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A large theropod metatarsal from the upper part of Jurassic Shishugou Formation in Junggar Basin, Xinjiang, China

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Abstract

The Shishugou Formation in the Junggar Basin was deposited during the late Middle Jurassic to the early Late Jurassic. It is known as a rich source of vertebrate fossils, including specimens of several different kinds of theropod. Here we report an isolated theropod left metatarsal IV (IVPP V 18060) from the upper part of the Shishugou Formation, exposed at the Wucaiwan Locality in the northeastern part of the Junggar Basin. Based on comparisons with the fourth metatarsals of other theropods, we refer this specimen to Allosauroidea. Similarities to the equivalent bone in other allosauroids include: the proximal end has a subtriangular outline with a tongue-like, posteriorly directed posteromedial process; the shaft has a gentle outward curve; a semi-lunate concave of muscle attachment is present on the posterolateral side of the shaft; and the cross-section of the shaft is triangular. Within Allosauroidea, V 18060 is most similar to the fourth metatarsal of *Sinraptor dongi*, a taxon that occurs in the same formation in the Jiangjunmiao area of the Junggar Basin. V 18060 displays several specific resemblances to *S. dongi*: the outline of the distal end is subtrapezoidal; the depression for muscle attachment on the posterior side of the shaft that borders the shaft's lateral side lacks a well-defined ridge. However, V 18060 also differs in some respects from the fourth metatarsal of *S. dongi*: V 18060 is much more robust, and the lateral condyle on the distal end is smaller than the medial one. These morphological differences could be ontogenetic variation or due to sexual dimorphism, taxonomical variations. We prefer the interpretation that V 18060 is a new species that has a close relationship to *S. dongi*, and a cladistic analysis based on the morphology of metatarsal IV supports this inference. The discovery of V 18060 suggests that the theropods from the Shishugou Fauna are more diversified during the Mid-Late Jurassic than previously thought. The presence of different sinraptorid species in the neighboring areas of Wucaiwan and Jiangjunmiao points to the possibility that these two regions within the Junggar Basin were geographically isolated or ecologically distinct from one another during the Mid-Late Jurassic.

Key words　Junggar Basin, Mid-Late Jurassic, Shishugou Formation, theropod, metatarsal

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新疆准噶尔盆地侏罗纪石树沟组上部一大型兽脚类跖骨

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摘要：准噶尔盆地中侏罗世晚期到晚侏罗世早期沉积的石树沟组产出过包括多种兽脚类恐龙在内的大量脊椎动物化石。描述了一件新的采自准噶尔盆地东北缘五彩湾地区石树沟组上部的兽脚类恐龙左第四跖骨标本(IVPP V 18060)。通过与其他兽脚类恐龙第四跖骨对比，该标本可归入异特龙超科(Allosauroidea)。它与其他异特龙超科第四跖骨的相似性包括：近端关节面三角形并有一向后方延伸的舌状突出，向外侧轻微弯曲的骨干，位于骨干后方靠近外侧边的半月形肌肉凹陷，三角形骨干横截面。在异特龙超科当中，V 18060与准噶尔盆地将军庙地区石树沟组中发现的董氏中华盗龙(*Sinraptor dongi*)最为相似(除了以上相似性，V 18060和董氏中华盗龙的相似性还包括远端关节轮廓呈近梯形，骨干后部肌肉凹陷与周围边界呈半开放状态)。但是，V 18060和董氏中华盗龙也存在着一些明显的区别：V 18060明显比董氏中华盗龙的第四跖骨粗壮，远端内外两髁大小差异相反。这些形态差异可能是由于个体发育或者性双形造成的，也可能代表分类学差异。对比研究和基于第四跖骨形态信息进行的分支系统学分析结果更偏向后一种解释：V 18060代表一个不同于董氏中华盗龙但与后者亲缘关系很近的新的兽脚类恐龙。新材料的发现增加了中晚侏罗世石树沟动物群兽脚类恐龙的分异度。在五彩湾和将军庙地区发现不同的中华盗龙类恐龙指示了晚侏罗世早期准噶尔盆地中相邻地区可能存在着一定的生态分异性或者地理隔离。

关键词：准噶尔盆地，中晚侏罗世，石树沟组，兽脚类恐龙，跖骨

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自2000年至今，中国科学院古脊椎动物与古人类研究所与美国乔治华盛顿大学组成的联合考察队一直在新疆准噶尔盆地和吐哈盆地开展科学考察活动，尤其是对准噶尔盆地五彩湾和将军庙地区广泛出露的石树沟组进行了深入的调查，采集到大量的地质学和古生物学资料，相关的报道涵盖了龟鳖类、鳄形动物、似哺乳爬行动物、哺乳动物、翼龙和恐龙6个类群的15个新属种(表1)。这些野外工作和相关的室内研究极大丰富了我们对于石树沟组的认识(Eberth et al., 2010), 也促进了我们对于若干重要恐龙类群早期演化的认识(Clark and Xu, 2009a; Xu et al., 2010)。

