

A 5.3-million-year-old deep-sea whale necropolis in the Diamantina Zone

<https://doi.org/10.1038/s41586-026-10546-z>

Received: 27 January 2026

Accepted: 15 April 2026

Published online: 10 June 2026

Open access

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Whale falls are biodiversity oases at seabeds^{1–6}, yet their record from the oceans has remained sparse and fragmentary^{6,7}. Here we report the discovery of a vast whale necropolis in the Diamantina Zone (4,616- to 7,001-m depth), extending about 1,200 km along the sea floor of the southeastern Indian Ocean. This area has a deep and extensive accumulation comprising five modern natural whale-fall communities and 476 fossil cetaceans recorded. We show that carcasses host specialized communities dominated by brittle stars, bone-boring worms and chemosynthesis-based bivalves and that the fossil record in this area comprises both extant and extinct deep-diving beaked whales. Isotopic dating shows that whale falls in this region have occurred since at least 5.3 million years ago. These findings reshape the understanding of the limits and biogeography of whale-fall ecosystems and establish some deep sea floors as a fossil archive for tracing cetacean evolution over geological time.

The deep sea is home to myriad life forms that have adapted to extreme environmental conditions. One of the most fascinating phenomena of the deep sea are whale-fall communities, whereby a whale carcass that sinks to the ocean floor^{1–3} initiates a highly idiosyncratic ecosystem in association with a variety of physiologically diverse organisms, thus providing crucial insights into the interplay of life and death in the ocean's depths^{4–7}. Although whale falls are abundant, with more than 70 sites documented across diverse ocean basins and depths⁶, their distribution remains patchy and only sporadically documented⁷.

The species composition and diversity of whale-fall communities are strongly influenced by water depth and related environmental factors, such as temperature and hydrodynamic regime^{6,8,9}. In contrast to deep-sea sites, shallow-water shelf whale falls generally yield different sets of taxa, indicating that highly specialized and species-rich whale-fall communities develop primarily in the food-limited setting of the deep ocean^{7,10–13}. So far, however, most whale falls are found between some tens of metres to around 4,000 m water depth^{6,7}, with the deepest example reaching 4,204 m in the southwest Atlantic Ocean¹⁴. The biogeography, evolutionary novelty and connectivity of deep-sea whale-fall communities remain poorly understood, first and foremost because of the paucity of data from abyssal and hadal depths⁷.

The Diamantina Fracture Zone lies to the south of the Broken Ridge and Perth Abyssal Plain in the Indian Ocean, stretching about 1,200 km parallel to the Southeast Indian Ridge (Fig. 1). It formed as the Australian and Antarctic continents separated between 60 million and 50 million years ago¹⁵. The rough sea floor topology is the result of block faulting¹⁶. The deepest regions of the Diamantina Zone cluster in its northwestern section, most notably at the Dordrecht Deep, which reaches a maximum depth of 7,079 m as measured by the conductivity–temperature–depth

sensor aboard the human-occupied vehicle (HOV) *Fendouzhe* in 2023. The Diamantina Zone has not been previously documented to be associated with any whale falls.

Whale-fall biota

From 8 February to 17 March 2023, using the *Fendouzhe* submersible capable of reaching depths of up to 11,000 m on board the R/V *Tansuoyi-hao*, we discovered extensive whale falls and fossils in the Diamantina Zone (Fig. 1 and Supplementary Video 1). During dive FDZ159, we first encountered whale fossils at a depth of 7,002 m, near the deepest point of the Dordrecht Deep. These fossils were found partially buried in soft surface sediments and lightly coated with black Fe–Mn oxides. Following the initial discovery, we conducted 32 dives to the sea floor, aiming at mapping the spatial distribution and extent of the whale falls and fossils, as well as identifying any associated whale-fall ecosystems. By doing this, we documented and collected samples from 485 whale-fossil sites and active whale falls (Fig. 2, Extended Data Tables 1 and 2 and Supplementary Table 1) from 1,200 km along the sea floor, representing an ecological landmark in the Diamantina Zone.

The five active whale falls are in the sulfophilic stage (Fig. 2). Bones are covered with dense, whitish microbial mats and bone-boring worms *Osedax*, indicating prolonged residence on the sea floor. At 6,789 m water depth, the Dordrecht Deep beaked-whale carcass WF1, consisting of three elongated vertebrae, has the deepest active whale-fall community. The largest carcass encountered, the 5-m-long skeleton WF3, was identified as the Antarctic minke whale *Balaenoptera bonaerensis* through the highly diagnostic earbone morphology¹⁷ and a nearly complete mitochondrial genome (GenBank: PX519993).

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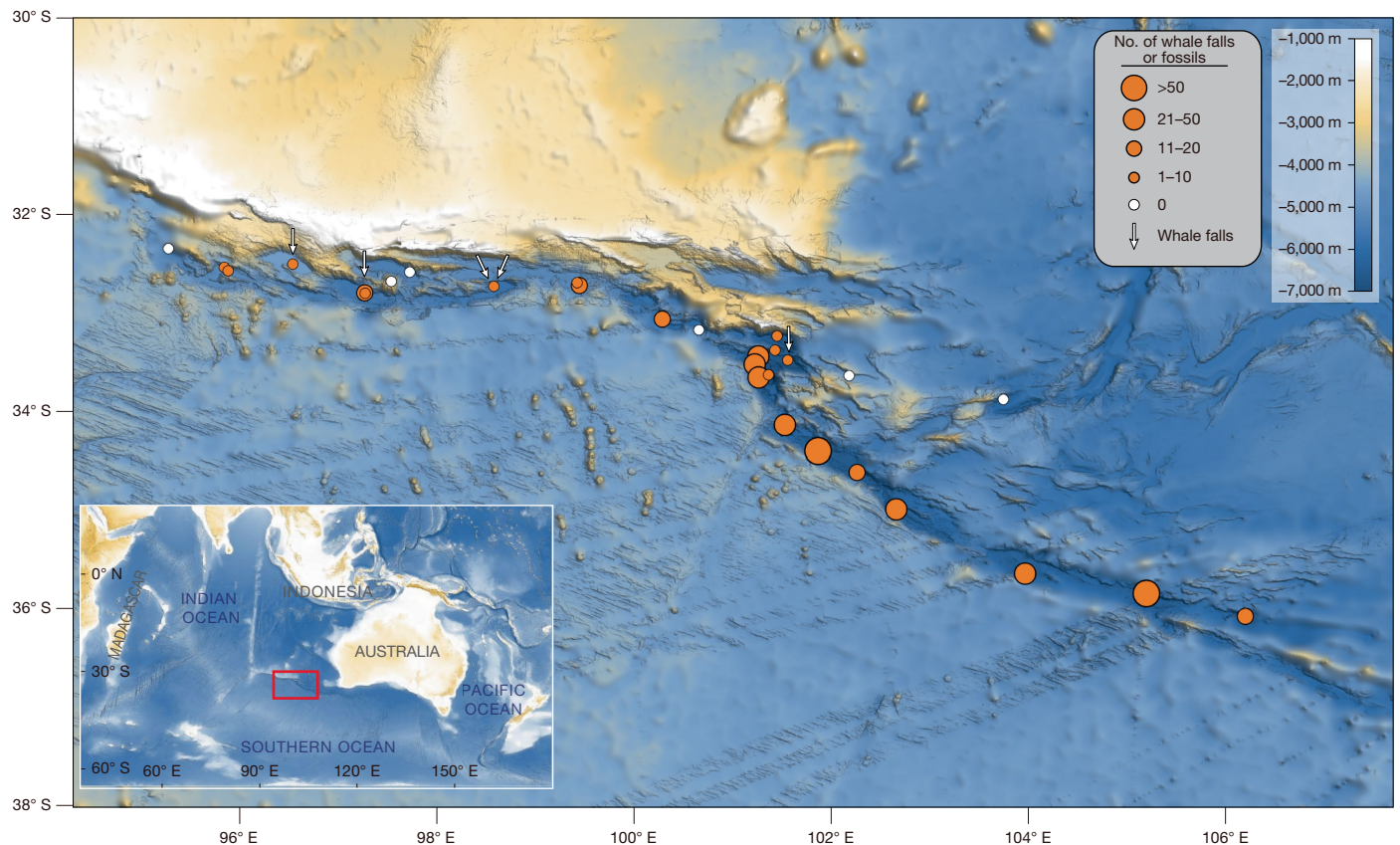


Fig. 1 | Distribution and abundance of whale fossils and whale falls in the Diamantina Zone. Orange circles indicate dive locations where whale fossils or whale falls were observed; circle size corresponds to the number of whale remains recorded per dive. Whale falls in the sulfophilic stage are marked with

white arrows. White circles denote dives with no observed whale fossil or whale fall. Notably, the distribution of both whale falls and whale fossils is restricted to the Diamantina Zone sea floor; none were detected outside this region. Figure adapted from ref. 51, Wiley, under a Creative Commons licence CC BY 4.0.

Across the five whale falls in the sulfophilic stage, the associated fauna are taxonomically broad, comprising 35 recognized macrofaunal taxa (more than 0.5 mm in size) documented from in situ imagery and collected specimens (Extended Data Table 1 and Extended Data Figs. 1 and 2). The macrofauna are dominated by annelids, crustaceans and molluscs, with further cnidarians and nematodes. Bone-eating worms, gastropods, vesicomyid bivalves and brittle stars dominate the mega-fauna (more than several centimetres in size), reaching local densities up to 2,840 individuals per square metre (Supplementary Table 2).

Most recovered taxa may be new to science. Molecular data were obtained for 21 species, but only the vesicomyid bivalve *Abyssogena southwardae* could be confidently assigned to species level through barcoding comparison with GenBank records; all remaining species were identified at genus or family rank, integrating morphological data. Three chemosymbiotic bivalves (*Adipicola* sp., *Abyssogena southwardae* and *Thyasiridae* sp.) hosting different sulfur-oxidizing microbial symbionts (Extended Data Fig. 2) and two bone-eating worms (*Osedax* sp. 1 and *Osedax* sp. 2) form the core of these communities^{18,19}. The observations at water depths of 5,609 m and 5,634 m of sea daisies (Asteroidea: *Xyloplax* sp.) provide, to our knowledge, the deepest evidence of this genus, as well as the first record on whale falls, expanding the habitat of *Xyloplax* beyond wood falls and hydrothermal vents²⁰. Three brittle-star species (*Ophiambix* sp., *Ophioscolecidae* gen. et sp. and *Silax* sp.) recovered from the whale skeletons differ notably from the dominant trench-floor ophiuroid genera *Ophiosphalma* and *Ophiuroglypha*. The absence of whale-fall species in the background sediments indicates that these brittle-star assemblages are highly specialized and confined to organic-rich whale substrates. In addition, some whale falls, for instance, at depths of 5,115 m, 6,470 m, 6,570 m and

6,772 m, are in the final reef stage (Extended Data Fig. 3). The exterior of these skeletons is primarily inhabited by common hard-substrate mega-fauna, such as the stalked sea anemone *Galatheanthemum profundale*, the pedunculate sponge *Caulophacus* sp. and the sea star *Freyastera* sp. The different faunal composition of the studied whale falls may be attributable to their sites, successional stages or carcass sizes.

