

*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



Image: Chip Clark, NMNH

MESSAGES IN THE MUD

OCEAN
EXPLORER
THEATER

Pyenson Lab: work in the field



Image: J. A. Goldbogen under NOAA permit

Pyenson Lab: work in the field

Vancouver Island (2009, 2012)



Iceland (2009, 2010, 2013)



Panama (2011)



Chile (2009, 2011, 2012, 2013*)



*sans PI because of shutdown

Pyenson Lab: work in the field

Vancouver Island (2009, 2012)



Iceland (2009, 2010, 2013)



Panama (2011)



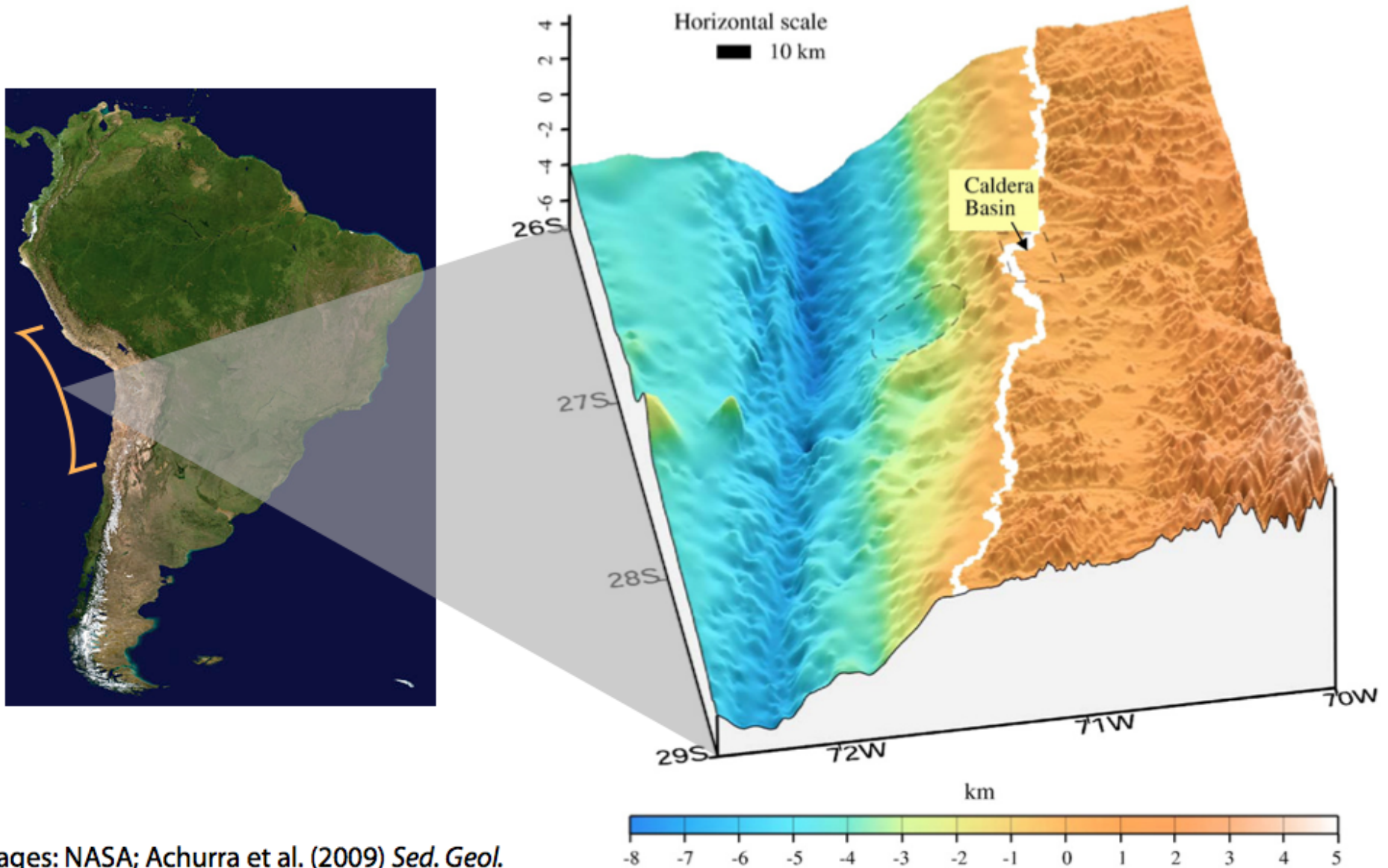
Chile (2009, 2011, 2012, 2013*)



*sans PI because of shutdown

Plate tectonics drives paleontological discovery

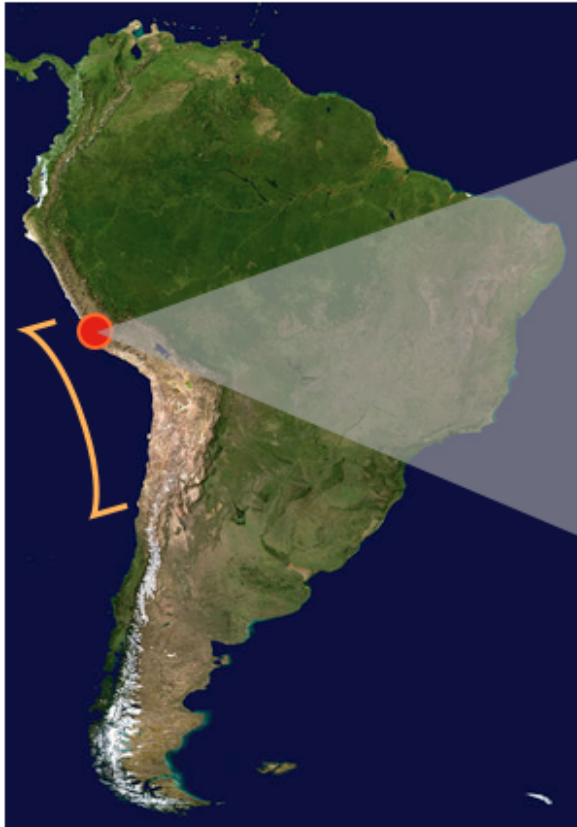
Seafloor preserves remains of marine ecosystems



Images: NASA; Achurra et al. (2009) *Sed. Geol.*

Weird, extinct marine mammals from South America

Neogene of Pisco Basin, Peru



Thalassocnus



Odobenocetops

Prospecting the Caldera Basin in the Chilean Atacama



Image: J. F. Parham

Discovering fossil marine mammals in Chile



Image: N. D. P.

Discovering fossil marine mammals in Chile



Image: N. D. P.

International collaboration linking museums and universities



Image: N. D. P.