石树沟组是一套出露于准噶尔盆地东缘的陆相沉积，整合于上侏罗统西山窑组之上，常被吐谷鲁群假整合所覆。石树沟组厚50~700 m, 主要为绿、灰黄和红色砂质泥岩及泥岩层，下部夹砂岩及砾岩。该组一般被划分为上下两段：下部被认为代表

中侏罗世的一套沉积，上部代表晚侏罗世的一套沉积(中国地层典编委会, 2000; 新疆维吾尔自治区区域地层表编写组, 1981)。赵喜进等(1987)基于上下两段岩性和化石组合的差异，把下段单独命名为五彩湾组，但这一方案没有得到广泛接受(Eberth et al., 2001)。近年来的研究表明，石树沟组的地质年代虽然从中侏罗世延续到晚侏罗世，但延续时间相对很短，其下部局限于中侏罗世最晚期，上部局限于晚侏罗世最早期(Eberth et al., 2010)。

石树沟组富含硅化木、无脊椎动物和脊椎动物化石，但上部化石远比下部丰富。截至本文完成，已经报道的脊椎动物化石属种包括似哺乳爬行动物、哺乳动物、龟鳖类、鳄形类、翼龙类、鸟臀类、蜥脚类以及兽脚类共27种(表1)。

表1 石树沟组已报道的主要脊椎动物化石

Table 1 List of the reported vertebrates of Shishugou Formation

Taxa	Species	Reference	Horizon	Locality
龟鳖类 Testudines	*Xinjiangchelys junggarensis*	Yeh, 1986	Upper	Jiangjunmiao
	X. macrocentrale	Brinkman et al., 2012	?	Wucaiwan
	X. radiplicatoides	Brinkman et al., 2012	Upper	Wucaiwan
	Annemys sp.	Brinkman et al., 2012	?	Wucaiwan
	X. chowi	Matgke et al., 2005	?	Wucaiwan
鳄形类 Crocodylomorpha	*Sunosuchus junggarensis*	Wu et al., 1996	Lower	Wucaiwan
	Junggarsuchus sloani	Clark et al., 2004	Lower	Wucaiwan
	Nominosuchus matutinus	Clark & Xu, 2009b	Upper	Wucaiwan
兽孔类 Therapsida	*Yuanotherium minor*	Hu et al., 2009	Upper	Wucaiwan
	Bienotherium zigongensis	Sun & Cui, 1989	Lower	Jiangjunmiao
	B. ultimus	Maisch et al., 2004	Upper	Jiangjunmiao
鸟臀类 Ornithischia	*Gongbusaurus wucaiwanensis*	Dong, 1989	Upper	Wucaiwan
	Jiangjunosaurus junggarensis	Jia et al., 2007	Upper	Jiangjunmiao
	Yinlong downsi	Xu et al., 2006a	Upper	Wucaiwan
蜥脚类 Sauropoda	*Tienshanosaurus chitaiensis*	Young, 1937	Upper	?
	Mamenchisaurus sinocanadorum	Russel & Zheng, 1993	Upper	Wucaiwan
	Bellusaurus sui	Dong, 1990	Lower	Jiangjunmiao
	Klamelisaurus gobiensis	Zhao, 1993	Lower	Jiangjunmiao
兽脚类 Theropoda	*Monolophosaurus jiangi*	Zhao & Currie, 1993	Lower	Jiangjunmiao
	Limusaurus inextricabilis	Xu et al., 2009	Upper	Wucaiwan
	Sinraptor dongi	Currie & Zhao, 1993	Upper	Jiangjunmiao
	Haplocheirus sollers	Choiniere et al., 2010a	Upper	Wucaiwan
	Zuolong salleei	Choiniere et al., 2010b	Upper	Wucaiwan
	Guanlong wucaii	Xu et al., 2006b	Upper	Wucaiwan
翼龙类 Pterosauria	*Sericipterus wucaiwanensis*	Andres et al., 2010	Upper	Wucaiwan
哺乳类 Mammal	*Klamelia zhaopengi*	Chow & Rich, 1984	Upper and lower	Laoshangou
	Acuodulodon sunae	Hu et al., 2007	Upper	Wucaiwan

石树沟组的脊椎动物化石组合传统上被认为和我国西南地区中晚侏罗世的沙溪庙动物群非常相似。近年来的新发现丰富了我们对于石树沟组脊椎动物化石组合的认识(Clark et al., 2006; Clark and Xu, 2009b), 显示出新疆准噶尔盆地石树沟组保存了一个独特的中晚侏罗世过渡期的动物群，在这里被正式命名为石树沟动物群。从石树沟组已经产出化石的情况看，石树沟动物群与沙溪庙动物群有着明显的区别。石树沟动物群中角鼻

