Occurrence of the Southernmost South American Ichthyosaur (Middle Jurassic—Lower Cretaceous), Parque Nacional Torres del Paine, Patagonia, Southernmost Chile

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An ichthyosaur discovered in the Ultima Esperanza Province, southern Chile, is the southernmost specimen of this group yet discovered in South America. The incomplete fossil consists of 17 vertebrae and associated neural arches and ribs. Occurring within a large block in glacio-fluvial sediments adjacent to the Campo de Hielo Patagónico Sur, the remains cannot be given a species designation nor be dated with precision or tied to one specific formation at this time. However, the rock type, geologic occurrence of the block, and glaciology of the sector enable the material to be placed within the upper part of the Middle to Upper Jurassic Tobifera Formation or the Lower Cretaceous Zapata Formation. Although the fairly broad stratigraphic range and limited fossil material hamper careful stage-level paleobiogeographic analysis, this occurrence documents the existence of ichthyosaurs in the now closed Rocas Verdes back-arc basin. This occurrence extends the distribution of ichthyosaurs in South America some 1500 km south of previously reported fossil material. The fossil provides support for the existence of a possible migration seaway between southern South America and western Africa during the Late Jurassic associated with the breakup of the southern sector of Gondwana. This seaway would be the southern counterpart to the Hispanic Corridor that connected the Pacific to the west Tethys around the northern end of South America.

INTRODUCTION

South American ichthyosaurs and other reptilian remains have been studied extensively from the Neuquen Basin (32–41°S, 68–72°W), where a diverse and abundant Jurassic herpetofauna exists in the Vaca Muerta Formation of Tithonian–Valanginian age (Gasparini and Fernández, 1997). Reports of ichthyosaur remains in northern and central Chile are few, and the fossil material is quite fragmentary, often consisting of a single fossilized vertebra or skull (Gasparini, 1985; Suarez and Bell, 1992). Von Huene (1925) described an ichthyosaur from the Neocomian of Cerro Belgrano, Santa Cruz Province, Patagonia, Argentina. It consisted of a fragment of paddle that was assigned to *Platypterigius hauthali* (Heune) (MacGowan, 1972); but this finding rarely is reported in later papers and it is unknown if the specimen was ever recovered.

During fieldwork in Torres del Paine National Park in southernmost Chile (Fig. 1), the mention of a large vertebrate fossil by local guides prompted a Stanford University group working in the area to investigate the fossil material. The fossil, located in a remote area in the easternmost side of the park (Fig. 1), was recognized as a marine reptile (possible Ichthyosauridae), and documented in the field with photographs and sketches. The occurrence was then reported to SERNAGEOMIN de Chile (Servicio Nacional de Geología y Minería de Chile), after which it was visited by staff of the Museo Nacional de la Historia Natural, Santiago de Chile, and confirmed to be in the Ichthyosauridae. The specimen currently is housed in the tourist center of the Parque Nacional Torres del Paine of the Corporacion Nacional Forestal (CONAF) and will be examined by the staff of the Museo Nacional de la Historia Natural for further studies. The existence of this fossil extends the known geographic distribution of verifiable ichthyosaurs in South America (Fig. 2), increases the paleoecological knowledge of the now-closed Rocas Verdes back-arc basin, and highlights the role of this seaway as an important migratory pathway within the evolving Jurassic Atlantic Ocean basin.

TECTONIC AND GEOLOGIC SETTING

Regional extension and rifting of the southern sector of Gondwana was initiated by Early Jurassic time in southern South America. The remains of Jurassic extensional rift basins are found along the eastern side of the Andean mountain belt and represent evidence of the rifting of southern Gondwana and the formation of the south Atlantic Ocean basin (Biddle et al., 1986). In the southern sector of South America, subaerial and subaqueous extrusive rhyolites, coarse volcaniclastics, and marine muds of the Jurassic Tobifera Formation were deposited as a heterogeneous suite of graben fill (Gust et al., 1985; Figs. 3, 4). By Middle Jurassic time, extension and related crustal thinning resulted in transgression and development of marine conditions in an interconnected system of rift grabens (Fig. 4B; Wilson, 1991). During the latest Jurassic / Early Cretaceous, complete continental separation lead to emplacement of mafic oceanic crust (Sarmiento and Tortuga ophiolites) and development of the Rocas Verdes Basin (Figure 4B). Deposition in the Early Cretaceous Rocas Verdes back-arc basin (Dalziel et al., 1974) is recorded by the Tobifera Formation and the Zapata Formation submarine slope deposit (Wilson, 1991). This phase of regional extension persisted until the onset of compression and development of the Andean fold-and-thrust belt, closing the Rocas Verdes Basin in Early Cretaceous time and imparting a regional low-grade metamorphism to older sediments, including the Tobifera and Zapata formations. This compressive regime was maintained throughout the remainder of the Mesozoic and well into the Tertiary, transforming the basin into a flexure-dominated foreland