Fossil whale fauna

The palaeontological analysis of 43 recovered fossils from the Diamantina Zone led to the identification of five beaked-whale species and one baleen-whale species. Most of the beaked-whale specimens, primarily consisting of isolated rostra, were attributed to two living ziphiid species: the Andrews' beaked whale, *Mesoplodon bowdoini* (Fig. 3a,b), and the strap-toothed whale, *Mesoplodon layardii* (Fig. 3c,d), both of which are known to inhabit the present-day southeastern Indian Ocean²¹. Diagnostic traits of *M. layardii* preserved in 14 specimens include a narrow, elongated, transversely compressed rostrum and a strongly pachyosteosclerotic vomer forming a prominent posterior bulge, a secondary anterior bulge and a midrostral dorsal depression in between (Fig. 3c,d and Extended Data Fig. 4a–g). Further matching traits, such as the shape of the prominent notch and maxillary tubercle and the size and position of the infraorbital and premaxillary foramina, further support this identification²². The seven rostra assigned to *M. bowdoini* are robust, moderately elongated and laterally compressed and provided with a single anterior vomeral bulge and a ventrally deflected apex, consistent with previous descriptions²² (Fig. 3a,b and Extended Data Fig. 4e–h).

Three exceptionally well-preserved skulls were identified as belonging to the extinct genera *Pterocetus* and *Izikozihius*, which were first

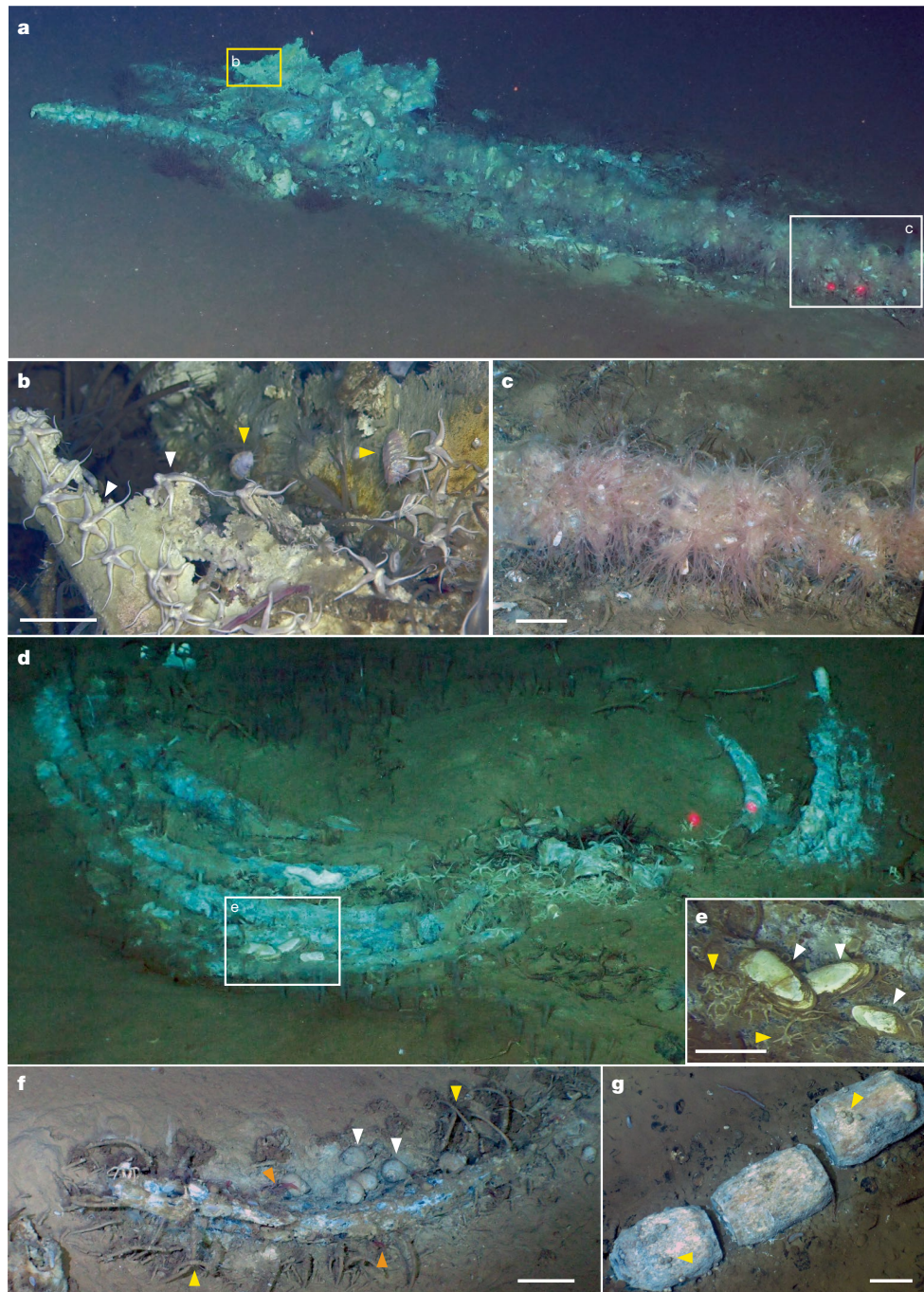


Fig. 2 | Whale falls in the sulfophilic stage in the Diamantina Zone.

a, A 3-m-long minke whale fall recorded during dives FDZ174/FDZ177 at 5,610 m depth. **b**, Close-up view of yellow box in **a** showing brittle stars *Ophiambix* sp. (white arrows) and scale worms polynoid (yellow arrows) on the cranium. **c**, Close-up view of white box in **a** showing numerous transparent tubes of the bone-eating worm *Osedax* sp. emergent from whale bone. **d**, A beaked-whale fall consisting of eight ribs and several thoracic vertebrae observed during dive FDZ178 at 5,609 m depth. Brittle stars *Ophioscolecidae* sp. and *Silax* sp. and chemosymbiotic vesicomyid bivalves *Abyssogena southwardae* are associated

with these bones. Tubeworm *Nicomache* sp. occurs in the surrounding sediments. **e**, Close-up view of the white box in **d** showing three vesicomyid bivalves (white arrows) and brittle stars (yellow arrows). **f**, A whale bone recorded during dive FDZ173 at 4,625.2 m depth, dominated by gastropods *Phymorhynchus* sp. 1 (white arrows), polychaetes *Nicomache* sp. (yellow arrows) and *Osedax* sp. (orange arrows). **g**, The deepest whale fall, consisting of three elongated vertebrae of a beaked whale, with small gastropods (yellow arrows) on their surface, observed during dive FDZ163 at 6,788.7 m depth. The two red laser points are spaced 10 cm apart. Scale bars, 5 cm.

described from fossils trawled from the sea floor off South Africa²³. As for *Pterocetus*, this extinct relative of the modern *Mesoplodon* spp. and bottlenose beaked whales is characterized by distinctive wing-like expansions of the preorbital processes²³. One *Pterocetus* specimen from the Diamantina Zone is referred to *P. benguelae* (Fig. 3h); the other represents a new species, *Pterocetus diamantinae* sp. nov. (Supplementary

Note, Fig. 3e–g, Extended Data Figs. 5a,b and 6 and Extended Data Table 3). The single *Izikoziphius* cranium closely resembles the type species *I. rossi* (Fig. 3i and Extended Data Fig. 5e,f). *Izikoziphius* is a close relative of the extant Cuvier's beaked whale but is recognized as a separate genus owing to the observation of a unique fossa on the premaxilla, a dome-shaped maxillary crest and a proportionally longer

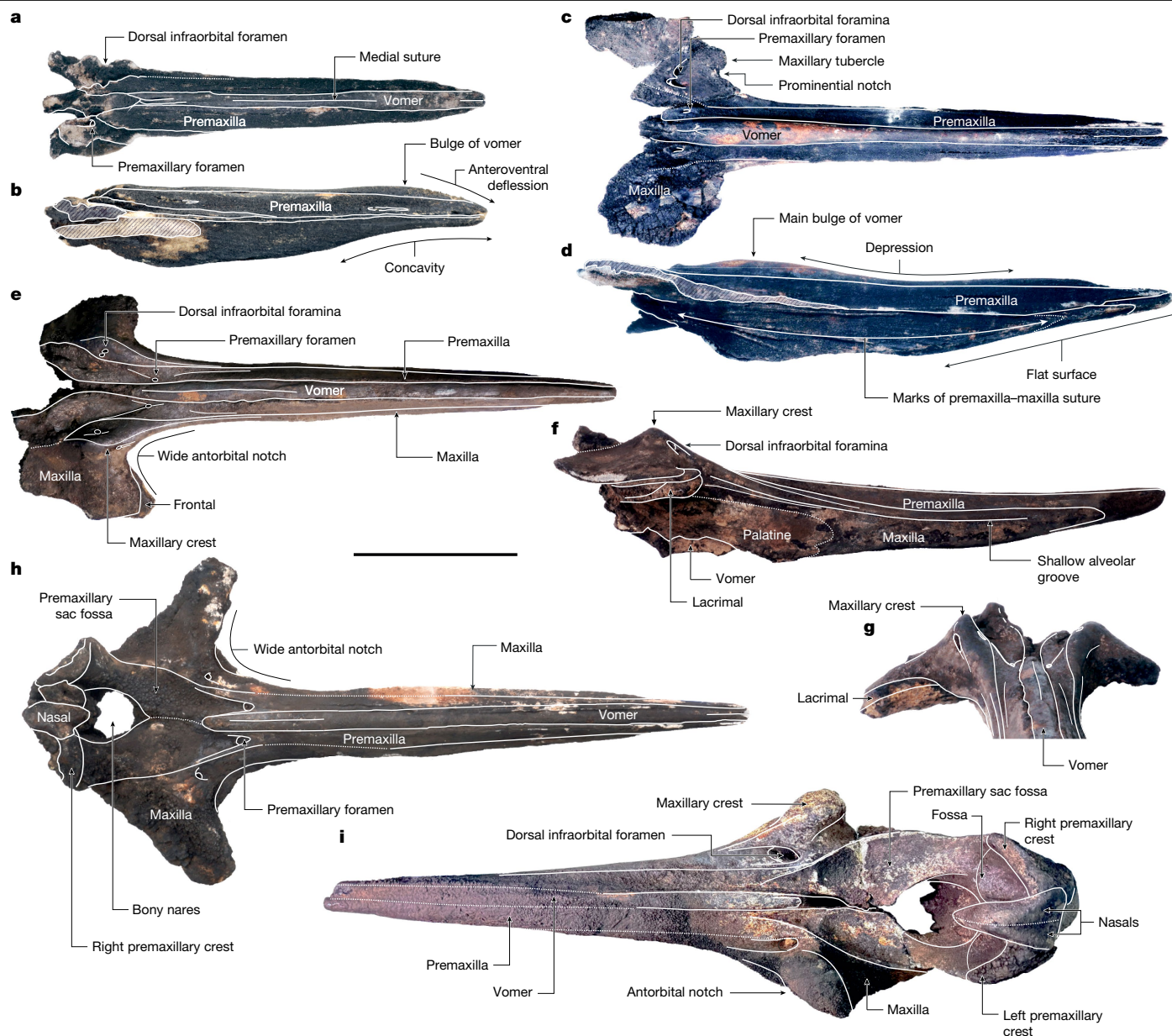


Fig. 3 | Fossil crania of Ziphiidae from the Diamantina Zone. a,b, *Mesoplodon bowdoini*, FDZ180-R1a dorsal (a) and lateral (b) views. **c,d**, *Mesoplodon layardii*, FDZ184-R1a dorsal (c) and lateral (d) views. **e–g**, *Pterocetus diamantinae* sp. nov., FDZ182-R1a, holotype dorsal (e), lateral (f) and anterior (g) views.

h, *Pterocetus benguelae*, FDZ186-R3a. **i**, *Izikoziphius rossi*, FDZ163-R7a. Dotted lines indicate uncertain sutures. Oblique lines indicate principal break surfaces. Scale bar, 20 cm.

rostrum²³. Baleen-whale fossils include a fairly well-preserved tympanic bulla of the sei whale, *Balaenoptera borealis* (Extended Data Fig. 5g–j) and several dilapidated, largely indeterminate cranial and postcranial remains of mostly balaenopterid mysticetes (Extended Data Fig. 5k–l).

