ABSTRACT

The fossil skull of a *Procellariidae*, *Pachyptila* sp., from late Miocene of the marine sediments of the Bahía Inglesa Formation (midde Miocene – Pliocene) of Northern Chile is described. The fossil is compared with extant species of the family *Procellariidae*. This discovery represents the first Neogene fossil record of the genus *Pachyptila* from South America.

Key words: Chile, Fossil Prion, Pachyptila, Procellariiformes, Neogene.

RESUMEN

El cráneo de un Prion petrel-paloma fósil (Aves: Procellariiformes) del Neógeno (Mioceno tardío) del norte de Chile. Se describe el cráneo fósil de un *Procellariidae*, *Pachyptila* sp., proveniente de sedimentos marinos del Mioceno tardío de la Formación Bahía Inglesa (Mioceno medio – Plioceno) del norte de Chile. El fósil es comparado con especies actuales de la familia *Procellariidae*. Este hallazgo representa el primer registro fósil Neógeno del género *Pachyptila* en América del Sur.

Palabras claves: Chile, Petrel-paloma fósil, Pachyptila, Procellariiformes, Neógeno.

INTRODUCCIÓN

Extant Procellariiformes comprise four families of seabirds: *Diomedeidae* (albatrosses), *Hydrobatidae* (storm-petrels), *Pelecanoididae* (diving-petrels), and *Procellariidae* (shearwaters,
THE SKULL OF A FOSSIL PRION (Aves: Procellariiformes) FROM THE NEOGENE (LATE MIOCENE)...

GEOLOGY

The fossil material reported here comes from a phosphatic conglomerate of the Bahía Inglesa Formation which represents the most important Neogene marine vertebrate deposit in Chile (Walsh and Naish, 2002; Suárez and Marquardt, 2003). The Bahía Inglesa Formation was defined by Rojo (1985) and emended by Marquardt (1999). The age of this unit ranges from the middle Miocene to early Pliocene, according to studies of shark teeth (Long, 1993; Suárez and Marquardt, 2003; Suárez et al., 2004), mollusks (Guzmán et al., 2000), micropaleontology (Herm, 1969; Marchant et al., 2000) and vertebrates (Marquardt, 1999; Marquardt et al., 2000; Suárez and Marquardt, 2003; Suárez et al., 2004). The Bahía Inglesa formation is formed of over 42 m of siltstones, fine sands, shelly coquinas, pebble beds, and phosphatites, interpreted as deposited in a shallow marine setting accumulated within 10 km of the shore (Marchant et al., 2000). An important exposure of the Bahía Inglesa Formation occurs in an area of arid badlands 1 km inland of Bahía Inglesa, on the coast of the northern part of central Chile (27°06´43.5´´S; 70°50´09.8´´W and 27°09´58.6´´S; 70°52´32.4´´W) (Fig. 1A). The closest settlement is the village of Bahía Inglesa, and the nearest town is Caldera, 10 km northeast of the study area, respectively. In this area the sequence was deposited in a serie of grabens formed in the Mesozoic igneous basement (Godoy et al., 2003), today visible as a series of roughly NE-SW trending inliers. Walsh and Suárez (2005) recognized three lithostratigraphic members in this region; the coarse conglomeratic basal Morro Member (Unit 1 of Suárez et al., 2004), the phosphoritic Bahía Inglesa Formation Bonebed Member (Unit 2 of Walsh and Hume, 2001), and the fine sand and siltstone Lechero Member (Unit 3 of Walsh and Hume, 2001). A phosphatite (sensus
M. Sallaberry, D. Rubilar-Rogers, M. Suárez y C. S. Gutstein

