标志着气候较为温和湿润，具有森林环境的特征，应为以森林为主的森林—草原环境。

5.8Ma 前后，剖面上反映出的哺乳动物生物事件以鼠科种类的发生、迁移与灭绝为主，对应于全球性的海平面下降(Haq *et al.*, 1988)，标志着气候有所变冷，环境开始朝着森林面积减小、草原面积增大的方向发展。

3.6Ma 前后发生的生物事件最为显著。鼢鼠类以丢失牙根使臼齿持续生长，从而极大

地加强了食物咀嚼的功能，导致了 *Yangia* 在更新世时期(郑绍华，1997)及 *Eospalax* 在第四纪时期和现代的繁荣；*Bahomys* 以齿冠极大地增高、齿脊增多、珐琅质褶皱极端复杂化来延长牙齿的使用时间及研磨粗劣食物的功能，从而极大地增强了适应恶劣环境条件的能力，使其一直延续至中更新世早期(约 0.65Ma 前后)才绝灭(周明镇，李传夔，1965；安芷生等，1990)；假沙鼠的牙齿结构复杂化，由 *Pseudomeriones abbreviatus* 向 *P. complicidens* 转化；*Chardinomys louisi* 以减小体形而减少食物摄入，增加齿根数目以加强臼齿研磨食物的稳固性；*Cromeromys* 与 *Borsodia* 从一出现就具有高冠齿等。以上所有形态功能的改变都清楚指示出动物赖以生存的环境已具有了干、冷草原环境的雏形。这与安芷生等(1999)根据灵台附近风积黄土—红粘土序列的磁化率曲线和沉积速率变化分别与赤道东太平洋$\sigma^{18}O$曲线和北太平洋风尘石英沉积通量变化等对比得出的 3.4Ma 青藏高原加速隆升，冬夏季风快速增强的结论基本吻合，也和 Repenning 等(1990)根据 arvicolids 得出的第四次全球生物扩散事件相一致。

文王沟剖面上显示的另一次大的生物事件发生在 3.0Ma 前后。由于生态压力的进一步加剧，鼢鼠科中的臼齿带根鼢鼠 *Mesosiphneus* 和 *Pliosiphneus*、沙鼠科中的 *Pseudomeriones*、鼠科中 *Chardinomys yusheensis*、*C. louisi*、兔科中的 *Trischizolagus* 等不适应环境的进一步恶化而绝灭，这一事件和 Repenning 等(1990)的全球第 5 次生物扩散事件相一致。

安芷生等(1999)认为从 2.6Ma 开始青藏高原再次加速隆升，东亚季风进入盛行期。在 2.6～2.0Ma 期间，文王沟剖面化石记录较少，但已显露出新时期开始的曙光。*Yangia* n. sp. 向 *Y. trassaerti*、*Cromeromys gansunicus* 向 *Allophaiomys* 的转换，可能还有 *Borsodia* n. sp. 向 *Hyperacrinus* 以及 *Trischizolagus* 向 *Lepus* 的转换，表明气候环境又一次发生突变。真正的黄色黄土开始堆积，其环境已完全变成草原环境。2.6Ma 发生的这一事件和 Repenning 等(1990)的全球第 6 次生物扩散事件可以相对比。

在 3.0～2.6Ma 时段内文王沟剖面化石发现较少，这可能是由于北半球大冰期来临前的一个沉寂阶段，也可能是化石采样只集中在同一剖面的缘故，更可能是从 3Ma 起大冰期已经来临，气候环境已经进一步恶化，接近黄土形成时的气候条件。

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LATE MIOCENE–EARLY PLEISTOCENE MICROMAMMALS FROM WENWANGGOU OF LINGTAI, GANSU, CHINA

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Summary

Since 1971, 5 micromammalian fossil localities have been found in the area near Leijiahe village, Lingtai County, Gansu Province (Fig. 1). Two of them, Loc. 93001(Wenwanggou) and Loc. 72074(4) (Xiaoshigou), are the best with continuous sections and yielding large amount of fossils (Zheng, 1994). However, there still left many gaps between fossil levels for sampling reason. In the field season of 1997, we further studied on these two sections. Here is the report on the first.

The Wenwanggou section was subdivided into 23 levels cyclostratigraphically and further into different layers lithologically in each level. Samples were extracted layer by layer and washed with screen. The result shows that almost every sampled layer produced fossil micromammals of different amount (Fig. 2).