Dating of whale fossils

To determine the ages of the fossils, we analysed 33 fossil bone specimens for their strontium isotope composition ($^{87}\text{Sr}/^{86}\text{Sr}$) (Fig. 4 and Extended Data Table 4). This method relies on comparing the isotopic signature preserved in the biominerals to the known historical record of seawater isotopes. Although this method is typically performed on compact dental tissues, the hyperdense bones of ziphiid rostra probably preserves a pristine Sr-isotope ratio²⁴. Eight samples exhibited Sr-isotope ratios identical to modern seawater, indicating complete geochemical exchange after death. The remaining 25 samples,

however, yielded $^{87}\text{Sr}/^{86}\text{Sr}$ ratios ranging from 0.709173 to 0.709029. When calibrated against the seawater $^{87}\text{Sr}/^{86}\text{Sr}$ curve²⁵, these values correspond to ages between 0.12 Ma and 5.26 Ma. The fossil species *Pterocetus benguelae* and *Izikoziphius rossi* were found to be the oldest, with Sr-isotope average ages of 5.26 Ma and 2.44 Ma, respectively, whereas the extant species *M. bowdoini* (1.14–0 Ma) and *M. layardii* (1.20–0 Ma) are geologically younger. The oldest date indicates that whale-fall events have occurred in the Diamantina Zone since at least the Early Pliocene.

Genesis of the whale necropolis

On the basis of submersible observations, the density of whale remains reaches up to 759.5 individuals per square kilometre. The concentration of whale falls and fossils in the Diamantina Zone raises fundamental questions about the origin of this whale necropolis. Active whale-fall

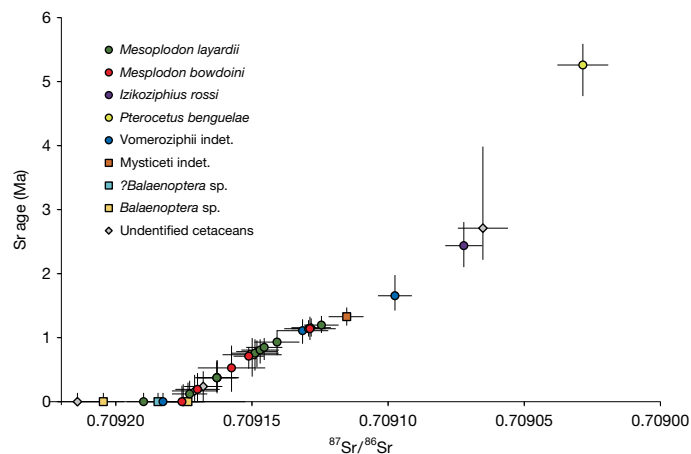


Fig. 4 | Strontium isotope dating of whale fossils from the Diamantina Zone. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are shown for a total of 33 samples, comprising 21 beaked whales (Ziphiidae), five baleen whales and seven unidentified cetacean specimens. Error bars indicate the range from minimum to maximum age (vertical) and plus or minus two standard errors (horizontal). Details in Extended Data Table 4.

ecosystems were found thriving around both baleen and beaked-whale carcasses. The former group also includes the skeleton of an Antarctic minke whale, a circumpolar migratory species that is known to travel northward into the waters off southern Australia^{26,27}. This epipelagic filter-feeder relies on krill in the upper ocean layers, mostly at depths not greater than 150 m (ref. 28). Most cetacean fossils consist of robust beaked-whale rostra, which have probably endured the destructive biostratigraphic processes at play on the sea floor thanks to their hyperostotic structure. Among the few exceptions are poorly diagnostic bone fragments of baleen-whale skulls and the well-mineralized tympanic bulla of a sei whale. Like the Antarctic minke whale, the sei whale migrates seasonally into the southeastern Indian Ocean²⁹. Observations of the diving behaviour of sei whales indicate feeding on copepods to depths of 50 m (ref. 30). Thus, the occurrence of remains of *B. bonaerensis* and *B. borealis* at such hadal depths is not related to deep-diving habits and rather is due to the carcasses sinking to the sea floor of this shared migratory corridor.

The vast majority of the cetacean remains belong to two deep-diving ziphiid species: the strap-toothed and Andrews' beaked whales, both of which are known to inhabit the southeastern Indian Ocean^{21,31,32}. Beaked whales are specialized predators of deep-water squid and fish, foraging along steep continental slopes, submarine canyons, abyssal plains and trenches³³. The Diamantina Zone, with its extreme depths ranging between 4,200 m and 7,000 m, complex V-shaped topography and abundant squid and fish resources as observed during our dives, provides an ideal deep-water foraging ground for beaked whales.

Natural mortality, combined with the inherent risks of deep diving, probably contributes to the accumulation of beaked-whale remains in the sea floor of this zone. These beaked whales possess extraordinary physiological adaptations for deep diving, routinely reaching depths more than 1,000 m and holding their breath for more than an hour^{33–35}. The maximum dive depth for beaked whales is estimated to be more than 3,000 m on the basis of lung collapse and oxygen storage^{34–38}. Thus, foraging at depths exceeding 3,000 m would be too physiologically taxing for beaked whales and may heighten the risk of fatal exhaustion or decompression sickness^{37–39}. Ultimately, the V-shaped topography of the Diamantina Zone may further contribute to this accumulation by funnelling and concentrating onto the sea floor the sinking carcasses caused by natural and accidental mortality.

Critically, the ultra-low regional sedimentation rate close to the Diamantina Zone (Broken Ridge, 0–5 Ma, 0.05–0.55 cm kyr⁻¹)⁴⁰ implies

a prolonged exposure of the skeletal remains at the sea floor: one that would probably last more than several hundred thousand years at least. On slopes or uplifted sea floor zones, skeletal remains may remain exposed for extended periods: up to 5.3 million years, according to our dating data. The fossilized remains we observed are almost exclusively beaked-whale rostra, some of which have the highest bone density and mineral content among extant vertebrates⁴¹. This high compactness probably inhibits rapid degradation, with long-term preservation on the sea floor being further enhanced by the progressive accumulation of ferromanganese oxides both within the bone matrix and on the outer bone surface. The latter process isolates the skeletal elements from the surrounding environment while increasing their robustness. For buried bones, additionally, authigenic carbonate precipitation during the organic degradation may also facilitate fossil preservation. The confluence of beaked whales' deep-diving ecology, extreme foraging physiology, topographic focusing, an ultra-low sedimentation rate and early fossilization may explain the formation of this whale necropolis.

Implications

The discovery of whale-fall communities in the Diamantina Zone at depths exceeding 6,700 m establishes one of the deepest known whale-fall ecosystems in the ocean, extending the known depth range of such habitats by more than 2,500 m. Isolation, imposed by extreme depth, apparently has facilitated the development of a distinct, specialized whale-fall community dominated by species that may be new to science, as indicated by our molecular data (Extended Data Table 1). This not only expands our understanding of metazoan species richness in the deep-sea ecosystems but, given that we are still in the early stages of discovery of deep-sea whale-fall fauna⁷, also indicates that these species probably exhibit ecological novelty and represent cases of adaptive radiation. For instance, these whale falls share key ecological and evolutionary links with deep-sea cold seeps and hydrothermal vents^{6,19}, including those in hadal trenches^{42,43}, as evidenced by shared taxa such as chemosymbiotic bivalves (*Adipicola*, *Abyssogena* and *Thyasiridae*), gastropods (*Phymorhynchus*) and squat lobsters (*Munidopsis*). The results support the hypothesis that deep-sea whale falls act as evolutionary hotspots and biogeographic stepping stones for sulfide-dependent fauna in the deep ocean^{2,7,44–47}. In the total survey area of 0.64 km² (from 32 dives), five active whale falls were observed. This yields a density of 7.81 whale falls per square kilometre. Aligned along a northwest–southeast axis for 1,200 km, these falls may form a previously unrecognized 'whale-fall community supercorridor'. This extensive biogeographic feature could have an important role in the dispersal, connectivity and evolution of deep-sea chemosynthetic communities across the Southern Indian Ocean.

As beaked whales are known primarily from rare strandings, their abundance, distribution and ecology remain poorly understood overall⁴⁸. Our discovery of an accumulation of skeletal remains of the two extant beaked-whale species *Mesoplodon bowdoini* and *M. layardii* provides an unparalleled source of information on these largely enigmatic cetaceans. Moreover, the investigated whale fossils, preserved for more than 5 million years, serve as an archive providing a direct, continuous record for tracing evolutionary trajectories. Comparative anatomical analysis of these remains can elucidate feeding behaviours, locomotion and ecological roles of deep-diving cetaceans. Thus, the Diamantina Zone necropolis constitutes a deep-sea fossil megasite: one that offers a window into the evolutionary history, palaeoecology and population dynamics of beaked whales from the Pliocene to the present day. Similar whale necropolises probably exist in other core beaked-whale habitats, such as South Africa²³, the Iberian Peninsula⁴⁹ and off the Crozet and Kerguelen islands⁵⁰, as indicated by the recovery of abundant fossils by trawling, indicating that comparable hidden archives may be widespread in the global deep oceans.

Systematic palaeontology

Pterocetus diamantinae Bianucci & Collareta, sp. nov

LSID. urn:lsid:zoobank.org:act:406FD05A-360B-4DD5-B146-4E355504AFD2.

Holotype. FDZ182-R1a (deposited at the Hadal Museum, IDSSE-CAS, Sanya, China), partial skull including the rostrum and anterior neurocranium.

Locality and age. Diamantina Zone sea floor, age unknown.

Etymology. Named after the type locality.

Diagnosis. *Pterocetus diamantinae* is a congener of *P. benguelae* based on the observation of notably wide and deep antorbital notches, anterolaterally expanded preorbital processes and premaxillary foramina that are located distinctly anterior to the antorbital notches; it differs from *P. benguelae* by having higher, medially located, anteroposteriorly long maxillary crests that extend onto the rostrum base and smaller premaxillary foramina. See full descriptions in the Supplementary Note.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at <https://doi.org/10.1038/s41586-026-10546-z>.

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Methods

HOV observations

We conducted this investigation during the TS29-3 cruise (7 February to 18 March 2023) aboard the R/V *Tan Suo Yi Hao*, using the full-ocean-depth HOV *Fendouzhe*.

Thirty-two HOV surveys were conducted on the sea floor along the trench axis, spanning more than 1,200 km and distributing relatively evenly from the western to the central and southeastern regions. The estimated trench-floor area is about 14,400 km², calculated in Global Mapper 26.1 by delineating the areal extent of the trench bottom. The HOV video survey had a field of view about 5 m in width, calibrated using 10-cm laser scale points. The surveyed area was estimated from the view width and the sea floor transect length recorded by the in situ footage. Each transect was 2.4–5.5 km long (4.3 km on average), with a cumulative length of 127.72 km for all 32 dives, yielding a total surveyed area of about 0.64 km². The diving map (Fig. 1) was generated using Global Mapper 26.1, with basemap data from Global Multi-Resolution Topography (GMRT) Synthesis (<http://www.gmrt.org>) under a CC BY 4.0 license⁵¹.

Collecting and processing of whale-fall fauna samples

Whale-fall fossil samples were collected using the submersible's two hydraulically powered manipulator arms, operated by the submersible's pilots, and stored in geological baskets. The whale-fall bones in the sulfophilic stage were collected using the arms and kept in the biobox. Some associated free-living whale-fall fauna species, including gastropods, squat lobsters and brittle stars, were collected using the slurp sampler mounted on the submersible. On retrieval of the submersible, the whale bones and associated specimens were immediately sorted, fixed and registered in the ship's laboratory. For taxonomic purposes, specimens were preserved using either a 10% formalin or a 75% ethanol solution. Specimens for molecular analysis were preserved directly in –80 °C freezers.

