

# A Review and Status of Fossil Cetacean Research in Taiwan

## 台灣鯨豚化石研究回顧與現況

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## Abstract

This study reviews the status of known fossil cetaceans and reported fossil cetacean-bearing localities in Taiwan, including published and formerly un-reported specimens and localities from field investigations, national and private collections. There are 15 known localities of cetacean fossils, spanning Late Pleistocene (~0.01 Ma) to Late Miocene (~5.4 Ma), and four cetacean families are recognized: Delphinidae, Balaenopteridae, Balaenidae, and Eschrichtiidae. The occurrences indicate the potential to discover more cetacean-bearing localities and specimens in Taiwan. In particular, the cetacean fossils of Quaternary age can provide valuable information on the origins of the modern cetacean fauna around Taiwan.

## 摘 要

此研究回顧先前台灣已知的鯨豚化石，並整理了台灣已發表及此研究在野外、博物館及私人收藏中所調查發現的鯨豚化石產地。共有 15 個地點有鯨魚化石的紀錄，年代涵蓋了中新世晚期(約 540 萬年前)到更新世晚期(約 1 萬多年前)，包含了海豚科、鬚鯨科、露脊鯨科及灰鯨科的化石。從此研究可以看出台灣的鯨豚化石產地及數量在目前可能都被低估了，原因可能包含了缺乏系統性的研究，而一部分的化石材料也在野外沒有被適當的挖掘而造成不可彌補的損失。此外，本研究所紀錄在第四紀時期的鯨豚化石對於解釋台灣現生鯨豚的多樣性提供了根本的資訊。

**Key words :** paleodiversity, whale, dolphin, Pleistocene, Quaternary

**關鍵詞：**古生物、鯨魚、海豚、更新世、第四紀

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## Introduction

Fossils of Cetacea (whales, dolphins, and porpoises) have been discovered and reported worldwide (Fordyce 2009), with hundreds of fossil species described on the basis of well-preserved skeletons as well as single elements (such as skull or ear bones). Fossil cetaceans are crucial for understanding cetacean phylogeny and evolutionary history. In particular, Quaternary fossils could help understand the origins of living cetacean species, while late Miocene-Pliocene fossils could elucidate patterns in rapidly-evolving groups such as the ocean dolphins, Delphinidae. Furthermore, cetacean fossils could help refine

the geological age and depositional settings of sedimentary rocks.

Given the abundance and diversity of fossil Cetacea in Japan (Oishi and Hasegawa 1995b), it is surprising that relatively few fossils of cetaceans have been recognized and reported in Taiwan in spite of the closeness of the two regions in the western North Pacific. Taiwanese localities of published specimens and newly-discovered localities with cetacean fossils are shown in Fig. 1. The oldest fossil cetaceans reported in Taiwan in the literature are from the latest Miocene to the earliest Pliocene (Kueichulin Formation; Chiu 1972). Figure 2A shows an example of an odontocete from the Kueichulin Formation of

Guoshing Township in the field. Several factors could explain the limited knowledge of cetacean fossils in Taiwan: few fossil cetaceans have been discovered (possibly relating to the amount of available marine sedimentary rock outcrop or the previous lack of direct research on fossil Cetacea), and most fossil cetaceans from Taiwan are unpublished specimens that have been found accidentally or recovered by amateur paleontologists. Examples of occurrences include fossil specimens trawled from the sea bottom of Penghu Channel by fishing boats (Chang 1996), fossils recovered during construction (Chang and Cheng 1998), and fossils recovered during drilling for petroleum (Meng 1961; Huang 1965, 1976; Chiu 1972). In Taiwan, cetacean-bearing rocks include alternating beds of sandstone and shale (Erchungchi, Liuchungchi, Kueichulin and Erjiou Formations), and massive conglomerate with a few layers of sandstone (Toukoushan Formation). Figure 3 gives examples of cetacean-bearing formations and fossils.