龙类(Ceratosauria)、暴龙类(Tyrannosauroidea)、阿尔瓦兹龙类(Alvarezsauroidea)以及角龙类(Ceratopsia)化石在沙溪庙动物群中没有记录(Peng et al., 2005)。石树沟组中进步的虚骨龙类(Coelurosauria)和角龙化石的发现与中国东北部中晚侏罗世的化石组合更为相似(Xu et al., 2010), 显示石树沟动物群从生物地理分区上可能更接近中国东北地区，表明中国侏罗纪中晚期恐龙动物群的组成可能更多地受纬度控制，在南北方的差异更甚于东西方的差异(这需要古生物地理学方面更进一步的验证)。对于石树沟动物群的更全面和深入的认识，将有助于我们更加准确地复原中国中晚侏罗世恐龙动物群的组成和对于全球恐龙生物地理区系的认识。

本文将报道采自准噶尔盆地五彩湾地区石树沟组上部的一件兽脚类恐龙标本(IVPP V 18060)。尽管该标本仅保存了第四跖骨，但它有可能代表了一种新的兽脚类恐龙，因此丰富了石树沟动物群的组成。本文将对该标本进行形态学描述，分析它的系统发育位置，并讨论这一发现的意义。

1 标本描述

IVPP V 18060仅保存了一完整的左侧第四跖骨(图1), 长约355 mm, 骨干中段横向直径约67 mm。与大小相近的其他兽脚类恐龙第四跖骨相比，V 18060非常粗壮。

V 18060近端明显膨胀。近端关节面近三角形，最大横向直径约135 mm, 明显大于最大前后向宽度。近端视，内侧缘凹陷。近端关节面内缘后半侧强烈内延，并在端部向后侧延伸。

前视，骨干微向外侧弯曲；侧视，骨干较为平直。骨干横截面总体呈扁三角形；越靠近近端，前后向长度越窄。骨干内侧面在靠近近端处有一与第三跖骨近端处相连接的斜向近三角形凹陷，横向宽。骨干后侧面平坦，但在中间有轻微挤压形成的沟槽，沟槽从近端一直延伸到接近远端处，长度约占骨干长度的3/4。骨干后侧面的远端1/2处具一近半月形凹陷，可能代表第三和第四脚趾屈肌(*M. lumbricalis*)附着处。该凹陷上部边缘破损，现存最长直径约95.4 mm, 宽约35 mm。凹陷靠近骨干外侧面，与周围界限清晰，与骨干外侧边缘接触带有一纵向延伸的脊，脊在近端处存在缺口，使凹陷相对骨干后部表面呈半开放状态。凹陷内非常粗糙，有大量附着肌肉的细小褶皱与凹坑。

远端关节头远端视呈近梯形，横向宽度稍大于前后向高度。仅在后侧有铰链关节，分隔内外侧髁的沟槽只延伸到远端关节面的中部。内侧髁近脊状，外侧髁横向宽度明显大于内侧髁。侧韧带窝发育，内侧韧带窝大于外侧韧带窝，并比后者深。

2 比较与讨论

准噶尔盆地石树沟组中已发现的兽脚类恐龙包括单脊龙*Monolophosaurus* (Zhao and Currie, 1993), 中华盗龙*Sinraptor* (Currie and Zhao, 1993), 冠龙*Guanlong* (Xu et al., 2006b), 泥潭龙*Limusaurus* (Xu et al., 2009), 简手龙*Haplocheirus* (Choiniere