Cerro Ballena: a fossil marine mammal graveyard



Image: J. F. Parham

Digitizing a fossil marine mammal graveyard



Image: A. Metallo

Digitizing a fossil marine mammal graveyard

Image: A. Metallo



Digitizing a fossil marine mammal graveyard



Image: J. Arevalo

Digitizing a fossil marine mammal graveyard



Digitizing a fossil marine mammal graveyard



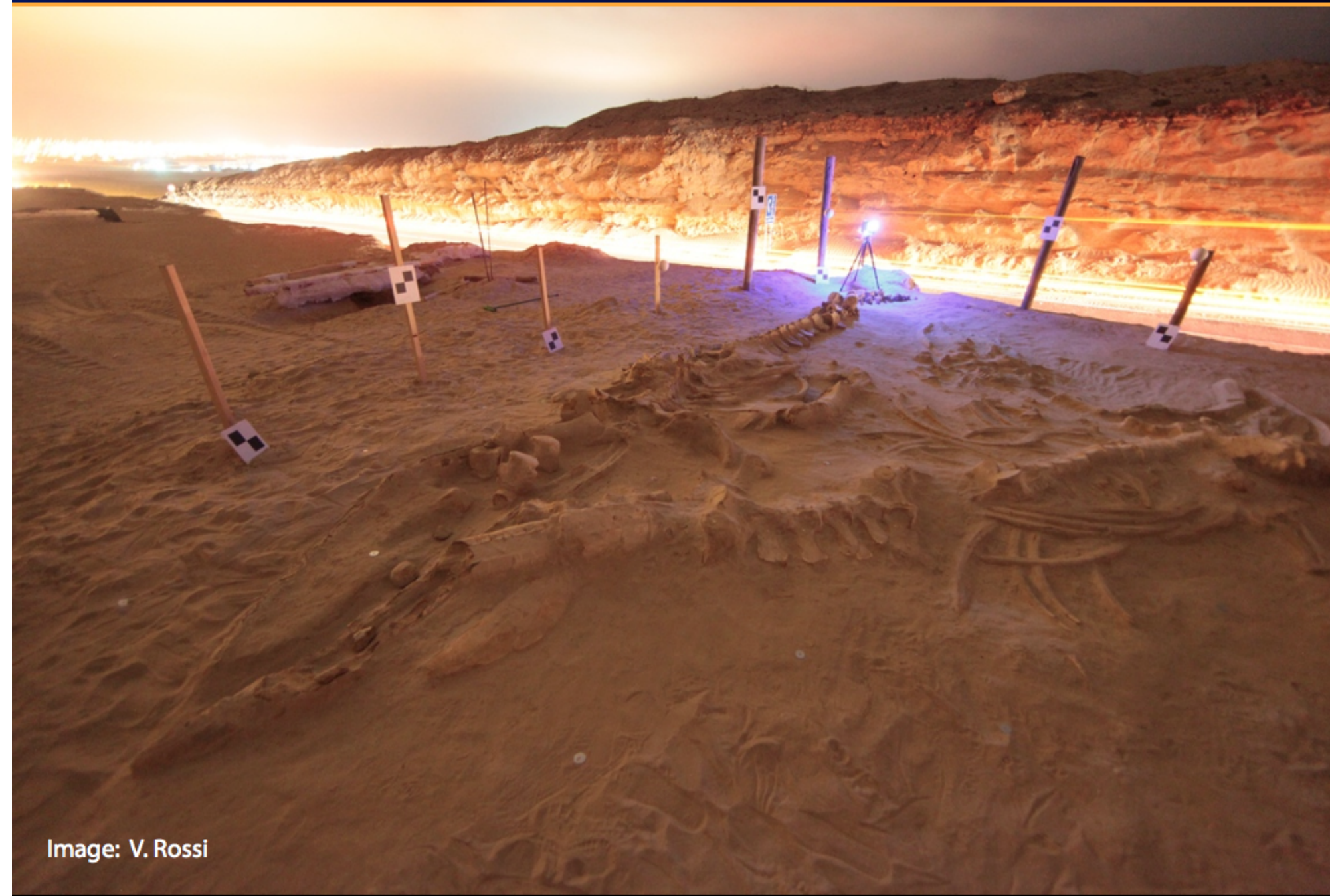
Image: J. Arevalo

Digitizing a fossil marine mammal graveyard



Image: F. Infante / MNHN, Santiago

Digitizing a fossil marine mammal graveyard



Digitizing a fossil marine mammal graveyard



Image: V. Rossi

Digitizing a fossil marine mammal graveyard



Image: N. D. P. in *Nature* (2011) and *Smithsonian Magazine* (2012)

Painting with laser light...



Image: Pyenson et al. (2014) *Proc. Roy. Soc. B*

Painting with laser light...and coloring it in



Image: Pyenson et al. (2014) *Proc. Roy. Soc. B*

Painting with laser light...and coloring it in



Image: Pyenson et al. (2014) *Proc. Roy. Soc. B*

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



Image: Pyenson et al. (2014) *Proc. Roy. Soc. B.*; 1 of 40 panels by 3D Systems

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



Image: Pyenson et al. (2014) *Proc. Roy. Soc. B.*; 1 of 40 panels by 3D Systems

Smithsonian X 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



Image: A. Metallo in *Smithsonian Magazine* (2012)

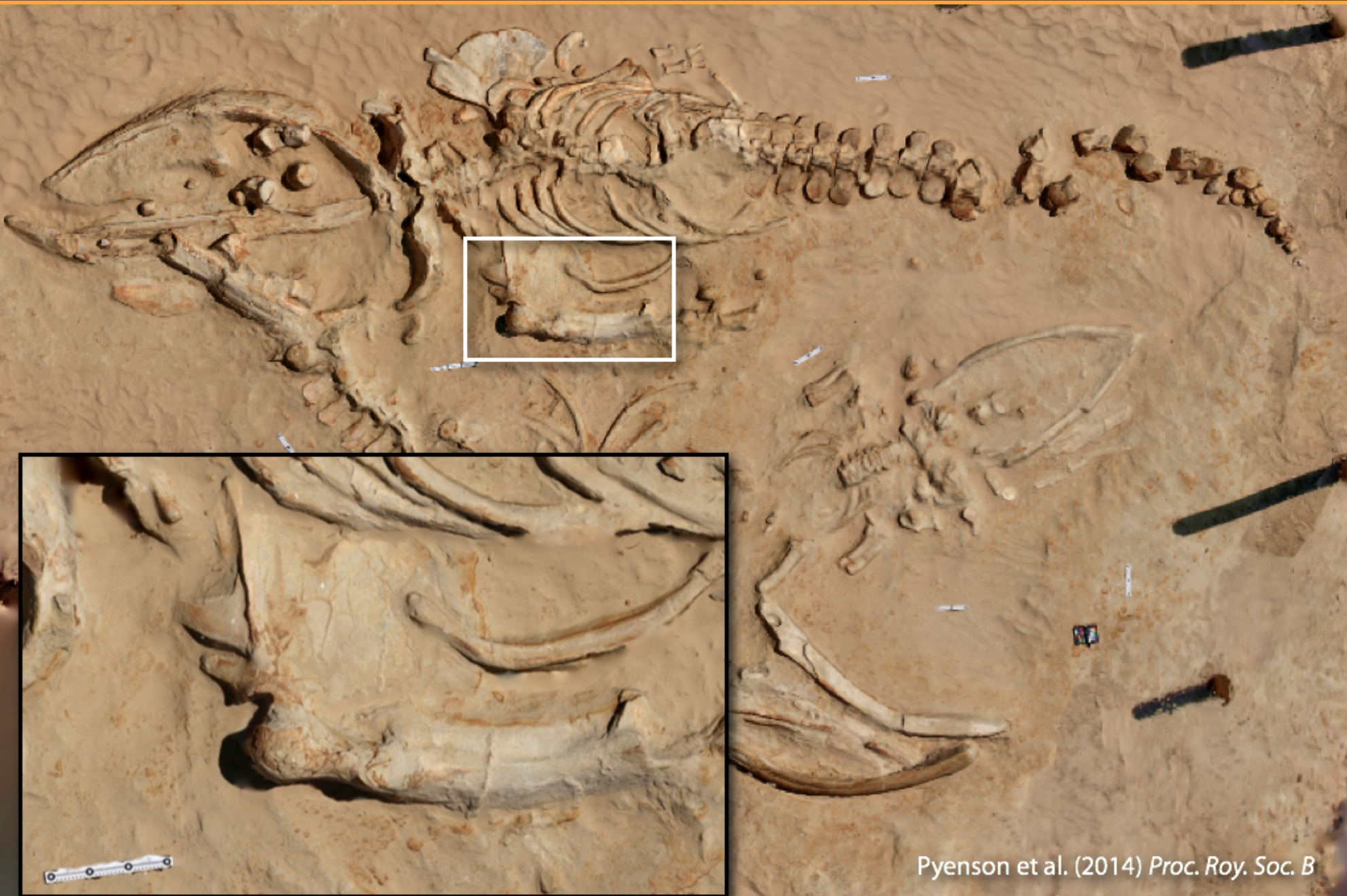
From photogrammetry to point cloud to 3D model



