Cetaceans in silico: 3D Digitizing a Fossil Whale Graveyard in the Atacama of Chile

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The legacy of studying whales at the Smithsonian
Pyenson Lab: work in the field

Vancouver Island (2009, 2012)


Panama (2011)


*sans PI because of shutdown
Pyenson Lab: work in the field

Vancouver Island (2009, 2012)


Panama (2011)


*sans PI because of shutdown
Plate tectonics drives paleontological discovery

Seafloor preserves remains of marine ecosystems

Weird, extinct marine mammals from South America

Neogene of Pisco Basin, Peru

Images: NASA; MNHN, Paris; M. Parrish, Smithsonian
Prospecting the Caldera Basin in the Chilean Atacama
Discovering fossil marine mammals in Chile

Image: N. D. P.
Discovering fossil marine mammals in Chile

Image: N. D. P.
Cerro Ballena: a fossil marine mammal graveyard

Image: J. F. Parham
Digitizing a fossil marine mammal graveyard
Digitizing a fossil marine mammal graveyard

Image: J. Arevalo
Digitizing a fossil marine mammal graveyard
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Image: V. Rossi
Digitizing a fossil marine mammal graveyard

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Painting with laser light...

Painting with laser light...and coloring it in

Painting with laser light...and coloring it in

Painting with laser light...and printing in 3D

Painting with laser light...and printing in 3D

Try it yourself at 3d.si.edu
Cetaceans *in silico* and in your pocket

Image: A. Metallo in *Smithsonian* Magazine (2012)
Cetaceans *in silico* and in your pocket
From photogrammetry to point cloud to 3D model

From photogrammetry to point cloud to 3D model

From photogrammetry to point cloud to 3D model

Cerro Ballena: four bone-bearing levels

Cerro Ballena: richness and abundance

Cerro Ballena: richness and abundance

Multiple species of marine vertebrates:
- Mostly rorquals (Balaenopteridae)
- Also toothed whales (incl. *Odobenocetops*)
- 3 different species of seals
- Aquatic sloths (*Thalassocnus*)
- Swordfish and shark teeth

Cerro Ballena: richness and abundance

Rorqual skeleton orientation

BL 4: 33% ventral up (n = 3)
BL 3: 66% ventral up (n = 3)
BL 2: 66% ventral up (n = 6)
BL 1: 91% ventral up (n = 11)

Cerro Ballena: taphonomy

Many species at Cerro Ballena; highly articulated

10 marine vertebrates; all high trophic consumers; herbivores & carnivores

<table>
<thead>
<tr>
<th>clade</th>
<th>taxon</th>
<th>BL occurrence</th>
<th>total MNI</th>
<th>articulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mysticeti</td>
<td>Balaenopteridae</td>
<td>BL 1–4</td>
<td>31</td>
<td>Stages 1–3</td>
</tr>
<tr>
<td>Phocidae</td>
<td>Acrophoca sp.</td>
<td>BL 2</td>
<td>2</td>
<td>Stages 2 and 3</td>
</tr>
<tr>
<td>Elasmobranchii</td>
<td>Carcharodon hastalis</td>
<td>BL 1, 2</td>
<td>2</td>
<td>Stage 3</td>
</tr>
<tr>
<td>Odontoceti</td>
<td>Delphinoida</td>
<td>BL 1</td>
<td>1</td>
<td>Stage 3</td>
</tr>
<tr>
<td>Odontoceti</td>
<td>Physeteroidea</td>
<td>BL 2</td>
<td>1</td>
<td>Stages 2 and 3</td>
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<tr>
<td>Odontoceti</td>
<td>Odobenocetops sp.</td>
<td>BL 1</td>
<td>1</td>
<td>Stage 2</td>
</tr>
<tr>
<td>Phocidae</td>
<td>Phocidae n. gen.</td>
<td>BL 2</td>
<td>1</td>
<td>Stage 3</td>
</tr>
<tr>
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<td>Thalassocetus natans</td>
<td>BL 4</td>
<td>1</td>
<td>Stage 3</td>
</tr>
<tr>
<td>Osteichythes</td>
<td>Isthiorhinae</td>
<td>BL 2</td>
<td>1</td>
<td>Stage 3</td>
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<tr>
<td>Osteichythes</td>
<td>Xiphiidae</td>
<td>BL 2</td>
<td>1</td>
<td>Stage 3</td>
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</table>

