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临夏盆地的新生代地层及其哺乳动物化石证据[1)]

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摘要: 临夏盆地的新生代地层相当发育,保存了从渐新世至全新世的连续沉积序列。更为重要的是,这些沉积物中含有丰富的哺乳动物化石,为划分和对比临夏盆地的新生代地层提供了可靠的证据。然而,此前关于这个盆地地层层序和时代的认识有许多矛盾之处,地层命名繁复,化石证据混乱。近年来我们对临夏盆地的野外考察已理清了沉积序列,并在充分的哺乳动物化石证据的基础上重新厘定了各个岩石地层单位所对应的地质时代。临夏盆地的新生代哺乳动物化石以晚渐新世的巨犀动物群、中中新世的铲齿象动物群、晚中新世的三趾马动物群和早更新世的真马动物群最为丰富。

关键词: 临夏盆地,新生代,地层,哺乳动物

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临夏盆地位于甘肃省东南部,是由青藏高原东北缘雷积山深大断裂、秦岭北深大断裂和祁连山东延余脉马衔山围成的一个山前拗陷盆地(方小敏等,1997)。临夏盆地新生代地层的岩性和层序与甘肃中部众多的新生代沉积盆地很接近,这些小盆地被统称为陇中盆地。临夏盆地的新生代沉积相对稳定,地层接近水平,含大量哺乳动物化石(图 1)。

20 世纪 50 年代及以前的有关文献多以新近纪甘肃群和第四纪沉积概括临夏盆地的新生代地层。甘肃地质局区测队(1965)将临夏盆地的第三纪红层命名为临夏组,并划分出 4 个岩性段。根据剖面上部发现的三趾马化石,临夏组时代被定为上新世。甘肃地质局区调队(1984)根据三趾马在建组剖面中的产出位置,主张将临夏组一名仅限于该剖面的第三、四段,而将第一段与兰州盆地古近纪的野狐城组和西柳沟组对比,将第二段与中新世的咸水河组对比。邱占祥等(1990)和谢骏义(1991)认为原来的临夏组 4 个段全部属于中新世(即现今的晚中新世),将其第一、二段命名为椒子沟组,时代为早中新世;将以第三段为主的地层命名为东乡层,时代为中中新世;将临夏组一名限于原划分的第四岩性段,时代为晚中新世。兰州大学在 20 世纪 90 年代对临夏盆地的晚新生代地层重新进行了详细的划分,命名了一套全新的岩石地层单位,并进行了以古地磁为主要方法的年龄测定(Li et al., 1995;方小敏等,1997;Fang et al., 2003)。

经过我们近年来的野外勘察和追索,发现在临夏盆地新生代地层的划分、对比和时代

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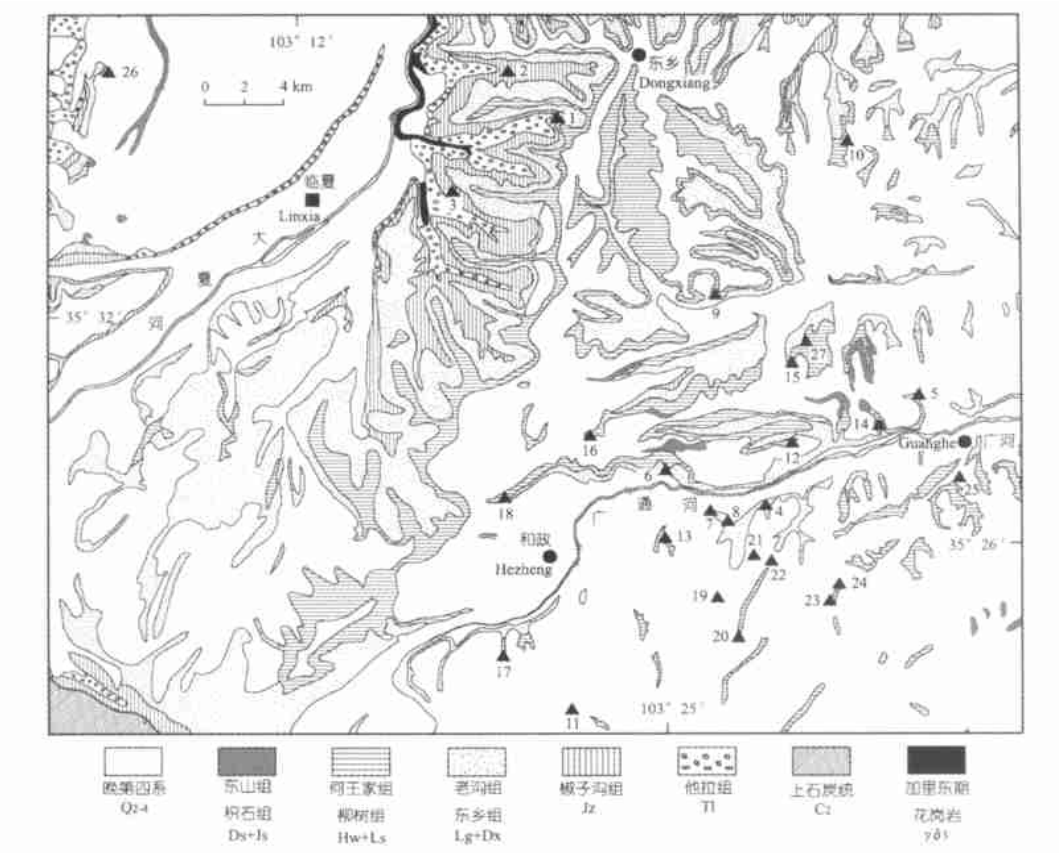

图 1 临夏盆地哺乳动物化石地点分布

Fig. 1 Distribution of mammal fossil localities in the Linxia Basin

1. **椒子沟**(Jiaozigou)；2. **他拉**(Tala)；3. **牙沟**(Yagou)；4. **大浪沟**(Dalanggou)；5. **王石阶**(Wangshijie)；6. **老沟**(Laogou)；7. **朱家川**(Zhujiachuan)；8. **虎家梁**(Hujialiang)；9. **郭泥沟**(Guonigou)；10. **汪集**(Wangji)；11. **大深沟**(Dashengou)；12. **后山**(Houshan)；13. **山庄**(Shanzhuang)；14. **寺沟**(Sigou)；15. **双拱北**(Shuanggongbei)；16. **杨家山**(Yangjiashan)；17. **黑林顶**(Heilinding)；18. **山家湾**(Shanjiawan)；19. **龙家湾**(Longjiawan)；20. **怀沟**(Huaigou)；21. **石磊**(Shilei)；22. **松树沟**(Songshugou)；23. **南面沟**(Nanmiangou)；24. **阳洼铺子**(Yangwapuzi)；25. **十里墩**(Shilidun)；26. **银川**(Yinchuan)；27. **龙担**(Longdan)；Ds. Dongshan Fm.；Js. Jishi Fm.；Hw. Hewangjia Fm.；Ls. Liushu Fm.；Lg. Laogou Fm.；Dx. Dongxiang Fm.；Jz. Jiaozigou Fm.；Tl. Tala Fm.

方面存在一些问题。根据在临夏盆地发现的大量哺乳动物化石,我们对地层的划分和时代的确定提出了新的看法(图 2,表 1)。各组之间的界线均为粗碎屑的砂岩或砾岩与细颗粒的泥岩、红粘土或黄土接触,上、下地层产状都近水平,因此它们代表了整合或平行不整合界面。

