# Taphonomy of fossil whales in the diatomaceous sediments of the Miocene/Pliocene Pisco Formation, Peru

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## INTRODUCTION

The Miocene/Pliocene Pisco Formation in Peru consists mostly of sandstones, siltstones, and tuffaceous beds in the lower units and diatomaceous mudstones in the upper units (Carvajal et al. 2000). Tuffaceous and diatomaceous sediments are rich in well-preserved fossil marine mammals (Esperante et al. 1999, 2000). Toothed whales (Suborder Odontoceti), baleen whales (Suborder Mysticeti), pinnipeds of the families Phocidae and Otariidae, dolphins, and shark teeth are the most abundant fossils, with sparse occurrences of other vertebrates. Invertebrates are rare, and are' concentrated in a few beds. The purpose of this paper is to describe the general taphonomic features of the fossil whales of the Pisco Formation. Degree of articulation and preservation before burial, presence and absence of fauna associated with the whale bones,, and the characteristics of the associated sediments are some of the features that will be addressed. These data will allow a more complete analysis of the paleoenvironment in which the whales died and were deposited.

## MATERIALS AND METHODS

We searched for fossil specimens on north Cerro Blanco, south Cerro Blanco, Cerro Queso Grande, and Cerro Hueco la Zorra in the west and south of the town of Ocucaje, western Peru. Several geologic sections were measured, and marker beds were selected and mapped in the study areas. Each fossil occurrence was recorded and its position and elevation determined with high precision GPS. Its position with respect to the marker beds was also measured. The following data were also collected for each fossil specimen: skull and body orientation, skull and body measurements, vertical position (up side down or right side up), elevation, degree of articulation, degree of preservation, occurrence of other associated fauna, and type of associated sediments.

Four hundred eighty four specimens were recorded in the field. Many specimens had been damaged by modem erosion, varying from relatively minor damage to almost complete destruction of the specimen. Parts of other specimens were still covered by sediment. In many cases it was not possible to determine how much of the whale was present when it was originally buried, but it appears likely that most specimens were originally more or less complete whales. In order to estimate a minimum number of whales, a specimen was counted as an individual whale if it met one of the following criteria: (a) a skull, with or without mandibles, (b) a group of two or more (almost always more) articulated or disarticulated vertebrae together with ribs, (c) five or more articulated vertebrae without ribs, (d) two or more of the former together. In some cases it was reasonable to conclude that a bone was buried as an isolated bone.

Data on articulation and parts preserved shown below reflect ranges in percentages due to uncertainty resulting from the partial covering of the sediment over some whales. We excavated eleven whales for detailed study of taphonomy and they showed diverse patterns of articulation, from fully articulated to mostly disarticulated but associated.

## RESULTS AND DISCUSSION

### Whale distribution and abundance

Whales are widely distributed in the four study locations although they are more abundant on north Cerro Blanco (Fig. 1) and Cerro Queso Grande (Fig. 2), where the diatomaceous beds are thicker. They also are distributed throughout most stratigraphic intervals in our study sections. No taxonomic determination was carded out on them, but based on skull characters most of the specimens seem to be of. Balaenoptera.

### Taphonomy

Out of n= 484 specimens, n=260 are regarded as individuals, and 230 of these have the skull preserved. There are 145 specimens (56% of individuals) that have the skull (with or without lower jaws), vertebrae, and ribs. These specimens can be considered as complete skeletons. Between 62 and 76% of the individuals have at

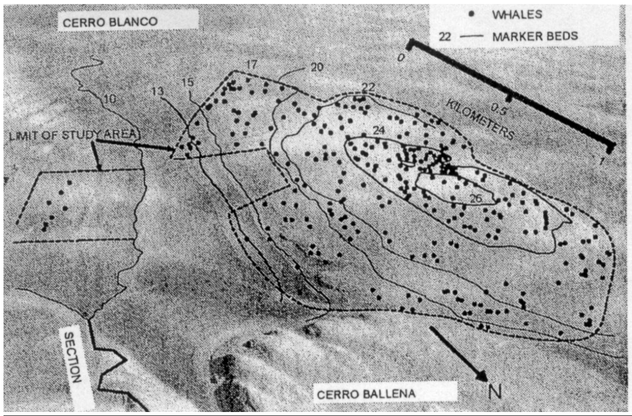


Figure 1. Whale distribution on north Cerro Blanco, superimposed on an aerial photograph. At this location whales occur through a 240-m thick sequence of diatomaceous and tuffaceous siltstones sequence. Dots indicate complete and incomplete whales (as defined in the text).