The scope of advanced research on cetacean fossils in Taiwan could include the following (based on Fitzgerald 2004): 1) to locate where fossil cetaceans have previously been discovered; 2) to recognize the faunal compositions of these localities from national institution or private collections; 3) to understand the sedimentary geology of these cetacean-bearing localities; and 4) to resolve the geological age of these fossil-bearing localities. The purpose of this study is to review the status of known fossil cetaceans, to summarize the published fossil cetacean-bearing localities in Taiwan, to record

formerly unknown specimens from field investigations, and to report on cetacean fossils in national museums and private collections.

## Materials and Methods

Most specimens discovered remain in the field because it is imprudent to recover them without systematic excavation due to risk of damage. Also, some specimens are in the care of private collectors, such as fossil balaenids reported by Tsai *et al.* 2012; such specimens could be described formally once the specimens go to national institutions. Two eschrichtiid fossils, NMNS-F051728 and LFMM-W-001, are deposited at National Museum of Natural Science, Taichung, Taiwan (NMNS) and Land Fossil and Mineral Museum, Tainan, Taiwan (LFMM) respectively.

### **Mysticeti (baleen whale)**

Fossil mysticetes from Taiwan were discovered during petroleum exploration by the Taiwan Petroleum Exploration Division of the Chinese Petroleum Corporation in the 1950's. Following a series of excavations, a few articles on fossil whales were published (Meng 1961; Huang 1965, 1976; Chiu 1972) and several fossil cetacean localities were reported (Fig. 1). These discoveries produced many mysticete fossils, though mainly they were non-diagnostic elements such as broken vertebrae and incomplete ribs. As no skulls were discovered, the fossils could not be identified with confidence. However, a new species, *Balaenoptera taiwanica*, was

established based on an isolated tympanic bulla (Huang 1965). Huang argued that morphological characters of the bulla (including an abrupt limbation (sic) and distinct deep furrow of the involucre, gentle depression and very weak grooves on the middle part of the inner lip, and narrow tympanic cavity) were sufficient to define a new species following criteria used by Kellogg (1924). However, Kellogg did offer a caution (Kellogg 1924) which states: “the tympanic bones are sufficiently diagnostic to be used as a guide in the determination of species... but no definite allocation will be made until more material is available for study”. More recently, Steeman (2010) concluded that ear bones may show sufficient diagnostic characters to allow identification at species level, but isolated ear bones or other isolated skeletal material should not be used to establish new scientific names (also see Barnes 1977; Oishi and Hasegawa 1995a). With that provision, if isolated specimens are used for taxonomical identification purposes, they may dramatically enhance our knowledge of cetacean paleo-diversity and paleo-distribution (Steeman 2010). The taxonomic status of *Balaenoptera taiwanica* Huang, 1965, will be treated in depth by Tsai separately.

Field research and examination of national and private collections identified the localities shown in Fig. 1. Newly-recognized specimens that are currently under study include two fossil eschrichtiid specimens (NMNS-F051728 and LFMM-W-001), comprising partial posterior crania (Tsai *et al.* 2011) and fossil balaenids, with cervical vertebrae and tympanic bulla

(Tsai *et al.* 2012). In spite of their incomplete preservation, these specimens show key diagnostic features, such as the presence of paired tuberosities on the supraoccipital shield for eschrichtiids (Ichishima *et al.* 2006) and the fused cervical vertebrae for balaenids (Kellogg 1928). These specimens should elucidate the evolutionary history and paleo-distribution of Eschrichtiidae and Balaenidae in the northwestern Pacific.

### **Odontoceti (toothed whale, dolphin, and porpoise)**

Only four odontocete bearing-localities have been documented in three publications (Fig. 1; Tan 1937; Chang 1996; Chang and Cheng 1998) and just one family, Delphinidae, has been reported to date. Eight vertebrae were discovered (seven in Houlong Township, Miaoli County and one in Chochen Township, Tainan City) and identified as posterior lumbar vertebrae based on the position of transverse processes and lack of ventral processes for chevron bones (Tan 1937). An isolated tooth (Fig. 2B) probably represents a species of Delphinidae from Liuchungchi Formation of Yujing Township. Two well-preserved skulls include one identified as the extant shortfinned pilot whale, *Globicephala macrorhynchus* Gray (Chang 1996), and the other proposed by Chang and Cheng (1998) as a new species, *Pseudorca yuanliensis*. The former specimen shows no major difference from extant *Globicephala macrorhynchus*, but does show minor differences that probably reflect postmortem erosion, for example, destruction of the globose and robust antorbital processes (therefore

