

The skull of a fossil Prion (Aves: Procellariiformes) from the Neogene (Late Miocene) of northern Chile

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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: *Diomedidae* (albatrosses), *Hydrobatidae* (storm-petrels), *Pelecanoididae* (diving-petrels), and *Procellariidae* (shearwaters,

petrels and fulmars) (Harrison, 1983).

Procellariiform fossil records are scarce. The oldest procellariiform record belong to the Paleocene and lowest Eocene from North America (Olson and Parris, 1987; Feduccia and McPherson, 1993). The oldest material belongs to the family *Diomedidae* (albatross), has been reported from the late Eocene of Antarctica (Tambussi and Tonni, 1998). Storm-petrels are known from the late Miocene, and the only fossil record of diving-petrel comes from the lower Pliocene, both from South Africa (Olson, 1985a). The oldest known *Procellariidae* record is from the Early Oligocene of Iran (Peters and Hamedani, 2000). However, the history of this group reveals a hiatus of fossil records till the early Pliocene, where the first occurrence is found in the Sub-Antarctic regions (Olson, 1985a, b,c).

In South America, fossil occurrences of this order are restricted to marine deposits from central Perú, southern Argentina and northern Chile (Walsh and Hume, 2001). Previously, isolated cranial remains of Chile were assigned to the Procellariiformes, family *Diomedidae*, from the Bahía Inglesa Formation (Walsh and Hume, 2001).

This paper will report the skull of a new fossil Procellariiformes from the Neogene of the Bahía Inglesa Formation. This find represents the first evidence of the genus *Pachyptila* in the fossil record of South America. Until now the only fossil record of *Pachyptila*, is restricted to one occurrence from the late Pliocene of South Africa (Olson, 1985c) and Quaternary deposits in the Amsterdam island of the Indian Ocean (Worthy and Jouventin, 1999).

Up until now, only a few records of procellariiforms were known from the Neogene (Miocene) of South America, including from the Miocene of Patagonia (Olson, 1984), and the late Miocene - early Pliocene of Perú (Cheneval, 1993). This is mainly because the majority of the South American deposits containing fossil birds come from continental formations. Both the Pisco Formation in Perú and the Bahía Inglesa Formation in Chile are equivalent in age and it is expected that it will be possible to compare faunistic similarities between the formations in the future. The paleogeographic and evolutionary implications of the Cenozoic bird fauna of the western portion of South America are in very early stages of research or are only beginning to be studied.

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

Slansky, 1986) bonebed with a lateral extent of around 4 km² occurs at the base of the Bahía Inglesa Formation Bonebed Member. This horizon comprises up to 77% (mostly fragmentary) vertebrate remains which, in addition to the *procellariidae* fossil described here, also includes

bony fish, reptiles, seabirds, sloths, seals, whales and dolphins (Walsh, 1999; Walsh and Hume, 2001; Walsh and Naish, 2002; Suárez and Marquardt, 2003; Suárez *et al.*, 2004). The skull MPC 601 of this study, was recovered from this horizon.