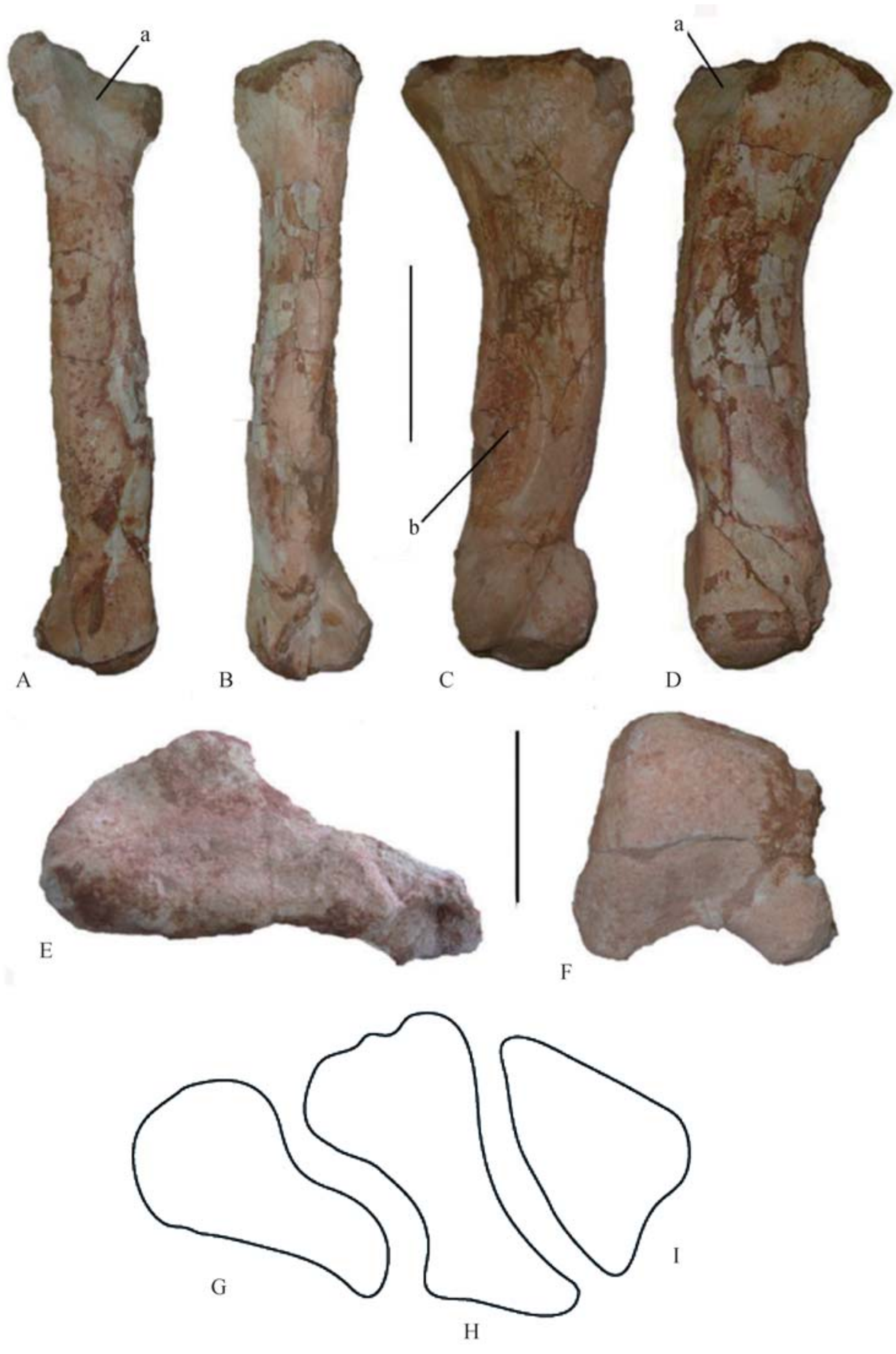

图 1　IVPP V 18060左侧第四跖骨内侧视(A)、外侧视(B)、后视(C)、前视(D)、近端视(E)和远端视(F)，以及董氏中华盗龙第四(G)、第三(H)和第二(I)跖骨近端关节面相互关系示意图

Fig. 1　Left metatarsal IV of IVPP V 18060, in lateral (A), medial (B), posterior (C), anterior (D), proximal (E) and distal (F) views, and left metatarsus of *Sinraptor dongi*, proximal views of metatarsals IV (G), III (H), and II (I)(from Currie and Zhao, 1993)

a. the concave with Met III; b. the depression for muscle (*M. lumbricalis*) attachment on the posterior side of the shaft; A, B, C, D scale bar=10 cm; E, F scale bar=5 cm et al., 2010a)和左龙*Zuolong* (Choiniere et al., 2010b), 以及中华盗龙类的牙齿标本IVPP V 15310 (Xu and Clark, 2008)。V 18060稍小于董氏中华盗龙正型标本(表2), 也小于V 15310(根据牙齿标本的大小对比，可知V 15310为目前已报道侏罗纪兽脚类恐龙中尺寸最大的), 但明显大于准噶尔盆地侏罗系地层中已发现的其他兽脚类恐龙。

表 2　IVPP V 18060与董氏中华盗龙IVPP V 10060第四跖骨相关数据对比

Table 2　Comparison of left metatarsal IV of IVPP V 18060 and *Sinraptor dongi* IVPP V 10060 (mm)

Specimen	Length (L)	Middle transverse width of shaft in anterior view (M)	Minimum transverse width of shaft in anterior view	Proximal width	Distal width	Minimum circumference (C)	C/L	C/M
IVPP V 18060	355	67	56	132	79	179	0.50	5.3
Sinraptor dongi IVPP V 10060	375	47	43	109	61	145	0.39	8.0

为了更进一步确认V 18060的系统位置，我们将包括V 18060在内的12种兽脚类恐龙建立了一个仅基于第四跖骨特征的特征列表和用于系统发育分析的矩阵(包括12个分类单元和14个特征)。我们用分支系统学软件TNT (Goloboff et al., 2008)对该矩阵进行了分析。所有特征均为无序和等权重，运用启发式搜索，重复1000次，每次保存10棵树，其他所有参数采用缺省设置。依据前人有关兽脚类系统发育研究的结论(Weishampel et al., 2004), 我们选择双脊龙(*Dilophosaurus*)作为外类群。考虑到角鼻龙类的单系性得到广泛认可，对其单系性进行了强制性设置。分析结果显示，异特龙、董氏中华盗龙与V 18060共同组成一个彼此关系很近的支系，其中V 18060与董氏中华盗龙关系最为密切。分析的结果产生了1个树(树长L=31, 一致性指数CI=0.548, 保留指数RI=0.576)(图2)。