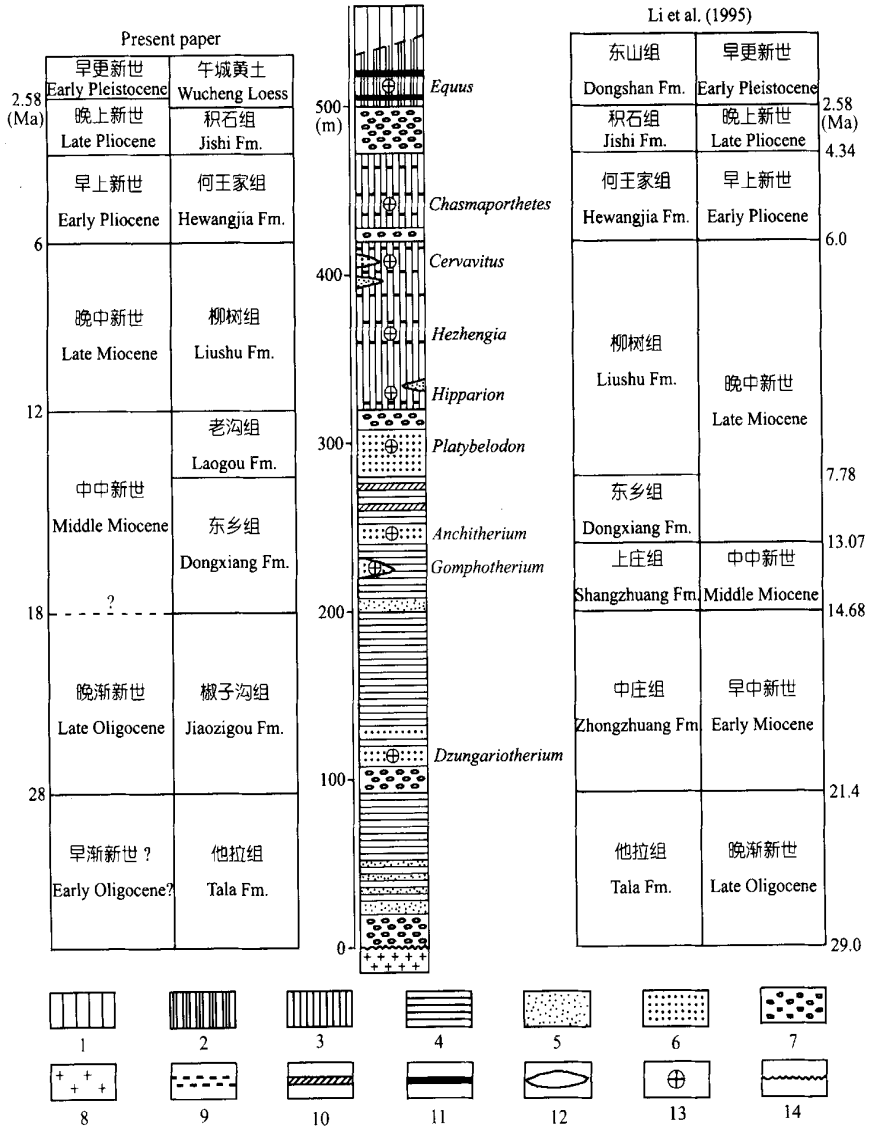

图 2　临夏盆地新生代地层综合柱状图

Fig. 2　Cenozoic stratigraphic column in the Linxia Basin

1. **马兰黄土**(Malan loess)；2. **午城黄土**(Wucheng loess)；3. **红粘土**(Red clay)；4. **泥岩**(Mudstone)；5. **粉砂岩**(Siltstone)；6. **砂岩**(Sandstone)；7. **砾岩**(Conglomerate)；8. **花岗岩**(Granite)；9. **钙结核**(Carbonate concretions)；10. **泥灰岩**(Marlite)；11. **古土壤**(Paleosol)；12. **透镜体**(Lenticular body)；13. **化石层**(Fossil bed)；14. **不整合**(Unconformity)

表 1 临夏盆地新生代地层划分沿革

Table 1 Divisions of the Cenozoic strata in the Linxia Basin

GRGIT, 1965		Xie, 1991		Li et al., 1995		Present paper	
Q_1^1	亚粘土 Clayey	Q	黄土 Loess	Q_1^1	东山组下段 Lower M., Dongshan Fm.	Q_1^1	午城黄土 Wucheng Loess
	胶结砾石层 Conglomerate			N_2^2	积石组 Jishi Fm.	N_2^2	积石组 Jishi Fm.
N_2	临夏组四段 4th M., Linxia Fm.	N_1^3	临夏组 Linxia Fm.	N_2^1	何王家组 Hewangjia Fm.	N_2^1	何王家组 Hewangjia Fm.
				N_1^3	柳树组 Liushu Fm.	N_1^3	柳树组 Liushu Fm.
						N_1^2	老沟组 Laogou Fm.
	临夏组三段 3rd M., Linxia Fm.	N_1^2	东乡层 Dongxiang Bed		东乡组 Dongxiang Fm.		东乡组 Dongxiang Fm.
				N_1^2	上庄组 Shangzhuang Fm.	?	
	临夏组二段 2nd M., Linxia Fm.	N_1^1	椒子沟组 Jiaozigou Fm.	N_1^1	中庄组 Zhongzhuang Fm.	E_3^2	椒子沟组 Jiaozigou Fm.
	临夏组一段 1st M., Linxia Fm.			E_3^2	他拉组 Tala Fm.	? E_3^1	他拉组 Tala Fm.

1 渐新世

1.1 早渐新世(?)他拉组

他拉组由 Li et al. (1995, fig. 2.3) 命名。该组地层不整合于加里东期花岗闪长岩之上,其岩性可分为三段:下段为紫红色砂砾岩,产准同生石膏;中段为紫红色粉砂岩和泥岩互层,钙质胶结强烈;上段为块状紫红色泥岩。他拉组在东乡县东塬乡他拉附近的厚度为 91 m。

他拉组相当于甘肃区测队(1965)划分的临夏组第一段。邱占祥等(1990)在临夏组第二段中发现了以晚渐新世分子为主的动物群,但有一枚象门齿也被认为出于同一层位,所以他们将包括临夏组第一和第二段在内的地层划归早中新世,命名为椒子沟组。他拉组即相当于邱占祥等(1990)的椒子沟组下部。实际上,他拉组中到目前为止尚未发现哺乳动物化石,因此其时代不能直接确定。仅推断其时代可能为早渐新世,也有可能仍属晚渐新世。

1.2 晚渐新世椒子沟组

由于临夏组第一段已被命名为他拉组,因此本文中椒子沟组的定义仅相当于临夏组第二段。Li et al. (1995) 将相当于临夏组第二段的地层命名为中庄组,时代为早中新世,其化石依据即邱占祥等(1990)发现的椒子沟动物群。我们认为该岩石地层单位的名称仍

以椒子沟组为妥。椒子沟组的岩性可分为两段:下段为褐黄色砂岩和砂砾岩,夹少量紫红色泥岩,含石膏;上段为褐红色泥岩,具韵律层理,含大量石膏。

邱占祥等(1990)报道了在东乡县东塬乡椒子沟发现的哺乳动物化石,包括 *Gomphotherium* sp., *Dzungariotherium orgosense*, Rhinocerotidae gen. et sp. indet. 和 *Paraentelodon macrognathus*。象是最可靠的新近纪的代表,它在欧亚大陆的出现不早于 Burdigalian 早期(相当于欧洲哺乳动物生物地层带的 MN3)。所以,尽管其他的化石都是典型的晚渐新世种类,椒子沟组的时代还是因为象的出现而被定为早中新世。然而,象的标本仅有一段门齿,是从药材收购站得到的,据说出于椒子沟。近年来我们在他拉和椒子沟一带进行了反复的调查和挖掘,发现的化石全部是晚渐新世的种类,没有任何象化石存在的迹象。另一方面,邱占祥等(1990)报道的其他种类在新材料中相当常见,我们还发现了不少新的晚渐新世巨犀动物群成员。因此,有理由相信原来的那段象门齿可能是混入椒子沟组化石中的。新材料中包括原来发现的 *D. orgosense* 和 *Paraentelodon macrognathus*,并确认原来的 Rhinocerotidae gen. et sp. indet. 应当是 *Ronzotherium* sp.,新发现了 *Tsaganomys* sp., *Allacerops* sp., *Aprotodon* sp. 和 *Schizotherium* sp. 等。

巨犀是亚洲大陆的代表性动物,东欧也有少量发现,它的繁盛期是渐新世中期,至晚渐新世则是进化程度很高的类型。椒子沟组中的 *Dzungariotherium orgosense* 最早发现于新疆准噶尔盆地,与嵴齿鼷鹿(*Lophimeryx*)共生,后者在欧洲的最晚记录是在 Stampian 晚期的中部地层(邱占祥,1973;邱占祥等,1990)。*Allacerops* 是生活于亚洲大陆渐新世的一类犀牛,它在中国发现于兰州盆地的渐新世地层中(邱占祥、王伴月,1999)。*Schizotherium* 也是中国渐新世的特征类型,它在兰州盆地发现于渐新世的南坡坪动物群中(邱占祥等,1997,1998)。*Aprotodon* 此前仅发现于巴基斯坦、哈萨克斯坦和兰州盆地,在这三个地点它都是与巨犀共生(邱占祥、谢骏义,1997)。*Ronzotherium* 在欧亚大陆也仅发现于渐新世(Heissig, 1969)。猪兽在欧亚大陆最繁盛的时期是在 Sannoisian 期和 Stampian 早、中期,而以 *Paraentelodon macrognathus* 为代表的猪兽化石在椒子沟组中相当丰富,所发现的标本数量仅次于巨犀。*Tsaganomys* 最早出现于早渐新世晚期,其确切的化石记录终止于晚渐新世早期,它是亚洲渐新世的标志性化石之一(Wang, 2001)。*Tsaganomys* 在兰州盆地出现于渐新世的南坡坪动物群中。因此,椒子沟组的时代应为晚渐新世。

在椒子沟组中发现的化石全部产于该组下段的砂砾岩中,而上覆的东乡组所含的化石已是典型的中中新世类型。因此,椒子沟组之上是否缺失早中新世地层或椒子沟组上段地层是否属于早中新世尚存在疑问。

2　中新世

2.1　中中新世早期东乡组

东乡组由 Li et al. (1995, fig. 2.8)命名,他们的定义是属于晚中新世的一套以紫红色泥岩夹大量青灰色泥灰岩条带为主的沉积,相当于临夏组第三段的上部;他们将相当于临夏组第三段下部的地层命名为上庄组,时代定为中中新世。本文的东乡组相当于整个临夏组第三段,即包括 Li et al. (1995)的上庄组和东乡组,时代为中中新世早期。东乡组的岩性可分为两段:下段为褐红色粉砂岩、砂岩递变为褐红色泥岩;上段为褐黄

色砂砾岩、钙质胶结粉砂岩、砂岩夹少量泥岩,递变为紫红色泥岩夹青灰色泥灰岩条带。

谢骏义(1991)在东乡县上沟和尕李家相当于临夏组第三段上部和第四段底部的地层中发现了通古尔早期的哺乳动物化石,因此认为其时代为中中新世,暂称为"东乡层"。由于"上庄组"与"东乡组"的岩性很接近,我们将其合并为东乡组。

我们在广河县买家巷乡大浪沟东乡组下段上部泥岩的砂砾岩透镜体中发现大量 *Gomphotherium* sp. 的化石,其他化石还包括 *Alicornops* sp. 和 *Kubanochoerus* sp. 等。在欧洲,*Gomphotherium* 最早出现于 MN3 的法国 Artenay(Tassy, 1985); *Alicornops* 最早出现于 MN3 的德国 Wintershof-West(Ginsburg and Guérin, 1979),到 MN6 时期在欧洲广泛分布(Heissig, 1999, Cerdeño and Sánchez, 2000),也发现于土耳其的中中新世地层(Heissig, 1976)。*Kubanochoerus* 见于高加索 MN6 的地层,在中国出现于中中新世的宁夏同心丁家二沟、内蒙古通古尔和陕西蓝田寇家村等地点,与铲齿象共生(邱占祥等,1988)。但铲齿象尚未出现在大浪沟。