In this paper, the magnetostratigraphic data of Wei *et al.* (1993) are adopted, and modified with updated geomagnetic polarity time-scale (GPTS). The age calibration is referred to Berggren *et al.* (1995).

1 Biostratigraphic division and biochronologic correlation

The Wenwanggou section can be subdivided into 5 biostratigraphic zones by fossil contents:

Zone 1(WL22～WL17). This zone is characterized by the dominance of murids (41% of the total species in the assemblage), and endemism of taxa discovered before from North China. Some species, including *Ochotona lagrelli*, *Prosiphneus* sp., *Micromys tedfordi*, *Huaxiamys* n. sp., *H. primitivus*, and *Pseudomeriones abbreviatus* etc., can be compared directly with those from the Mahui Fm., and the lower Gaozhuang Fm. of Yushe Basin (Flynn *et al.*, 1997; Tedford *et al.*, 1991), though *Ochotona lagrelli*, *Huaxiamys primitivus*, *Pseudomeriones abbreviatus* and *Micromys tedfordi* survived much longer in Lingtai than in Yushe. *Huaxiamys* n. sp. is more primitive than *H. primitivus*. *Prosiphneus* sp. can be compared with *P. murinus* of

Yushe from the evolutionary level point of view. Therefore, zone 1 can be considered equivalent biostratigraphically to Mahui Fm. The complex of *Ochotona lagrelli*, "*Kanimata*" *hipparionum*, *Pseudomeriones abbreviatus*, *Paralactaga*, ? *Occitanomys* n. sp., *Nannocricetus mongolicus*, and *Prosiphneus*, etc. are similar to those from Ertemte (Fahlbusch *et al.*, 1983; Qiu, 1987; Storch, 1987; Wu, 1991). As in the fauna of Yushe, no characteristic genera *Microtoscoptes* and *Microtodon* was found in this section. This may also suggest the same biogeographic difference as Mahui Fm. to Ertemte (Flynn *et al.*, 1997). The fauna of zone 1 seems biogeographically more similar to that of Yushe rather than to Ertemte. Magnetostragraphically, zone 1 is correlative to C3A and C3Br. 1n, dated about 7～5.8Ma, roughly the same as Mahui Fm. (Tedford *et al.*, 1991; Flynn *et al.*, 1995). Biochronologically and magnetochronologically, this zone can be correlated with Ertemte and Mahui Formation of Yushe basin.

Zone 2 (WL16). This conglomerate layer distributes in a large area and its source materials may be from far away to the south Qinling Mountains according to geological survey. No fossil was found in it. Sedimentologically, it shows that between Zone 1 and Zone 3 there exist a long time-span erosion period.

Zone 3 (WL15～WL13). Fossils are quite paucity in this zone. However, great numbers of fossils from the other section nearby (Xiaoshigou) about the same level can be complement (to be published). Some taxa of zone 1, *Pseudomeriones abbreviatus*, *Micromys tedfordi*, *Huaxiamys primitivus*, *Chardinomys yusheensis* survived, and *Chardina sinensis*, *Micromys* cf. *M. chalceus* first appeared. The murids are still dominant. By its higher crowned molars, *Chardina sinensis* is evidently more derived than *Prosiphneus* from the late Miocene (Zheng, 1997). *Micromys* cf. *M. chalceus* has been found from localities of Turolian to Ruscinian (Storch, 1987). In Yushe basin, *Huaxiamys primitivus* survived from the upper Mahui to lower Gaozhuang Formation, while *Chardinomys yusheensis* in upper Gaozhuang Formation (Wu et Flynn, 1992). Synthetically, zone 2 can be roughly correlated with Gaozhuang Formtion. The magnetic data show the Gilbert reversal polarity period, but only have three positive events recorded.