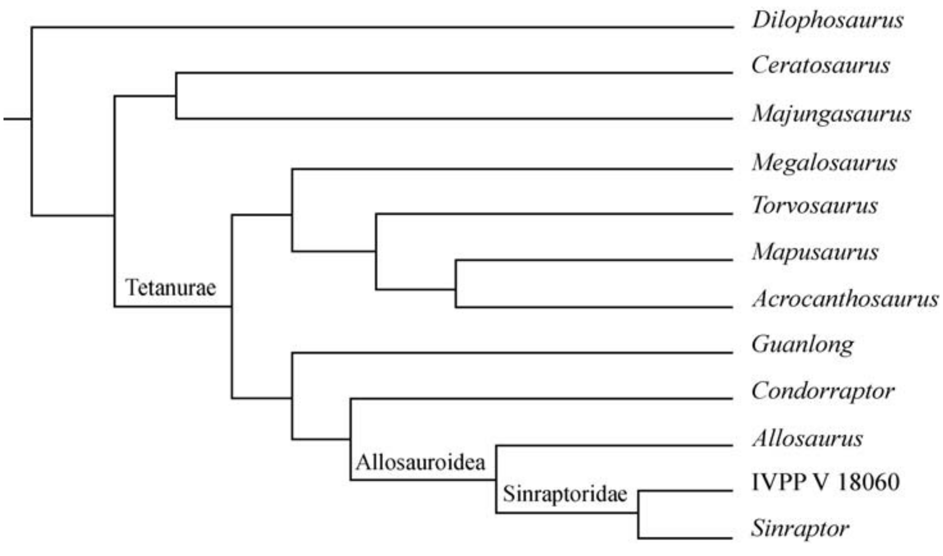

图 2　根据第四跖骨特征所做的兽脚类恐龙支序图

Fig. 2　Phylogeny tree based on the Met IV of theropod dinosaurs characters

After constraining Ceratosauria as monophyletic group, tree length=31; consistency index (CI) =0.548; retention index (RI) =0.576

支序图虽然只是基于一根第四跖骨特征而作，但我们还是可以简单地做一些分类区分。除高脊龙(*Acrocanthosarus*), 马普龙(*Mapusaurus*)和冠龙(*Guanlong*), 包括V 18060及其他几种坚尾龙类(Tetanurae)在其近端关节面上均有相似的外形，呈近三角形状(Currie and Zhao, 1993; Madsen, 1976; Britt, 1991)。Rauhut (2005)将神鹰盗龙(*Condorraptor*)近端关节形状描述为“近四边形”(见图3), 但通过对比外形轮廓，划为近三角形更为合适，且它们均存在近端关节面内后端向内侧的明显延伸。而双脊龙、角鼻龙、高脊龙和冠龙第四跖骨近端关节面呈近四边形(Gilmore, 1920; Currie and Carpenter, 2000), 玛君颅龙(*Majungasaurus crenatissimus*)则被描述为“D”字形(Carrano, 2007)。