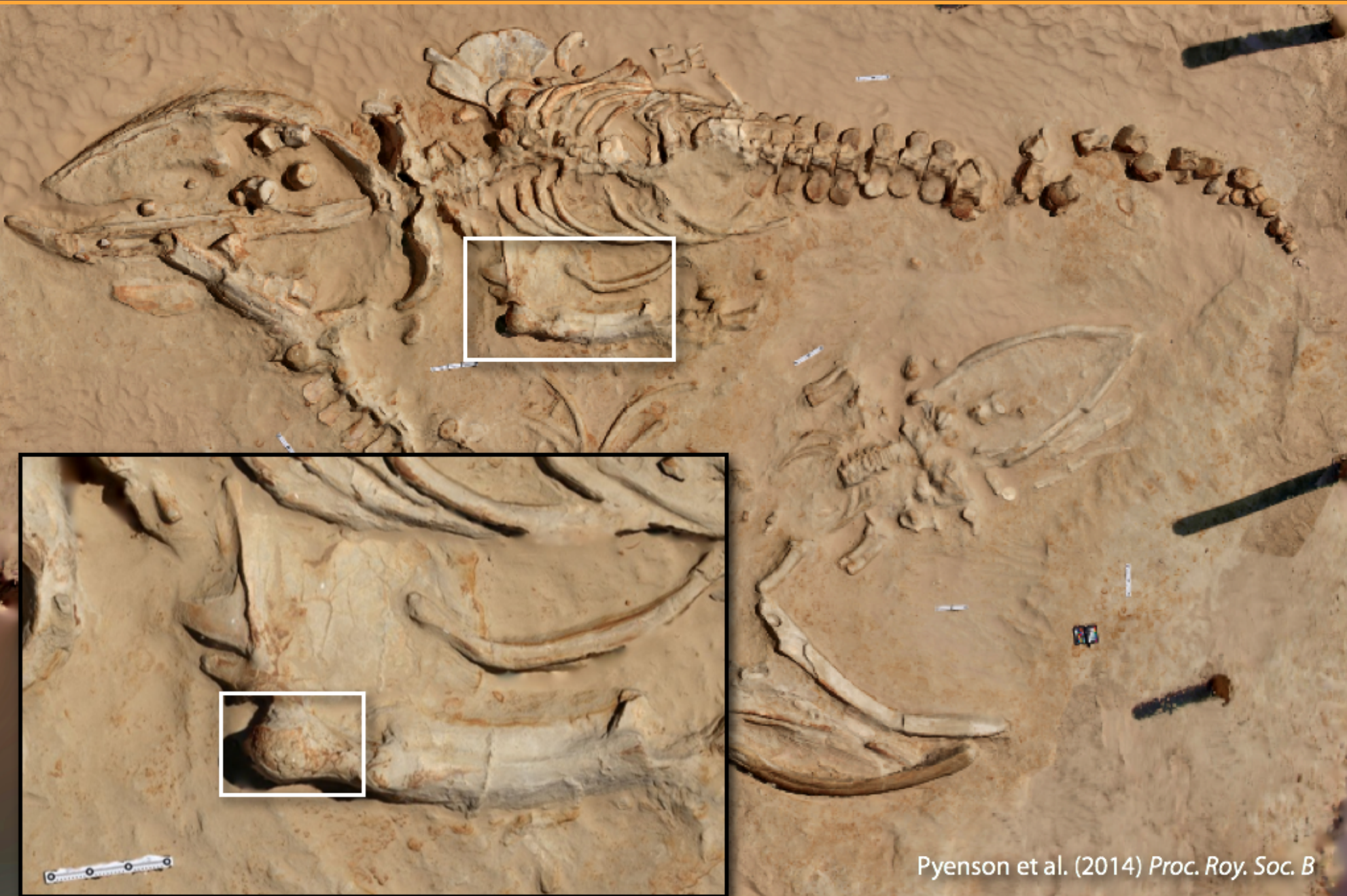
From photogrammetry to point cloud to 3D model



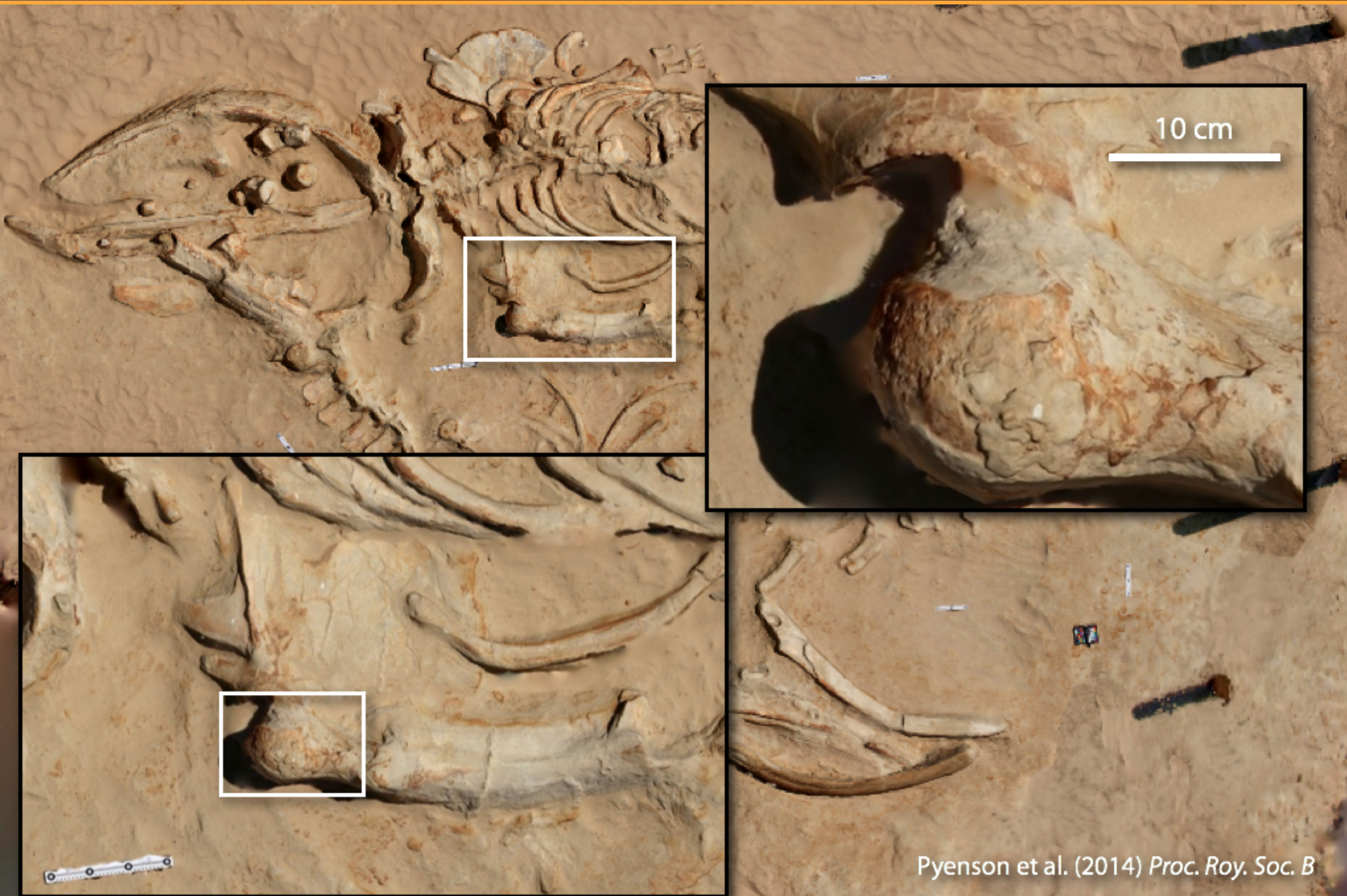
From photogrammetry to point cloud to 3D model