obliterating the deep and wide antorbital notch) or to continuous wear which caused the maxillary alveoli to be absent from ventral view. The similarities to extant *Globicephala macrorhynchus* include a short and wide rostrum, posterior extension of the maxillae compressing the occipital shield which is not visible in dorsal view, and rugosities on the dorsal surface of the premaxillae near the anterior tip of the rostrum. The Late Pliocene or Early Pleistocene holotype specimen of *Pseudorca yuanliensis* is well-preserved, including a nearly-complete skull, cervical and thoracic vertebrae and ribs, but its morphology, paleoecology and phylogenetic relationships need to be reevaluated. Furthermore, the name, *Pseudorca yuanliensis*, is a *nomen nudum* because publication of the name does not fulfill requirements of availability (ICZN 1999: Art. 13). For now, the name is best used in quotes, thus: “*Pseudorca yuanliensis*”.

Few well-preserved fossil odontocetes were encountered during this study. However, the quantity of fossil odontocetes seems higher than previously thought. For example, according to an amateur paleontologist (L. C. Wang, pers. comm. ), a fossil odontocete with a nearly complete skeleton was discovered, but without financial support and human resource, the fossil had to be excavated quickly before a typhoon and only fragments were recovered. Though few diagnostic bones (such as skulls) were recognized during this study, other bones could also be useful for studying the paleo-diversity of fossil odontocetes in Taiwan (ear bones, see Bianucci 1996; limb bones, see Kazár and Bohaska 2008).

## Discussion

The known published fossil localities, in addition to newly-recognized specimens in national museums and private collections and those remaining in the field (Fig. 1), indicate clearly the scope of fossil whale studies in Taiwan as well as the potential to improve knowledge of the natural history, paleontology, and geological context of Cetacea in this region. Until recently, the published fossil record of Cetacea in Taiwan represented only two families, Balaenopteridae and Delphinidae. However, recent findings of geologically young eschrichtiids (gray whales) and balaenids (right whales) (Tsai *et al.* 2011, 2012) reveal a higher paleo-diversity at the family level than at present (eschrichtiids and balaenids do not now live in Taiwanese waters). In Taiwan, the limited fossil record of Cetacea could be attributed to a combination of the biases outlined by Uhen and Pyenson (2007): taxonomic, time scale, collection effort, available rock area, research effort, and taphonomic biases. Among these seven biases, the previously limited research effort is probably significant in Taiwan. Few papers that mention fossil Cetacea have been published since the first report that recorded fossil cetaceans from Houlong and Chochen Township by Tan (1937).