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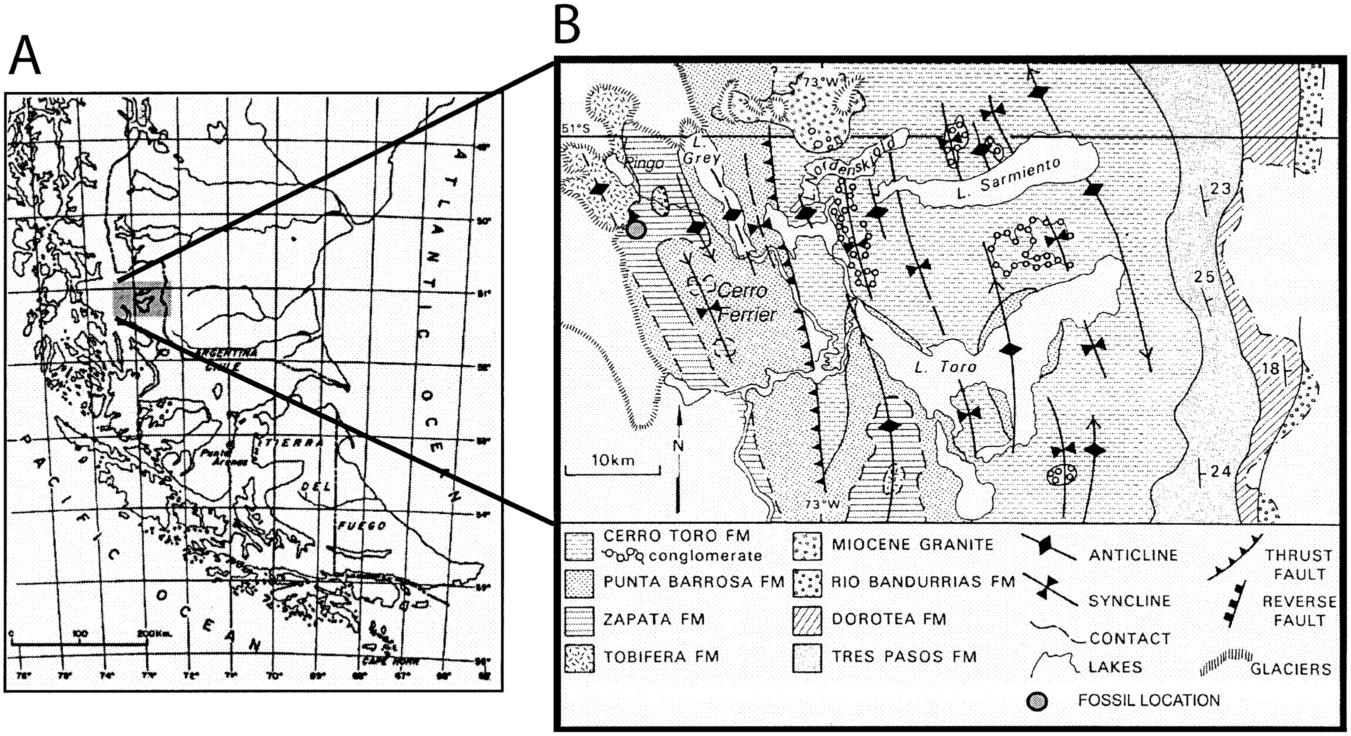

FIGURE 1—Location of Torres del Paine National Park. (A) South America, with shaded area enlarged in (B). (B) Geologic map of vicinity of Torres del Paine with exact location of the fossil. Modified after Wilson (1991).

basin, the Magallanes Basin (Soffia and Harambour, 1989).