From photogrammetry to point cloud to 3D model



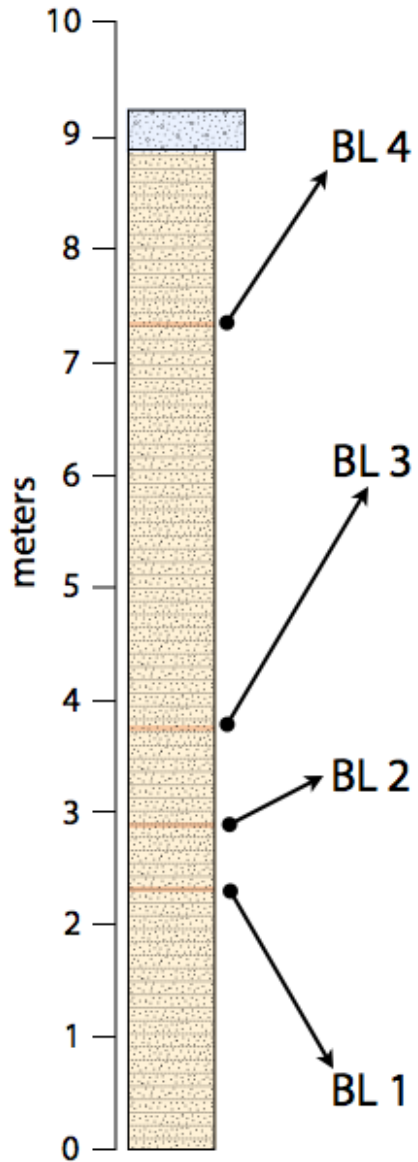
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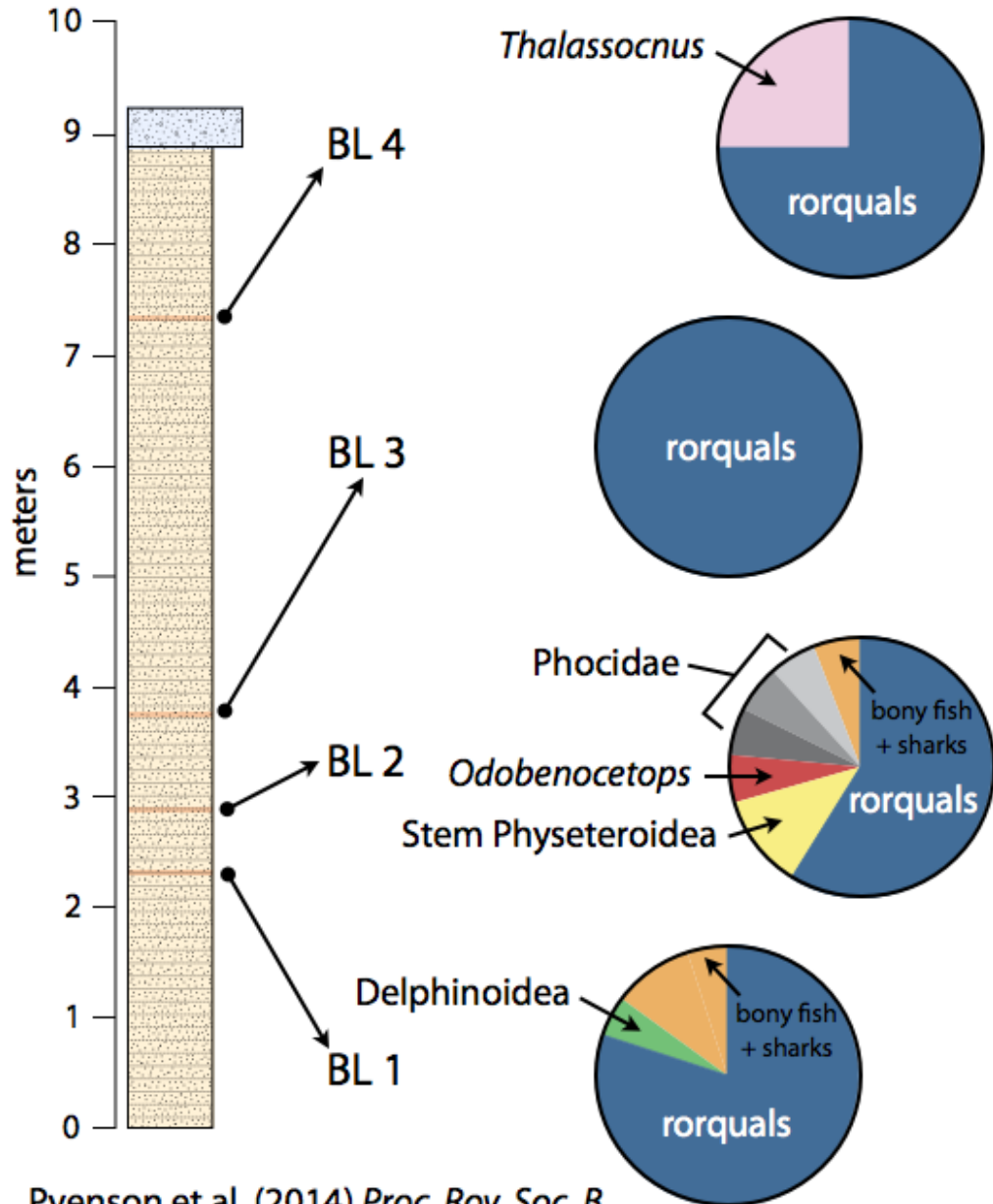
From photogrammetry to point cloud to 3D model