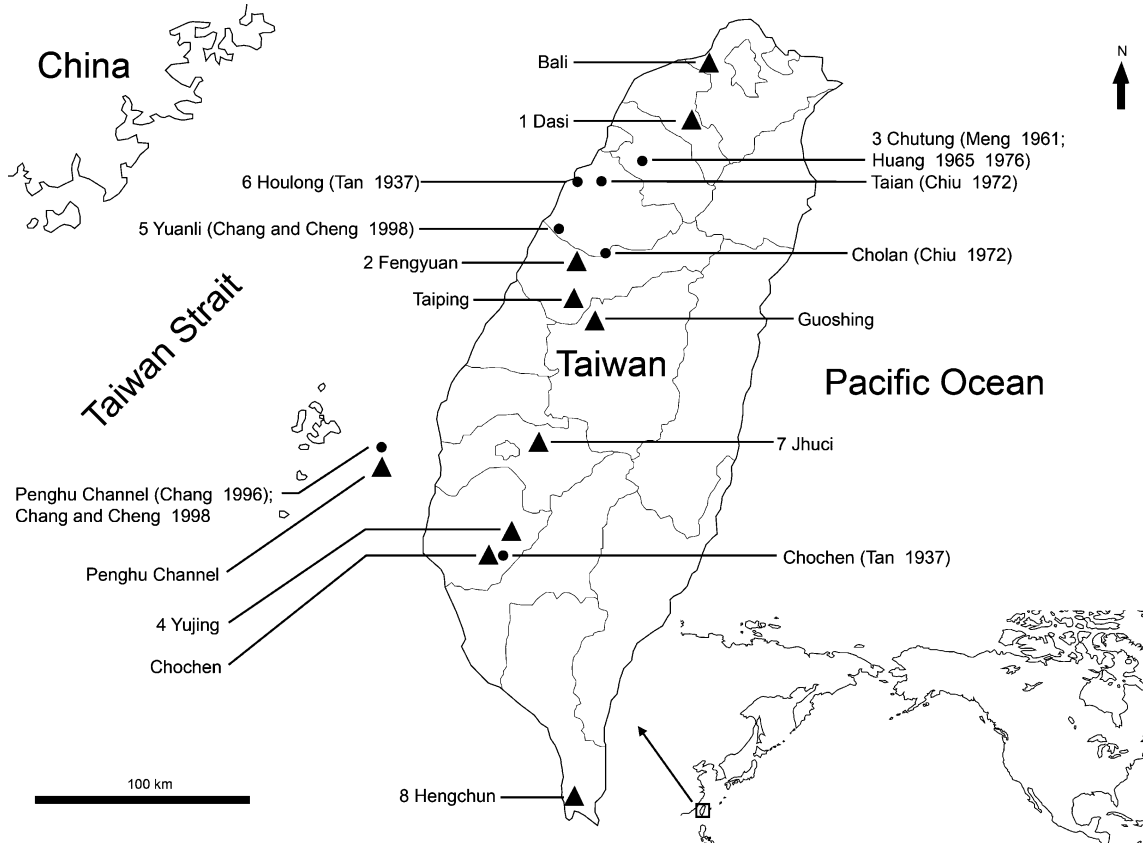
The seven localities (Fig. 1) identified from previous publications have expanded to 15 by recent field work. The new localities expand the regions yielding fossil cetaceans northwards (Bali) and southwards (Hengchun). All the fossil cetacean-bearing localities are restricted to

western Taiwan, partly because sedimentary rocks in eastern Taiwan are often metamorphosed or volcanoclastic sediments, which are unlikely to yield vertebrate fossils. However, these new localities reveal that more cetacean-bearing localities could be discovered. Considering the extant cetacean diversity around Taiwan (Yang 1976; Chou 2004) and diverse cetacean fossil assemblages discovered in Japan (Oishi and Hasegawa 1995b), a more diverse fossil record of Taiwanese Cetacea could be expected. Fossil specimens dredged from sea bottom are occasionally reported from other countries (Fordyce 1984; Whitmore *et al.* 1986; Post and Kompanje 1995), but this happens frequently in Taiwan (Chang 1996; Tsai *et al.* 2011, 2012).