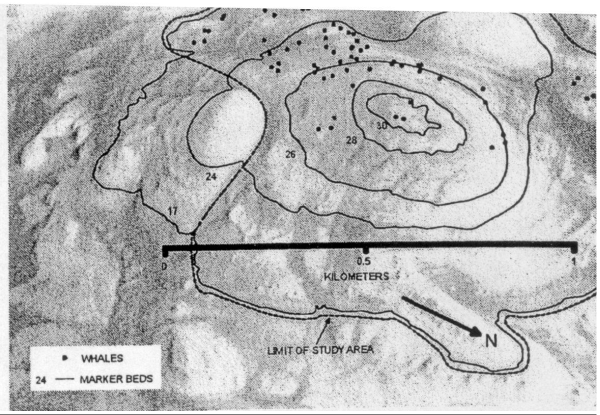


Figure 2. Distribution of fossil whales on Cerro Queso Grande, superimposed on an aerial photograph. Dots indicate complete and incomplete wbales (as defined in the text).

least one lower jaw articulated to the skull, which indicates that the skull might have fallen together with the mandibles to the seafloor and was buried before disarticulating. Between 51 and 69% of these individuals are articulated with the cervical vertebrae as well, which indicates that the majority of the carcasses did not undergo significant disarticulation before burial (Figs. 3 and 4). Most of the individuals with vertebrae preserved (n=203) have the vertebrae all articulated (42%) or partially articulated (17%), which yield a percentage of 59% of whales with articulated vertebrae, and 22% with no articulated vertebrae, and 19% are uncertain due to sedimentary cover. The non-articulated vertebrae point to higher degrees of disarticulation before burial, and usually they are the ones that have more missing skeletal elements.

There are approximately equal numbers of upside down (n=62) and rightside up (n=74) skulls. Barnes et al. (1987, p. 8) state that fossil baleen whales are 'commonly' found lying upside down. Whether these authors mean that fossil whales are upside down most of the time or are often upside down when they are found is not clear. Their conclusion may be drawn from smaller numbers of well-preserved skulls and skeletons in other areas studied (Monterey, Calvert, Choptank, Capistrano Formations, and others). Here we give figures calculated on 136 fossil individuals in one formation.

The position of a whale carcass will be influenced by its burial location and the processes that brought it there. When whales bloat, the abdomen contains the gasses resulting from decomposition, so a bloated whale will almost always strand upside down (Mason Weinrich, written communication). However, at a certain point the gasses will escape (or the carcass will explode) and the carcasses go into a free-fall, and can land in any position. The Pisco Formation whales are not beached animals, but have sunk to the bottom of a bay and show a random pattern of orientation. Individuals that have both skull and mandibles preserved (n=120) are likely to

Figure 3. Whale WCBa-20. This specimen is fully articulated and well preserved. The two flippers are preserved. Seven shark teeth were found associated with the bones, although no shark tooth marks were found on the bones.

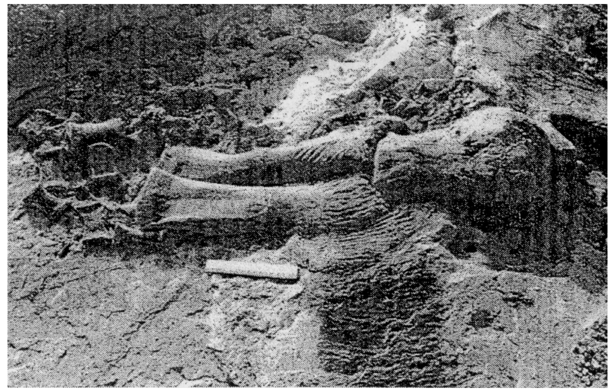

Figure 4. Detail of one of the flippers of the whale WCBa-20 showing the scapula, humerus, ulna, radius and phalanges. The striped structure is the whale's baleen, which moved apart from the mouth before burial and rested on the flipper and associated sediment.

have these skeletal elements articulated. Individuals' with at least one lower jaw articulated to the skull represent 2/3 (61.6%) of the total number of individuals with the two skeletal elements preserved, whereas those with two mandibles disarticulated account for only 1/3 of the total. According to Schäfer (1962) mandibles disarticulate rapidly in a floating decaying whale carcass, so the large percentage of individuals with skulls articulated to the jaws indicates that most whales reached the seafloor and became buried before the skull and mandibles disarticulated, which suggests rapid burial of ' the carcass in order to preserve the bone association.

Individuals with cervical bones preserved represent approximately 30% of the total number of individuals. When cervical vertebrae occur, they almost always (97.4%) occur articulated with the skull. Individuals that have both skull articulated with mandibles and skull articulated with cervical bones are more numerous than those showing some degree of disarticulation in any of these bones. Individuals with some degree of articulation in their vertebrae outnumber (72.8%) those that have no articulated vertebrae (27.1%).