The Tobifera Formation (Figs. 3, 4) is present throughout southern South America, and rests with angular unconformity on Gondwanide basement rocks (Katz, 1963). Silicic volcanic rocks characterize the lower part of the formation, whereas the upper part is mostly marine mudstone, fine sandstone, and siltstone, with very rare local occurrences of tuffaceous turbidites. The thickness of the formation in the vicinity of the fossil occurrence is known poorly because of structural repetitions and cover by glaciers to the west, but has been estimated to be 1000 m. Ammonites, belemnites, and inoceramids preserved in mudstones within the upper Tobifera Formation indicate a Late Jurassic (Kimmeridgian–Tithonian) age (Fuenzalida and Covacevich, 1988). Late Jurassic radiolarians found very close to the base of the formation (Allen, 1982) and isotopic dates from equivalent silicic volcanics in southern Argentina indicate a Middle to Late Jurassic age for the entire Formation (Riccardi and Rolleri, 1980).

The overlying Zapata Formation (Fig. 3, 4), interpreted to represent shallow- to deep-marine deposits, consists of dark iron-stained mudstone rhythmically interbedded with thin siltstones. The absence of wave activity indicators and the presence of verging isoclinal folds indicate a very quiet depositional environment of moderately deep water (Wilson, 1991). Inoceramids, belemnites, and ammonites occur throughout the Zapata Formation and indicate a late Tithonian to Aptian–Albian age (Cortes, 1964; Katz, 1963). Shales of the upper part of the Tobifera Formation and the lower part of the Zapata Formation are very similar lithologically and indicate quiet, shallow- to moderately deep-marine depositional environments. In fact, the shales form a continuous stratigraphy, differing only in the absence of volcanic strata in the lower part of the Zapata Formation. Observations of the black, iron-stained, pyritic mudstone of the Zapata Formation in the surroundings of the fossil site, combined with the distribution of this unit and geologic evidence cited in the next section of this paper, make the Zapata Formation the most probable provenance for the ichthyosaur fossil. The tectonic and paleogeographic setting in which the Torres del Paine ichthyosaur lived thus corresponds to one of two possibilities: either a juvenile, yet flooded rift, or nascent ocean basin (Figs. 4A, 4B).

GEOLOGIC OCCURRENCE AND CHARACTERIZATION OF THE TORRES DEL PAINE NATIONAL PARK ICHTHYOSAUR

The fossilized remains of the ichthyosaur reported here are located along the east bank of the Rio de Los Hielos, at the base of a large terminal or lateral moraine of a glacier emerging from the Patagonian Ice Cap (Campo de Hielo Sur) in Torres del Paine National Park, Ultima Esperanza region of southern Chile (Fig. 1). The fossil is exposed in a large, angular, glacial-erratic block that is fractured along a bedding plane, providing excellent exposures of an incomplete vertebral sequence on both the top and bottom of the bed. The remains consist of 17 biconcave vertebrae, about twice as tall as they are long, associated with their respective neural arches and ribs. The neural arches are obscured somewhat by matrix, and only part of the neural spines can be recognized. Long, slender, ribs are well exposed (Fig. 5). The presence of strongly anficelic vertebrae and double-headed trunk ribs allows the fossil to be placed