Examination of the whale-fall fauna and bivalve chemosymbionts

Morphological identification was based on published literatures of deep-sea macrobenthos faunas, especially that reported from whale falls, cold seeps and hydrothermal vents.

For further molecular examination, whale faunal tissues (up to 0.5 cm³) were subjected to DNA extraction, library preparation and metagenomic sequencing at Novogene Co., Ltd. Metagenomic sequencing was conducted using DNBSEQ-T10 (MGI) at Novogene to generate 2 bp × 150 bp pair-ended reads of about 50 Gb. Raw sequencing reads were qualified and assembled into contigs routinely. Assembled contigs were searched against the MetaCOXI database using the BLASTN program to extract mitochondrial 16S ribosomal RNA (rRNA) and cytochrome c oxidase I sequences⁵². The 18S and 28S rRNA gene sequences were predicted using rRNA_HMM⁵³.

To detect potential chemosynthetic symbionts in three bivalves, microbiome analyses were conducted to obtain metagenome-assembled genomes (MAGs) of associated microbes from the investigated bivalve gill tissues. The assembled metagenomes were subjected to genome binning, duplicate removal and quality evaluation and finally were annotated using GTDB-tk (v2.4.0)⁵⁴ against the GTDB database R220 (ref. 55). The dominate symbiont MAGs are listed in Extended Data Fig. 3d according to relative abundances of all microbial reads from each host bivalve species.

Density assessments

Density assessments for the macro- and megafauna in whale-fall communities were conducted by analysing high-definition video recorded by the HOV's dual camera system. Scale was provided by two parallel laser pointers (10 cm apart) visible in the footage, allowing the sizing of individual animals and communities (Supplementary Table 2). Each

whale fall, including both the bone region (dominated by *Osedax*) and the surrounding sediment region influenced by the carcass (dominated by jellyfish or tubeworms), was measured as an entire whale-fall community by species. For three smaller whale falls (WF1, WF2, WF4), faunal density was analysed for the whole whale fall by directly counting the total number of faunal individuals observed. For two larger whale falls, 16 (WF3) or 6 (WF5) quadrats, each 4 dm², were randomly selected and counted. In the latter case, the average density and the maximum density (the highest count observed in a single quadrat) were analysed.

Sr isotopic dating for whale fossils

Twenty-five fossil bone specimens were analysed for Sr isotopes at Nanjing FocuMS Technology Co. Ltd., and eight specimens were analysed at the Radiogenic Isotope Facility, University of Queensland. Samples (about 0.1 g) were fully digested in nitric acid. At Nanjing FocuMS Technology Co. Ltd., Sr separation was performed by means of a two-step column chemistry (HCl elution on Bio-Rad AG50W-X8 resin and then Milli-Q water elution on Sr-specific resin); at the Radiogenic Isotope Facility, the Sr purification protocol used in ref. 56 was adopted. Sr-isotope ratios of final solutions were determined using Nu Plasma MC-ICP-MS at both laboratories. Raw data were corrected for exponential mass fractionation by normalizing to ⁸⁶Sr/⁸⁸Sr = 0.1194. Periodical measurements of the Sr standard (SRM 987) were used for instrumental drift correction. Accuracy was monitored using United States Geological Survey reference materials (BCR-2, BHVO-2, EN-1), and the results agreed with published values^{57,58}. Best-fit ages were calculated from the mean isotopic ratios using the seawater ⁸⁷Sr/⁸⁶Sr curve of ref. 24.

Phylogenetic analysis

The phylogenetic relationships of *Perucetus diamantinae* sp. nov. with the other Ziphiidae were investigated with the software PAUP (v.4.0a169)⁵⁹, using the same morphological data matrix and assumptions as ref. 60, with the addition of the following new character, which shows only the derived state (1) in *Pterocetus benguelae* and *P. diamantinae*: antorbital notch: narrow, V- or U-shaped (0); deep and broad, bordered posterolaterally by an anteroventrolaterally expanded antorbital process (1). Homoplastic characters were down-weighted using the method of ref. 61. The result of this analysis is presented in the Extended Data Fig. 6.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The original in situ images for the whale fossils and whale falls, and microbial MAGs for the dominant bivalve symbionts, are available on Science Data Bank (<https://doi.org/10.57760/sciencedb.28830>)⁶². The original images of 35 investigated whale-fall species are available on MorphoBank (<https://morphobank.org/permalink/?P6064>)⁶³. Sixty-seven DNA barcoding gene sequences and one mitochondrial genome were deposited in GenBank (PX673207–PX673224; PX684580–PX684631; PX519993).

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Acknowledgements We thank the crews, pilots and scientists aboard R/V *Tansuoyihao* with the full-ocean-depth HOV *Fendouzhe*. We thank A. Collins, A. Maiorova, C. Mah, J. Wang, K. Schnabel, N. Bezio, N. Davey, S. Zhang and T. O'Hara for helping to identify the whale-fall fauna. This work was under the scheme of the Global Trench Exploration and Dive Programme (Global TRENd). Funding statements: X.P. discloses support for the research of this work from the National Key R&D Program of China (grant no. 2022YFC2805400) and the Program for Fostering International Mega-Science of the Chinese Academy of Sciences (grant no. 183446KY SB20210002). M.D. discloses support for the research of this work from the National Key R&D Program of China (grant no. 2025YFE0214500). X.S. discloses support for the research of this work from the National Natural Science Foundation of China (grant no. 42276090).

Author contributions X.P. and X.S. conceived the research. T.X., P.Z., K.T., M.D., Y.H., S.L. and X.P. performed the geochemical measurements. X.S., Z.G., D.L., S.M. and X.P. contributed the fauna data analysis. G.B. and A.C. performed fossil analyses. X.P., X.S., G.B., A.C., M.D. and P.Z. interpreted data. X.P., P.Z., X.S., J.L., T.W., S.D., M.T., H.L., W.X. and H.Z. conducted the cruise and collected samples. All co-authors participated in the discussion. X.P., X.S., G.B., A.C., P.Z. and M.D. wrote the manuscript with input of all co-authors.

Competing interests The authors declare no competing interests.

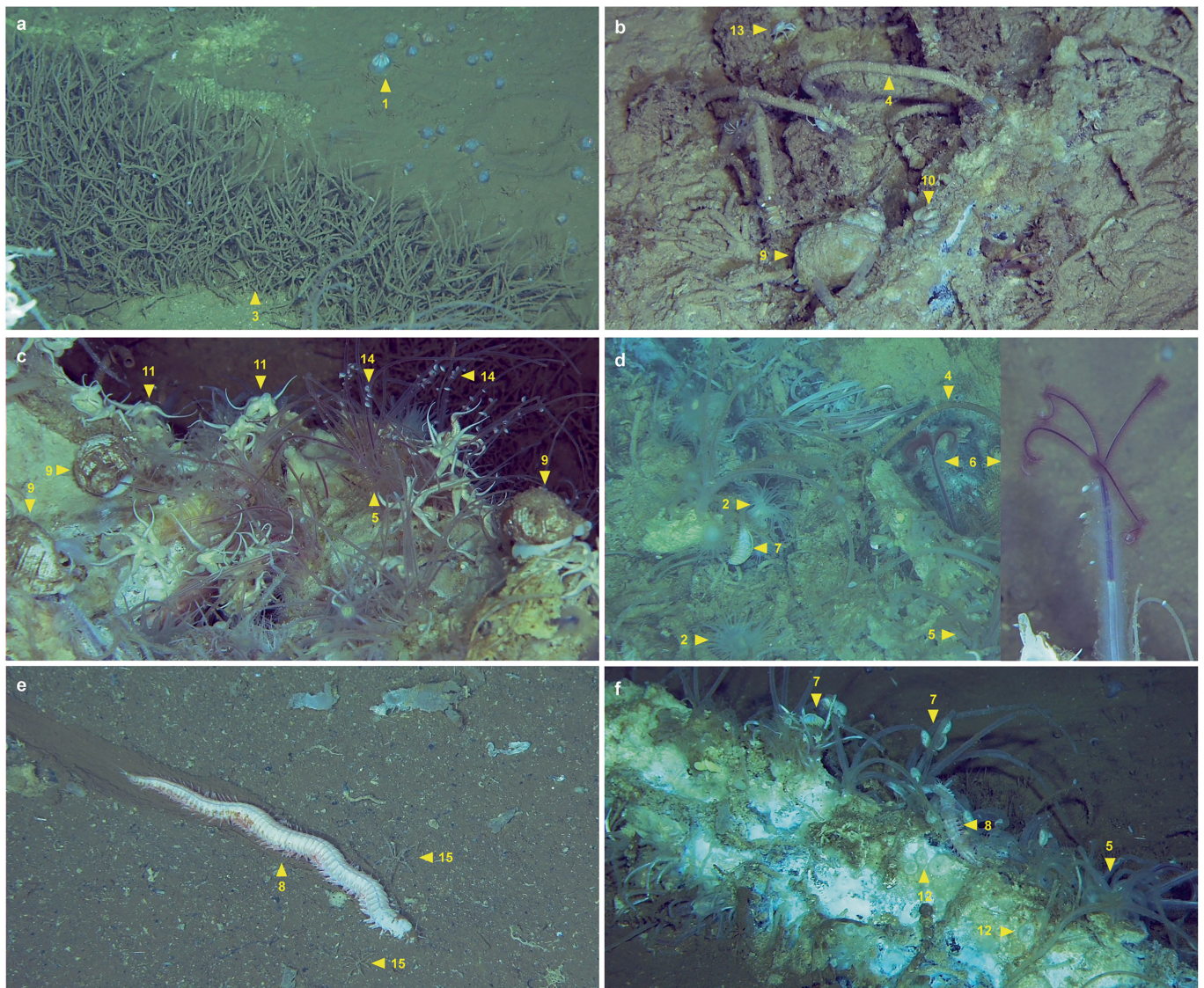
Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s41586-026-10546-z>.

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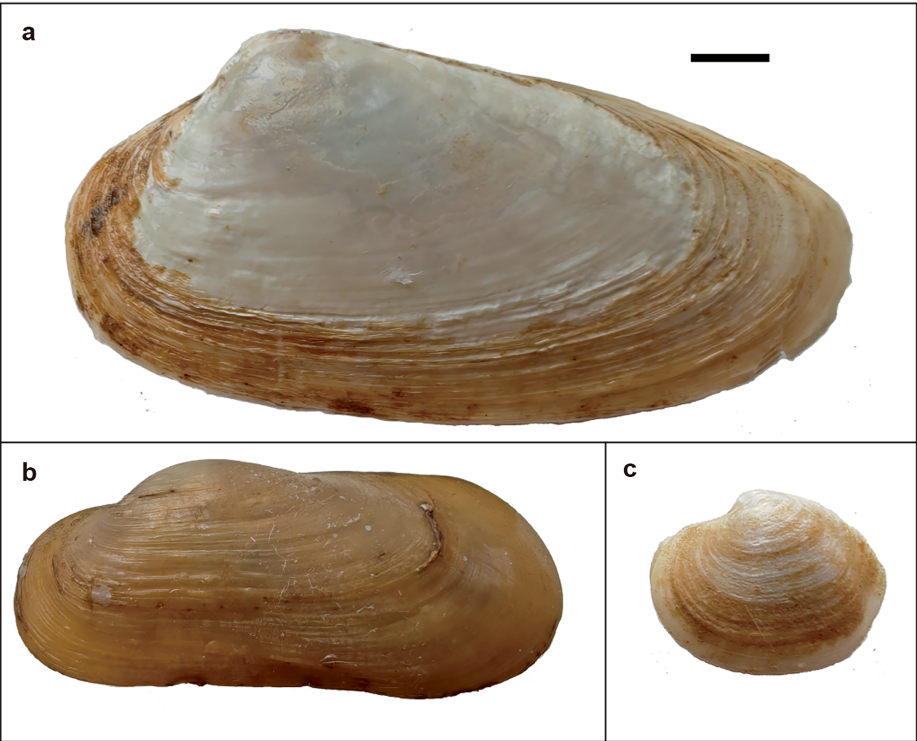
Peer review information *Nature* thanks Stephen Godfrey, Craig Smith and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. Peer reviewer reports are available.