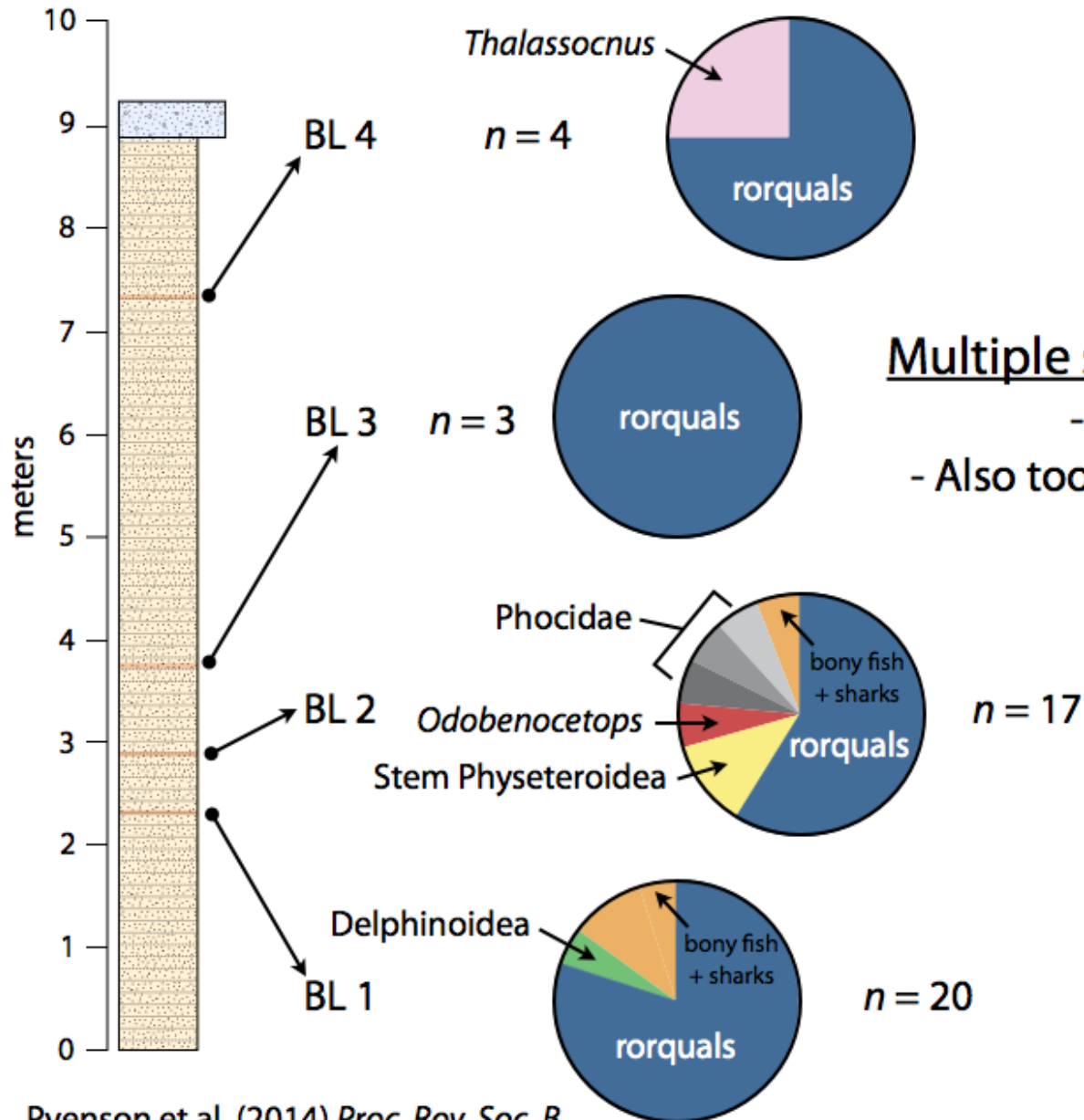
Cerro Ballena: four bone-bearing levels



Cerro Ballena: richness and abundance



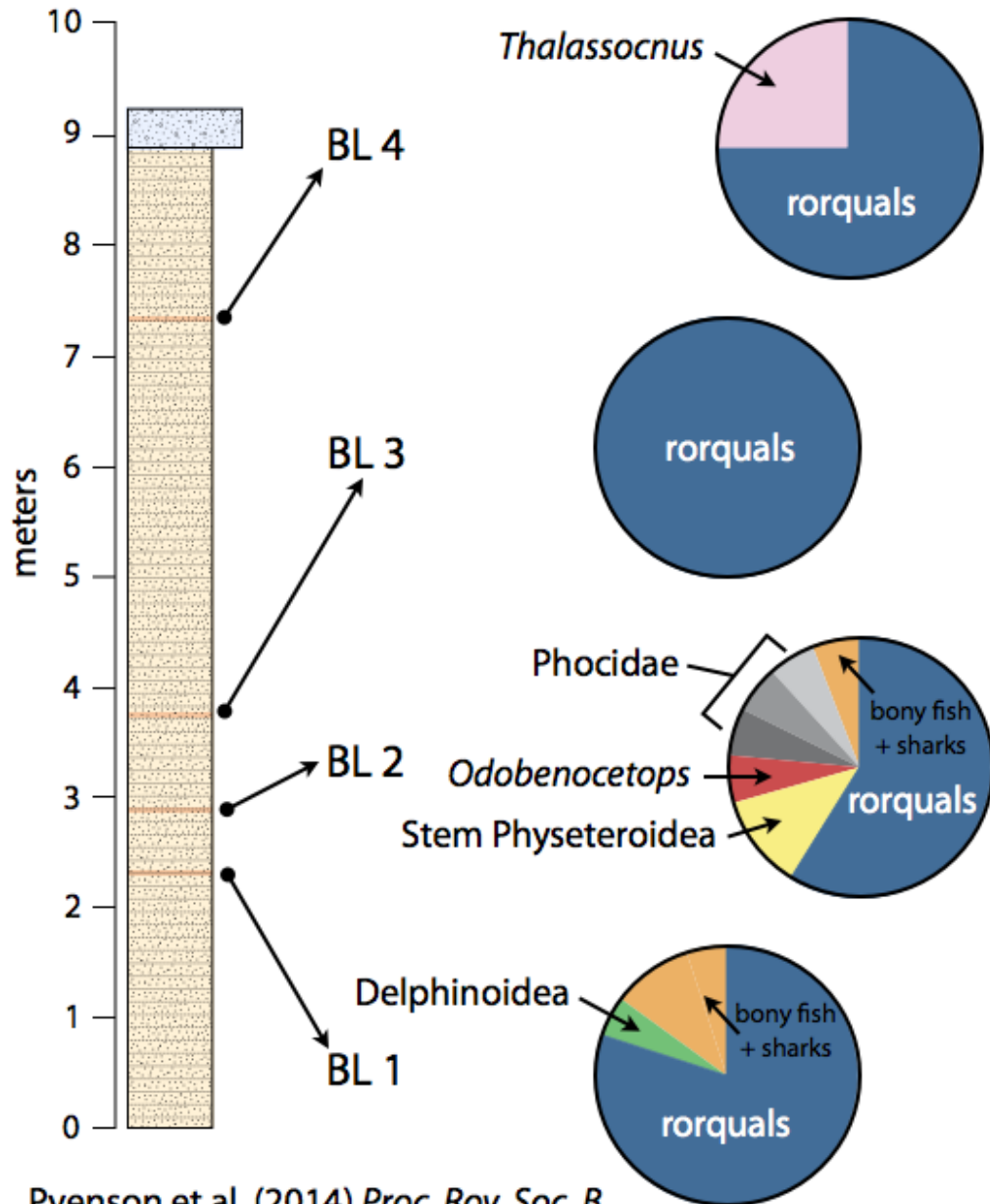
Cerro Ballena: richness and abundance



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

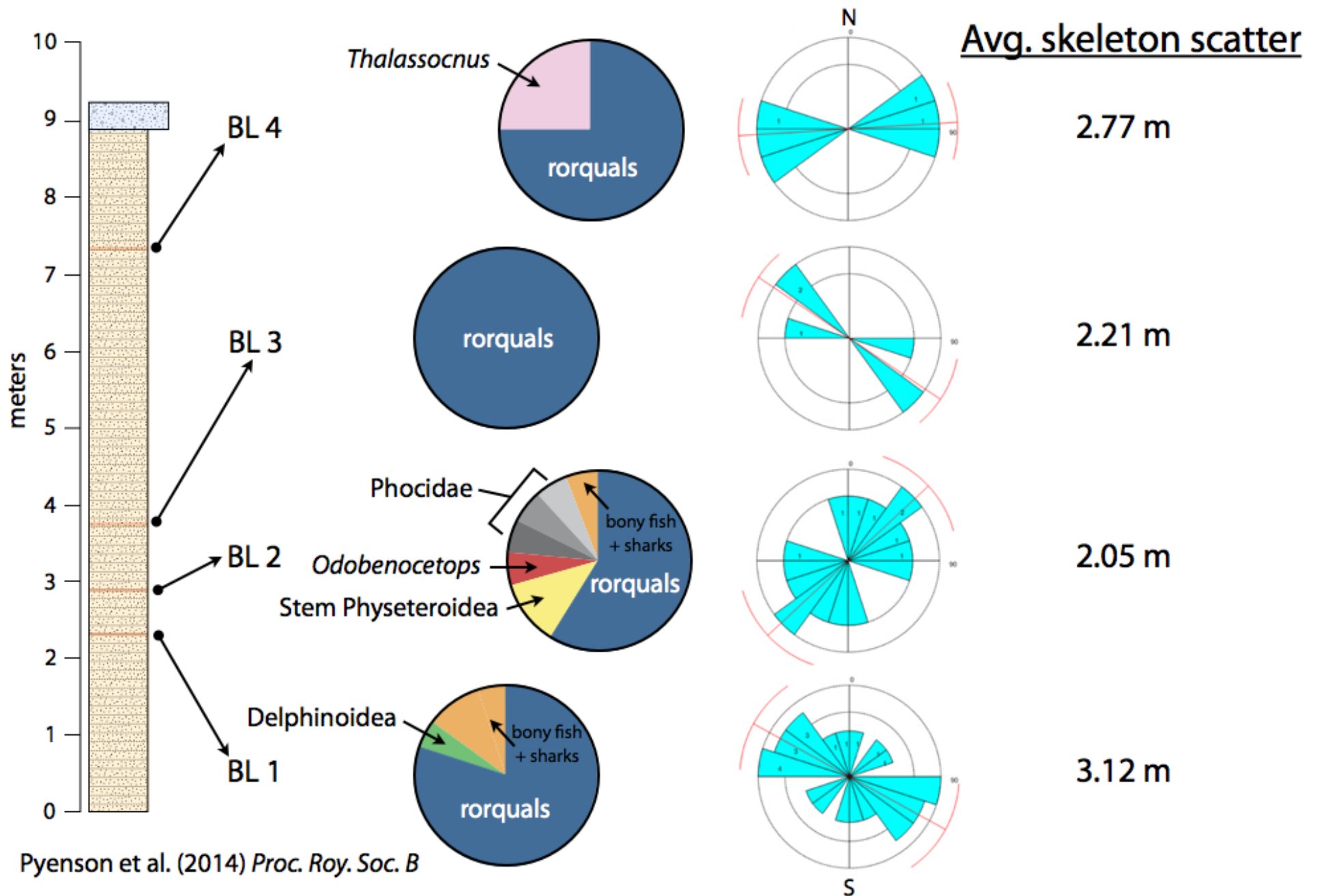
BL 4: 33% ventral up ($n = 3$)