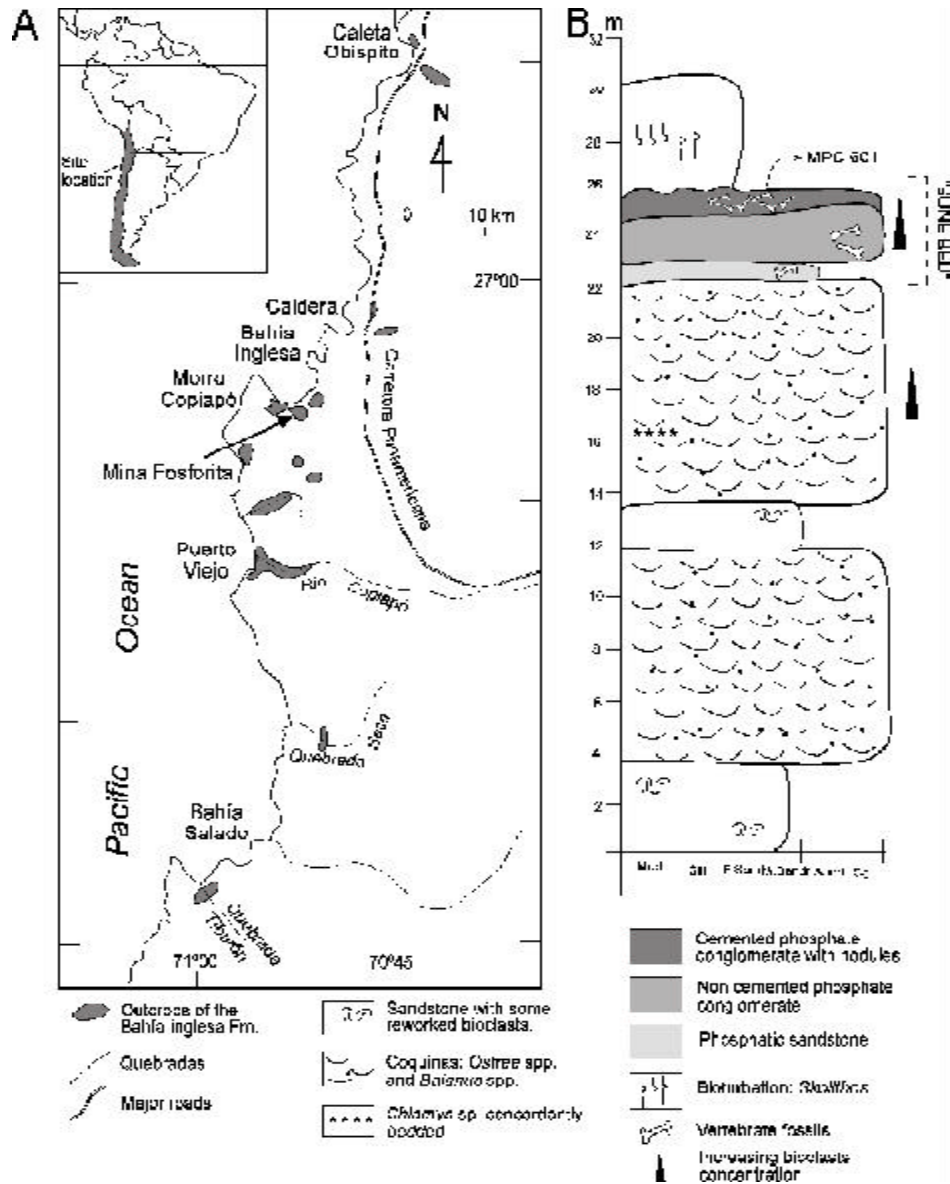


Figure 1: (A) Map showing fossiliferous outcrops of the Bahía Inglesa Formation in the Atacama Region, modified from Walsh and Suárez (2005); (B) Stratigraphic column of the "Mina Fosforita" site showing the bonebed, provenience of MPC-601 (Modified from Walsh and Suárez, 2005). Abbreviations: (Mud) mudstone; (Silt) Siltstone; (F. Sand) fine sandstone; (M. Sand) medium sandstone; (T. Sand) coarse sandstone; (Cg) conglomerate.

AGE

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 *Carcharodon carcharias*. In a study of these shark fossils at the Pisco Formation in Perú, Muizon (1988) proposed that *Cosmopolitodus hastalis* and *Carcharodon 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*).

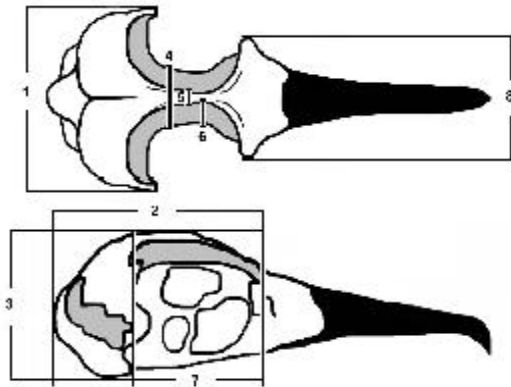
MATERIAL AND METHODS

Material: the material consists of complete braincase, belonging to the collection of the Museo Paleontológico de Caldera, under the catalogue number MPC-601.

The skulls from different species of Procellariiformes were studied from the Ornithological Collection of the Museo Nacional de Historia Natural, Santiago, and the Museo de Historia Natural, San Antonio. In both museums we

found specimens of *Pachyptila belcheri* (Mathews), *Pachyptila vittata* (= *P. desolata*; Gmelin) and *Puffinus griseus* (Gmelin). We also prepared skulls of the following species: *Puffinus griseus*, *Pelecanoides garnotii* (Lesson), *Fregetta tropica* (Gould) and *Oceanites oceanicus* (Kuhl), which were added to the collection of the Laboratorio de Zoología de Vertebrados (Universidad de Chile). Information on the genera *Callonectris* (Cory),

Thalassoica (Gmelin), *Pagodroma* Bonaparte and *Halobaena* Bonaparte was obtained from a bank of photographic material of the Procellaride group (Seabirds Skull Gallery). A comparison of MPC-601 with extant skull material prepared in our laboratory of *Pachyptila belcheri*, *Pelacanooides garnotii*,



Text-Fig. 2: Schematic drawing indicating location of skull measurements mentioned in the text.