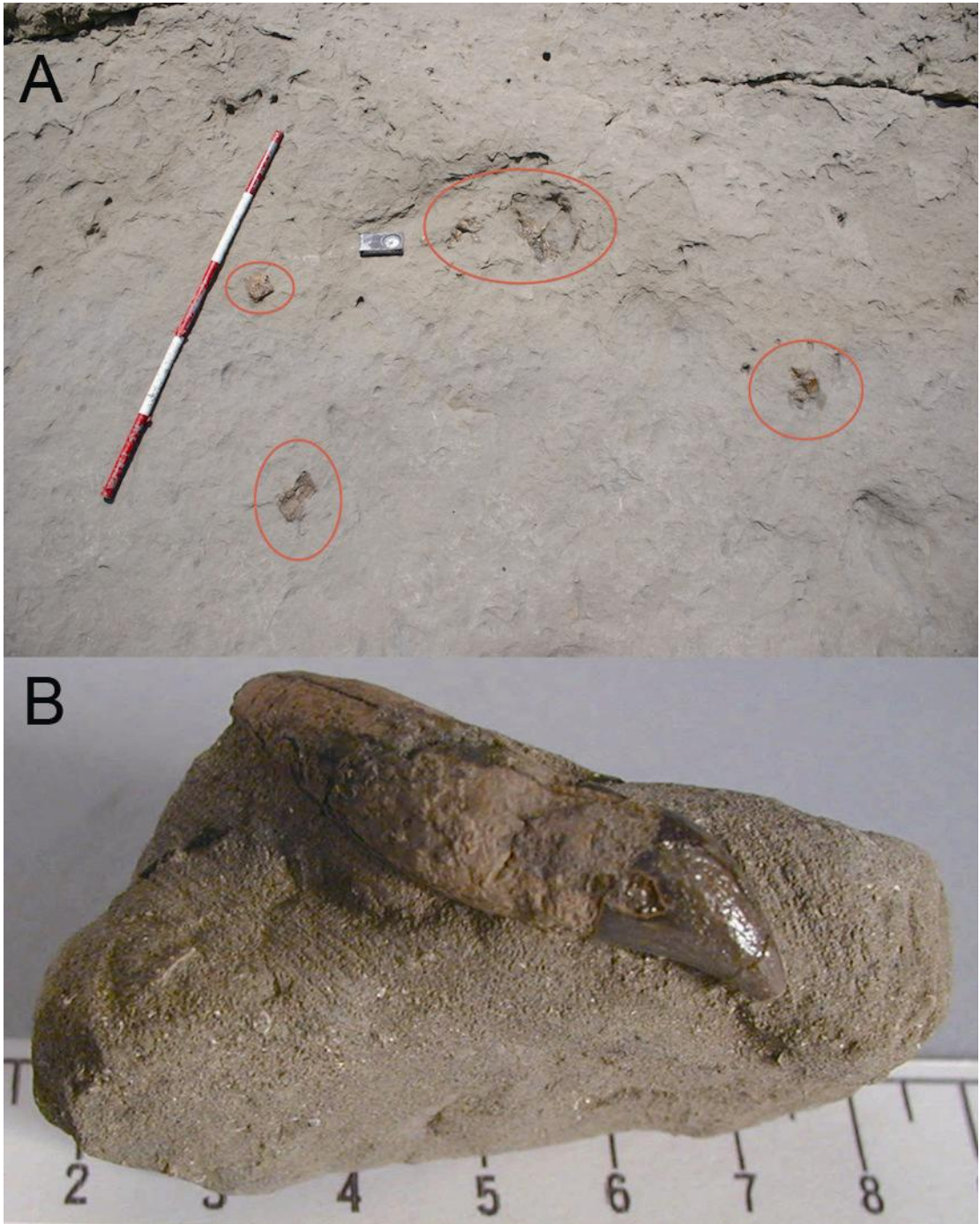
Long-term changes in geography could be a driving force of cetacean evolution, such as the opening of the Drake Passage and the initiation of the Antarctic Circumpolar Current (Steeman *et al.* 2009). Pleistocene alternations between glacial and interglacial affected the geography between continental Asia and Taiwan: interglacial high sea levels precluded migration of terrestrial mammals, and allowed passage of Cetacea, while glacial low sea levels linked landmasses and allowed terrestrial movement while limiting cetaceans. Fossils from the sea bottom of Penghu Channel (elephants - Takahashi *et al.* 2001; gray whales-Tsai *et al.* 2012) are consistent with the notion of alternating terrestrial and marine migration routes. Fluctuating conditions from shallow marine and lagoon to terrestrial settings around Taiwan, especially Taiwan Strait (Ku *et al.* 2005), also changed cetacean habitat

on a local scale. Such temporal variation in habitats may have affected the migration route, mating and calving regions of gray whales, *Eschrichtius robustus*, but the behavior of the modern western population of gray whales is too inadequately understood to predict the nature of possible change (Jones and Swartz 2009). For other gray whale populations, glacial and interglacial changes in Pleistocene sea level may have forced them to change their feeding mode from benthic feeders to generalists (Pyenson and Lindberg 2011).