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

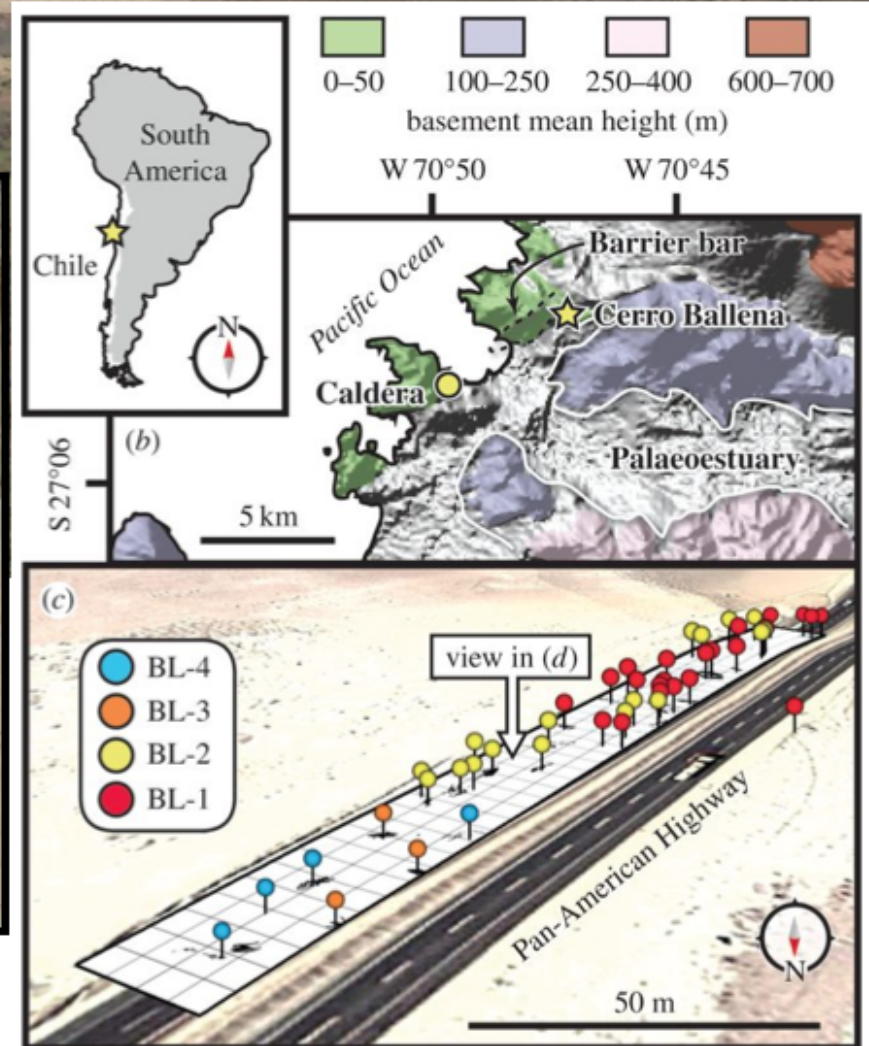
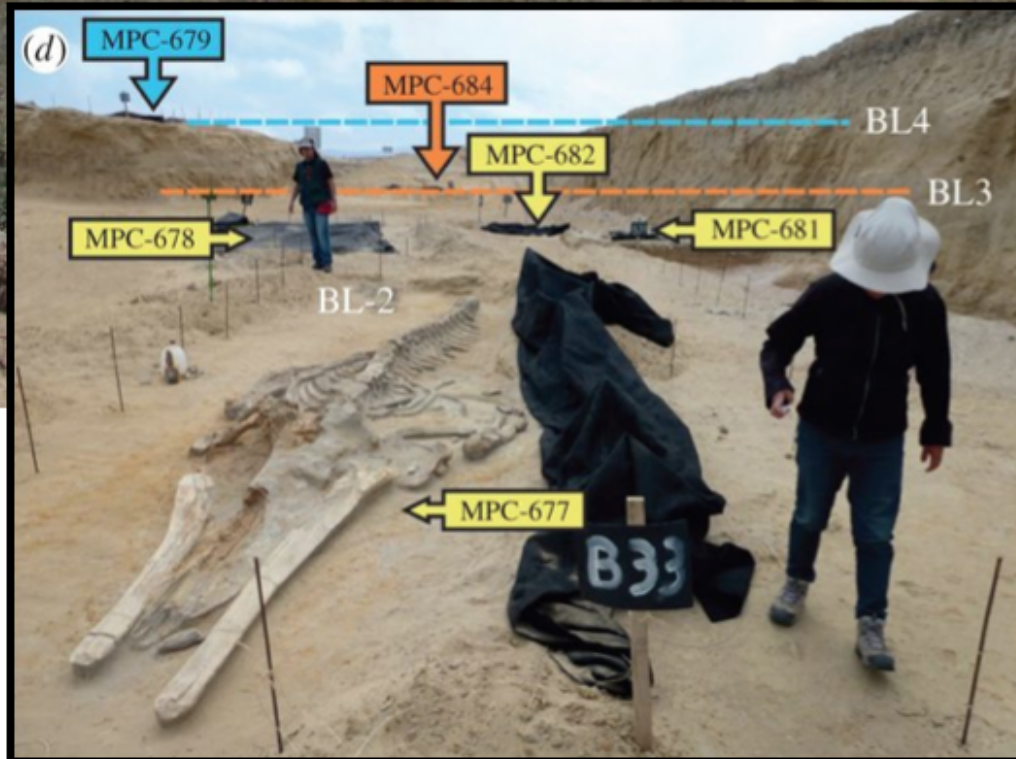
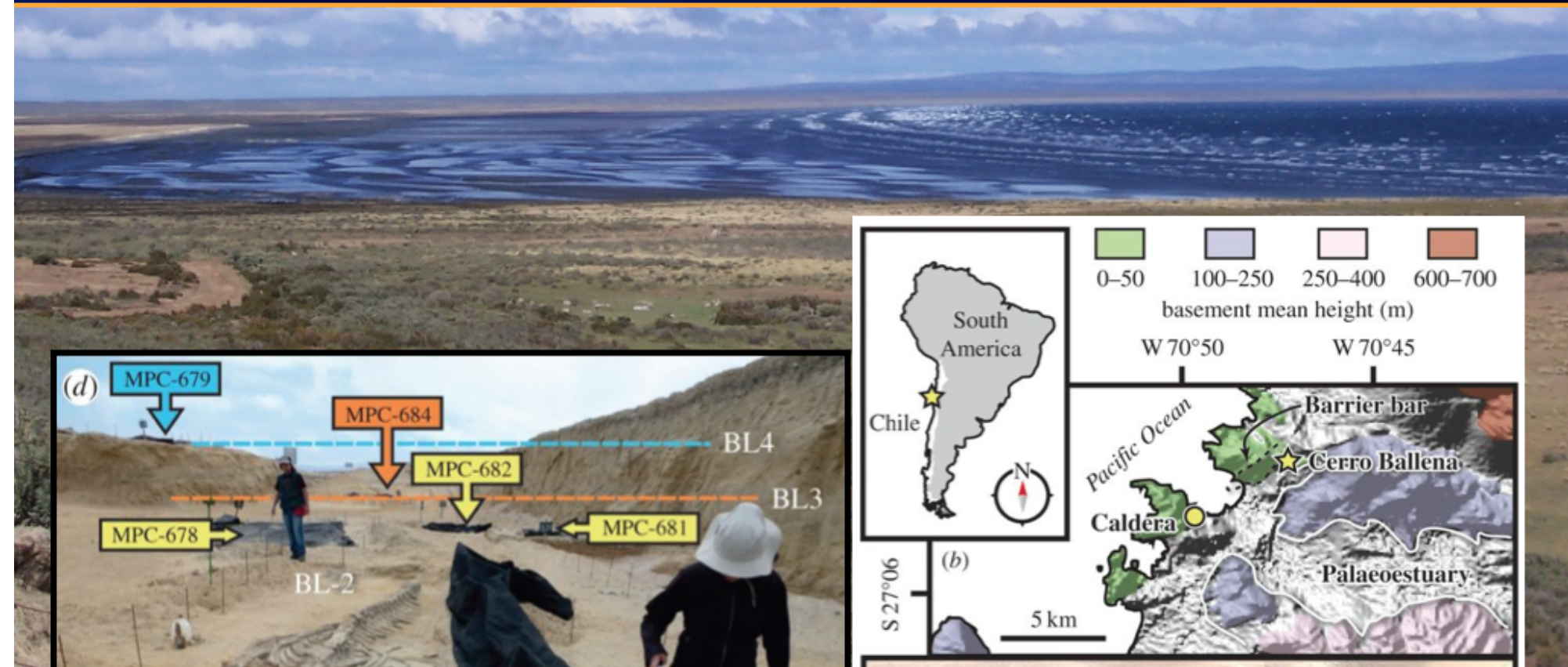
10 marine vertebrates; all high trophic consumers; herbivores & carnivores