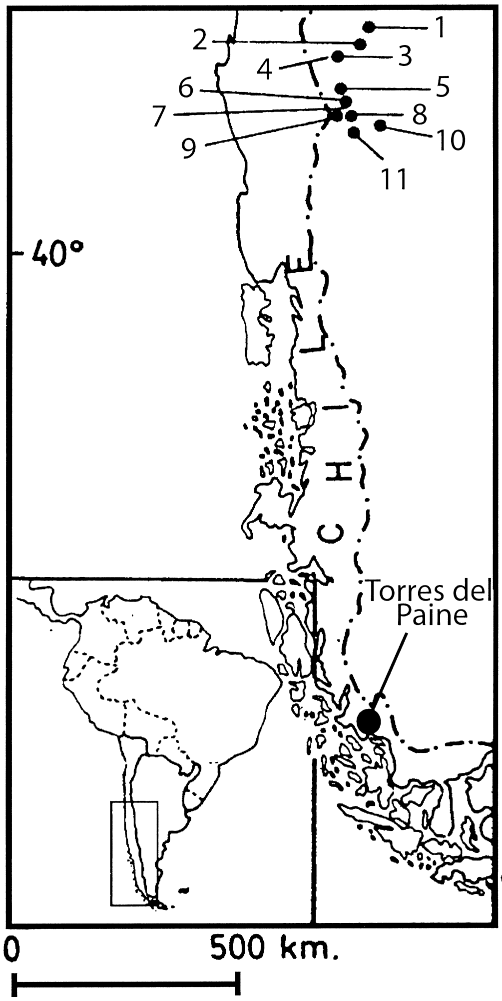

FIGURE 2—Map showing ichthyosaur localities in Chile and Argentina and the location of Torres del Paine National Park ichthyosaur. 1—Sierra de Reyes, 2—Ruta 40 (Neuquen), 3—Chacay, 4—Trauncura, 5—Las Lajas, 6—Manzano Guacho, 7—El Ministerio, 8—Carro Quebrado, 9—Los Catutos, 10—Cerro Lotena, 11—Curru Charauilla, 12—Torres del Paine. Modified after Gasparini (1985).

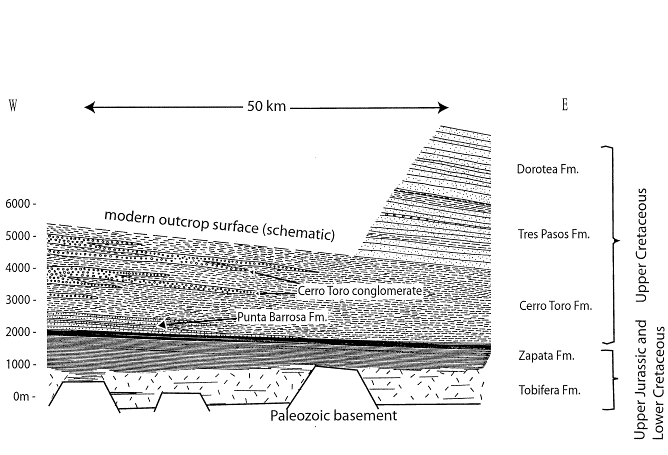

FIGURE 3—Schematic west-east cross section of the Magallanes basin at 50°S. After Katz (1963).

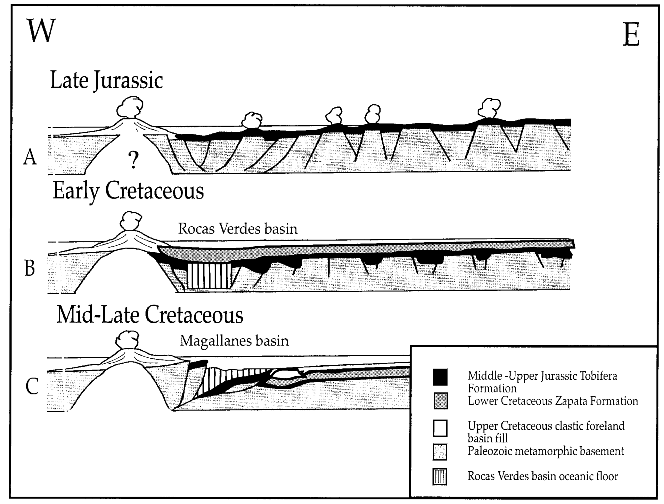

FIGURE 4—Schematic diagram showing different stages of tectonic evolution in the area of interest. (A) Early development of the Rocas Verdes basin and deposition of the Tobifera formation. (B) Later stage of the Rocas Verdes with deposition of the Zapata formation in the paleogeographic setting in which the Torres del Paine Ichthyosaur lived. (C) Closure of the basin and formation of the modern Andean Cordillera. Modified after Herve, et al. (2000).

in the order Ichthyosauria (*Ichthyosauria* Blainville, 1835, *Ichthyosauria* incertae sedis).