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Extended Data Fig. 1 | In situ images showing selected fifteen macrobenthos observed on the whale falls in the Diamantina Zone. a, FDZ174. b, FDZ173. c, FDZ174. d, FDZ177. e, FDZ177. f, FDZ174. Each species is annotated with arrows and numbers. Cnidaria: 1, Ctenophore jellyfish; 2, sea anemone *Ostiactis* sp. Polychaeta: 3, abundant tubeworms *Phyllochaetopterus* sp. on around sediments; 4, tubeworm *Nicomache* sp.; 5, bone-eating worm *Osedax* sp. 1;

6, *Osedax* sp. 2 with four pinnule-bearing palps (in detail); 7, scale worm Polynoidae sp.; 8, Phyllodocida *Nereis* sp. Mollusk: 9, gastropod *Phymorhynchus* sp. 1; 10, bivalve *Adipicola* sp. Echinodermata: 11, brittle star *Ophiambix* sp. Crustacea: 12, sea daisy *Xyloplax* sp. 13, squat lobster *Munidopsis* sp.; 14, amphipods Lysianassidae sp. and Stegocephalidae sp. (as white spots); 15, sea spider *Nymphon* sp. See full species list in Extended Data Table 1.

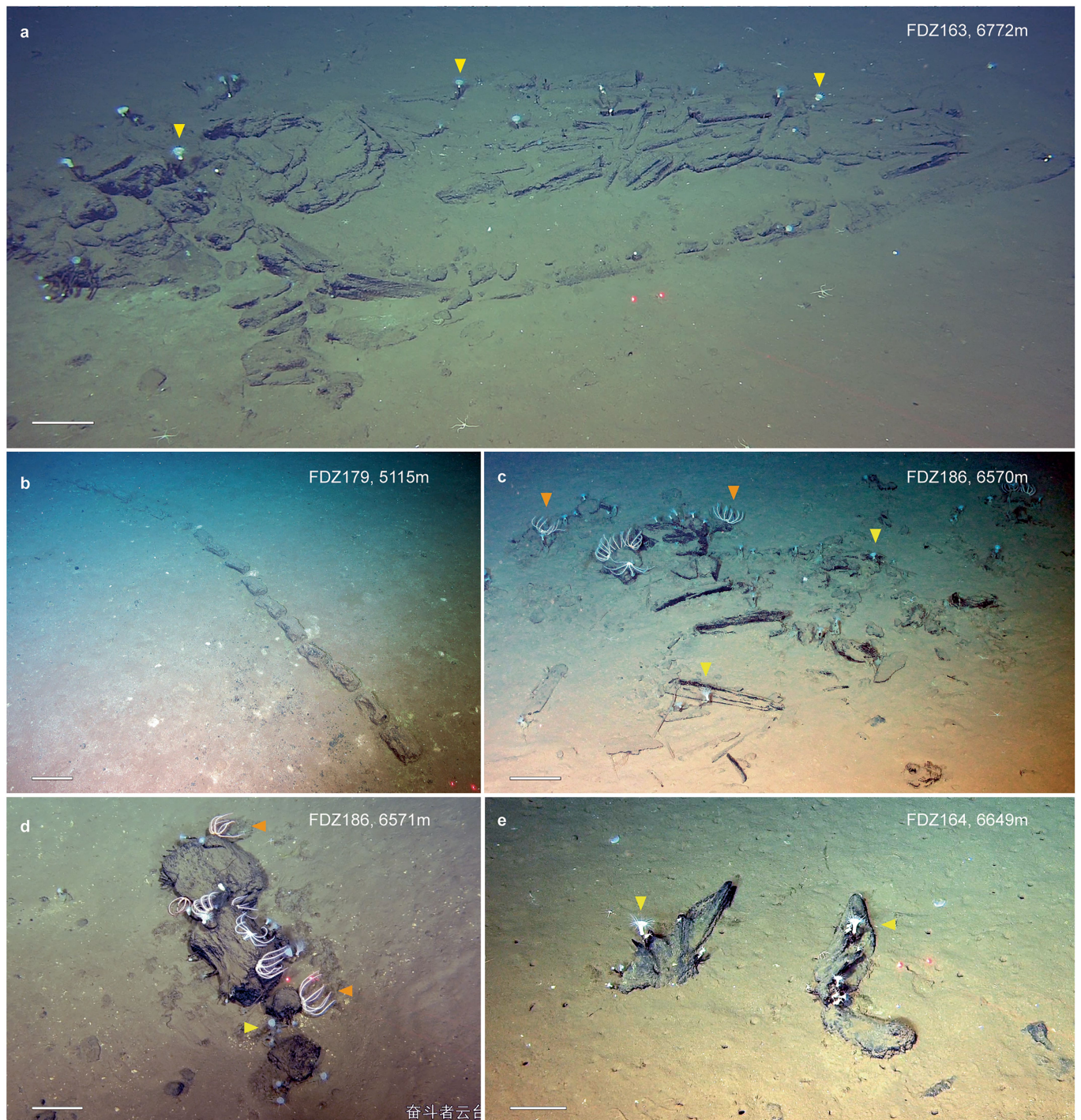


d

Bivalve hosts	Genome Ids	Relative abundance (%)	GTDB Taxonomy	Red values	Completeness
<i>Abyssogena southwardae</i>	W13.MAG1	80.57	Thioglobaceae, <i>Ruthia</i>	N/A	84.69
Thyasiridae sp.	W14.MAG1*	25.34	Sulfurovaceae, <i>Sulfurovum</i>	0.97	66.48
	W14.MAG2*	23.67	Sulfurovaceae, <i>Sulfurovum</i>	0.97	56.55
	W14.MAG3*	21.94	Sulfurovaceae, <i>Sulfurovum</i>	0.95	43.18
<i>Adipicola</i> sp.	W15.MAG1	78.24	Thioglobaceae, <i>Thiodubiliella</i>	0.97	100

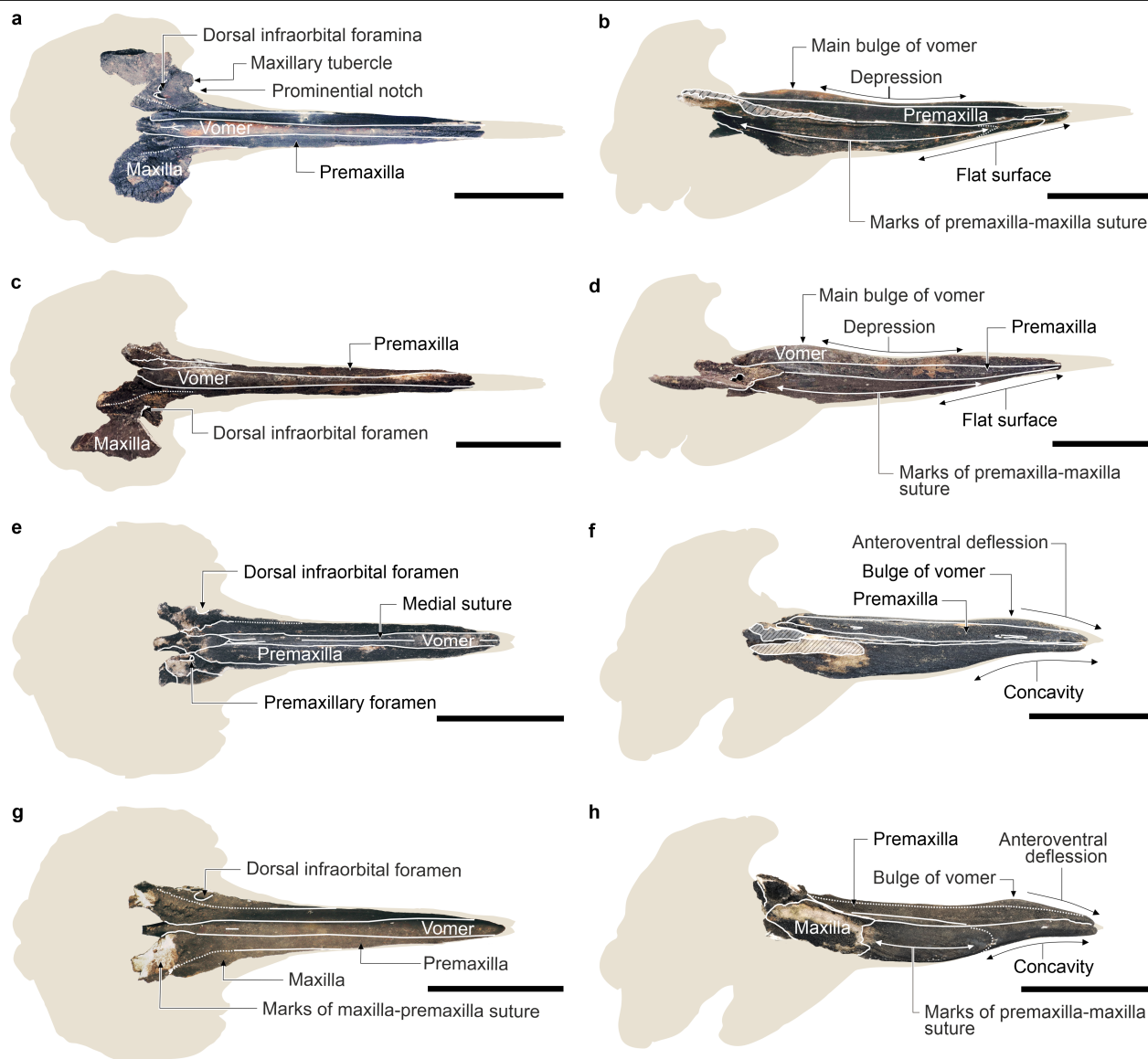
Extended Data Fig. 2 | Left shells of three chemosymbiotic bivalve species recovered from the investigated whale falls. a, *Abyssogena southwardae*, dive FDZ178. b, *Adipicola* sp., FDZ178. c, Thyasiridae sp. FDZ174. d, Metagenomic analysis showing the dominant symbionts inhabiting the gill tissues of the bivalve specimens shown in a, b and c. Red values indicate relative evolutionary divergence. *The *Sulfurovum* symbiont exhibits high intraspecific divergence

and was therefore assembled into three low-quality MAGs (metagenome-assembled genomes). Their combined relative abundance reaches up to 71%, representing a typical symbiotic pattern. These MAGs are available from Science Data Bank (<https://doi.org/10.57760/sciencedb.28830>)⁶². Scale bar, 5 mm, all images at the same magnification.