Most rorquals are belly-up; highly articulated; low scatter

<table>
<thead>
<tr>
<th>BL level</th>
<th>% ventral up</th>
<th>NISP</th>
<th>dominant mode(s) of articulation</th>
<th>average scatter (m)</th>
<th>NISP for scatter</th>
<th>average TL (m)</th>
<th>NISP for TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL-4</td>
<td>33</td>
<td>3</td>
<td>Stage 2</td>
<td>2.77</td>
<td>3</td>
<td>8.62</td>
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<tr>
<td>BL-3</td>
<td>67</td>
<td>3</td>
<td>Stage 1</td>
<td>2.21</td>
<td>3</td>
<td>7.63</td>
<td>2</td>
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<tr>
<td>BL-2</td>
<td>67</td>
<td>6</td>
<td>Stages 1 and 3</td>
<td>2.80</td>
<td>7</td>
<td>7.43</td>
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<tr>
<td>BL-1</td>
<td>92</td>
<td>12</td>
<td>Stage 1</td>
<td>3.45</td>
<td>13</td>
<td>7.97</td>
<td>9</td>
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<tr>
<td>average</td>
<td>75</td>
<td>12</td>
<td>Stage 1</td>
<td>2.83</td>
<td></td>
<td>7.91</td>
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</table>

Depositional setting and modern analogs

Harmful algal blooms and mass strandings

HUMPBACK WHALES, a total of 14, died suddenly from exposure to a bloom of _Alexandrium tamarense_ in Cape Cod Bay, Mass., in 1987. Researchers later learned that the whales had eaten mackerel whose organs contained high concentrations of saxitoxin, a neurotoxin produced by the algae.

Harmful algal blooms and mass strandings

Images: WHOI; Pyenson et al. (2014) *Proc. Roy. Soc. B*
Sudden death at sea - Cerro Ballena is a graveyard

Repeated mass strandings of Miocene marine mammals from Atacama Region of Chile point to sudden death at sea

Nicholas D. Pyenson\textsuperscript{1,3,4}, Carolina S. Gutstein\textsuperscript{1,5}, James F. Parham\textsuperscript{6}, Jacobus P. Le Roux\textsuperscript{7}, Catalina Carreño Chavarría\textsuperscript{7}, Holly Little\textsuperscript{1}, Adam Metallo\textsuperscript{8}, Vincent Rossi\textsuperscript{8}, Ana M. Valenzuela-Toro\textsuperscript{5,9}, Jorge Velez-Juarbe\textsuperscript{1,10}, Cara M. Santelli\textsuperscript{2}, David Rubilar Rogers\textsuperscript{5,11}, Mario A. Cozzuol\textsuperscript{12} and Mario E. Suárez\textsuperscript{5,9}

Roadside whales in the Atacama
Comparisons: Pisco Formation

Area near Cerro Blanco, Pisco Formation: **300 rorquals / km²**

Cerro Ballena, Bahia Inglesa Formation: **9200 rorquals / km²**
(based on 46 skeletons / 0.005 km²)

Cerro Ballena has 30 times the density of whales observed in the Pisco Fm

Western continental margins and upwelling

Images: D.R.R.
Western continental margins and upwelling

Images: D.R.R.; BBC Films; Moloney et al. (2005) ICES JMS
Specimen-based research & 3D digitization

What are our workflows?

What do we archive? How will we use it?
Acknowledgments

Collaborators:

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DIAMOND DME