在广河县石那奴乡王石阶东乡组上段下部的砂岩中发现了安琪马动物群的化石,包括 *Hemicyon* sp., *Gomphotherium* sp., *Anchitherium* sp., *Hispanotherium matritese*, *Alicornops* sp. 和 *Chalicotherium* sp. 等,组合显示了典型的中中新世性质。*Hemicyon* 和 *Hispanotherium* 出现于丁家二沟动物群,*Hispanotherium* 和 *Gomphotherium* 出现于冷水沟动物群,而 *Hemicyon*, *Anchitherium* 和 *Hispanotherium* 出现于通古尔动物群(Qiu and Qiu, 1995)。另一方面,王石阶的 *Anchitherium* 和 *Hispanotherium* 明显小于通古尔者。

2.2 中中新世晚期老沟组

老沟组为本文新建立的岩石地层单位,命名地点为和政县三合乡老沟(图 3)。我们发现在东乡组紫红色泥岩之上和柳树组褐黄色泥岩(红粘土)之下发育一套河流相的砂砾岩沉积,其中含大量的通古尔期铲齿象动物群化石。尽管厚度变化较大,但这一地层在临夏盆地的分布相当广泛,且岩石特征明显,常可作为在野外进行追索对比的标志。老沟组

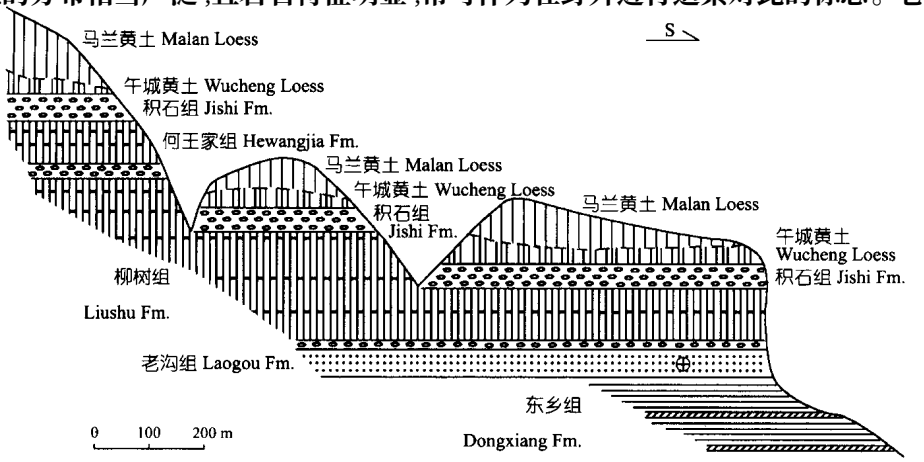

图 3 老沟地点剖面图(图例见图 2)

Fig. 3 Sections at Laogou (Legend see Fig. 2)

的岩性可分为两段:下段为灰色、黄色含砾砂岩,胶结疏松,为主要的化石层位;上段为灰色、局部呈锈黄色砾岩。老沟组由于为河流相的砂砾岩沉积,在各个地点的厚度变化较大,已知最厚的地点广河县城关乡十里墩的厚度超过 50 m,在东乡县那勒寺乡龙担的厚度也达 30 m,而在老沟以及广河县买家巷乡虎家梁和朱家川的厚度为 10～20 m 左右。此外,老沟地点的积石组砾岩形成一个三级古阶地(图 3)。

Li et al. (1995)的毛沟剖面"东乡组"与柳树组之间未描述有砂砾岩,但我们的实地调查发现这一层确实存在,只是厚度不大,为 10 m 左右的一段块状砂岩。在他们描述的王家山剖面柳树组底部有一大套砂岩和粉砂岩夹泥岩存在,厚度超过 50 m。

关键(1988)报道了在广河县买家巷发现的丰富的中中新世铲齿象动物群化石,但没有指明化石产出的具体层位。我们最近在老沟、虎家梁和朱家川等地点的老沟组中发现了大量的中中新世铲齿象动物群化石(Deng, 2003),已知的种类包括 *Alloptox* sp., *Pliopithecus* sp., *Hemicyon* sp., *Amphicyon* sp., *Gomphotherium* sp., *Platybelodon grangeri*, *Zygolophodon* sp., *Anchitherium* sp., *Alicornops* sp., *Hispanotherium matritense*, *Kubanochoerus gigas*, *Listriodon* sp., *Palaeotragus* sp. 和 *Turcocerus* sp. 等。

老沟组的化石是典型的中中新世类型,大多数种类都能在通古尔动物群中见到(Qiu and Qiu, 1995)。*Alloptox* 广泛发现于中国的中中新世动物群,如内蒙古通古尔(Young, 1932)、陕西蓝田冷水沟(李传夔,1978)、青海民和齐家(邱铸鼎等,1981)和宁夏同心丁家二沟(吴文裕等,1991)。*Pliopithecus* 在欧洲的生存时代为 MN5～9,而在中国发现于丁家二沟和新疆准噶尔盆地的中中新世哈拉玛盖组(邱占祥、关键,1986;吴文裕等,2003)。*Hispanotherium matritense* 发现于欧洲的西班牙、葡萄牙和法国以及亚洲的土耳其、巴基斯坦和蒙古,在中国的分布也相当广泛,出现于中中新世的丁家二沟、冷水沟及湖北房县二郎岗动物群中,它比通古尔动物群中的 *H. tungurense* 更原始(翟人杰,1978;阎德发,1979;关键,1988;Cerdeño,1996; Deng, 2003)。

2.3　晚中新世柳树组

柳树组由 Li et al. (1995)命名,相当于临夏组第四段的中、下部,时代为晚中新世。邱占祥等(1987,1988,1991)记述了在临夏盆地发现的晚中新世哺乳动物化石,谢骏义(1991)因此认为临夏组一名应限定于含三趾马化石的原临夏组第四段,时代为晚中新世。临夏组第四段主要为红粘土,但中、下部颜色相对较深,所含三趾马动物群属晚中新世;上部颜色较浅,含早上新世三趾马动物群;二者之间有一层或厚或薄的砂砾岩。因此,将原临夏组第四段的中、下部地层命名为柳树组是合理的。

柳树组的岩性在整个组内相当均一,为褐黄色粉砂质泥岩,即典型的红粘土沉积,含大量 2～10 cm 的钙质结核层。柳树组的厚度在不同剖面差别很大,这主要是后期的侵蚀作用造成的。例如,在老沟地点柳树组的厚度仅为 17 m,其上直接覆盖晚上新世的积石组砾岩,显示柳树组上部和整个何王家组都已被剥蚀掉。临夏组厚度较大的如和政县三合乡杨家山有 130 m,十里墩有 90 m。还有一些可间接判断厚度的地点,如广河县官坊乡怀沟和石磊的柳树组可达 150 m。而在靠近临夏盆地西南缘的地点,由于中间夹有多层砾石,柳树组的厚度将近 200 m。柳树组中的三趾马动物群化石地点根据其在剖面中的位置,可以明显地分为下、中、上 3 个层位。

2.3.1 柳树组下部动物群

柳树组下部的化石主要发现于东乡县那勒寺乡郭泥沟和汪集乡马其沟,化石层之下为老沟组砂砾岩(图 4)。郭泥沟的哺乳动物化石包括 *Dinocrocuta gigantea*, *Machairodus* sp., *Tetralophodon* sp., *Hipparion dongxiangense*, *Parelasmotherium linxiaense* 和 *Shaanxispira* sp. 等(邓涛,2001c)。邱占祥、谢骏义(1998)描述了产自汪集的 *Hipparion dongxiangensis* 和 *Parelasmotherium simplum*,但没有确切地点和层位。新的野外工作证明汪集化石产于马其沟,该地点出露巨厚的柳树组红粘土,化石即产于红粘土底部距老沟组砂砾岩 5～10 m 的位置(图 4)。

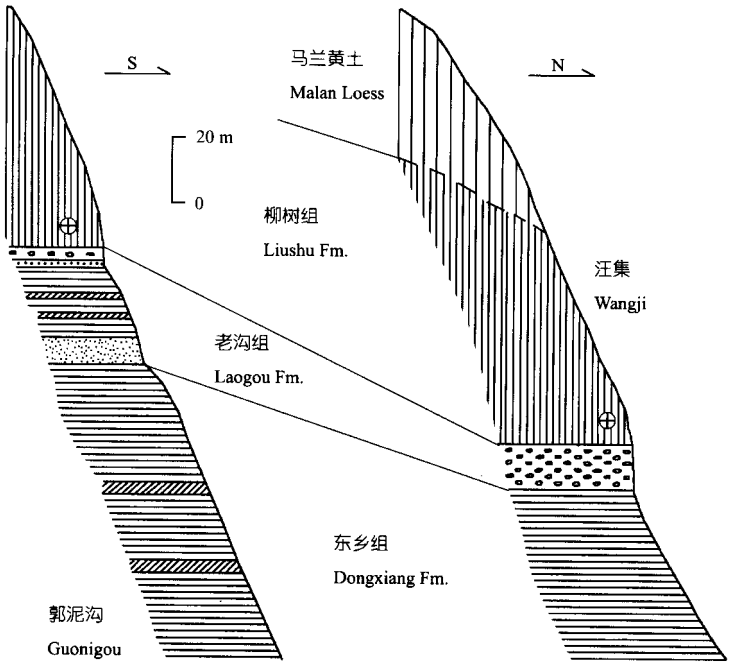

图 4 郭泥沟和汪集地点剖面图(图例见图 2)