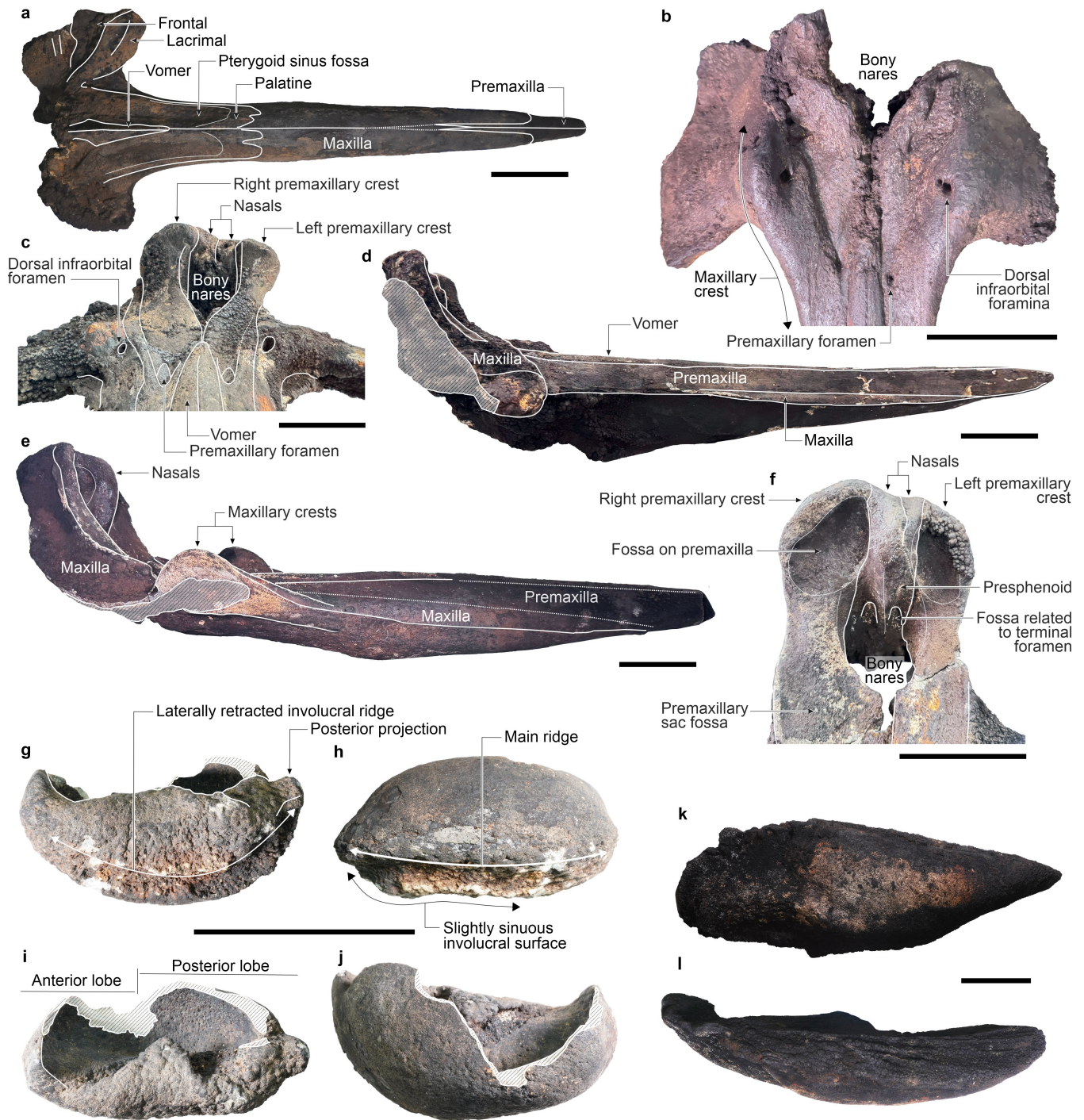
Extended Data Fig. 3 | In situ images of whale falls in reef stage. **a**, Partially destroyed cranium and articulated mandible of a baleen whale. **b**, Articulated lumbar and caudal vertebrae of a beaked whale. **c**, Disarticulated skeleton of an indeterminate cetacean. **d**, Fragmentary vertebrae of an indeterminate

cetacean. **e**, Fragmentary cranial bones of a baleen whale. The exterior of these skeletons is mainly inhabited by common hard-substrate megafauna, such as the stalked sea anemone *Galatheanthemum profundale* (yellow arrows) and the sea star *Freyastera* sp. (orange arrows). Scale bars, 20 cm.



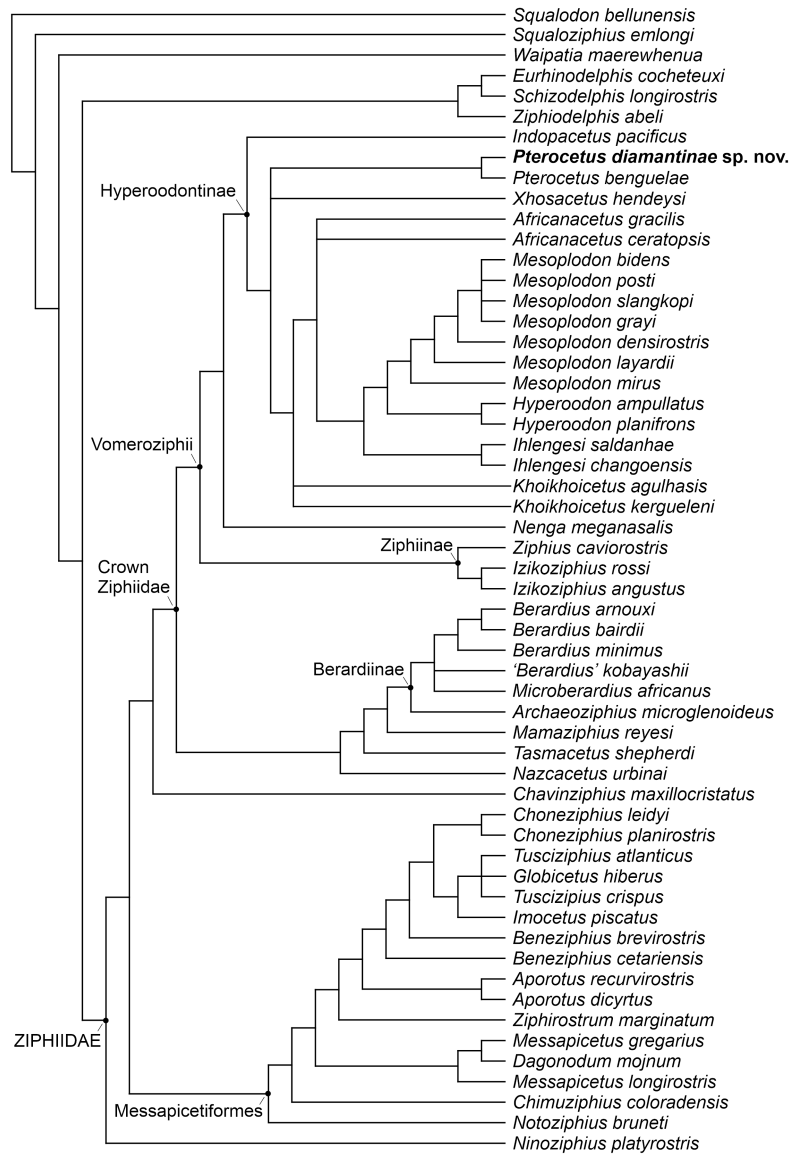
Extended Data Fig. 4 | Fossil crania of *Mesoplodon layardii* and *Mesoplodon bowdoini* (Ziphiidae) from the Diamantina Zone. a-d, *Mesoplodon layardii*, FDZ184-R1a (a, b) and FDZ179-R1a (c, d). e-h, *Mesoplodon bowdoini*, FDZ180-R1a (e, f) and FDZ182-R4a (g, h). a, c, e, g, dorsal views. b, d, f, h, lateral views. Dotted lines indicate uncertain sutures. Oblique lines indicate major break surfaces.

Scale bars, 20 cm. The superimposed silhouettes of *M. layardii* and *M. bowdoini* were redrawn here based on photographs of their extant conspecific skull specimens MM002133 and MM002655, respectively. Both extant skulls are held at the Museum of New Zealand Te Papa Tongarewa (<https://collections.tepapa.govt.nz>).



Extended Data Fig. 5 | Fossil cetaceans from the Diamantina Zone. **a-f**, Crania of Ziphiidae. **a,b**, *Pterocetus diamantinae* sp. nov., FDZ182-R1a, holotype. **(c,d)** *Pterocetus benguelae*, FDZ186-R3a. **e, f**, *Izikoziphius rossi*, FDZ163-R7a. **g-l**, Cranial remains of Mysticeti. **g,j**, Right tympanic bulla of

Balaenoptera borealis, FDZ185-R5a. **k, l**, Right zygomatic process of squamosal of *Balaenopteridae* indet, FDZ164-R1a. **a, j**, Ventral views. **b, g, i**, Dorsal views. **c, f**, Anterior views. **d, e, i, k**, Lateral views. **h**, Medial view. Dotted lines indicate uncertain sutures. Oblique lines indicate major break surfaces. Scale bars, 10 cm.



Extended Data Fig. 6 | Strict consensus tree of 270 most parsimonious trees describing the phylogenetic relationships of *Pterocetus diamantinae* sp. nov. among Ziphiidae. The tree has a length of 233, a Goloboff fit of -44.04, an ensemble consistency index (CI) of 0.40, and an ensemble retention index (RI) of 0.80.

Extended Data Table 1 | Macrofauna associated with five active whale falls from the Diamantina Zone

No	Taxa	Habitation	WF1		WF2		WF3		WF4		WF5		GenBank accession numbers			
			V	S	V	S	V	S	V	S	V	S	16S	18S	28S	COI
1	Ctenophora: ctenophoran jellyfish	Bottom dwelling					+									
2	Cnidaria: scyphozoan jellyfish	Bottom dwelling					+									
3	*Cnidaria: Actiniaria: <i>Ostiactis</i> sp.	Sessile			+		+	+		+	+		PX684612	PX684631	PX684596	PX673224
4	Cnidaria: Actiniaria sp. 2	Sessile							+		+					
5	*Annelida: Sabellida: <i>Osedax</i> sp. 1 (bone-eating worm 1)	Sessile			+	+	+	+	+	+	+	+	PX684607	PX684624		PX673218
6	Annelida: Sabellida: <i>Osedax</i> sp. 2 (bone-eating worm 2)	Sessile			+		+	+			+	+				
7	*Annelida: Maldanidae: <i>Nicomache</i> sp. (tubeworm 1)	Sessile	+		+	+	+	+	+		+	+	PX684606	PX684623	PX684589	PX673216
8	*Annelida: Chaetopteridae: <i>Phyllochaetopterus</i> sp. (tubeworm 2)	Sessile					+	+					PX684600	PX684615	PX684581	PX673210
9	Annelida: Polynoidae (scale worm)	Associated	+		+		+				+					
10	Annelida: Phyllodocida: ? <i>Pseudomystides</i> sp.	Associated					+									
11	*Annelida: Phyllodocida: <i>Nereis</i> sp.	Associated	+				+	+								PX673217
12	Annelida: Polychaeta sp.	Infaua										+				
13	Echiura: Bonellidae sp. (spoon worms)	Infaua										+				
14	*Echinodermata: Ophiroscolecidae: <i>Ophiambix</i> sp.	Associated					+	+					PX684601	PX684616	PX684582	PX673211
15	*Echinodermata: Ophiroscolecidae sp.	Associated									+	+	PX684608	PX684627	PX684592	PX673220
16	*Echinodermata: Amphiuridae: <i>Silax</i> sp.	Associated									+	+	PX684609	PX684628	PX684593	PX673221
17	Echinodermata: Peripodida: <i>Xyloplax</i> sp. (sea daisy)	Associated					+	+			+					
18	Echinodermata: <i>Molpadias</i> sp. (Sea cucumber)	Infaua										+				
19	*Arthropoda: Decapoda: <i>Munidopsis</i> sp. 1 (squat lobster)	Associated			+	+	+				+		PX684597	PX684613		PX673207
20	Arthropoda: Decapoda: <i>Munidopsis</i> sp. 2 (squat lobster)	Associated			+											
21	*Arthropoda: Amphipoda: Caprellidae sp.	Associated					+	+					PX684602	PX684619	PX684585	PX673212
22	*Arthropoda: Amphipoda: Lysianassidae sp.	Associated					+	+						PX684617	PX684583	
23	*Arthropoda: Amphipoda: Stegocephalidae sp.	Associated					+	+						PX684618	PX684584	
24	*Arthropoda: Pantopoda: <i>Nymphon</i> sp. (sea spider 1)	Associated					+	+					PX684598			PX673208
25	Arthropoda: Pantopoda sp. (sea spider 2)	Associated					+	+								
26	*Mollusca: Gastropoda: <i>Phymorhynchus</i> sp. 1	Associated	+		+	+	+	+			+		PX684603	PX684620	PX684586	PX673213
27	*Mollusca: Gastropoda: <i>Phymorhynchus</i> sp. 2	Associated					+						PX684605	PX684622	PX684588	PX673215
28	*Mollusca: Gastropoda: Raphitomidae sp.	Associated					+						PX684604	PX684621	PX684587	PX673214
29	Mollusca: Gastropoda: Abyssochrysidae sp.	Associated					+									
30	*Mollusca: Bivalve: <i>Abyssogena southwardae</i>	Associated									+	+	PX684610	PX684629	PX684594	PX673222
31	*Mollusca: Bivalve: <i>Adipicola</i> sp.	Associated			+	+	+	+			+		PX684611	PX684630	PX684595	PX673223
32	*Mollusca: Bivalve: Thyasiridae sp.	Associated					+						PX684599	PX684614	PX684580	PX673209
33	? Chaetognatha: Sagittidae: <i>Sagitta</i> sp.	Bottom pelagic			+											
34	*Nematoda: Anticomidae sp.	Associated				+		+						PX684625	PX684590	PX673219
35	*Nematoda: Linhomoeidae sp.	Associated					+							PX684626	PX684591	
Total species (by video / by specimen)		35	4	0	10	6	19	20	3	2	12	9				
Total species by dive (all)		35	4		11		26		4		16					