Zone 4 (WL12～WL7). This zone falls totally into the Gauss normal polarity period, which dated as 3.6～2.6 Ma in Berggren *et al.* (1995). It yielded the most diverse (43 species) and abundant fossils in the section. The component of murids (20%) decreased in number of species, while the siphneids, cricetids, arvicolids, scuirids, ochotonids etc. booming. From WL8 on, the leporids, *Alilepus brachypus*, appeared which was only found before from the early Pleistocene localities, e.g. Loc. 18 of Choukoutian (Teilhard, 1940), Sunjiashan, Zibo (Zheng *et al.*, 1997). Some Pliocene taxa, *Ochotona* cf. *O. lagrelli*, *Mesosiphneus*, *Paralactaga*, *Protozapus*, *Chardinomys louisi* became extinct at the same time. By sharing *Chardinomys louisi*, *Micromys tedfordi*, *Allocricetus bursae*, *Allocricetus ehiki*, and *Ochotonoides complicidens*, this zone can be correlated with Mazegou Formtion directly. *Chardinomys louisi* and the primitive *Borsodia* are in the same evolutionary level as those from Jingle (Zhou, 1988). By the *Chardinomys louisi* and the most derived *Mesosiphneus*, the fauna can be compared with that of Daodi (Cai, 1987, 1989; Cai et Qiu, 1993). Thus, this zone is evidently of late Pliocene in age.

Zone 5 (WL7～WL1). The species diversity decreased significantly in this zone. The early Pleistocene elements from North China, *Yangia* cf. *Y. trassaerti* and *Allophaiomys terrae-rubrea* appeared. The former lasted from 2.5 to 1.8Ma in Yushe basin (Zheng, 1997); the latter, most primitive species of *Allophaiomys* (Repenning *et al.*, 1990), discovered before from Loc. 18, Choukoutian (Teilhard, 1940), Zibo (Zheng *et al.*, 1997) and Huangkan, near Beijing (Huang *et al.*, 1983). Magnetostratigraphically, this zone is equivalent to the early Matsuyama polarity time, of early Pleistocene.

Conclusively, apart from a period of missing gap, the Wenwanggou section represented the geological time from late Miocene to early Pleistocene.

2 Faunal turnover and bioevents

1) 3.6～3.0Ma: The micromammals discovered from Zone 4 are the most abundant found in China so far, much more in diversity (43 species) than those from Mazegou Formation (19) (Flynn *et al.*, 1997), Jingle (8) (Zhou, 1988), and Daodi (21) (Cai, 1987, 1989; Cai et Qiu, 1993). Many bioevents can be recognized from the almost continuous section, e. g. faunal turnover, extinction of the Pliocene taxa, and first appearance of Pleistocene taxa.

In this zone, there recorded first appearance of *Ochotonoides complicidens*, *Yangia omegodon*, *Eospalax*, *Allosiphneus teilhardi*, *Cromeromys gansunicus*, *Borsodia*, *Bahomys*, *Pseudomeriones complicidens* and *Chardinomys louisi*; and last appearance of *Trischizolagus dumitrescuae*, *Chardina truncatus*, *Mesosiphneus praetingi*, *M. intermedius*, *Cricetinus mesolophidus*, *Pseudomeriones abbreviatus*, *Atlantoxerus*, *Huaxiamys downsi*, *Micromys tedfordi* and *Chardinomys yusheensis* etc. The faunal turnover is evidently reflected.

Many turnover events took place in siphneids. About 3.5Ma BP, the most derived molar-rooted concave-occipital siphneids, *Mesosiphneus intermedius*, was evolved from *M. praetingi*, and slightly later on, itself evolved into the molar-rootless *Yangia* n. sp. and *Y. omegodon*. At the same time, most advanced molar-rooted convex-occipital *Pliosiphneus* n. sp. 2 evolved into the most primitive rootless *Eospalax* n. sp., and another rootless *Allosiphneus teilhardi* in about 3.3Ma, though the appearance of *Eospalax* is earlier than *Pliosiphneus* n. sp. 2 in the section.

The cricetids, *Bahomys* might be evolved from the large sized *Cricetinus mesolophidus* in about 3.4Ma BP with great changes of the check tooth morphology.

Pseudomeriones complicidens (Zhang, 1999) evolved from *P. abbreviatus* by the complication of the m1 in about 3.5Ma.

From *Chardinomys yusheensis* to *C. louisi*, the tooth size decreased significantly, and the root number increased from 4 to 5.

2) In 2.4Ma, *Allophaiomys terrae-rubrae*, which was thought as the most primitive species in *Allophaiomys* (Zheng et Li, 1990; Repenning *et al.*, 1990), first appeared in this section, which might evolved directly from the *Cromeromys gansunicus* (Zheng, 1976; Zheng et Li, 1990; Flynn *et al.*, 1997). Meanwhile, *Yangia trassaerti* evolved from *Yangia* n. sp.