The bones of the whales are not heavily mineralized and remain relatively light, porous, and brittle, although they are excellently preserved. There are no differences in degree of preservation, color, degree of mineralization, and hardness between articulated and disarticulated bones. Bones that have not been exposed by modem erosion have smooth surfaces, and bear no marks left by weathering processes, or damage from chemical dissolution or boring by invertebrates.

Whales are incased in light gray diatomite which contains some thinly laminated to very thinly bedded sections, but is not generally well laminated. Bones of each

Figure 5. Whale WCBa-248, showing skull, lower jaws, articulated vertebrae, ribs and limb bones. The skull rested above several vertebrae and ribs, which indicates that it moved back from its original position before burial.

whale are within the same horizon. Small scour-and-fill structures parallel to the vertebrae occur in the sediment associated with some skeletons. No other sedimentary structures were found in the sediment associated with the skeletons. Sediment very close to the bones is sometimes orange-brown, probably due to the staining caused by soft tissue decomposition. In some whales specific tissues, like intervertebral disks or spinal cord, have been replaced by hard, black mineral (yet to be identified). A number of whales (n=5) have the baleen preserved (fig 4). In four of them, the baleen is mineralized and preserved in life position within the mouth. In another individual a section of baleen drifted out of the mouth and lies above one of the limbs. The occurrence of baleen has important preservational and paleoenvironmental implications. Since the baleen is an organic structure made of keratin and decays rapidly, its preservation requires a high rate of deposition for the diatomite in which it is buried.

Shark teeth are commonly found associated with the whale skeletons. Some specimens had up to seven shark teeth associated, some with the tip embedded in a whale bone indicating that predation and/or scavenging occurred before burial. However, some of the specimens that contain shark teeth associated have no shark tooth marks and the whale skeleton is quite complete, which argues against a high intensity of scavenging by sharks.

Allison et al. (1991), Bennett et al. (1994), and Smith et al. 1998 describe a whale carcass lying on the Santa Catalina Basin seafloor (off California) that bears a large community of invertebrate scavengers, and Naganuma et al. (1996) describe a similar case at the Torishima Seamount (Western Pacific Ocean). In both cases, the whale carcasses act as biological oases in anoxic deep-sea basins lacking organisms over large areas. Ancient examples that have been documented include a Middle Eocene Archaeocete whale (Hulbert et al. 1998), several whales from deep-water Oligocene rocks in the Olympic Peninsula, Washington State (USA) (Goedert et al. 1995), an Archaeocete whale in Louisiana (Lancaster 1986), and several cetaceans from the Cuevas and Espiritu Santo Formations, Almeria, southern Spain (Sendra and De Renzi 1999). All these specimens have invertebrate faunas (oysters, bivalves, barnacles, etc.) associated and, in some cases (the Santa Catalina Basin whale, some of the Olympic Peninsula whales, and the specimens from Spain), this fauna or remains of its presence are found not only in the sediment but also on the bones. In contrast with these examples, the Pisco Formation whales have no invertebrate fauna associated. Bones show no evidence of scavenging, boring, or degradation caused by invertebrates that could live on the skeleton before burial, and the associated sediment shows no bioturbation.

Also, in some of the ancient specimens and in the Santa Catalina Basin whale bones show a differential pattern of surface damage: approximately the upper half of the bones are weathered whereas the lower half is better preserved, indicating that surfaces exposed above the sediment underwent corrosion and eventual loss of compact bones, whereas buried surfaces were protected and thus show better preservation of the surface. This implies along term of exposure on the seafloor and that "burial of the carcass was not rapid" (Hulbert et al. 1998). Pisco Formation whales bones, in contrast, are well preserved over their entire surface. These features suggest that the Pisco Formation whales underwent taphonomic processes different from modem whale carcasses lying on the seafloor and from other ancient examples. The whales are not associated with sedimentary features characteristic of intertidal deposits; rather they are in sediments that were deposited in a protected embayment with strong tidal influence (Carvajal, in prep.).

## CONCLUSIONS

Baleen whales are the most abundant fossils in the Pisco Formation. They represent different degrees of articulation from fully articulated to partially disarticulated, although articulation prevails over disarticulation. Both articulated and disarticulated whales have well preserved bones. The degree of articulation and preservation indicate that most of the whales did not undergo deterioration due to long exposures on the sea bottom and that they were rapidly covered by diatomaceous sediments in an embayment. This is also supported by the occurrence of baleen plates preserved in several specimens and sedimentary structures indicating rapid deposition (scour-and-fill, ripples, scouring below the bones). Taphonomic and sedimentologic features point to relatively short periods of time between death of the whales and burial of the carcasses.

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