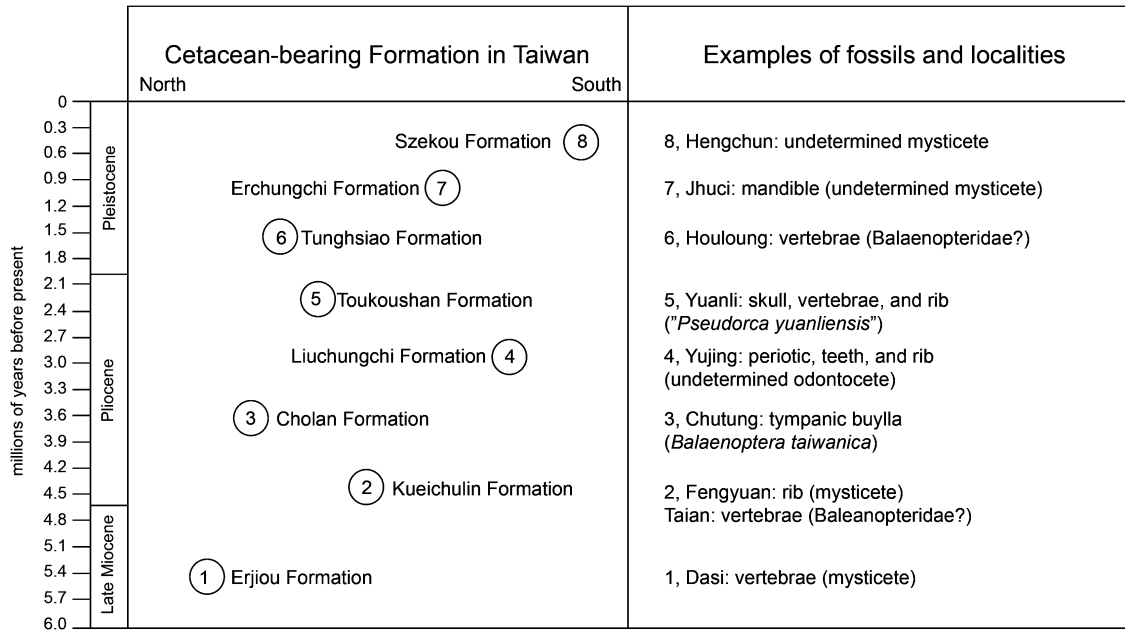
The identification of more cetacean-bearing localities, and the (re)identification of published and newly-discovered cetacean fossils (Fig.1) both suggest that Taiwan could be a high-yielding region for future discoveries and could improve the knowledge of the cetacean fossil record along the western Pacific rim. The fossil record of Cetacea in Japan could be an analogue for Taiwan; Japan is stratigraphically well-sampled, yielding an extremely diverse assemblage of extinct cetaceans, such as *Aetiocetus*, *Chonecetus*, *Herpetocetus*, and *Balaenula* (Mysticeti) and *Kentriodon*, *Scaldicetus*, and *Eurhinodelphis* (Odontoceti) (Oishi and Hasegawa 1995b). This review concludes that comparable taxonomic and stratigraphic diversity could be developed for fossil marine mammals in Taiwan.



**Figure 1.** Localities of cetacean fossils in Taiwan. ● represents the fossil sites in the literature and ▲ stands for the new localities reported in this study. Of note, there are two localities overlapping with fossils found in the past and newly-discovered material, Chochen and Penghu Channel. The number beside the locality corresponds to Figure 3. The miniature at the bottom right shows the relative position of Taiwan in the northern Pacific.



**Figure 2.** An odontocete fossil in the field, Kueichulin Formation of Guoshing Township (A). Red circles indicate the positions of the fossil material; an fossil odontocete tooth with matrix, Liuchungchi Formation of Yujing Township (B).



**Figure 3.** Comparison between cetacean-bearing formations and fossil specimens and localities in Taiwan. Holo., Holocene; L. Mio., Late Miocene.

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