Whale fall (WF) information: WF1, FDZ163 (6,788.7m); WF2, FDZ173 (4,625.7m); WF3, FDZ174, FDZ177 (5,608.9m); WF4, FDZ178 (Whale fall 1, 5,609.2m); WF5, FDZ178 (Whale fall 2, 5,634.3m). ‘+’ indicates species record taken by in situ videos (V) or specimens (S) recovered by the manned submersible.

Morphological data: In situ or specimen images all 35 species (962 M) have been deposited in MorphoBank (<https://morphobank.org/permalink/?P6064>)⁶³.

Molecular data: ‘*’ indicates 21 species with DNA barcoding data (16S rRNA, 18S rRNA, 28S rRNA, COI) deposited on GenBank.

Taxonomic remarks (according to taxon number):

1, 2. First record of jellyfish dwelling on the sediments around an active whale fall.

3. Highly genetically closest to *Ostiactis pearseae* (genetic similarity: 18S, 99.6%; 28S, 99.4%) recorded from a whale fall in Monterey Canyon, California, 2,893 m^{64,65}.

5, 6. Bone-eating worms are representative sessile organisms of whale falls in the sulfophilic stage, 21–4204 m⁷¹⁴.

7, 8. Tubeworms arising from sediments around the whale fall. *Nicomache* sp. is genetically closest to *N. lokii* (similarity: 18S, 99.9%; COI 87.2%) recorded from Loki’s Castle vent field, Arctic mid-ocean ridge, 2,350 m^{66,67}; *Phyllochaetopterus* sp. is genetically closest to *P. gigas* (similarity: 18S, 99.9%; 28S 99.5%, COI 86.2%) associated with a whale fall in the Monterey Submarine Canyon, Off California, 2,892 m⁶⁴.

11. The genus *Nereis* has been recorded from whale falls collected off eastern and southwestern Australia, 952–1,530 m^{68,69}.

13. Spoon worms are a new record associated with whale falls⁷⁶⁹.

14–17. Brittle stars and sea daisies are new records of organisms directly associated with whale fall bones in the sulfophilic stage^{714,69}. Two *Ophiambix* species have been recorded from reducing habitats: *Ophiambix kagutsuchi* was found at hydrothermal vents in the Okinawa Trough and in wood falls in the Ryukyu Trench, southwest of Japan, 276–1,979 m⁷⁰; *Ophiambix macrodonta* is

known from the Kuroshima Knoll cold seep, southwest of Japan, 638–644 m⁷⁰. Sea daisies (genus *Xyloplax*) comprise three species previously known only from wood falls off New Zealand, Oregon and Bahamas, 1,057–2,675 m^{71–73}. The recent forth species, *Xyloplax princealberti*, was recently recorded not only from woods but also from *Ridgeia vestimentifera* tubeworm bushes at active hydrothermal vents along the Canada–Costa Rica margin in the Eastern Pacific, 1,845–2,421 m²⁰.

19, 20. Some squat lobster species are common in whale falls (California, 385–2,893 m)⁷ as well as at hydrothermal vents and cold seeps in New Zealand (2,000–2,750 m)⁷⁴, Nankai Trough seeps, Japan (1,100–4,600 m)⁷⁵, Manus back-arc Basin and South China Sea (1,918–1,940 m)⁷⁶, Costa Rica margin (300–3,600 m)⁷⁷.

21–23. Amphipods have been recorded from whale falls in Southwest Indian Ridge (1,444–1,447 m)⁷, Southwest Atlantic Ocean (4,204 m)¹⁴ and Nankai Trough seeps off Japan (2,000–2,500 m)⁷⁵. Caprellids have been found associated with vesicomyid bivalves in cold seeps in the transition connection zone between the Kuril–Kamchatka Trench and the western Aleutian Trench, 5,743 m⁴³.

24, 25. Sea spiders have been reported from whale falls in Southwest Indian Ridge (732 m)⁷ and cold seeps of the Southern California and off Aleutian Islands (379–2,020 m)⁷⁸.

26, 27. Eleven species of the genus *Phymorhynchus* have been recorded from hydrothermal vents or cold seep habitats in Japan, mid-Atlantic Ridge, Off West Africa, Manus Back-Arc Basin, Fiji Basin and East Pacific Rise, 1,160–3,700 m⁷⁹. The two *Phymorhynchus* species investigated here are genetically closest to *P. moskalevi* from vent habitat of the mid-Atlantic Ridge, 3,400–3,700 m: *Phymorhynchus* sp. 1 (similarity: 16S, 97.3%; COI, 94.2%); *Phymorhynchus* sp. 2 (similarity: 16S, 100%; COI, 98.2%).

30–32. These three chemosymbiotic bivalves host different sulfur-oxidising microbial symbionts (Extended Data Fig. 2). They represent the main clades of chemosymbiotic bivalves recorded from whale falls, hydrothermal vents and cold seeps at water depth of 0–2,893 m in New Zealand, Japan, Atlantic, Indian Ridge and California⁷, as well as from the deepest known cold seeps in the Kuril–Kamchatka Trench and the western Aleutian Trench (5,800–9,533 m)⁴³.

33. Abundant millimetre-sized, *Sagitta*-like, unknown organisms were observed swimming around the whale fall bones; these organisms were difficult to recover by the submersible.

34, 35. Two large nematode species were isolated from within the investigated whale fall bones. Nematode assemblages from natural (4,204 m) and deployed (1,500 m, 3,300 m) whale bones resembled those of hydrothermal vents and cold seeps in the Southwest Atlantic Ocean, off Brazil⁸⁰. The nematode family Anticomidae found here, is also dominant in the natural whale fall off Brazil⁸⁰.

Extended Data Table 2 | Statistic of the whale fall/fossils per each HOV dive

Dive number	Longitude (°)	Latitude (°)	Water depth*	Whale fossil assemblages	Whale fall	Beak fossils	Total Whale fossils observed (length>20cm)	HOV route length (km)	Average HOV Video observing width (m)	Observed Area (km ²)	Density (whale remains/km ²)
FDZ157	103.73880	-33.87090	6204.5	-	-	-	-	2.43	5	0.01215	-
FDZ158	102.17495	-33.62885	4938.4	-	-	-	-	3.55	5	0.01775	-
FDZ159	101.36321	-33.62016	7002.1	10	-	7	18	3.41	5	0.01705	586.5
FDZ160	101.44456	-33.22860	6520.4	3	1	1	6	5.5	5	0.0275	145.5
FDZ161	101.35826	-33.62054	7003.3	7	-	2	27	4.7	5	0.0235	297.9
FDZ163	101.55155	-33.47175	6789.2	8	-	3	56	3.92	5	0.0196	408.2
FDZ164	101.25620	-33.43540	6657.7	38	-	8	218	4.33	5	0.02165	1755.2
FDZ165	101.42377	-33.37185	6724.7	7	-	4	9	5.51	5	0.02755	254.1
FDZ166	101.21820	-33.51668	6812.2	22	-	9	77	3.95	5	0.01975	1113.9
FDZ167	100.65242	-33.16756	5953.5	-	-	-	-	4.67	5	0.02335	-
FDZ168	100.28129	-33.05833	5880.0	18	-	3	40	4.21	5	0.02105	855.1
FDZ169	99.41926	-32.68810	5154.0	3	-	0	8	5.41	5	0.02705	110.9
FDZ170	95.84345	-32.53349	5163.8	3	-	0	22	3.77	5	0.01885	159.2
FDZ171	95.27823	-32.34288	5321.5	-	-	-	-	3.78	5	0.0189	-
FDZ172	95.88200	-32.56789	5163.8	4	-	0	4	4.39	5	0.02195	182.2
FDZ173	96.53645	-32.50141	4626.6	2	1	0	4	3.64	5	0.0182	164.8
FDZ174	97.26709	-32.79041	5660.0	18	1**	5	80	2.54	5	0.0127	1496.1
FDZ175	97.53592	-32.67657	3059.5	-	-	-	-	3.39	5	0.01695	-
FDZ176	97.72273	-32.58192	5333.2	-	-	-	-	4.55	5	0.02275	-
FDZ177	97.27103	-32.79523	5657.2	4	1**	1	17	3.45	5	0.01725	289.9
FDZ178	98.57400	-32.72553	5676.8	5	2	0	11	4.04	5	0.0202	346.5
FDZ179	99.44087	-32.71788	5135.2	18	-	12	59	4.82	5	0.0241	746.9
FDZ180	101.52319	-34.12744	6607.1	23	-	15	29	4.2	5	0.021	1095.2
FDZ181	102.25509	-34.60463	6615.8	18	-	11	53	3.66	5	0.0183	983.6
FDZ182	101.25745	-33.64626	6879.4	34	-	19	59	5.18	5	0.0259	1312.7
FDZ183	101.85969	-34.39074	6521.2	87	-	35	246	4.82	5	0.0241	3610.0
FDZ184	102.65266	-34.97806	6528.8	22	-	14	74	4.73	5	0.02365	930.2
FDZ185	103.95883	-35.62685	6599.8	32	-	13	84	4.43	5	0.02215	1444.7
FDZ186	105.18872	-35.82890	6573.9	74	-	13	637	5.33	5	0.02665	2776.7
FDZ187	106.18917	-36.05971	6349.4	20	-	10	55	5.41	5	0.02705	739.4
Total	/	/	/	480	5	185	1893	127.72	/	0.6386	759.5

*The water depth represents the deepest depth of each dive.
**Two asterisks indicate the same whale fall observed by two dives.
- The hyphens indicate no whale fall or whale fossils observed.

