

FIRST LATE JURASSIC DINOSAUR BONES FROM CHILE

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Skeletal remains of dinosaurs from Chile are rare, unlike the ichnological record, which includes sauropods, theropods, and ornithopods, mostly from the Upper Jurassic-Lower Cretaceous (Moreno and Pino, 2002; Moreno et al., 2004). The first record of dinosaur bone in this country—a few remains of a titanosaur sauropod from the Upper Cretaceous of the Fourth (IV) Región—was reported by Casamiquela et al. (1969). Since then, the reported materials have been very scarce: only some titanosaur bones collected in the Upper Cretaceous of the Third (III) Región (Iriarte et al., 1999). Concerning their geographic distribution, most of the Chilean dinosaur remains occur north of 39° S Lat. (Salinas et al., 1991; Rubilar, 2003).

In this paper, an assemblage of dinosaur bones from the Central Patagonian Cordillera at Aysén (southern Chile; ca. 46° S.), south of Lago General Carrera, is reported. Previous records of Jurassic dinosaurs of Chile consisted of footprints (Chong and Gasparini, 1976; Moreno and Rubilar, 1999). Thus, the remains from southern Chile are the first undoubted Jurassic dinosaurs found in this country, and the first significant remains of carnivorous dinosaurs, which previously were known only from isolated teeth found in the Upper Cretaceous Viñita Formation at the Monumento Natural Pichasca, in the Fourth (IV) Región (Rubilar, 2003).

Institutional Abbreviations—SNGM, Servicio Nacional de Geología y Minería, Santiago, Chile.

GEOLOGY

The fossils were collected from exposures of the Toqui Formation, which crops out in the mountains south of Lago General Carrera; the mountains are flanked by the Maitenes and Horquetas rivers (Fig. 1). The succession of clastic sedimentary rocks with intercalated tuffs, locally bearing dinosaur bones, assigned to this unit is 300–320 m thick, with no exposed top. The dinosaur fossils occur in an approximately 100 m succession of alternating green volcanoclastic pebbly sandstones and sandy sedimentary breccias, with intercalations of lapilli tuffs and red ignimbrites with eroded tops (Fig. 1). The base of the succession is a 20-m thick red ignimbrite. A Late Jurassic age was obtained from zircon samples extracted from this ignimbrite (see below).

The sandstones are coarse-grained, frequently passing into conglomerates. They are formed by fragments of andesites, rhyo-

lites, dacites, basalts, quartzites, micaceous schists, plagioclase, quartz, and zircons. Two beds of fine-grained tuffaceous sandstones with abundant trace fossils include abundant detrital biotite. They probably represent reworked pyroclastic detritus. The sedimentary breccias are tuffaceous, with mainly volcanic clasts 2–8 mm in diameter, and isolated fragments up to 20 cm in diameter. The clasts are mainly volcanic in origin, including tuffs, volcanic breccias, and coherent andesite. The cement is calcite and locally chlorite and hematite or limonite. Glauconite has been locally identified by X-ray diffractometry. These rocks experienced low-grade metamorphism of prehnite-pumpellyite facies.

Apart from the dinosaurs, other fossil material is rare. Locally, fossil tree trunks of *Podocarpoxylon* and trilete spores occur, indicating humid and bleak conditions. Vertical and horizontal trace fossils (e.g., *Thalassinoides*) occur in two beds of medium to fine-grained tuffaceous sandstones. The vertical trace fossils are badly preserved; these are preliminary identified as *Skolithos*.

These sedimentary beds resemble braided river deposits. However, the identification of glauconite in some of the green sandstones, and the occurrence of two tuffaceous sandstone layers with fossil traces of *Thalassinoides* and probably *Skolithos* indicates marine sedimentation for those beds (see Frey, 1975; Ekdale et al., 1984; Goldring, 1991; Pemberton et al., 1992), at least. Therefore, the depositional setting of these beds is interpreted as that of a braided-river delta.

Underlying this facies association, north of the Las Horquetas river, an association of green conglomerates and tuffs, with well-sorted dinosaur remains, is interpreted as a braided river deposit. Therefore, a change from braided rivers to deltaic environment is proposed for the dinosaur-bearing beds.

The dinosaur-bearing beds overlie a 30–50 m thick sandy-calcareous facies association, composed of calcareous laminites representing algal mats, minor stromatolite intercalations, and interbedded tuffites, tuffs, and conglomerates. These rocks, in turn, overlie tuffs of the Ibáñez Formation. The calcareous laminites represent peritidal deposits, which could be marine or lacustrine, although their relative proximity to shallow marine beds that they underlie, may favour a marine setting.