clade	taxon	BL occurrence	total MNI	articulation
Mysticeti	Balaenopteridae	BL 1–4	31	Stages 1–3
Phocidae	<i>Acrophoca</i> sp.	BL 2	2	Stages 2 and 3
Elasmobranchii	<i>Carcharodon hastalis</i>	BL 1, 2	2	Stage 3
Odontoceti	Delphinoidea	BL 1	1	Stage 3
Odontoceti	Physeteroidea	BL 2	1	Stages 2 and 3
Odontoceti	<i>Odobenocetops</i> sp.	BL 1	1	Stage 2
Phocidae	Phocidae n. gen.	BL 2	1	Stage 3
Nothrotheriidae	<i>Thalassocnus natans</i>	BL 4	1	Stage 3
Osteichythes	Istiophoridae	BL 2	1	Stage 3
Osteichythes	Xiphiidae	BL 2	1	Stage 3

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

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

Depositional setting and modern analogs

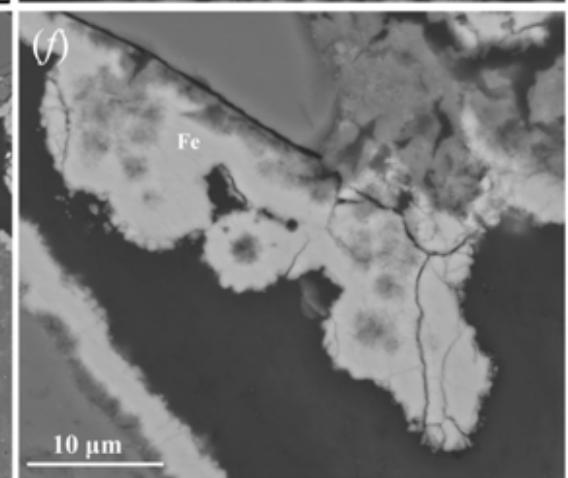
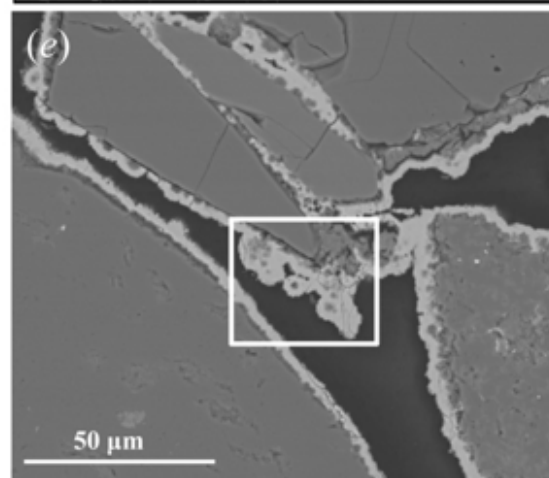
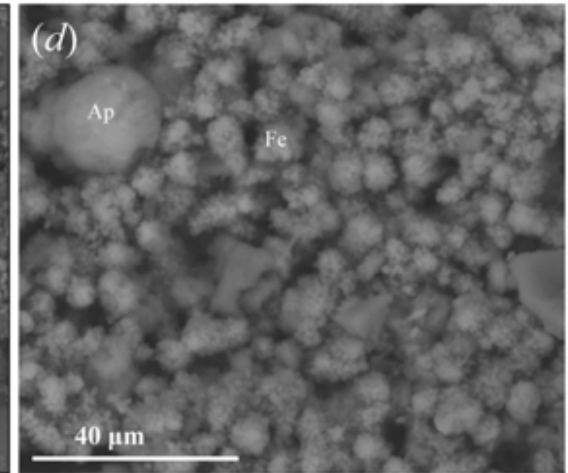
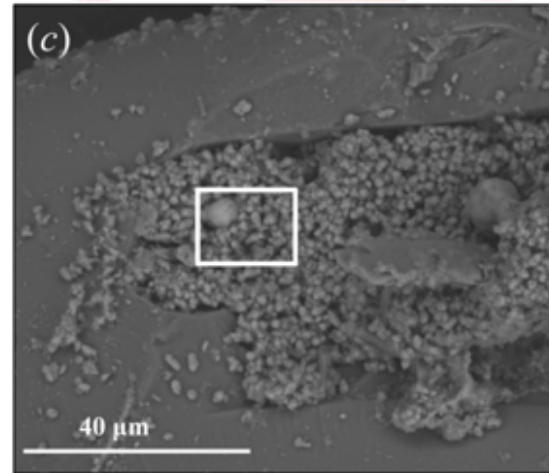
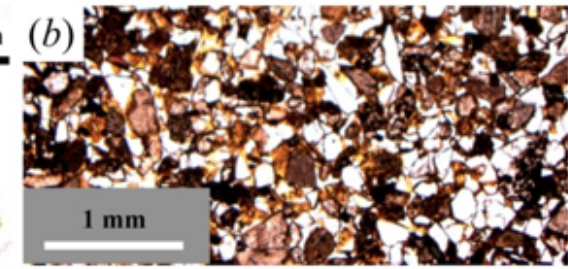