Extended Data Table 3 | Measurements of partial crania of three fossil beaked whale *Pterocetus* species (in mm)

Measurements	<i>Pterocetus diamantinae</i> nov. sp. FDZ182-R1a (holotype)	<i>Pterocetus benguelae</i> FDZ186-R3a	<i>Pterocetus benguelae</i> SAM PQ 1770 (holotype)
Rostrum length	600	618	+480
Length of maxilla on rostrum	513	510	390
Length of premaxillary portion of rostrum	87	108	+90
Width of rostrum at mid-length	63	76	70
Height of rostrum at mid-length	73	75	57
Maximum opening of mesorostral groove	24	24	30
Width of rostrum base at antorbital notch	155	165	e136
Width of premaxillae at rostrum base (anterior notch)	68	91	e72
Distance between rostrum base and anterior apex of palatine	195	190	156
Preorbital width of skull	e320	385	-
Longitudinal distance between apex of rostrum– and anteromedian corner of bony naris	665	700	+538
Longitudinal distance between premaxillary foramen and anteromedian corner of bony naris	86	108	82
Width of premaxillary sac fossae	e116	130	128
Width of right premaxillary sac fossa	-	61	59
Width of left premaxillary sac fossa	-	55	50
Width of bony nares	-	67	50
Minimum width of right ascending process of premaxilla	-	51	36
Width of premaxillary crests	-	163	+114
Width of right premaxillary crest	-	61	43
Width of left premaxillary crest	-	57	26
Minimum distance between premaxillary crests	-	46	39
Maximum width of nasals	-	53	59
Length of medial suture of nasals on vertex	-	37e	40
Minimum posterior distance between maxillae	-	59	55
Vertical distance between terminal foramen and top of vertex	-	-	97
Transverse distance between dorsal tips of maxillary crests	121	170	-
Vertical distance between line that joins the dorsal tips of maxillary crests and dorsal surface of rostrum	29	5	-

*Measurements of the holotype cranium of *P. benguelae* (SAM PQ 1770, Iziko South African Museum, Cape Town) from the seafloor off the South African coast, are from Bianucci et al. (2007)²³.
e, estimate; +, nearly complete; -, no data.

Extended Data Table 4 | Strontium isotope dating of whale fossils from the Diamantina Zone

Sample Name	⁸⁷ Sr/ ⁸⁶ Sr	2 standard errors (s.e.)	Mean Age (Ma)	Minimum Age (Ma)	Maximum Age (Ma)	Taxa	Depth (m)
FDZ163-R13a	0.709065	0.000009	2.71	2.22	3.99	Unidentified cetaceans	6738.0
FDZ163-R3a*	0.709128	0.000007	1.16	1.02	1.30	Unidentified cetaceans	6772.0
FDZ163-R7a	0.709072	0.000007	2.44	2.10	2.81	<i>Izikoziphius rossi</i>	6740.6
FDZ164-R4a*	0.709148	0.000008	0.78	0.54	0.96	Unidentified cetaceans	6656.5
FDZ164-R6a	0.709115	0.000007	1.33	1.19	1.47	Mysticeti indet.	6574.0
FDZ165-R6a	0.709174	0.000006	0.00	0.00	0.30	<i>Balaenoptera</i> sp.	5876.0
FDZ166-R3a	0.709173	0.000006	0.12	0.00	0.33	<i>Mesoplodon layardii</i>	6605.4
FDZ168-R1a	0.709185	0.000007	0.00	0.00	0.14	? <i>Balaenoptera</i> sp.	5774.6
FDZ168-R2a	0.709205	0.000008	0.00	0.00	0.14	<i>Balaenoptera</i> sp.	5723.3
FDZ168-R4a	0.709168	0.000007	0.24	0.00	0.48	Unidentified cetaceans	5846.8
FDZ169-R17a	0.709214	0.000010	0.00	0.00	0.14	Unidentified cetaceans	5139.0
FDZ174-R1a*	0.709163	0.000008	0.37	0.13	0.65	<i>Mesoplodon layardii</i>	5651.3
FDZ174-R2a	0.709146	0.000007	0.85	0.65	0.99	<i>Mesoplodon layardii</i>	5651.3
FDZ174-R5a	0.709147	0.000007	0.81	0.60	0.98	<i>Mesoplodon layardii</i>	5652.5
FDZ174-R6a	0.709129	0.000009	1.14	0.96	1.33	<i>Mesplodon bowdoini</i>	5649.6
FDZ174-R9a*	0.709175	0.000008	0.00	0.00	0.27	Unidentified cetaceans	5611.7
FDZ179-R1a	0.709129	0.000006	1.14	1.02	1.27	<i>Mesoplodon layardii</i>	5124.5
FDZ180-R1a	0.709176	0.000006	0.00	0.00	0.25	<i>Mesplodon bowdoini</i>	6584.3
FDZ180-R2a*	0.709141	0.000008	0.93	0.73	1.12	<i>Mesoplodon layardii</i>	6518.6
FDZ180-R3a	0.709151	0.000006	0.71	0.52	0.85	<i>Mesplodon bowdoini</i>	6600.6
FDZ180-R4a	0.709183	0.000009	0.00	0.00	0.14	Vomerorophii indet.	6565.7
FDZ180-R5a	0.709163	0.000007	0.37	0.16	0.62	<i>Mesoplodon layardii</i>	6606.2
FDZ180-R6a	0.709170	0.000008	0.19	0.00	0.45	<i>Mesplodon bowdoini</i>	6518.7
FDZ180-R7a	0.709098	0.000006	1.65	1.42	1.98	Vomerorophii indet.	6485.5
FDZ181-R1a	0.709143	0.000009	0.89	0.65	1.10	<i>Balaenoptera</i> sp.	6615.6
FDZ181-R1a (Replicate)	0.709157	0.000006	0.56	0.33	0.74	<i>Balaenoptera</i> sp.	6615.6
FDZ181-R1a (Average)	0.709150	0.000011	0.73	0.39	0.99	<i>Balaenoptera</i> sp.	6615.6
FDZ182-R2a*	0.709131	0.000009	1.11	0.90	1.29	Vomerorophii indet.	6827.2
FDZ182-R4a	0.709153	0.000008	0.66	0.39	0.90	<i>Mesplodon bowdoini</i>	6837.9
FDZ182-R4a (Replicate)	0.709162	0.000009	0.40	0.13	0.69	<i>Mesplodon bowdoini</i>	6837.9
FDZ182-R4a (Average)	0.709158	0.000012	0.53	0.16	0.88	<i>Mesplodon bowdoini</i>	6837.9
FDZ184-R1a	0.709125	0.000006	1.20	1.07	1.34	<i>Mesoplodon layardii</i>	6486.1
FDZ185-R1a*	0.709163	0.000008	0.37	0.16	0.65	<i>Mesoplodon layardii</i>	6593.5
FDZ185-R2a	0.709190	0.000006	0.00	0.00	0.14	<i>Mesoplodon layardii</i>	6596.4
FDZ185-R4a	0.709149	0.000009	0.76	0.49	0.98	<i>Mesoplodon layardii</i>	6598.5
FDZ185-R7a*	0.709171	0.000008	0.17	0.00	0.42	Unidentified cetaceans	~6599.8
FDZ186-R3a	0.709029	0.000009	5.26	4.77	5.59	<i>Pterocetus benguelae</i>	6569.3
Reference material: EN-1*	0.709168	0.000006	/	/	/	/	/
Reference material: BHVO-2	0.703446	0.000008	/	/	/	/	/
Reference material: BCR-2	0.704984	0.000008	/	/	/	/	/

*The asterisks indicate samples analysed at the Radiogenic Isotope Facility, University of Queensland; the remaining samples were analysed at Nanjing FocuMS Technology Co. Ltd.

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Last updated by author(s): Apr 2, 2026

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Data collection Photomicrographs (Leica LAS v4.9 software, Leica LAS X software, StrangeView v1.1 software)

Data analysis Global Mapper 26.1; PAUP 4.0a169; Fastp v0.23.2; trimAl v1.4.1; MEGAHIT v1.2.95; BLASTn v2.5.0; MetaWRAP v1.2; CheckM v1.2.2; rRNA_HMM; GTDB-tk v2.4.0; GTDB database R220

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The original in situ images for the whale fossils and whale falls, and microbial MAGs for the dominant bivalve symbionts are available on Science Data Bank (<https://doi.org/10.57760/sciencedb.28830>). The original images of 35 investigated whale fall species are available on MorphoBank (<https://morphobank.org/permalink/>)

P6064). Sixty-seven DNA barcoding gene sequences and one mitochondrial genome were deposited in GenBank (PX673207–PX673224; PX684580–PX684631; PX519993). All these data have been released, and are openly accessible with the provided web-links.

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Study description	We used human occupied vehicle to discover the whale falls and whale fossils in the Diamantina Zone.
Research sample	All samples were obtained during 32 dives carried out in the Diamantina Zone.
Sampling strategy	We used the manipulators and slurp of the submersible to recover the investigated samples.
Data collection	In situ images and videos were taken with pan-tilt still and video cameras. Biodiversity and geochemistry data were collected on-land laboratory. Cruise participants collected onboard data.
Timing and spatial scale	Dives were conducted during February 7–March 18, 2023.
Data exclusions	No data was excluded.
Reproducibility	All in situ images and videos were recorded. All analyses were conducted based on duplicate materials.
Randomization	No randomization was used.
Blinding	Blinding is inapplicable and irrelevant.

Did the study involve field work? ☒ Yes ☐ No

Field work, collection and transport

Field conditions	Water depth, 4616m –7001 m.
Location	Dives were conducted in the Diamantina Zone along the trench axis.
Access & import/export	The cruise, conducted on the high seas, was approved by the Chinese government.
Disturbance	No disturbance to the environment.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☐	☒ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Animals and other research organisms

Policy information about [studies involving animals](#); [ARRIVE guidelines](#) recommended for reporting animal research, and [Sex and Gender in Research](#)

Laboratory animals	No laboratory animals were used in the study.
Wild animals	Whale-fall fossil samples were collected using the submersible's two hydraulically powered manipulator arms, operated by submersible pilots, and stored in the geological baskets. The whale falls investigated are remains of naturally dead whales. Details of the invertebrate whale-fall species are provided in Extended Data Table 1. Only a small number of invertebrate specimens associated with whale bones were collected and fixed for taxonomic and molecular studies. Several whale-fall bones in the sulfophilic stage were collected using the manipulator arms and kept in the biobox. Some associated free-living whale-fall fauna species like gastropods, squat lobsters and brittle stars were collected using the slurp sampler mounted on the submersible. Upon retrieval of the submersible, all whale-fall fauna died due to the water pressure changes. All investigated whale fossils and whale-fall specimens are deposited at room temperature, -20 °C, or -80 °C during on board. Now they are kept in the same method in the Hadal Museum, Institute of Deep-sea Science and Engineering, Chinese Academy of Sciences.
Reporting on sex	Sex is inapplicable for the investigated animals and irrelevant.
Field-collected samples	Whale-fall fossil samples were sorted and registered in the ship's laboratory, then deposited in the cold room under -20 °C during the cruise. The whale bones and associated invertebrate specimens were immediately sorted, fixed, and registered in the ship's laboratory. For taxonomic purposes, these whale fall specimens were preserved using either 10% formalin or 75% ethanol solution. Specimen tissues for molecular analysis were preserved directly in -80 °C freezers. Now all investigated whale fossils and whale-fall specimens are deposited at room temperature, -20 °C, or -80 °C, in the Hadal Museum, Institute of Deep-sea Science and Engineering, Chinese Academy of Sciences.
Ethics oversight	The study did not require an ethical approval.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Plants

Seed stocks	n/a
Novel plant genotypes	n/a
Authentication	n/a