Fig. 4 Sections at Guonigou and Wangji (Legend see Fig. 2)

柳树组下部动物群带有鲜明的晚中新世早期的特点,*Dinocrocuta gigantea* 是亚洲早期三趾马动物群中的代表类型,Howell and Peter(1985)曾指出 *Dinocrocuta* 主要发现于晚中新世早期,亦即相当于欧洲 Vallesian 期或 MN9～10。在中国发现的材料也显示了这种倾向,*Dinocrocuta* 被发现于陕西蓝田灞河(刘东生等,1978;张兆群等,2002)和西藏比如布隆(郑绍华,1980),都产于相当于欧洲 Vallesian 期的地层中(李传夔等,1984;邱占祥、邱铸鼎,1990)。*Dinocrocuta* 也被报道发现于甘肃天祝松山(郑绍华,1982)和陕西府谷老高川(Xue et al., 1995;张云翔、薛祥煦,1996),这两个地点被认为与欧洲的 Turolian 期相当,但前者的标本来源于药材收购站,而后者的年龄尚需要更多的证据来证实。*Hipparion dongxiangense* 的尺寸比中国已知最小的三趾马种 *H. parvum* 还要小,它的次尖和次尖沟构造在北美中中新世的三趾马中很常见,但在后期的三趾马中很少见,显示它代表了较早的年代(邱占祥、谢骏义,1998)。*Parelasmotherium* 比保德动物群中的代表类型 *Sinotherium* 更原

始,是目前所知向高冠齿方向发展的大型板齿犀的最早代表(邱占祥、谢骏义,1998;邓涛,2001c)。*Shaanxispira* 也出现于灞河动物群中(刘东生等,1978;张兆群等,2002)。综上所述,柳树组下部动物群的时代应为晚中新世早期,相当于欧洲的 Vallesian 期。根据对比,柴达木动物群(Bohlin, 1937)的进化水平可能与柳树组下部动物群相当(邱占祥、邱铸鼎,1990; Qiu et al., 1999),但二者的种类都不多,相同的属仅有 *Tetralophodon* 和 *Hipparion*。

2.3.2　柳树组中部动物群

柳树组中部的化石地点相当丰富,包括和政县新庄乡大深沟,广河县买家巷乡山庄、阿力麻土乡后山和寺沟,东乡县那勒寺乡双拱北等。

大深沟靠近临夏盆地的南缘,地表被草甸和灌木覆盖,可见部分地层露头。接近山顶处出露何王家组底砾岩,化石层位于柳树组中下部一层胶结坚硬的钙质结核层之下的红粘土中(图 5)。该地点的哺乳动物化石丰富,包括 *Pararhizomys hipparionum*, *Promephitis* sp., *Dinocrocuta gigantea*, *Tetralopodon exoletus*, *Hipparion chiai*, *Acerorhinus hezhengensis*, *Chilotherium wimani*, *Samotherium* sp., *Honanotherium schlosseri*, *Gazella* sp., *Hezhengia bohlini* 和 *Miotragocerus* sp. 等。

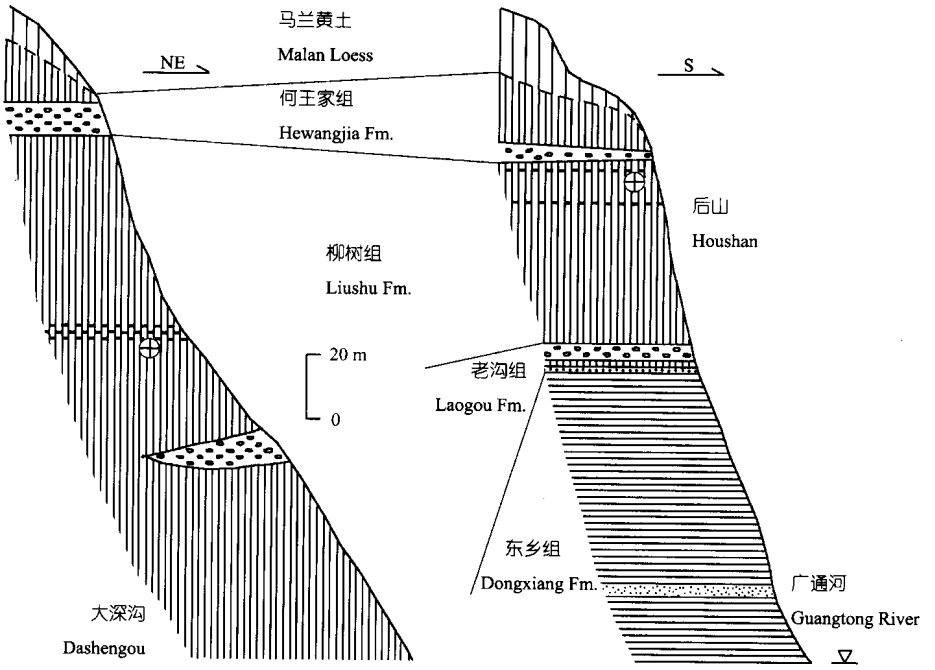

图 5　大深沟和后山地点剖面图(图例见图 2)

Fig. 5　Sections at Dashengou and Houshan (Legend see Fig. 2)

后山地点的层位与大深沟相近,该地点地层出露良好,发育从东乡组至何王家组沉积。化石层位于柳树组内的一层钙质结核层之下,距老沟组顶部的垂直距离约为 50 m(图 5)。根据与其他剖面的对比,后山地点的柳树组上部显然已被剥蚀掉相当大的厚度。哺乳动物化石丰富,*Hezhengia bohlini* 是最优势的种类(邱占祥等,2000),还有 *Promephitis* sp., *Hyaenictitherium wongii*, *Dinocrocuta gigantea*, *Tetralophodon exoletus*, *Hipparion chiai*,

H. weihoensis, *Acerorhinus hezhengensis*, *Chilotherium wimani*, *Iranotherium morgani*, *Dicrocerus* sp., *Samotherium* sp., *Honanotherium schlosseri*, *Gazella* sp. 和 *Miotragocerus* sp. 等。柳树组中部地点所产的化石还包括 *Promephitis hootoni*, *Melodon majori*, *Sinictis* sp., *Ictitherium* sp., *Hyaenictitherium hyaenoides*, *Machairodus palanderi*, *Felis* sp. 和 *Chleuastochoerus stehlini* 等。

柳树组中部动物群仍然包括晚中新世早期的类型,如在柳树组下部出现的 *Dinocrocuta gigantea*。其他灞河动物群中的重要分子在柳树组中部也相当丰富,以 *Hipparion weihoense* 和 *H. chiai* 为典型代表。这两种三趾马的个体大,眶前窝距眼眶较远并相当深,原尖扁长,这些特征表明它们无疑都是 *H. primigenius* 型的,而在欧洲和非洲的 *H. primigenius* 型三趾马都是 Vallesian 期的(邱占祥等,1987)。灞河动物群与柳树组中部动物群共有的种还包括 *Tetralophodon exoletus* 和 *Chleuastochoerus stehlini*(刘东生等,1978),但张兆群等(2003)认为 *C. stehlini* 可能产于蓝田组。*Hezhengia bohlini* 是柳树组中部最典型的种类之一,它的角明显不如晚中新世中、晚期的麝牛,如 *Plesiaddax* 的角特化,牙齿也更原始,上前臼齿相对较长,具强外褶和肋,因此 *H. bohlini* 的时代应该更早(邱占祥等,2000)。*Acerorhinus hezhengensis* 具有非常狭窄的下颌联合部,顶嵴相当靠拢以至形成高耸的矢状嵴,与柴达木动物群的 *A. tsaidamensis* 接近,而不同于保德动物群的 *A. palaeosinensis*(邱占祥等,1987)。从柳树组中部动物群的总体面貌看,它应相当于欧洲 Vallesian 的晚期。柳树组中部动物群可能还与陕西府谷的喇嘛沟动物群同时(Xue et al., 1995),二者相同的种类更多,如 *Dinocrocuta gigantea*, *Hyaenictitherium wongii*, *Hipparion chiai*, *Chilotherium wimani*, *Samotherium* sp. 和 *Miotragocerus* sp. 等,喇嘛沟的 *Acerorhinus fuguensis* 也与柳树组中部的 *A. hezhengensis* 非常接近(邓涛,2000)。

2.3.3 柳树组上部动物群

柳树组上部的化石地点更多,包括和政县三合乡山家湾和杨家山、关滩沟乡黑林顶,广河县官坊乡松树沟、石磊和怀沟、庄禾集乡阳洼铺子和南面沟,买家巷乡龙家湾等。

杨家山地点完全缺失何王家组,化石层位于柳树组顶部(图 6),已知的种类有 *Pararhizomys hipparionum*, *Simocyon* sp., *Promephitis hootoni*, *Ictitherium* sp., *Hyaenictitherium wongii*, *H. hyaenoides*, *Machairodus palanderi*, *Metailurus minor*, *Hipparion* sp., *Chilotherium wimani* 和 *Cervavitus novorossiae* 等。