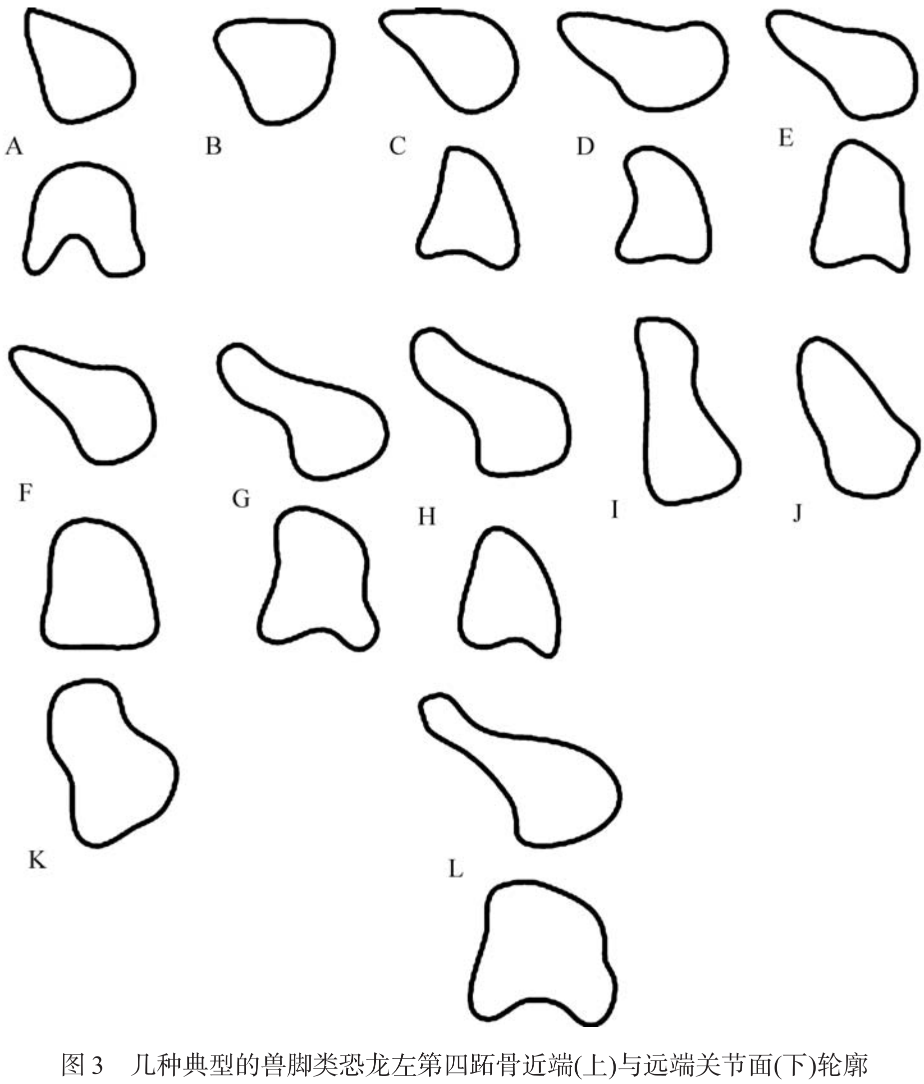

图 3　几种典型的兽脚类恐龙左第四跖骨近端(上)与远端关节面(下)轮廓

Fig. 3　Comparison of theropod left metatarsal IV in proximal (top) and distal (bottom) views

A. *Dilophosaurus wetherilli* (based on UCMP 37302)(Welles, 1984); B. *Ceratosaurus nasicornis* (based on USNM 4735)(Gilmore, 1920); C. *Majungasaurus crenatissimus* (based on FMNH PR 2278)(Carrano, 2007); D. *Megalosaurus bucklandii* (Huene, 1926); E. *Condorraptor currumili* (based on MPEF-PV 1692)(Rauhut, 2005); F. *Torvosaurus tanneri* (based on BYUVP 5278)(Britt, 1991); G. *Sinraptor dongi* (based on IVPP V 10600)(Currie and Zhao, 1993); H. *Allosaurus fragilis* (Madsen, 1976); I. *Acrocanthosaurus atokensis* (based on NCSM 14345)(Currie and Carpenter, 2000); J. *Mapusaurus roseae* (based on MCF-PVPH 10834)(Coria and Currie, 2006); K. *Guanlong wucaii* (based on IVPP V 14532); L. IVPP V 18060

V 18060与异特龙超科的成员具有最多的相似性。中华盗龙、异特龙与V 18060在近端关节面上还有如下相似点：内侧边缘凹陷弯曲；后部边缘与外部边缘之间角度近于直角。尽管V 18060近端有磨损，但仍可观察到其后内侧端部有与中华盗龙和异特龙一样的向后延伸的趋势，外形上呈“舌”状。

异特龙超科中，V 18060骨干与中华盗龙和异特龙类似，均向外侧轻微弯曲，但弯曲程度明显不如双脊龙、角鼻龙和犸君颅龙(Carrano, 2007)。骨干后部的附着肌肉凹陷区域，V 18060与中华盗龙和异特龙都具有相似的形状，均呈半月形。骨干横截面三者也很类似，均为近三角形。不同之处在于V 18060横截面较扁，但不排除是后期保存挤压原因所致。而巨齿龙(*Megalosaurus*)和神鹰盗龙骨干横截面则为半圆形(Benson, 2010; Rauhut, 2005)。

支序分析支持V 18060与中华盗龙同属中华盗龙科成员，它们之间共享了最多的相似特征。

V 18060与中华盗龙跖骨外侧类似，均较为圆滑，而神鹰盗龙和异特龙近端关节外侧与前方边缘之间部分棱角分明。

V 18060和中华盗龙具有相似的骨干后部肌肉凹陷结构，但V 18060的凹陷区域宽度更宽(中华盗龙2.5 cm × 10 cm, V 18060为3.5 cm × 9.5 cm), 两者凹陷的外侧边均在外侧面边缘上重合，并都有一个近端方向有缺口的脊，缺口长度分别约占凹陷长度的1/3和1/2。该脊状物的存在使其呈现为半开放状态(见图4), V 18060的脊比中华盗龙的略高。V 18060与中华盗龙凹陷上的缺口均位于上方。在分布位置上，只有马普龙的凹陷位于骨干中心，呈全向封闭状态；而中华盗龙、异特龙、犸君颅龙和冠龙与V 18060一样均紧贴跖骨的外侧面边缘，凹陷外侧边与骨干的外侧边缘平滑过渡接触，呈全开放状态。

V 18060远端关节轮廓呈近梯形，远端关节内外两侧韧带凹陷表现明显，内侧面侧韧带凹陷不论大小还是深度相对均大于外侧面的侧韧带凹陷，这两点与中华盗龙相似。而异特龙和犸君颅龙等内外侧韧带凹陷均不是非常明显，神鹰盗龙外侧韧带凹陷不发育，而蛮龙(*Torvosaurus*)和角鼻龙等则几乎没有两侧韧带凹陷。