3) In about 5.8Ma, two important bioevents were recorded at the 93002 locality. By their tooth characters and co-existence of *Chardinomys yusheensis* and ? *Occitanomys* n. sp., we assume that the former was probably evolved from the latter. The other event is the first appearance of *Micromys tedfordi*.

There are not enough fossil materials found from the section during 5.8～3.6Ma, and no evident bioevents can be recognized. Fortunately, in the other section (Xiaoshigou), abundant fossils of the same time can be ideal complement.

3 Bioevents and environmental changes

Almost all the taxa from the Wenwanggou section are endemic elements of North China. The primitive forms of some taxa, such as *Beremendia*, *Trischizolagus*, *Cromeromys*, *Borsodia*, *Kowalskia*, *Allocricetus*, *Pseudomeriones*, *Protozapus*, *Atlantoxerus*, *Occitanomys* etc. may be allochthonous. For adapting to environmental variation, whatever endemic or immigrates, all have to constantly change their structures. Some successors survived, while others died out under crucial ecological pressure. Meanwhile, many bioevents happened.

The evident climatic events that can be recognized from the Wenwanggou section happened in about 5.8, 3.6, 3.0 and 2.4Ma BP respectively.

In the late Neogene, global climatic changes and the uplift of the Tibet Plateau largely controlled the climates of North China. The eolian accumulation of the Loess Plateau area started about 7Ma ago, which marks the onset of the present day East Asia monsoon system (Sun *et al.*, 1997, 1998; An *et al.*, 1999). From the base of the section, *Pseudomeriones*, a dry grassland dweller, migrated to China from West Asia. The typical grassland animals, *Ochotona* and *Prosiphneus* are also discovered. However, large amount of murid rodents existed still indicates a warm, humid forest or forest-grassland ecological environment.

The bioevents of 5.8Ma are coincided with the time of a global sea level drop (Haq *et al.*, 1988).

In 3.6Ma BP, Many bioevents took place with tooth morphology changes. The lost of tooth roots in siphneids that makes teeth grow all life-time span enhanced significantly masticatory ability which leads to the flourish of *Yangia* and *Eospalax* in Pleistocene and Recent (Zheng, 1997). The high tooth crown, complicated enamel folds, and much more crests etc. of *Bahomys*, enable this genus survived to Middle Pleistocene (about 0.65Ma) (Zhou et Li, 1965; An *et al.*, 1990). By the complication of the tooth enamel, *P. complicidens* evolved from *Pseudomeriones abbreviatus*. The body size of *Chardinomys louisi* minimized, the root numbers increased. *Cromeromys* and *Borsodia* got high crowned teeth from the very beginning. That all the functional morphology changes above occurred at almost the same time strongly indicates that the habitat of these animals became drier and colder grassland. The similar conclusion of the climatic change came from the study on the red clays of Loess Plateau (An *et al.*, 1999), based on magnetic variation correlated with the $\sigma^{18}O$ curve of the East Pacific Ocean. This event is also coincided with the fourth arvicolid dispersal event (Repenning *et al.*, 1990).

Another pulse of massive distinction took place in about 3.0Ma BP. Under more severe ecological pressure, the rooted siphneids, *Mesosiphneus* and *Pliosiphneus, Pseudomeriones, Chardinomys yusheensis* and *C. louisi, Trischizolagus* etc. died out at almost same time, when the fifth arvicolid dispersal event happened (Repenning *et al.*, 1990).

An *et al.* (1999) figured that in about 2.6Ma BP, the Tibet Plateau uplifted to a significant level, and the East Asian winter monsoon became much stronger. Though there are not many bioevents recorded during 2.6～2.0Ma in the section, the faunal turnovers, *Yangia* n. sp.-*Y. trassaerti*, *Cromeromys gansunicus*-*Allophaiomys* and possibly *Borsodia* n. sp.-*Hyperacrius*, *Trischizolagus*-*Lepus* evidently reflect an abrupt climatic deterioration event, coincident with the 6th global arvicolid dispersal event (Repenning *et al.*, 1990).

There not many fossil materials found from the section of about 3.0～2.6Ma. This may be partly of the sampling reason. The most probable explanation may be that from 3Ma, the fast growth of global ice volume started and the environment had already deteriorated to the extent as the loess accumulated.

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