黑林顶处在临夏盆地南缘,地层沉积厚度巨大,夹有多层砂砾岩。该地点沿冲沟两侧发育巨厚的柳树组红层,夹密集的钙质结核层,结核在风化的剖面上呈砾石状突出。化石层位于柳树组上部的红粘土中(图 6),种类包括 *Hystrix gansuensis*, *Promephitis* sp., *Pleisiogulo* sp., *Ictitherium* sp., *Hyaenictitherium wongii*, *H. hyaenoides*, *Adcrocuta variabilis*, *Machairodus* sp., *Metailurus* sp., *Felis* sp., *Hipparion* sp., *Chilotherium wimani* 和 *Chleuastochoerus stehlini* 等。柳树组上部各地点所产的化石还包括 *Parataxidea sinensis*, *Hipparion coelophyes*, *H. dermatorhinum*, *Acerorhinus hezhengensis*, *Dicerorhinus ringstromi*, *Ancylotherium* sp., *Microstonyx major*, *Metacervulus* sp., *Honanotherium schlosseri*, *Palaeotragus microdon*, *Miotragocerus* sp., *Sinotragus* sp., *Protoryx* sp. 和 *Gazella* sp. 等。

代表晚中新世早期的 *Dinocrocuta gigantea* 和 *Hezhengia bohlini* 在柳树组上部已经消失。而柳树组上部动物群与中国晚中新世晚期代表性的保德动物群共有的分子很多,包

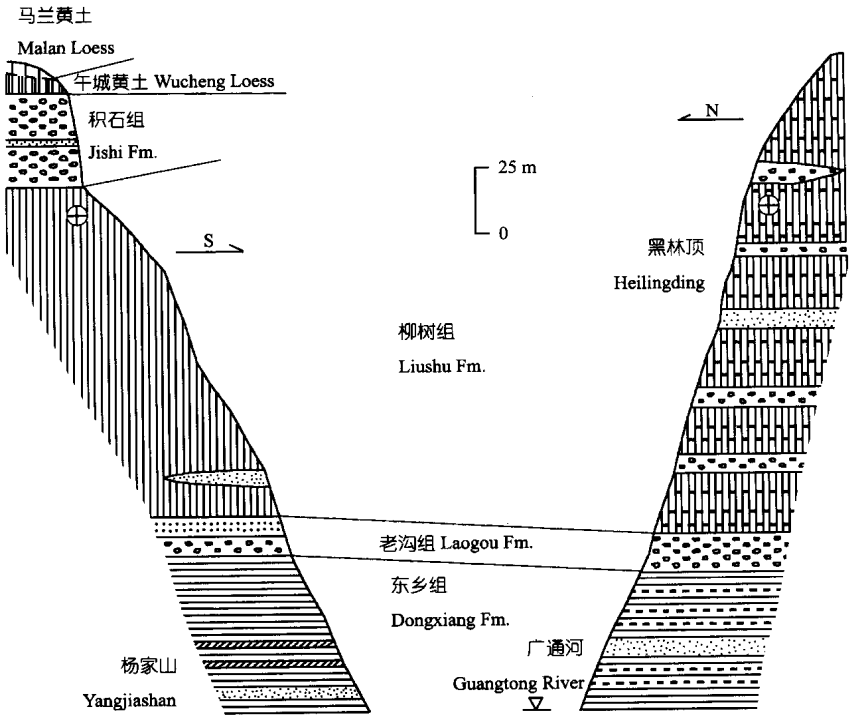

图 6　杨家山和黑林顶地点剖面图(图例见图 2)

Fig. 6　Sections at Yangjiashan and Heilinding (Legend see Fig. 2)

括 *Simocyon* sp., *Plesiogulo* sp., *Parataxidea sinensis*, *Promephitis hootoni*, *Hyaenictitherium wongii*, *H. hyaenoides*, *Adcrocuta variabilis*, *Machairodus* sp., *Metailurus minor*, *Dicerorhinus ringstromi*, *Chleuastochoerus stehlini*, *Microstonyx major*, *Cervavitus novorossiae*, *Palaeotragus microdon*, *Honanotherium schlosseri* 和 *Sinotragus* sp. 等。尽管被称为三趾马动物群,实际上柳树组上部与保德一样,动物群中个体数量占绝对优势的是大唇犀类。然而,柳树组上部比较原始的 *Chilotherium wimani* 在保德动物群中已被更进步的 *C. anderssoni* 替代(邓涛, 2001a, b; Ringström, 1924)。在柳树组上部还发现了 *Hystrix gansuensis*(王伴月、邱占祥, 2002)、*Ancylotherium* sp. 和 *Metacervulus* sp.。柳树组上部动物群的时代可能早于保德动物群。

3　上新世

3.1　早上新世何王家组

何王家组由 Li et al. (1995) 命名,相当于原临夏组第四段的上部或谢骏义(1991)的狭义临夏组的上部。何王家组的岩性可分为两段:下段为砂砾岩,钙质胶结或未胶结;上段为褐黄色粉砂质泥岩(红粘土),含大量钙结核。何王家组地层的厚度极不稳定,在不少地点被完全剥蚀,其底砾岩的变化也很大。在命名地点临夏县坡头乡王家山,何王家组厚 60 m, 其中底砾岩厚 11 m, 红粘土厚 49 m。其他可直接测量厚度的地点,如十里墩和龙

担的何王家组底部未形成砾岩,只有厚度不到 1 m 的砾石层,而红粘土的厚度分别为 50 m 和 20 m。何王家组的化石主要发现于十里墩和积石山县银川乡巩家湾(图 7)。

十里墩地点剖面发育相当好,化石层位于何王家组底部砾石层之上 3 m 处的的红粘土中,化石包括 *Hystrix gansuensis*, *Promephitis* sp., *Chasmaporthetes* sp., *Hyaenictitherium wongii*, *Cervavitus novorossiae*, *Palaeotragus* sp. 和 *Sinotragus* sp. 等。银川地点的化石层位于何王家组近顶部的红粘土中,已知的种类有 *Hipparion* sp., *Shansirhinus ringstromi* 和 *Gazella* sp. 等。

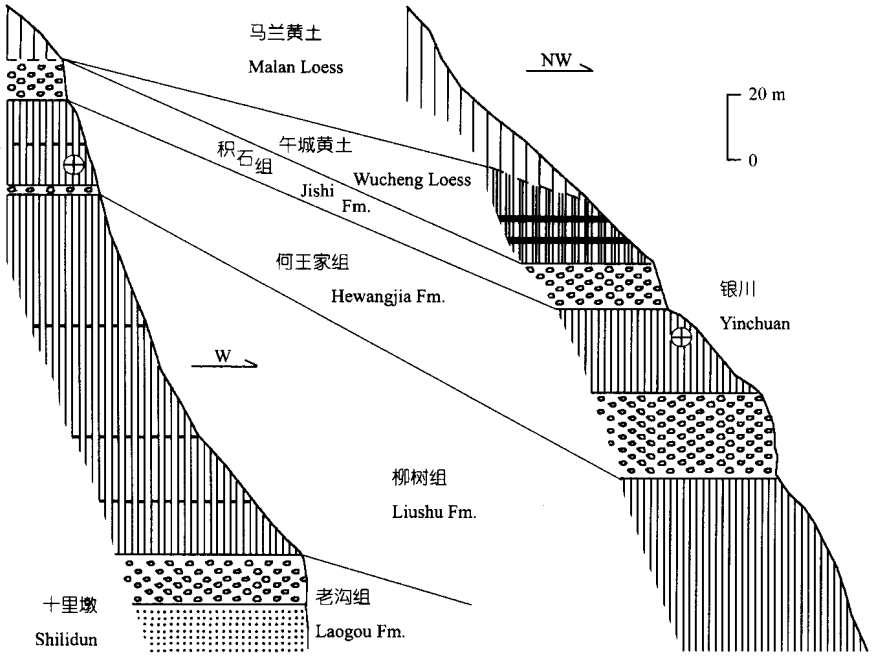

图 7 十里墩和银川地点剖面图(图例见图 2)

Fig. 7 Sections at Shilidun and Yinchuan (Legend see Fig. 2)

在何王家组中新出现了 *Chasmaporthetes* sp. 和 *Shansirhinus ringstromi*,而在晚中新世三趾马动物群中极度繁盛的 *Chilotherium* 已经消失,其他一些晚中新世三趾马动物群分子,如 *Adcrocuta*, *Ictitherium* 和 *Chleuastochoerus* 等也不再出现。*Chasmaporthetes* 在世界上的分布广阔,在欧洲、亚洲、非洲和北美都有发现,它最早出现于上新世早期,相当于欧洲的 Ruscinian 期。在中国,*Chasmaporthetes* 被发现于山西的榆社和寿阳、河北的泥河湾以及河南的渑池(Qiu, 1987)。在榆社盆地,*Chasmaporthetes* sp. 首次出现于年龄在 5.2～3.4 Ma 之间的早上新世高庄动物群中,同时 *Chilotherium* 也已经消失(Qiu, 1987; Qiu and Qiu, 1995)。高庄动物群被认为应与欧洲的 MN14～15 相当(邱占祥、邱铸鼎,1990)。Kretzoi (1942)以 Schlosser(1903)描述的 *Rhinoceros brancoi* 为模式种建立了新属 *Shansirhinus*,并将 Ringström(1927)描述的 *Rhinoceros* aff. *R. brancoi* 修订为 *S. ringstromi*。*S. brancoi* 没有确切的地点和层位。*S. ringstromi* 产于榆社盆地泥河地区的黄石沟,邱占祥等(1987)认为这一地区的化石主要产于高庄组,因此 *S. ringstromi* 的时代也应为早上新世。鉴于何王家

组中还保留有晚中新世三趾马动物群中常见的 *Hystrix gansuensis*, *Cervavitus novorossiae* 和 *Sinotragus* sp. 等分子,而高庄动物群中较进步的 *Ursus*, *Nyctereutes*, *Canis*, *Hipparion houfenense* 和 *Sus* 等在何王家组中没有发现,因此何王家组的时代可能为早上新世早期,约与 MN14 相当。