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 Procellariidae Boie, 1822
Genus *Pachyptila* Gmelin, 1789

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

***Pachyptila* sp.** (Fig. 3)

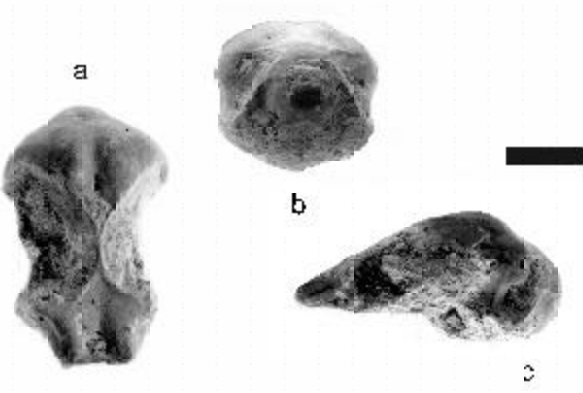
Material: an incomplete skull numbered MPC-601, Late Miocene. Bahía Inglesa locality.

Description: in this incomplete skull (Figure 3), the supraoccipital, exoccipitals, frontal, prefrontal and part of the complex ectethmoid-lacrimar, 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.



Text.-Fig. 3: *Pachyptila* sp. MPC-601, Late Miocene (Tortonian), Bahía Inglesa Formation, Caldera. a) Dorsal view; b) Posterior view; and c) Left lateral view. Scale bar = 1 cm

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

Taxa	Measurements*								NHW/PPW
	1	2	3	4	5	6	7	8	
MPC-601	20.47	35.46	18.7	8.2	0	4.3	18.4	16.78	0.82
<i>Pachyptila vittata</i>	23.9	37.13	20	5.39	0	4.06	16.7	13.9	0.58
<i>Pachyptila belcheri</i>	18.9	33.15	16.9	7.4	3.01	3.84	14.5	14.93	0.79
<i>Pachyptila belcheri</i>	20.48	34.22	18.9	7.2	3.3	3.52	14.2	15.94	0.78
<i>Pachyptila belcheri</i>	20.23	33.34	16.6	7.87	2.54	3.54	12.9	14.58	0.72
<i>Pachyptila belcheri</i>	19.85	33.95	17	7.15	2.5	3.28	14	15.95	0.8
<i>Pachyptila belcheri</i>	22.27	33.55	16.8	7.6	2.57	3.8	15.3	14.49	0.63
<i>Pelacanooides gamotii</i>	20.46	29.11	19.4	5.07	0	2.6	14.1	9.98	0.49
<i>Pelacanooides gamotii</i>	18.23	25.45	16.6	3.63	0	2.55	12.2	10.59	0.58
<i>Puffinus griseus</i>	30.4	44.67	22.2	9.94	0.53	4.67	18.5	11.48	0.38
<i>Puffinus creatopus</i>	30.1	45.53	24.4	10.5	4.14	3.2	17.7	12.91	0.43
<i>Pterodroma cooki</i>	21.13	33.93	17.9	8.68	3.66	3.19	15.7	8.42	0.4
<i>Pterodroma externa</i>	34.56	46.01	24.4	12.9	4.93	3.94	16.6	13.66	0.4

* as described in methodology

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*, *Fregetta* 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 *Thalassoica*, *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 vittata*, 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*, *Thalassoica*, *Puffinus* and *Callonectris* plus the clade *Diomedidae*. In this clade, the genus *Pelecanoides* represent the basal group, and the genus *Pachyptila* shows major affinity with *Thalassoica*, *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 Bahía 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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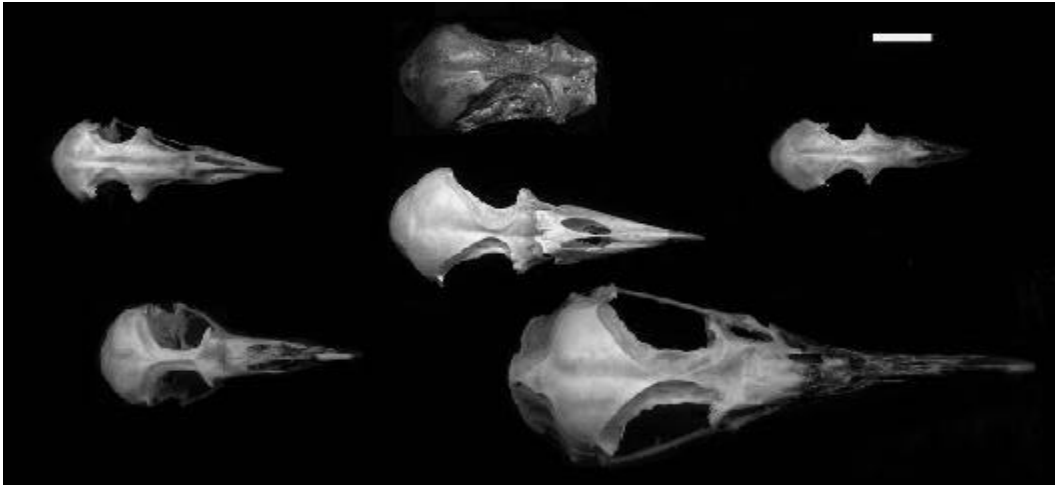
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PLATE 1**Skulls of procellariids in dorsal and lateral view**
(Scale bar = 1 cm)

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

DORSAL VIEW



LATERAL VIEW