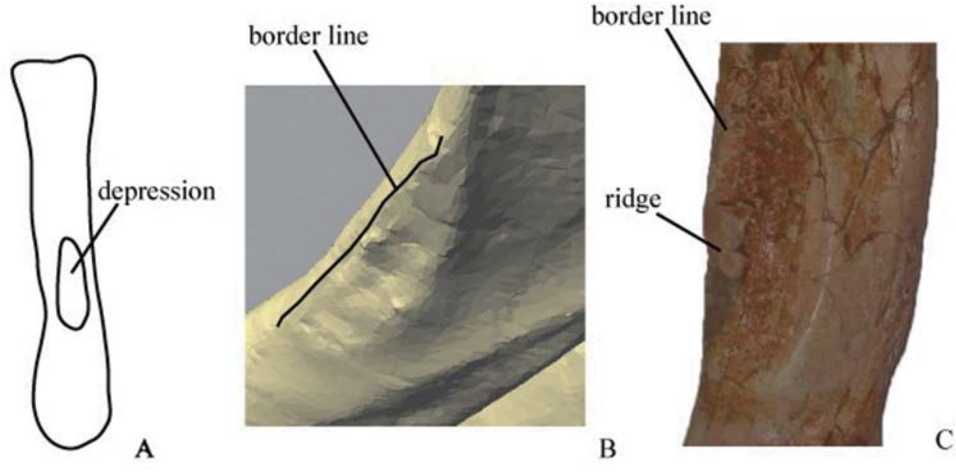

图4 骨干后部的三种肌肉凹陷(第三和第四脚趾屈肌)边界形式示意图

Fig. 4 The depression for muscle (*M. lumbricalis*) attachment on the posterior side of the shaft's border line
A. *Mapusaurus roseae*, based on MCF-PVPH 10834, closed; B. *Allosaurus fragilis*, 3D model, opened; C. IVPP V 18060, open over 50% of its length

V 18060也具有一些相对独特的特征。如：骨干后部有较深的凹陷，而大部分兽脚类第四跖骨后部相对平坦；V 18060的远端关节前后向与内外侧长度分别为71和79 mm，前后向长度略小于内外侧长度，而其他除双脊龙外的多数兽脚类第四跖骨均为内外侧长度小于前后向长度。V 18060远端呈现为一个上部圆钝的粗壮梯形，异特龙末端则为一个尖锐的三角，中华盗龙介于二者之间，而双脊龙则为近矩形。在末端两髁大小上，V 18060与原始的双脊龙一样，末端外侧髁大于内侧髁，而中华盗龙则相反。

中华盗龙正型标本第四跖骨与V 18060具有一些不同点：V 18060骨干粗壮程度远超中华盗龙，我们通过计算骨干全长与骨干中部横向直径的比值来进行粗壮程度的区分。V 18060比值为5.3, 在侏罗纪兽脚类恐龙中，仅比蛮龙略细(蛮龙最为粗壮，比值为4.3)，而中华盗龙比值为8.0; 两者远端关节内外两髁大小差异相反：中华盗龙远端关节两髁内大外小，而V 18060是外大内小；V 18060骨干后方相比中华盗龙凹陷程度更深。我们认为这些形态差异不是由于个体发育造成的，原因在于中华盗龙正型标本第四跖骨与V 18060的长度非常接近，指示两者可能处于相近的个体发育阶段。

我们怀疑V 18060的差异可能代表了性双形差异。前人的研究显示一些兽脚类恐龙可能能够通过头后骨骼特征来区分性双形。其中，Raath (1990)通过区分合踝龙(*Megapnosaurus rhodesiensis*)的前肢、骨盆、骶骨和股骨的形状，特别是股骨的粗壮程度，划分出纤细型与粗壮型，将其作为性双形的依据。而Chinsamy (1990)则是通过对合踝龙股骨进行骨组织学分析，发现在粗壮型股骨内部的环髓带存在侵蚀现象，认为其代表了钙质或磷酸盐类的流失，这与现生鸟类在产卵期时的现象一致(Bloom et al., 1941)，因而认为粗壮型代表了雌性个体。对暴龙(*Tyrannosaurus rex*)性双形的区分判断依据包括：Carpenter (1990)发现在几件暴龙的“粗壮型”标本中，坐骨骨干远端部位指向与“纤细型”存在明显差异，他认为“粗壮型”的这种解剖学结构是为了有利于产卵(反对意见见Brochu, 2003); Carpenter and Smith (2001)通过测量暴龙肱骨与尺骨的形状与比例，划分出纤细型与粗壮型, 并认为其中肱骨的差异可能代表了性双形, 而Molnar (2005)认为尺骨也可以与此相联系; Larson (1994)指出暴龙人字骨最前端的形状和位置与暴龙性双形有联系(反对意见见Brochu, 2003)。人字骨的位置也被Larson (1994)参照以区分“亚洲伤齿龙”(Asian troodontids)。Colbert (1989, 1990)通过对比腔骨龙(*Coelophysis bauri*)的头骨、颈部、前肢和骶骨神经棘愈合处的形态及比例，指出了其中包含的两种分异类型。Rowe and Gauthier (1990)针对腔骨龙和合踝龙的前后肢长度与局部形态比较，进行了性别区分。以上是通过头后骨骼区分兽脚类性双形的报道，但其中部分文章存在争议，如统计材料的数量较少，部分化石保存不完全，也不能完全排除可能存在无关性别的个体变异因素(Molnar, 2005)。在本文中，董氏中华盗龙正型标本与V 18060在粗壮程度和远端关节面上存在明显差异，不排除为性双形的可能。但由于标本数量稀少，缺乏足够、合理的统计数据支撑，因此，我们难以肯定判断其为性双形。