Figure 1: (A) Map showing fossiliferous outcrops of the Bahía Inglesa Formation in the Atacama Region, modified from Walsh and Suárez (2005); (B) Stratigraphic column of the “Mina Fosforita” site showing the bonebed, provenance of MPC-601 (Modified from Walsh and Suárez, 2005). Abbreviations: (Mud) mudstone; (Silt) Siltstone; (F. Sand) fine sandstone; (M. Sand) medium sandstone; (T. Sand) coarse sandstone; (Cg) conglomerate.
The age of the Bahía Inglesa Formation bonebed can be constrained using radiometric data, and microfossil and vertebrate assemblages in the beds above and below the Bahía Inglesa Formation bonebed. Based on the study of the stratigraphy of the microfossils, the overlying Lechero Member is 4.5–2.6 million years (Tsuchi et al., 1988; Ibaraki, 1990, 1995). The shark assemblage of this member is characterized by the abundance of *Carcharodon carcharias* Linnaeus (Long, 1993), and the additional presence of *Prionace glauca* Linnaeus provides good evidence supporting a Pliocene age (Suárez and Marquardt, 2003). However, an ash layer occurs within the Lechero Member, approximately seven metres above the top of the Bahía Inglesa Formation Bonebed Member. This provides a K-Ar age of 7.6 ± 1.3 million years (Marquardt et al., 2000; Godoy et al., 2003), indicating that the lower part of the Lechero Member is late Miocene, and thus the bonebed would be no younger than Tortonian. However the shark fauna of the bonebed is dominated by *Cosmopolitodus hastalis* Agassiz while *Carcharodon carcharias* Linnaeus is present in low abundances. The teeth of these species have been used to differentiate Miocene from Pliocene sediments in South America (e.g., Muizon and DeVries, 1985; Walsh and Hume, 2001; Walsh and Naish, 2002), but the presence of *C. carcharias* in Chilean late Miocene sediments suggests that *C. carcharias* teeth are not a reliable indicator of age. A record of a *Monachinae* seal, *Acrophoca* sp., provides evidence of a late Miocene age for the bone bed (Walsh and Naish, 2002) and cetaceans from the Pontoporiidae family are also consistent with this age. Unpublished data from one of the authors (C.S.G.) recognizes the same taxa, *Brachydelphis mazeasi* Muizon from middle-late Miocene beds from the Pisco Formation, Perú. We therefore propose a late Miocene (Tortonian) age for MPC-601. The vertebrate assemblage from the unit 2 (bone-bed member) is dominated by the fossil shark *Cosmopolitodus hastalis*, the most common species in the marine sediments of middle-late Miocene age in Chile (Suárez and Marquardt, 2003; Suárez et al., 2006). The abundance of fossils on this strata could be explained by the reworking of the phosphatic beds consistent with a transgressive-regressive model. Evidence of reworking was observed, like the state of preservation of the mainly broken fossils.

The diversity of fossils is also impressive in the Bahía Inglesa Formation bonebed; most vertebrate taxa from marine Miocene are well-represented here. There mainly appear remnants of sharks such as *Cosmopolitodus hastalis* and *Charcharodon carcharias*. In a study of these shark fossils at the Pisco Formation in Perú, Muizon (1988) proposed that *Cosmopolitodus hastalis* and *Charcharodon carcharias* were indicative of late Miocene and early Pliocene, respectively. Yet at the Bahía Inglesa Formation, *C. hastalis* and *C. carcharias* appear together (with a greater number of *C. hastalis*).
Thalassoica (Gmelin), Pagodroma Bonaparte and Halobaena Bonaparte was obtained from a bank of photographic material of the Procellarid group (Seabirds Skull Gallery). A comparison of MPC-601 with extant skull material prepared in our laboratory of Pachyptila belcheri, Pelacanoides garnotii, Fregetta tropica, Oceanites oceanicus and Puffinus griseus is provided in plate 1.

The following skull measurements were obtained with a digital caliper (+0.01 mm) as indicated in text.-Figure 2:

1) Postorbital processes: maximum width of the skull at the post-orbital processes.
2) Nasofrontal hinge-basicranium: length between nasofrontal hinge and the dorsal edge of the basicranium.
3) Skull height: from the uppermost surface to the lowest point on the base of the skull.
4) Intergland width: measurement between the edge of the salt gland in the center of the ocular cavity.
5) Interorbital width: width of the two salt glands at the frontal crest.
6) Salt gland width: width between the edge at the center of the right salt gland.
7) Orbital length: length along the antero- and post-orbital processes.
8) Nasofrontal hinge width: width between the two antero-orbital processes

NHW(8)/PPW(1) = relation between the nasofrontal hinge and the postorbital processes.