U-Pb SHRIMP Age

A new U-Pb SHRIMP age of 147 ± 1.0 Ma was obtained from zircon samples from the ignimbrite at the base of the measured section in Fig. 1. This corresponds to the Tithonian (Gradstein et

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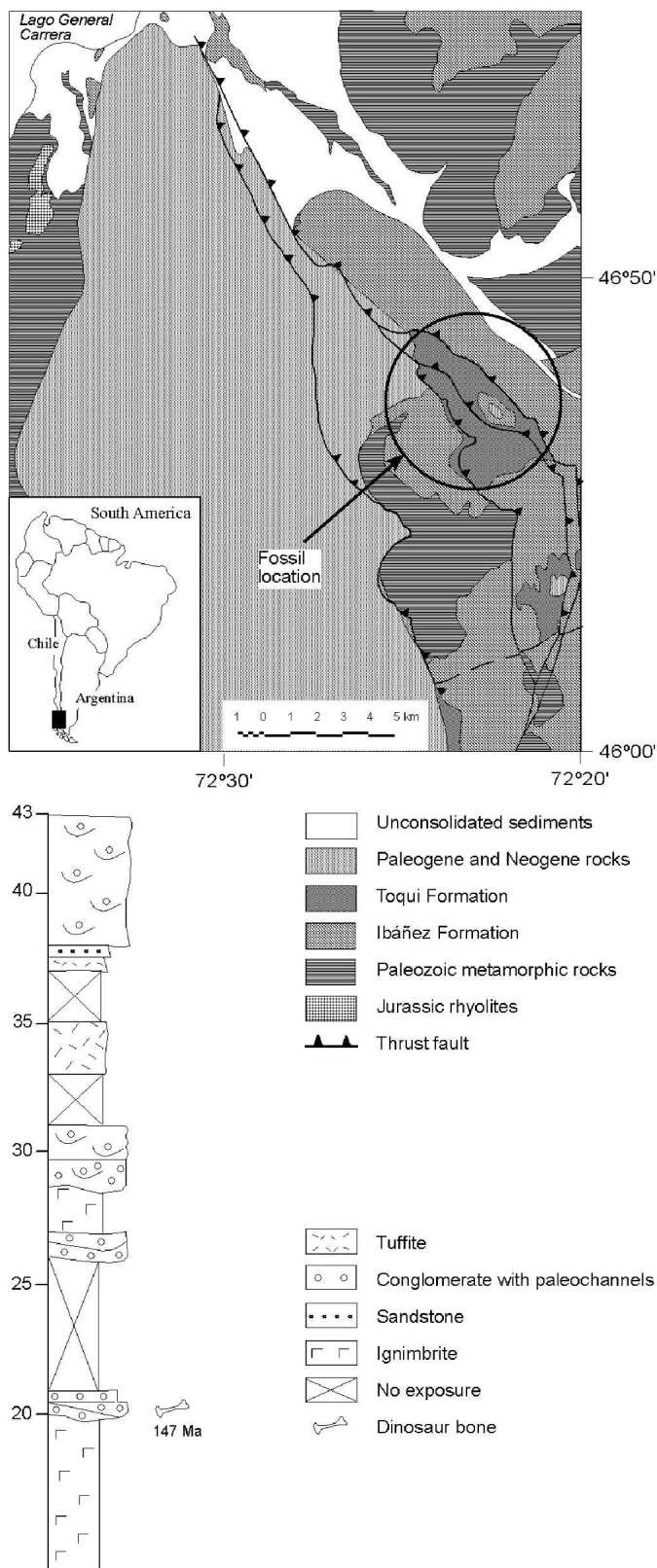


FIGURE 1. Map of the fossil location and stratigraphic column.

al., 2004), in agreement with other Tithonian ages for the marine transgression in the Aysén Basin, as demonstrated in beds exposed in the Palena area (43° 30'S). It has been established that this transgression was diachronous, being Tithonian, Berriasian,

Valanginian and early Hauterivian in different localities (Covacevich et al., 1994; De La Cruz et al., 1996, 2003; Suárez et al., 1996; Pankhurst et al., 2003).

The SHRIMP ion microprobe U-Th-Pb zircon dating was carried out at the Australian National University; the SHRIMP analytical procedures follow those summarized in Williams (1998). The results are interpreted as representing magmatic ages.