3.2　晚上新世积石组

积石组由 Li et al. (1995, fig. 2.3) 命名,岩性为灰黑色砾岩,钙质胶结坚硬,表面常被钙质壳包裹;砾石成分复杂,主要为石英岩、板岩和火成岩;磨圆和滚圆均好,可见巨砾;局部含黑色薄层、具斜层理的砂岩和棕红色粉砂岩透镜体。积石组厚度变化较大,在命名地点积石山县城附近厚 60 m,通常厚度为 10～30 m。甘肃区测队 (1965) 曾将此层看作下更新统亚粘土(即午城黄土)的底砾岩。积石组不含化石,但它位于有确切化石证据的早上新世和早更新世沉积之间,并在古地磁松山/高斯界线之下,因此其时代应为晚上新世。

4　早更新世

Li et al. (1995) 将临夏盆地下更新统下部地层命名为东山组,并分为 3 段:下段为褐黄色湖相粉砂岩,含层状钙质结核,产 *Equus* 等化石,厚 35 m; 中段为褐黑色湖沼相粉砂岩,含腐树,厚 30 m; 上段为块状含大量钙质结核的褐黄色湖相粉砂岩,厚 12 m。但在临夏盆地东部,与东山组下段相当的层位为黄土堆积,应相当于中国中、东部的午城黄土。临夏盆地早更新世午城黄土中的哺乳动物化石主要产于龙担 (邱占祥等,2002; 邓涛,2002; Wang and Qiu, 2003; 邱占祥等,出版中)。龙担地点出露的午城黄土可见厚度为 25 m, 下伏积石组砾岩,其上被晚更新世马兰黄土披盖。龙担动物群中具有以大型原始 *Equus* 为代表的丰富化石,但无典型的中更新世动物群的成员,所以它的时代应相当于欧洲的早—中维拉方期或中国的早更新世,且稍早于 Teilhard and Piveteau (1930) 描述的泥河湾动物群。由于有关临夏盆地早更新世哺乳动物群的专著即将出版,本文对此不再赘述。

5　问题讨论

“山庄动物群”被指明产于“上庄组”下段(即本文的东乡组下段下部)的砂岩中,含有三趾马和铲齿象等化石(方小敏等,1997,表 1),但其组成和层位有误。实际上,“山庄动物群”是产于晚中新世的柳树组红粘土中,化石层之下约 80 m 可见老沟组砂砾岩(图 8)。我们在山庄发现的化石包括 *Promephitis* sp., *Melodon majori*, *Hyaenictitherium wongii*, *H. hyaenoides*, *Dinocrocuta gigantea*, *Machairodus palanderi*, *Felis* sp., *Tetralophodon* sp., *Acerorhinus hezhengensis*, *Chilotherium wimani*, *Iranotherium morgani*, *Honanotherium schlosseri*, *Samotherium* sp., *Gazella* sp. 和 *Hezhengia bohlini* 等。所谓的“山庄动物群”显然是混杂了柳树组红粘土的三趾马动物群和老沟组砂砾岩的铲齿象动物群,并依铲齿象化石确定其时代,因而造成错误。

“寺沟动物群”被指明产于“东乡组”下段(即本文的东乡组上段下部)的砂岩中,含三趾马动物群化石(方小敏等,1997,表 1),但其层位有误。实际上,“寺沟动物群”的化石也

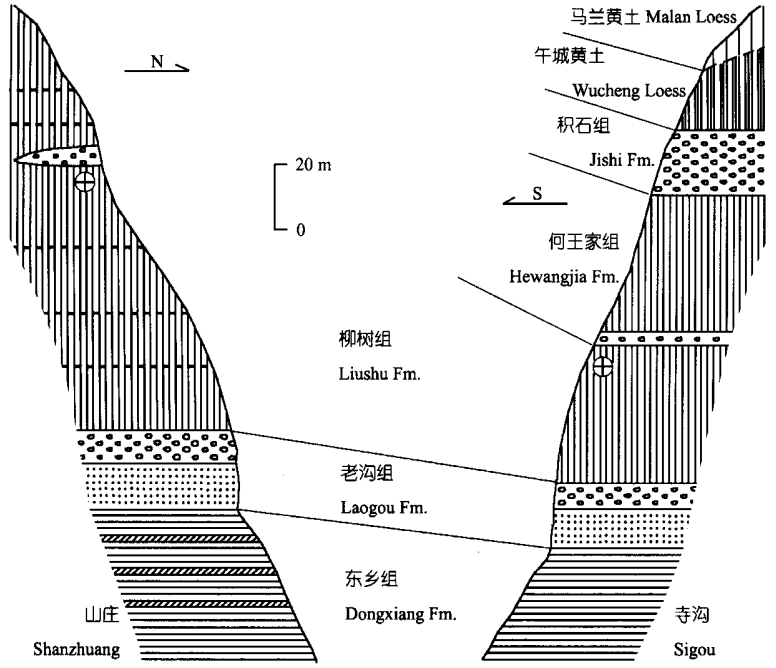

图 8 山庄和寺沟地点剖面图(图例见图 2)

Fig. 8 Sections at Shanzhuang and Sigou (Legend see Fig. 2)

产于柳树组的红粘土下部。寺沟地点的柳树组红粘土之下为老沟组砂砾岩,下伏未见底的东乡组紫红色泥岩,所谓的"东乡组"下段砂岩未出露(图 8)。我们在寺沟发现的化石包括 *Pararhizomys hipprionum*, *Promephitis* sp., *Ictitherium* sp., *Hyaenictitherium wongii*, *Dinocrocuta gigantea*, *Tetralophodon* sp., *Hipparion* sp., *Acerorhinus hezhengensis*, *Chilotherium wimani*, *Chleuastochoerus stehlini* 和 *Miotragocerus* sp. 等。

临夏盆地的所谓"龙光动物群"本身就存在矛盾之处,在方小敏等(1997)的表 1 中,这个动物群产出于晚中新世早期的"东乡组"上部紫红色泥岩中;而在其图 6 中,这个动物群则产出于晚中新世晚期的柳树组下部褐黄色泥岩和上部褐黄色粉砂岩中。经过我们的野外考察,实际上"龙光动物群"就产于上述的银川地点,层位与"东乡组"和柳树组无关,而是在早上新世的何王家组红粘土内。

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CENOZOIC STRATIGRAPHIC SEQUENCE OF THE LINXIA BASIN IN GANSU, CHINA AND ITS EVIDENCE FROM MAMMAL FOSSILS

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Summary

Key words　Linxia Basin, Cenozoic, stratigraphy, fossil mammal

The Linxia Basin is situated in the southeastern part of Gansu Province, China, and it is a flexural basin bounded by the Leijishan fault, North Qinling fault, and the Maxian mountain (Fang et al., 2003). The Cenozoic strata are very thick and well-exposed in the Linxia Basin, and abundant mammal fossils are discovered from the strata (Fig. 1).

Before the 1950s, there were few works done about the Tertiary strata in the Linxia Basin, and the sediments were mostly referred to the informal name "Gansu Group". Subsequently, the Tertiary red beds in the Linxia Basin were given the formal name Linxia Formation, the age being determined to be Pliocene, and was divided into four lithologic members (GRGIT, 1965). Qiu et al. (1990, 1991) first described the Early and Late Miocene fossils in the Linxia Basin. After comparing the Jiaozigou section with the stratotype of the Linxia Fm., Qiu et al. (1990) and Xie (1991) suggested that the Linxia Fm. limited to the fourth member of the original Linxia Fm., with an age of Late Miocene. Li et al. (1995) further divided the Linxia strata, and renamed different formations from the Late Oligocene to the Holocene. We adopt some of their divisions and revised others, and we recognized the following sequences (from lower to upper): ? Early Oligocene Tala Formation, Late Oligocene Jiaozigou Formation, Middle Miocene Dongxiang and Laogou Formations, Late Miocene Liushu Formation, Early Pliocene Hewangjia Formation, Late Pliocene Jishi Formation, and Early Pleistocene Wucheng Loess (Fig. 2; Table 1).

1　Oligocene

1.1　? Early Oligocene Tala Fm.

The Tala Fm. is composed of brownish red conglomerates, sandstones and mudstones. No any mammal fossil is found from this formation. The age of the Tala Fm. may be Early Oligocene, because it is underlying the Late Oligocene Jiaozigou Fm.

1.2　Late Oligocene Jiaozigou Fm.

The Jiaozigou Fm. is composed of brownish yellow sandstones and brownish red mudstones. The mammal fossils in this formation are found at Jiaozigou, Tala and Yagou in Dongxiang County, including *Tsaganomys* sp., *Dzungariotherium orgosense*, *Allacerops* sp., *Ronzotherium* sp., *Aprotodon* sp., *Schizotherium* sp., and *Paraentelodon macrognathus*. Qiu et al. (1990) reported that *Gomphotherium* sp. might be collected from the Jiaozigou Fm. However, our recent fieldwork proves that this proboscidean specimen may be interfused from other strata.

The giant rhinoceros is a representative mammal in Asia, and infrequently discovered in Eastern Europe. The giant rhinoceros was diversified in the middle Oligocene, and it became very advanced in the Late Oligocene. *Dzungariotherium orgosense* was first found from the Junggar Basin in

Xinjiang, with a large size, rudimental lower incisors, well-developed antecrochets, and wide foot bones. In Xinjiang, *D. orgosense* coexists with *Lophimeryx*, and the last record of the latter is from the middle late Stampian Age in Europe (Chiu, 1973; Qiu et al., 1990). *Allacerops* was a rhinocerotid form lived in the Oligocene of Asia, and it was found from the Oligocene in the Lanzhou Basin adjacent to the Linxia Basin (Qiu and Wang, 1999). *Schizotherium* was also a characteristic Oligocene form in China, and it was found from the Oligocene Nanpoping Fauna in the Lanzhou Basin (Qiu et al., 1997, 1998). *Aprotodon* was previously found only from Pakistan, Kazakstan, and the Lanzhou Basin, and it coexisted with the giant rhinoceros in these three regions (Qiu and Xie, 1997) like in the Jiaozigou Fm. of the Linxia Basin. *Ronzotherium* was found only in the Oligocene of Eurasia (Heissig, 1969). The entelodont was the most diversified during the Sannoisian and the early-middle Stampian Ages, and *Paraentelodon macrognathus* was very abundant in the Jiaozigou Fm. *Tsaganomys* appeared first in the late Early Oligocene, and its assured record ended in the early Late Oligocene. As a result, *Tsaganomys* is one of the index fossils for the Asian Oligocene (Wang, 2001). *Tsaganomys* was found from the Oligocene Nanpoping Fauna in the Lanzhou Basin. Apparently, the age of the Jiaozigou Fm. should be Late Oligocene.