Harmful algal blooms and mass strandings



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

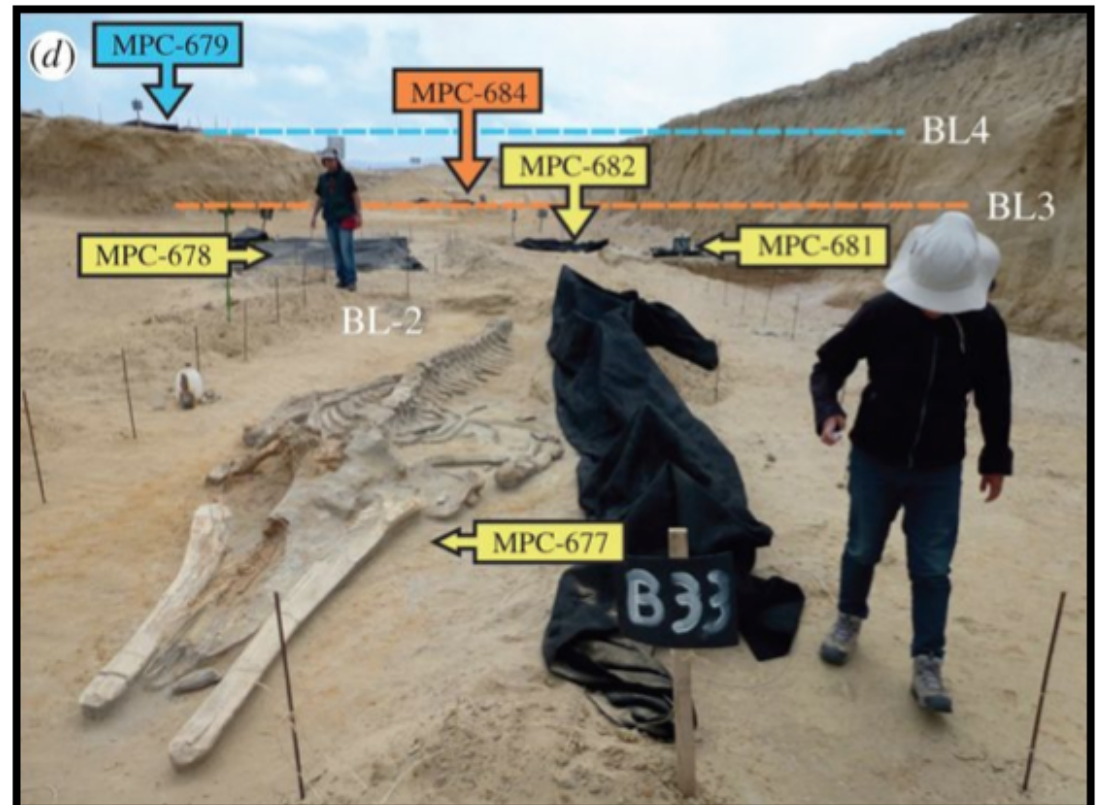
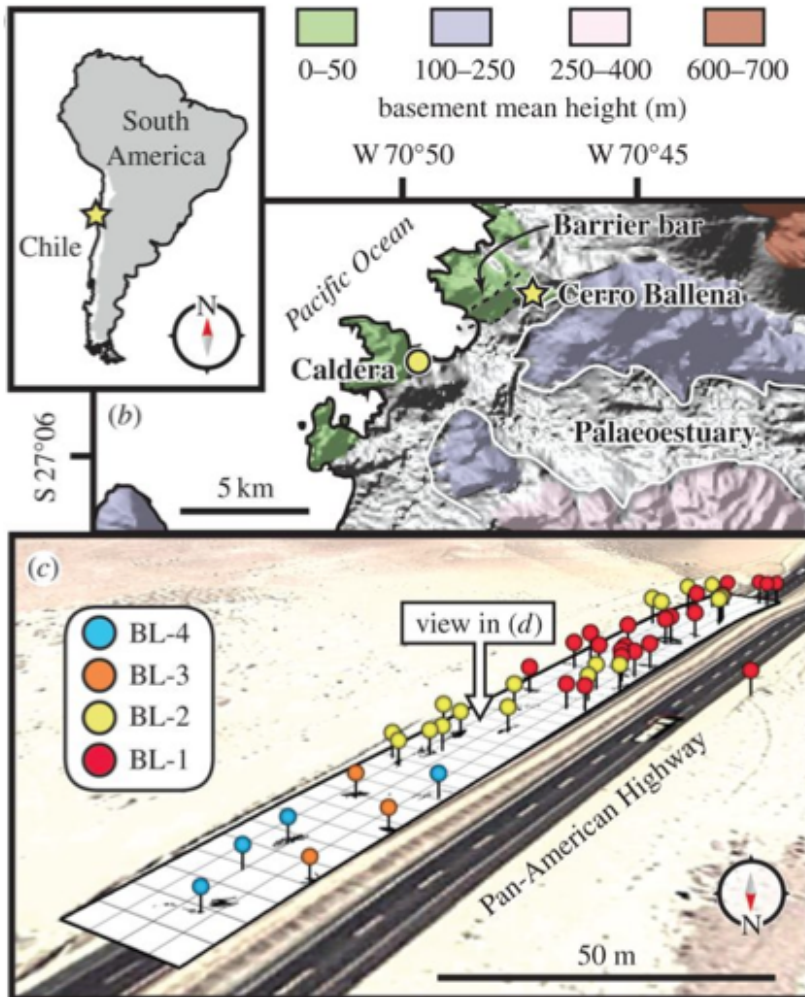
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Research



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Cerro Ballena is a unique fossil site in the Atacama Desert of Chile. This website shares the paleontological discoveries from this site made by Chilean and Smithsonian scientists.

3D



Image Gallery



Roadside whales in the Atacama

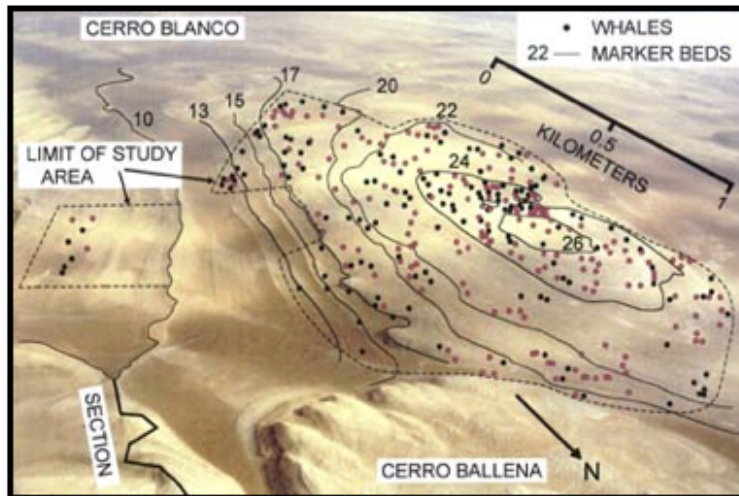


Image: J. Velez Juarbe

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)



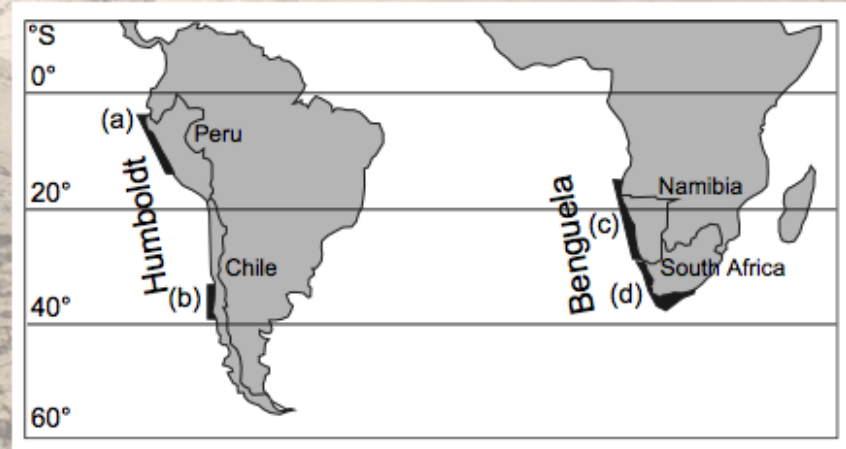
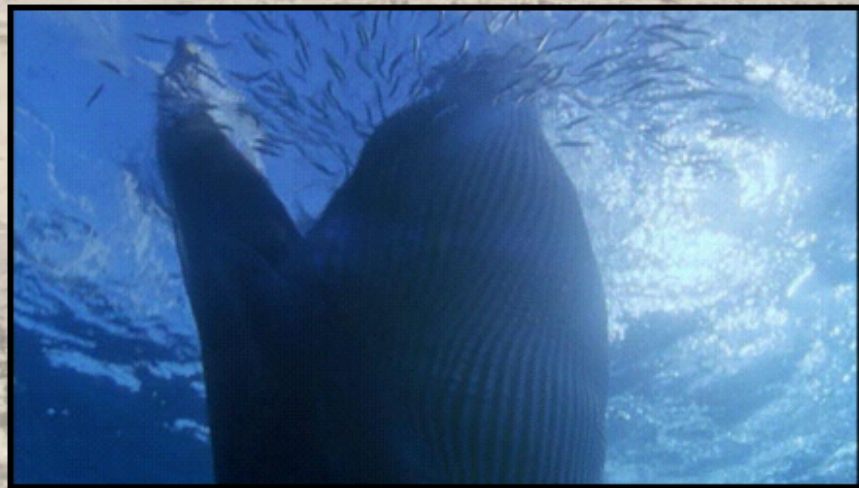
*Cerro Ballena has 30 times
the density of whales
observed in the Pisco Fm*

Western continental margins and upwelling



Images: D.R.R.

Western continental margins and upwelling



Specimen-based research & 3D digitization

What are our workflows?



What do we archive? How will we use it?

Acknowledgments

Collaborators:

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