SYSTEMATIC PALEONTOLOGY

DINOSAURIA Owen, 1842

THEROPODA Marsh, 1881

Gen. et sp. indet.

Material—Right ilium, SNGM-1889; proximal end of left tibia, SNGM-1895; partial left pes, comprising articulated distal end of tibia and fibula, astragalus and calcaneum, distal tarsal IV, metatarsals II-IV and many articulated phalanges; SNGM-1888; distal end of right tibia, SNGM 1901.

Locality and Horizon—Aysén, south of Lago General Carrera, IV Región (ca., 46° S Lat.), Chile. Toqui Formation (Tithonian), Aysén Basin.

DESCRIPTION

The preacetabular process of the ilium SNGM-1889 is laminar and relatively high, as in all the theropods (Fig. 2A). The postacetabular blade is broad; its dorsal margin is unusually robust laterally. The central part of the acetabular lamina is broken; thus it is impossible to see scars of sacral ribs on the medial side. The brevis fossa is not well-developed. The ischiadic process is robust, and the pubic peduncle is anteroposteriorly narrow.

The proximal end of a left tibia has been collected (SNGM-1895). Most of the cnemial crest has not been preserved (Fig. 2B). The distal end of the tibia is transversely expanded (Fig. 2C). Anteriorly, a wide median buttress (Molnar et al., 1996) is seen in SNGM-1888 and SNGM-1901, which surrounds proximally a depression on which lays the astragalus ascending process (Fig. 2C). The fibular flange of the tibia backs the distal end of the fibula posteriorly. Distally, the medial and lateral malleoli are at the same level.

The astragalus, preserved in SNGM-1888, is not fused to the tibia or fibula (Fig. 2C). Its condyles are directed ventrally, unlike in *Allosaurus* and other Tetanurae, in which they are anteroventrally directed (Madsen, 1976:pl. 52; Holtz et al., 2004). Anteriorly, at the base of the ascending process, there is a shallow, transversally elongated fossa (Fig. 2C). The ascending process in SNGM-1888 is blocky and low (Fig. 2C), as on the astragali of non-coelurosaurian theropods (Holtz et al., 2004). This process is even notably lower than in *Allosaurus* (Madsen, 1976:pl. 5), and, in view of the notch on the anterior face of the distal end of the tibia, than in *Piatnitzkysaurus* (Bonaparte, 1986:fig. 26).

The distal tarsal IV of SNGM-1888 articulates only with metatarsal IV, and is oval in proximal view (Fig. 2D). Metatarsal II is the shortest and metatarsal III the longest. Proximally, metatarsal IV has a lateral expansion, which is absent in *Allosaurus* (Fig. 2D); hence, in the latter, the proximal surface of metatarsal IV articulates completely with the distal tarsal IV (Madsen, 1976:fig. 25B), whereas in the new material from Chile, part of this surface does not articulate with distal tarsal IV, but probably directly with the calcaneum.

In SNGM-1888, phalanx II-1 is similar in length to II-2, although the latter is somewhat more slender.

The distal end of the ungual phalanx is broken; the lateral side of the ungual has a simple furrow, not bifurcated as in abelisauroids (Novas and Bandyopadhyay, 2001).