2 Miocene

2.1 Early Middle Miocene Dongxiang Fm.

The Dongxiang Fm. is composed of brownish red sandstones and mudstones with greyish white marlite beds. The mammal fossils of the Dongxiang Fm. are found at Dalanggou and Wangshijie in Guanghe County, including *Hemicyon* sp., *Gomphotherium* sp., *Anchitherium* sp., *Alicornops* sp., *Hispanotherium matritense*, *Chalicotherium* sp., and *Kubanochoerus* sp.

In Europe, *Gomphotherium* appeared first in MN3 at Artenay in France (Tassy, 1985). *Alicornops* appeared first in MN3 at Wintershof-West in Germany (Ginsburg and Guérin, 1979), and distributed widespread in Europe during MN6 (Heissig, 1999). In China, *Kubanochoerus* appeared first at Dingjiaergou in Tongxin, Ningxia with the age corresponding to MN6 of Europe, accompanying abundant fossils of *Platybelodon*. On the other hand, *Platybelodon* has not been found at Dalanggou. *Hemicyon* and *Hispanotherium* coexist in the Dingjiaergou Fauna; *Hispanotherium* and *Gomphotherium* coexist in the Lengshuigou Fauna; *Hemicyon*, *Anchitherium* and *Hispanotherium* coexist in the Tunggur Fauna (Qiu and Qiu, 1995). But *Anchitherium* and *Hispanotherium* from the Dongxiang Fm. are obviously smaller than those from Tunggur.

2.2 Late Middle Miocene Laogou Fm.

The Laogou Fm. is a new lithologic unit established in this paper. This formation is composed of grayish yellow fine conglomerates and sandstones (Fig. 3).

Many mammal fossils are collected from the Laogou Fm. at Laogou in Hezheng County, and Hujialiang and Zhujiachuan in Guanghe County (Deng, 2003), including *Alloptox* sp., *Pliopithecus* sp., *Hemicyon* sp., *Amphicyon* sp., *Gomphotherium* sp., *Platybelodon grangeri*, *Zygolophodon* sp., *Anchitherium* sp., *Alicornops* sp., *Hispanotherium matritense*, *Kubanochoerus gigas*, *Listriodon* sp., *Palaeotragus* sp., and *Turcocerus* sp.

The fossils from the Laogou Fm. are the typical Middle Miocene forms, represented by Tunggurian *Platybelodon* and *Anchitherium* (Qiu and Qiu, 1995). As above-mentioned, *Platybelodon* has not appeared in the Dongxiang Fm., and *Anchitherium* from the Laogou Fm. is obviously larger than its ally from the Dongxiang Fm. The shared genera between the Laogou Fm. and the Tunggur Fauna include *Alloptox*, *Hemicyon*, *Amphicyon*, *Platybelodon*, *Zygolophodon*, *Anchitherium*, *Hispanotherium*, *Kubanochoerus*, *Listriodon*, *Palaeotragus*, and *Turcocerus*. *Alloptox* was widespread found from the Middle Miocene faunas in China, such as Tunggur in Nei Mongol (Young, 1932), Lengshuigou in Lantian, Shaanxi (Li, 1978), Qijia in Minhe, Qinghai (Qiu et al.,

1981), and Dingjiaergou in Tongxin, Ningxia (Wu et al., 1991). *Pliopithecus* existed during MN5～9 in Europe, and it was found from the Dingjiaergou and Halamagai (Junggar, Xinjiang) Faunas of the Middle Miocene in China (Qiu and Guan, 1986; Wu et al., 2003). In Eurasia, *Hispanotherium matritense* was found in Spain, Portugal and France of Europe, and Turkey, Pakistan, Mongolia and China of Asia. In China, *H. matritense* distributed widespread, found from the Middle Miocene Dingjiaergou, Lengshuigou and Erlanggang (Fangxian, Hubei) Faunas (Zhai, 1978; Yan, 1979; Guan, 1988). *H. matritense* is smaller than *H. tungurense* of the Tunggur Fauna (Cerdeño, 1996; Deng, 2003). *Alicornops* distributed widespread in Europe during MN6～10 (Cerdeño and Sánchez, 2000), and it was found from the Middle Miocene strata in Turkey (Heissig, 1976). *Kubanochoerus* appeared in the strata of MN6 in Caucasia, and it was found at Dingjiaergou, Tunggur and Koujiacun (Lantian, Shaanxi). Therefore, *Kubanochoerus* is a typical Middle Miocene form (Qiu et al., 1988).

2.3 Late Miocene Liushu Fm.

The Liushu Fm. is composed of red clay, and its thickness is variable in different sections, which is caused by later differential erosions. At Laogou, its thickness is only 17 m, and the Jishi conglomerate is directly overlying above the red clay of the Liushu Fm. At some localities near the southern margin of this basin, on the other hand, its thickness is close to 200 m, because several sandstone and conglomerate beds are interbedded in the red clay of the Liushu Fm. According to their positions in the sections, the fossil localities of the *Hipparion* fauna in the Liushu Fm. can be divided into three levels (Fig. 2).

2.3.1 Lower part of the Liushu Fm.

The mammal fossils of the lower part of the Liushu Fm. are found at Guonigou and Wangji in Dongxiang County (Fig. 4), including *Dinocrocuta gigantea*, *Machairodus* sp., *Tetralophodon* sp., *Hipparion dongxiangense*, *Parelasmotherium simplym*, *P. linxiaense*, and *Shaanxispira* sp.

These fossils are characteristic of early Late Miocene age. *Dinocrocuta gigantea* is a representative of the early *Hipparion* fauna in Asia, and it is discovered mainly from the early Late Miocene, corresponding to the European Vallesian Age or MN9～10 (Howell and Peter, 1985). The materials discovered in China show the same trend. The fossils of *Dinocrocuta* were found from Bahe in Lantian, Shaanxi (Liu et al., 1978; Zhang et al., 2002) and Bulong in Biru, Tibet (Zheng, 1980), and they came from strata corresponding to the Vallesian (Li et al., 1984; Qiu and Qiu, 1995). *Dinocrocuta* was also reported from Songshan in Tianzhu, Gansu (Zheng, 1982) and Laogaochuan in Fugu, Shaanxi (Xue et al., 1995; Zhang and Xue, 1996), and the two localities were considered to be equivalent to the European Turolian Age. However, the specimens of the former came from a drug store, and the age of the latter need further studies. The size of *H. dongxiangense* is smaller than that of *H. parvum*, the smallest known species of *Hipparion* in China, and its characteristic structures of the hypocone and the hypocone groove frequently occur among the Middle Miocene hipparionines from North America, but are infrequent among the late hipparionines. As a result, *H. dongxiangense* indicates an earlier age (Qiu and Xie, 1998). *Parelasmotherium* is more primitive than *Sinotherium*, the representative taxon in the Baode Fauna, and the former is the earliest member of the giant elasmothere developing toward hypsodont teeth (Qiu and Xie, 1998; Deng, 2001c). *Shaanxispira* also appeared in the Bahe Fauna (Liu et al., 1978; Zhang et al., 2002). Consequently, the age of the lower part of the Liushu Fm. should be early Late Miocene, corresponding to the Vallesian Age of the Europe. According to this correlation, the Qaidam Fauna (Bohlin, 1937) may have the same evolutionary level with the fauna from the lower part of the Liushu Fm. (Qiu and Qiu, 1995; Qiu et al., 1999). However, both faunas do not have many taxa, and the shared genera include only *Tetralophodon* and *Hipparion*, whose materials are too rare to be certain about their specific status.

2.3.2 Middle part of the Liushu Fm.

The mammal fossils of the middle part of the Liushu Formation are found at Dashengou in Hezheng County, Houshan, Shanzhuang and Sigou in Guanghe County, and Shuanggongbei in Dongxiang County (Figs. 5, 8), including *Pararhizomys hipparionum*, *Promephitis* sp., *P. hootoni*, *Melodon majori*, *Sinictis* sp., *Ictitherium* sp., *Hyaenictitherium wongii*, *H. hyaenoides*, *Dinocrocuta gigantea*, *Machairodus palanderi*, *Felis* sp., *Tetralophodon exoletus*, *Hipparion* sp., *H. chiai*, *H. weihoensis*, *Acerorhinus hezhengensis*, *Chilotherium wimani*, *Iranotherium morgani*, *Chleuastochoerus stehlini*, *Dicrocerus* sp., *Samotherium* sp., *Honanotherium schlosseri*, *Gazella* sp., *Hezhengia bohlini*, and *Miotragocerus* sp.