**SYSTEMATIC DESCRIPTIONS**

*Aves Linnaeus, 1758*
*Order Procellariiformes Fürbringer, 1888*
*Family Procellaridae Boie, 1822*
*Genus Pachyptila Gmelin, 1789*

**Type Species:** *Pachyptila desolata* Gmelin, 1789. Living species, with circumglobal distribution in the southern ocean.

*Pachyptila sp.*
(Fig. 3)

**Material:** an incomplete skull numbered MPC-601, Late Miocene. Bahía Inglesa locality.

**Description:** in this incomplete skull (Figure 3), the supraoccipital, exoccipitals, frontal, prefrontal and part of the complex ectethmoid-lacrimal, are clearly identifiable. The skull length is 36 mm from the nasofrontal hinge to the basicranium, and the maximum width at postorbital processes is 21 mm. The well-preserved upper part of the skull is rounded, showing the two hemispheres of the cranium separated by a medial furrow. The skull is partially eroded on the edges, but it is possible to distinguish the basicranium and part of the rostrum, which is limited by the naso frontal hinge. Both the postorbital and orbital processes of the prefrontal bone are poorly developed. The supraorbital rings...
of the salt gland groove join together to form a dorsal crest (4 mm long) at the midline of the skull. The ventral region is partially covered with sediment, making it impossible to distinguish the area of the orbital septum. Nevertheless, it is possible to see part of the base of the temporal and the insertion of the quadrate bones. In dorsal view it is observed part of the foramen magnum, which is filled with sediment. The groove for the depressor mandibulae muscle is projected posterodorsally, resulting in a separation of 7.85 mm in the parietal bone. In the dorsal view the grooves are not evident. The main measurements of this fossil and other possible relative species are on table 1.

Table 1: Principal skull measurements of MPC-601 and other species of procellariiforms.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Measurements*</th>
<th>NHW/PPW</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPC-601</td>
<td>20.47 35.46</td>
<td>18.7 8.2 4 3 18.4 16.78 0.82</td>
</tr>
<tr>
<td><em>Pachyptila vitata</em></td>
<td>23.9 37.13</td>
<td>20 5.39 0 4.06 16.7 13.9 0.58</td>
</tr>
<tr>
<td><em>Pachyptila belcheri</em></td>
<td>18.9 33.15</td>
<td>16.9 7.4 3.01 3.84 14.5 14.93 0.79</td>
</tr>
<tr>
<td><em>Pachyptila belcheri</em></td>
<td>20.48 34.22</td>
<td>18.9 7.2 3.3 3.52 14.2 15.94 0.78</td>
</tr>
<tr>
<td><em>Pachyptila belcheri</em></td>
<td>20.23 33.34</td>
<td>16.6 7.87 2.54 3.54 12.9 14.58 0.72</td>
</tr>
<tr>
<td><em>Pachyptila belcheri</em></td>
<td>19.85 33.95</td>
<td>17 7.15 2.5 3.28 14 15.95 0.8</td>
</tr>
<tr>
<td><em>Pachyptila belcheri</em></td>
<td>22.27 33.55</td>
<td>16.8 7.6 2.57 3.8 15.3 14.49 0.63</td>
</tr>
<tr>
<td><em>Pelacanoides garnotii</em></td>
<td>20.46 29.11</td>
<td>19.4 5.07 0 2.6 14.1 9.98 0.49</td>
</tr>
<tr>
<td><em>Pelacanoides garnotii</em></td>
<td>18.23 25.45</td>
<td>16.6 3.63 0 2.55 12.2 10.59 0.58</td>
</tr>
<tr>
<td><em>Puffinus griseus</em></td>
<td>30.4 44.67</td>
<td>22.2 9.94 0.53 4.67 18.5 11.48 0.38</td>
</tr>
<tr>
<td><em>Puffinus creatopus</em></td>
<td>30.1 45.53</td>
<td>24.4 10.5 4.14 3.2 17.7 12.91 0.43</td>
</tr>
<tr>
<td><em>Pterodroma cooki</em></td>
<td>21.13 33.93</td>
<td>17.9 8.68 3.66 3.19 15.7 8.42 0.4</td>
</tr>
<tr>
<td><em>Pterodroma externa</em></td>
<td>34.56 46.01</td>
<td>24.4 12.9 4.93 3.94 16.6 13.66 0.4</td>
</tr>
</tbody>
</table>