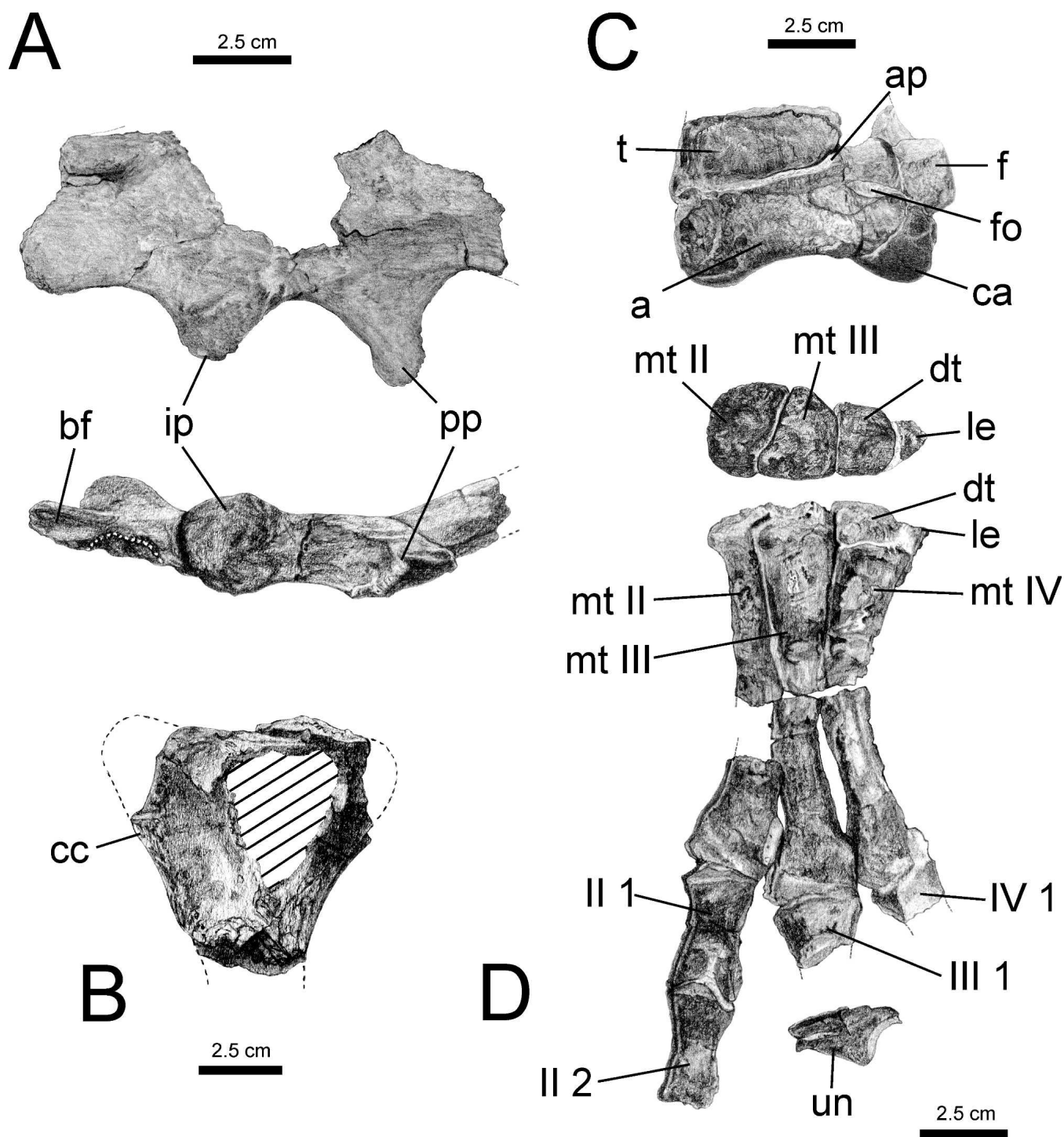


FIGURE 2. Theropoda gen. et sp. indet. **A**, SNGM-1889, right ilium in lateral and ventral views, **B**, SNGM-1895, proximal end of left tibia in lateral view, **C**, SNGM-1888, left tarsus in anterior view, and **D**, left metatarsus in proximal and anterior views, unguis phalanx in lateral view. **Abbreviations:** a, astragalus; ap, ascending process; bf, brevis fossa; ca, calcaneum; cc, cnemial crest; dt, distal tarsal; f, fibula; fo, lateral fossa; ip, ischiatic peduncle; le, lateral expansion; mt, metatarsals; pp, pubic peduncle; t, tibia; un, unguis phalanx.

TETANURAE Gauthier, 1986
Gen. et sp. indet.

Material—Dorsal vertebrae, SNGM-1894, SNGM-1898, SNGM-1900, SNGM-1903; partial left manus, SNGM-1887.

Locality and Horizon—As for the previous material.

DESCRIPTION

Axial Skeleton—Many dorsal centra have been preserved. Some are laterally compressed and have a relatively well developed ventral keel (SNGM-1894, 1898 and 1903) (Fig. 3A). Others (e.g. SNGM-1900), possibly from a more posterior position