This fauna is still composed of early Late Miocene taxa, such as *Dinocrocuta gigantea*, which first appeared in the lower part of the Liushu Fm. Other important components of the Bahe Fauna are relatively richly represented in the middle part of the Liushu Fm., such as *Hipparion weihoense* and *H. chiai*. These two species of *Hipparion* have a large size, deep preorbital fossae far from the orbit, and narrow and long protocones. These characters show that both of them apparently belong to the *H. primigenius* group, and the hipparionines of this group in Europe and Africa are predominantly Vallesian in age (Qiu et al., 1987). The shared species in the Bahe Fauna and the middle part of the Liushu Fm. also include *Tetralophodon exoletus* and *Chleuastochoerus stehlini* (Liu et al., 1978). *Hezhengia bohlini* is one of the most typical taxa in the middle part of the Liushu Fm. The horncores of *Hezhengia* are obviously less specialized than those of the midldle-late Late Miocene ovibovines, such as *Plesiaddax*, and its premolars are relatively long, with strong ribs and styles. Therefore, the primitive characters of *H. bohlini* imply that its age should be earlier than that of the middle-late Late Miocene ovibovines (Qiu et al., 2000). *Acerorhinus hezhengensis* has a very narrow mandibular symphysis and little separated parietal crests to form a high sagittal crest, and thus it is close to *A. tsaidamensis* in the Qaidam Fauna but different from *A. palaeosinensis* in the Baode Fauna (Qiu et al., 1987). Judging from the whole components of the fauna of the middle part of the Liushu Fm., it should be correlated to the late Vallesian Age of Europe. Besides the Bahe Fauna, the Lamagou Fauna in Fugu, Shaanxi (Xue et al., 1995) may be contemporaneous with the fauna of the middle part of the Liushu Fm. There are many common taxa between the Lamagou Fauna and the middle part of the Liushu Fm., including *Dinocrocuta gigantea*, *Hyaenictitherium wongii*, *Hipparion chiai*, *Chilotherium wimani*, *Samotherium* sp., and *Miotragocerus* sp. Moreover, *Acerorhinus fuguensis* from Lamagou also is very close to *A. hezhengensis* from the middle part of the Liushu Fm. (Deng, 2000).

The "Shanzhuang Fauna" and "Sigou Fauna" in Fang et al. (1997, 2003) are apparently a mixture of the Middle Miocene *Platybelodon* fauna and Late Miocene *Hipparion* fauna. Our field observations show that the majority of the Late Miocene components were actually collected from the red clay of the middle part of the Liushu Fm. instead of the underlying sandstone of the "Shangzhuang Fm." or the conglomerate of the "Dongxiang Fm.", which produced the *Platybelodon* fauna. Parts of Fang et al.'s (1997, 2003) "Shanzhuang Fauna" and "Sigou Fauna" are probably our fauna from the middle part of the Liushu Fm (Fig. 8).

2.3.3 Upper part of the Liushu Fm.

The mammal fossils of the upper part of the Liushu Fm. are found at Yangjiashan, Heilinding, and Shanjiawan in Hezheng County, Songshugou, Shilei, Huaigou, Yangwapuzi, Nanmiangou and Longjiawan in Guanghe County (Fig. 6), including *Hystrix gansuensis*, *Pararhizomys hipparionum*, *Simocyon* sp., *Promephitis* sp., *P. hootoni*, *Parataxidea sinensis*, *Pleisiogulo* sp., *Ictitherium* sp., *Hyaenictitherium wongii*, *H. hyaenoides*, *Adcrocuta variabilis*, *Machairodus* sp., *M. palanderi*, *Metailurus* sp., *M. minor*, *Felis* sp., *Hipparion* sp., *H. coelophyes*, *H. dermatorhinum*, *Acerorhinus hezhengensis*, *Chilotherium wimani*, *Dicerorhinus ringstromi*, *Ancylotherium* sp., *Chleuastochoerus stehlini*, *Microstonyx major*, *Metacervulus* sp., *Cervavitus novorossiae*, *Honanotherium schlosseri*, *Palaeotragus microdon*, *Miotragocerus* sp., *Sinotragus* sp., *Protoryx* sp.,

and *Gazella* sp.

In this fauna, the early Late Miocene representatives, such as *Dinocrocuta gigantea* and *Hezhengia bohlini* have disappeared. This fauna is similar to the Baode Fauna, the typical fauna of the late Late Miocene in China. They share many taxa, including *Simocyon* sp., *Plesiogulo* sp., *Parataxidea sinensis*, *Promephitis hootoni*, *Hyaenictitherium wongii*, *H. hyaenoides*, *Adcrocuta variabilis*, *Machairodus* sp., *Metailurus minor*, *Dicerorhinus ringstromi*, *Chleuastochoerus stehlini*, *Microstonyx major*, *Cervavitus novorossiae*, *Palaeotragus microdon*, *Honanotherium schlosseri*, and *Sinotragus* sp. Like the Baode fauna, rhinocerotids are absolutely dominant in the upper part of the Liushu Fm., although both of them are named as the *Hipparion* faunas. On the other hand, the more primitive *Chilotherium wimani* in the upper part of the Liushu Fm. is replaced by the more derived *C. anderssoni* in the Baode Fauna. The primitive characters of *C. wimani* include the low position of orbit, well-developed supraorbital tubercle, weak postorbital process, concave dorsal skull profile, little separate parietal crests, narrow braincase, and strong paracone rib on premolars (Deng, 2001a, b), while the derived characters of *C. anderssoni* include the high position of orbit, absence of supraorbital tubercle, well-developed postorbital process, flat dorsal skull profile, broadly separate parietal crests, rounded braincase, and weak or absent paracone rib on premolars (Ringström, 1924). *Hystrix*, *Ancylotherium* and *Metacervulus* appeared in the upper part of the Liushu Fm. In conclusion, the fauna of the upper part of the Liushu Fm. may be appreciably earlier than the Baode Fauna.

3 Pliocene

3.1 Early Pliocene Hewangjia Fm.

The Hewangjia Fm. is composed of red clay and a basal conglomerate. The thickness of this formation is also greatly variable, and it was eroded away completely in some localities. The fossil localities of the *Hipparion* fauna in the Hewangjia Fm. can be united into one level, as typified by Shilidun where the red clay of the Hewangjia Fm. is 50 m thick (Fig. 7).

The fauna of the Hewangjia Fm. comes from the red clay at Shilidun in Guanghe County and Yinchuan in Jishishan County, including *Hystrix gansuensis*, *Promephitis* sp., *Chasmaporthetes* sp., *Hyaenictitherium wongii*, *Hipparion* sp., *Shansirhinus ringstromi*, *Cervavitus novorossiae*, *Palaeotragus* sp., *Sinotragus* sp., and *Gazella* sp.

Chasmaporthetes sp. and *Shansirhinus ringstromi* newly appeared in the Hewangjia Fm., while the extremely dominant *Chilotherium* in the Late Miocene *Hipparion* fauna disappeared in this fauna. Other members of the Late Miocene *Hipparion* fauna, such as *Adcrocuta*, *Ictitherium* and *Chleuastochoerus* are absent in the Hewangjia Fm. *Chasmaporthetes* has a widespread distribution in the world, and its fossils were discovered from Europe, Asia, Africa, and North America; it first appeared in the Early Pliocene, corresponding to the Ruscinian Age of Europe. In China, *Chasmaporthetes* was discovered from Yushe and Shouyang in Shanxi, Nihewan in Hebei, and Mianchi in Henan (Qiu, 1987). In the Yushe Basin, *Chasmaporthetes* appeared first in the Gaozhuang Fauna with a paleomagnetic age of 5.2～3.4 Ma, when *Chilotherium* had disappeared (Qiu, 1987). The Gaozhuang Fauna should be correlated to MN14～15 of the European mammal ages (Qiu and Qiu, 1995). Kretzoi (1942) established a new genus *Shansirhinus* on the basis of *Rhinoceros brancoi* described by Schlosser (1903) as the type species, and renamed *Rhinoceros* aff. *R. brancoi* described by Ringström (1927) as *S. ringstromi*. *S. brancoi* does not have exact locality and horizon. *S. ringstromi* is collected from Huangshigou in the Nihe district of the Yushe Basin. Qiu et al. (1987) indicated that the mammal fossils in the Nihe district came mainly from the Gaozhuang Fm., so the age of *S. ringstromi* should be Early Pliocene. Some common species of the Late Miocene *Hipparion* fauna, such as *Hystrix gansuensis*, *Cervavitus novorossiae*, and *Sinotragus* sp. still survived in the Hewangjia Fm., while the derived taxa in the Gaozhuang Fauna, such as *Ursus*,

Nyctereutes, *Canis*, *Hipparion houfenense*, and *Sus* have not been found in the Hewangjia Fm. As a result, the age of the Hewangjia Fm. may be early Early Pliocene, approximately corresponding to MN14.

The "Longguang Fauna" in Fang et al. (1997, 2003) was also misallocated. Our own field observations indicate that it was actually from the red clay of the Hewangjia Fm., in the same fossil bed as *Shansirhinus ringstromi* in the Yinchuan locality, rather than the mudstone of the "Dongxiang Fm." or the siltstone of the Liushu Fm. in the Late Miocene.

3.2 Late Pliocene Jishi Fm.

The Jishi Fm. is composed of grey and partially carbonate-cemented coarse conglomerates. No any mammal fossil is found from this formation. Because the Jishi Fm. intervenes between the Early Pliocene and Early Pleistocene deposits with the assured fossil evidence, its age should be Late Pliocene.

4 Early Pleistocene

The Pleistocene deposits of the Linxia Basin are composed of yellowish brown massive siltstones of the Dongshan Fm. or the contemporaneous Wucheng Loess. The abundant mammal fossils are found from the Wucheng Loess at Longdan in Dongxiang County (Qiu et al., in press). The existence of true horse (*Equus*) and the absence of typical Middle Pleistocene forms immediately put the Longdan fauna in the Early Pleistocene, and the Longdan Fauna seems slightly older than the Nihewan Fauna (Teilhard and Piveteau, 1930).

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