* as described in methodology
ACKNOWLEDGEMENTS

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DISCUSSION

In the specimen MPC-601, the two grooves of the depressor mandibulae muscles are projected posterodorsally and noticeably separated by the parietal bone. This particular characteristic is present in almost all the species of the genus Pachyptila (except P. vittata Gmelin), Pelecanoides, Fregata and Oceanites. On the contrary, in Pachyptila vittata, Callonectris and Puffinus the two grooves for the insertion of the depressor mandibulae muscles are almost connected by a very narrow edge, at the rear of the skull, evident in dorsal view.

On MPC-601 the supraorbital furrows are medially connected, forming a crest at the midline of the skull which is also present in Pelecanoides and Pachyptila vittata. Other living species of Pachyptila do not have this feature, displaying instead a rather wide middle bar between the supraorbital furrows. The same condition is evident for other genera such as Thalassoaica, Pagodroma and Halobaena, in which this bar is even larger. Nevertheless, in MPC-601 the contact along the supraorbital furrows is smaller than in Pelecanoides and Pachyptila vitatta, comprising about 1/10 of the length between the nasofrontal hinge and the posterior edge of the basicranium, in contrast to these two genera and species, which comprise only 1/5 of the length.

Using the ratio of the relation between the nasofrontal hinge and the postorbital processes (NHW(8)/PPW(1)), we found that MPC-601 is similar to Pachyptila belcheri (mean ratio 0.82 and 0.74 respectively). The other species (Pachyptila vittata, Pelecanoides garnotii, Puffinus griseus, Puffinus creatopus, Pterodroma cooki y Pterodroma externa) show a lower ratio (<0.6).

The phylogenetic hypothesis based on molecular evidences of living Procellariiformes, shows that the genus Oceanites and Oceanodroma are the sister group of a larger clade composed by Pelecanoides, Macronectes, Pterodroma, Pachyptila, Thalassoaica, Puffinus and Callonectris plus the clade Diomedeidae. In this clade, the genus Pelecanoides represent the basal group, and the genus Pachyptila shows major affinity with Thalassoaica, Puffinus y Callonectris (Sibley and Ahlquist, 1990). However, in MPC-601, the morphological characters are related to both, Pelecanoides and Pachyptila. Based on this information there is not relationship between the affinities obtained with the molecular evidence and morphological characters. Then, the morphological characters present in Pachyptila and Pelecanoides may be convergent characters. With this in mind, any relation of affinity between MPC-601 with Pelecanoides or Pachyptila could be possible. Nevertheless, the ratio (NHW/PPW) estimated above indicates that the fossil form MPC-601 has a stronger affinity to Pachyptila than Pelecanoides. This leads us to refer MPC-601 to Pachyptila sp. Then, MPC-601 represents the first record of non-diomedeid procellariiforms of the genus Pachyptila from the late Miocene of the Bahia Inglesa Formation in Chile, and the first occurrence of this genus in the Neogene of the Southern Hemisphere, which is in accord with the actual distribution of the genera.
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PLATE 1

Skulls of procellariids in dorsal and lateral view
(Scale bar = 1 cm)

Lower left  Pelecanoides garnotii (Lesson)
Upper center  Pachyptila sp. (Gmelin) (MPC-601)
Middle center  Pachyptila belcheri (Mathews)
Upper left  Oceanites oceanicus (Kuhl)
Upper left  Fregetta tropica (Gould)
Lower left  Puffinus griseus (Gmelin)