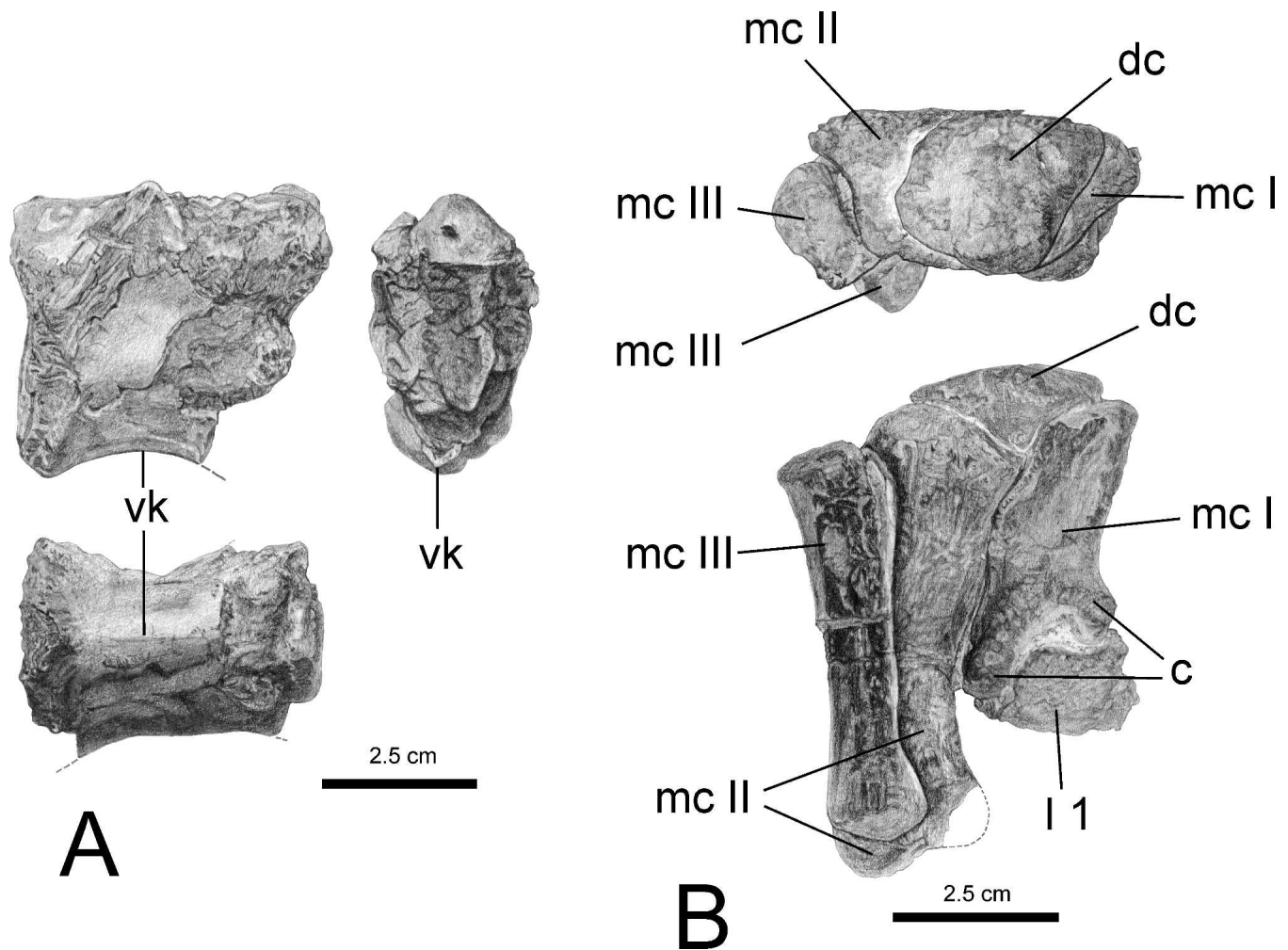


FIGURE 3. Tetanurae gen. et sp. indet. **A**, SNGM-1894, dorsal centrum in right lateral, anterior, and ventral views, **B**, SNGM-1887, left manus in proximal and palmar views. **Abbreviations:** c, condyles; distal carpal; mc, metacarpals; vk, ventral keel.

compared to the former, lack such a keel. The vertebral centra have no pleurocoels.

Appendicular Skeleton—The manus (SNGM-1887, Fig. 3B) is basically similar to that of *Allosaurus* (Madsen, 1976; Chure, 2001). It was probably functionally tridactyl. The distal carpal I, metacarpals I-III, the proximal articulation of the phalanx I-1 articulated to the metacarpal I, and the articulated phalanges II-2, III-2, and III-3 are preserved.

Distal carpal I contacts metacarpals I and II; this element seems a parallelogram, being more equidimensional than that of *Acrocantiosaurus* (Currie and Carpenter, 1999:fig. 10). Metacarpal I is short and wide (length = 5.2 cm); it is the shortest of the three metacarpals, its length being nearly 66% that of metacarpal II (Fig. 3B). The shaft of metacarpal I is anteroposteriorly compressed and closely attached to the lateral surface of the second metacarpal.