董氏中华盗龙正型标本与V 18060的形态差异有可能代表分类学差异，这些不同的形态特征有可能指示V 18060代表一个与中华盗龙亲缘关系很近，但又截然不同的新种。由于材料的局限性，这一判断还有待更完整材料发现来确认。其他中华盗龙类恐龙，如上游永川龙(*Yangchuanosaurus shangyouensis*)和巨型永川龙(*Y. magnus*), 由于未保存第四跖骨，因而不在本文讨论对比之列。

大型兽脚类牙齿标本IVPP V 15310的发现(Xu and Clark, 2008)也支持五彩湾地区存在一个不同于董氏中华盗龙的中华盗龙类的存在。V 15310甚至有可能和V 18060同属一种。如果V 18060(以及V 15310)确实代表一个新种，那么在准噶尔盆地较小的区域里(五彩湾化石点和发现董氏中华盗龙的将军庙化石点直线距离约100 km)存在着亲缘关系很近的不同兽脚类种。对其他类群的研究(比如龟鳖类)也显示了同样的现象(Brinkman et al., 2012)。这一现象指示五彩湾和将军庙化石点可能存在着一定的生态差异性或者某种程度的地理隔离，从而导致了不同中华盗龙类在准噶尔盆地东北缘的出现。但由于V 15310和董氏中华盗龙的产出层位是否存在差异还有待确认，因此我们不能排除时间因素对形态差异产生的影响。在石树沟组发现更完整的化石材料、准噶尔盆地侏罗纪古地理的精确恢复以及对五彩湾和将军庙化石点地层层序的更精确对比将有助于我们理解这一现象产生的原因。

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Appendix I Character list

1. Shaft length divided by mid-shaft diameter: (0) >6.9 (slim); (1) ≤6.9 (robust).
2. Proximal end, lateral side: (0) flat; (1) convex.
3. Proximal end, at the medial side, the posteromedial process: (0) weakly medially directed; (1) strongly medially directed.
4. Proximal end, posterior side: (0) flat; (1) posteromedial process posteriorly directed.
5. Proximal end, medial side: (0) flat; (1) depressed.
6. Shaft in anterior view: (0) straight; (1) slightly convex laterally; (2) strongly convex laterally.
7. Distal end, shape in distal view: (0) trapezoidal, with anterior side shorter than posterior side; (1) subrectangular.
8. Distal end, lateral condyle's size: (0) subequal to the medial one; (1) larger than the medial one; (2) smaller than the medial one.
9. Distal end anteroposterior length compared to mediolateral length: (0) larger; (1) smaller.
10. The depression for muscle (*M. lumbricalis*) attachment on the posterior side of the shaft: (0) absent or shallow; (1) deep.
11. The shape of the depression for *M. lumbricalis*: (0) proximodistally oval; (1) semi-lunate with a lateral straight edge.
12. The depression for *M. lumbricalis*, lateral borderline: (0) closed; (1) open over 33% to 50% of its length; (2) totally opened.
13. The cross-section of the shaft: (0) triangular; (1) semi-circular.
14. Posterior surface of the shaft: (0) flat; (1) concave.

Appendix II Character matrix of 14 features among 12 taxa of theropod dinosaurus, *Dilophosaurus* was taken as outgroup

Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Dilophosaurus	0	0	0	0	0	2	0	1	1	0	?	?	?	?
Ceratosaurus	0	0	0	0	0	2	?	0	0	?	?	?	?	?
Majungasaurus	0	1	1	0	1	2	0	1	0	0	1	2	0	0
Megalosaurus	0	0	1	0	0	0	0	0	0	?	0	?	1	0
Torvosaurus	1	0	1	0	0	0	1	0	0	0	?	?	?	0
Condorraptor	0	1	1	0	0	1	0	2	0	0	1	?	1	0
Sinraptor	0	1	1	1	1	1	0	2	0	1	1	1	0	0
Allosaurus	0	0	1	1	1	1	0	2	0	0	1	2	0	0
Acrocanthosaurus	1	1	0	0	0	0	?	?	?	?	?	?	?	?
Mapusaurus	0	1	0	1	0	0	?	?	0	1	0	0	?	0
Guanlong	0	1	0	0	1	?	?	?	?	0	1	2	0	0
IVPP V 18060	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**