Most ichthyosaurs lack diagnostic features in the axial skeleton, which, without the skull, can complicate taxonomic assignations. However, certain features in the axial

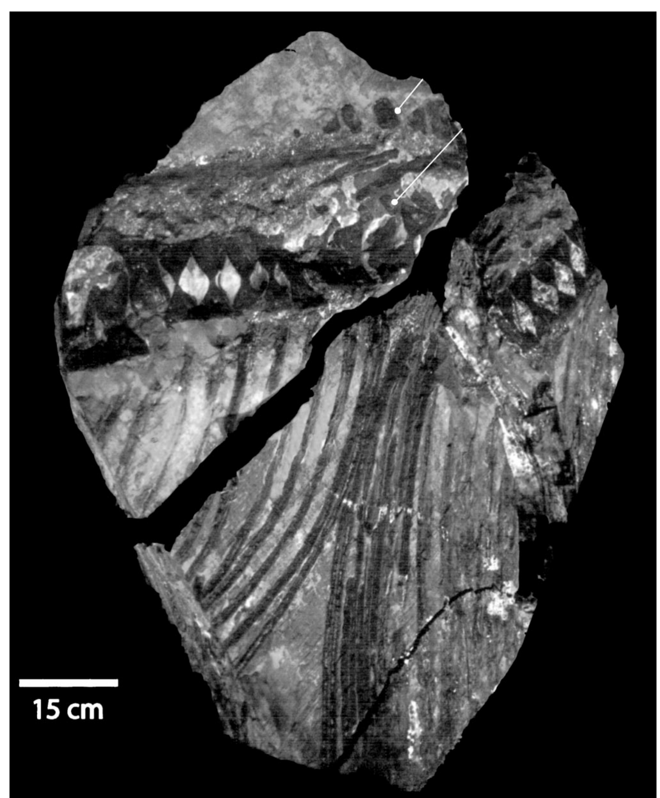

FIGURE 5—The Torres del Paine National Park ichthyosaur.

skeleton of lower taxa (e.g., *Parvipelvia*, Motani, 1999) may help in identification within the group. *Parvipelvia* has double-headed ribs in the mid-dorsal region and very thin discoidal vertebrae—a combination of features unique to this group. Even though the Chilean specimen has double-headed ribs, the observed pattern, shape, and proportions of its vertebrae distinguishes it from *Parvipelvia*.

The fossiliferous lithology is hard, black, slightly metamorphosed mudstone containing pyrite, with an iron oxide stain, which gives it a brilliant red luster. When fresh, the lithology is hard, but it is reduced quickly to pencil shale when weathered. The angular shape and large size of the fossil block (0.5 m x 0.5 m x 0.4 m), and the poorly sorted nature of the associated unconsolidated glacial and glaciofluvial sediments indicate that the block was deposited as morainal material during the latest period of glacial retreat, which occurred no more than 20,000 years ago (Hervé et al., 2000). Also, angularity of the readily weatherable block indicates that it came to its resting-place without significant fluvial transport and reworking. These data constrain the provenance of the fossil to outcrops near to the site, which consist of the upper part of the Middle-Late Jurassic Tobifera Formation and the Lower Cretaceous Zapata Formation (Fig. 1). A transition between the two formations is not clearly identifiable, but, based on character of lithology and associated rock types, the ichthyosaur fossil is believed to have originated in the lower Zapata Formation (Lower Cretaceous) or in the upper part of the Tobifera Formation.

DISCUSSION

The discovery of an Upper Jurassic / Lower Cretaceous ichthyosaur in southern South America establishes the existence of this reptilian order in the Rocas Verdes backarc basin or its predecessor rift graben. Ichthyosaur teeth have been reported from the Antarctic peninsula (Whitham and Doyle, 1989) and now it can be concluded that ichthyosaurs were present in basins along the entire South American / Antarctic Pacific margin during Late Jurassic / Early Cretaceous time. Ichthyosaurs reached their maximum abundance during the Jurassic and maximum diversity during the Early Jurassic (McGowan, 1978). The most common genus reported in Late Jurassic and Early Cretaceous deposits is *Opthalmosaurus*, which is considered a cosmopolitan form and is known from Tithonian rocks of Argentina (Fernández, 1997a). Remains of a new specimen of *Caypullisaurus banapartei* Fernández, which recently have been reported from the Neuquen Basin (Fernández, 1998), allow a better understanding of ichthyosaur distribution. Other specimens of the same taxon have been re-described for paleogeographic implications (Fernández, 2001) of the taxon distribution.