The distal condyles of metacarpal I are markedly asymmetrical, the lateral condyle being larger than the medial one (Fig. 3B). The lateral condyle is well below the medial condyle, and manual digit I forms an angle of approximately 45° with the axis of the manus.

Metacarpal II, with a length of 7.8 cm, is the longest, reaching 150% of the length of metacarpal I. Metacarpal III (6.4 cm long) is shorter than metacarpal II. Metacarpal III is articulated to metacarpal II, and partially rotated onto the palmar surface. Its

proximal articular end is subtriangular. The base of metacarpal III lies on the palmar surface of metacarpal II.

DISCUSSION AND CONCLUSIONS

Some of the material found in Aysén (dorsal vertebrae and carpal and metacarpal elements, SNGM-1894, 1898, 1903, and 1887), probably belongs to a tetanuran based on the following features: 1) pronounced ventral keel on the dorsal centrum (Rauhut, 2005a); 2) metacarpal I closely applied to the lateral surface of the metacarpal II (Gauthier, 1986; Currie and Carpenter, 2000; Coria and Currie, 2006); 3) medial and lateral condyles of the metacarpal I asymmetrical (a synapomorphy of Maniraptora according to Sereno [1999 character 85] although, according to Gauthier [1986], this condition is found in all saurischians, including prosauropods and almost all non-avian theropods); 4) metacarpal III shorter than metacarpal II (Holtz, 2000: character 263; although this difference is not so marked in the material from Aysén, and the condition also occurs in *Ceratosaurus* [Gilmore, 1920]); 5) articular end of metacarpal III subtriangular (condition interpreted as synapomorphic for *Torvosaurus* + more derived Tetanurae [Holtz, 2000: character 267]), and 6) base of metacarpal III placed on the palmar surface of metacarpal II (Holtz, 2000: character 266; Holtz et al., 2004).

On the other hand, the assignment of some of the remains is

dubious, especially the tarsus and metatarsus (SNGM-1888, 1895, 1899, 1901). In the tarsus, some synapomorphies of derived theropods are seen: a median buttress at the distal end of the tibia of SNGM-1899 and SNGM-1901—a probable diagnostic character of neotheropods (according to Sereno et al., 1998), although a median buttress is present in all basal saurischians (Rauhut, 2005a); the presence of a transverse fossa in the astragalus separating the ascending process from the condylar portion of SNGM-1888, which is a tetanuran condition (Holtz, 2000). However, in general, the tarsus shows a primitive structure, especially in the massive ascending process of the astragalus, the ventrally directed condyles (although undoubted tetanurans, such as the Tyrannosauridae and Carcharodontosauridae, have the plesiomorphic condition [Coria and Currie, 2006:character 110]), and the lateral expansion of the tibia is scarcely developed. The pes is likewise primitive, even more so than in basal tetanurans, which generally have an hourglass-shaped proximal outline of metatarsal III (Madsen, 1976:fig. 25A). These differences between the anterior and posterior limb elements indicate that the remains from Aysén represent at least two different forms of theropod, one tetanuran and one non-tetanuran.

Late Jurassic theropods are still scarce in the Southern Hemisphere. A few are known in Africa: the ceratosaurian *Elaphrosaurus bambergi* and a probable allosauroid, *Allosaurus? tendagurensis*, (Holtz et al., 2004:table 4 I); other remains collected at the beginning of the twentieth century have recently been described (Rauhut, 2005b). The new specimens from Aysén can now be added to this list. Except for the type material of *Elaphrosaurus bambergi* from Tendaguru, the material here described is the most complete theropod record found to date in the Late Jurassic of Gondwana.

Aysén is the second South American locality of Late Jurassic age with an abundance of dinosaur remains, the other being the Cañadón Calcáreo Formation in Chubut, Argentina. In addition, the specimens represent the first good record of Theropoda from the Upper Jurassic of South America. Previously, only a few fragmentary teeth were reported by Rich et al. (1999) from the Cañadón Calcáreo Formation and by Perea et al. (2003) from the Tacuarembó Formation of Uruguay.

The record of tetanurans in the Jurassic of the Southern Hemisphere is more extensive for the Middle Jurassic (Rauhut, 2005b). The material from Aysén indicates that in South America, as in other continents, tetanurans probably coexisted with other, more primitive theropods toward the end of the Late Jurassic.

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