South American ichthyosaurs are related closely to Tethyan forms, and migrations of these forms between the two regions occurred through two possible corridors. A northern route through the Caribbean region (Hispanic Corridor) is based on brachiopod, ammonoid, plesiosaurid, and crocodilian faunal affinities between the west Tethys and south central South America (Gasparini and Fernández, 1997), as well as marine reptile affinities (Fernández and Iturralde-Vinent, 2000). A possible southern route

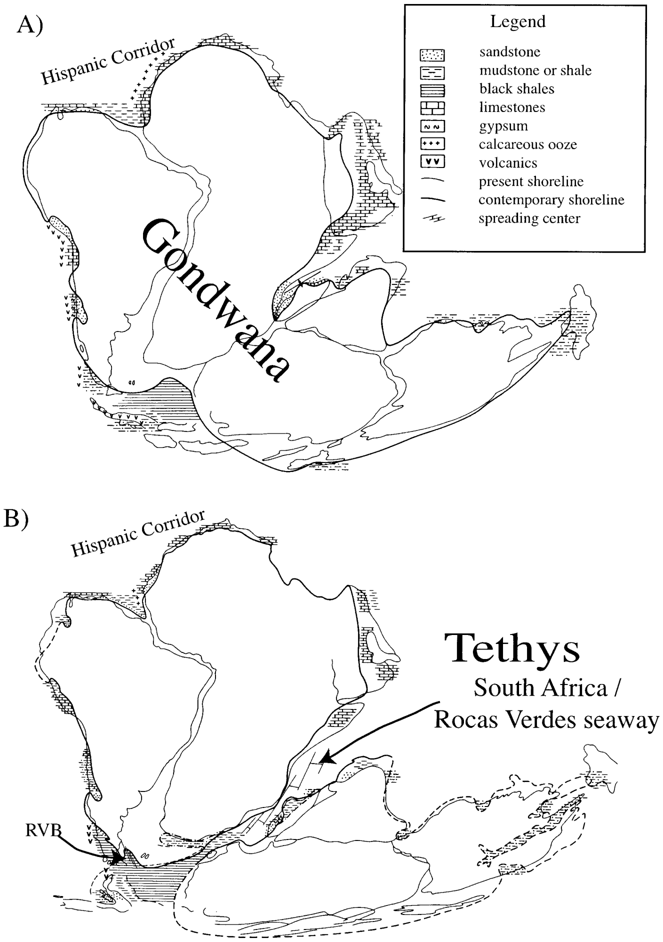

FIGURE 6—Paleogeography and marine facies maps of the Gondwana margins showing development of possible dispersion routes from west Tethys to east Pacific basins of South America. (A) Oxfordian-Kimmeridgian. (B) Tithonian-Berriasian. RVB= Rocas Verdes basin. Base maps adapted from Scotese (1987). Modified after Riccardi (1991).

through interconnected rift grabens developed in southern Patagonia during regional extension and breakup of southern Gondwana is based on ammonite and other faunal assemblages (Riccardi, 1991; Fig. 6). The southern route was postulated as a possible route for marine reptiles (Fernández, 1997b). The southern Gondwana breakup occurred before the opening of the South Atlantic, therefore, propagation of the graben system was from the Tethys (NE) toward the Southeast Pacific. As evidence of this early breakup, Leanza (1995) used the similarities between ammonites from the Andean area and the Iraq / Kurdistan area to propose that a migration seaway through Mozambique, Somaliland, eastern India, Madagascar and eastern Antarctica to southern Gondwana was more probable than the Hispanic Corridor for faunal interchange. The existence of this shallow epicontinental seaway between east Africa and southern Patagonia during the latest Tithonian-Barresian also is supported by the presence in both areas of the bivalve *Megacucullaea* (Reyment and Tait, 1972). Similar evidence of this connection is given by the Late Tithonian belemnite faunas (Mutterlose, 1986). Occurrence of an ichthyosaur fossil in the seas of the Rocas Verdes back-arc basin or predecessor rift graben provides additional support for the existence of this southern migratory route with adequate living conditions for marine reptiles during the Late Jurassic. Living conditions were supported by thermohaline circulation with a warmer surface current from the Tethys ocean, and by warmer climatic conditions beginning in the Oxfordian (Riccardi, 1991).

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