

PALEONTOLOGY

Earliest octopuses were giant top predators in Cretaceous oceans

Shin Ikegami^{1†}, Jörg Mutterlose², Kanta Sugiura¹, Yusuke Takeda³, Mehmet Oguz Derin⁴, Aya Kubota⁵, Kazuki Tainaka⁶, Takahiro Harada⁴, Harufumi Nishida⁷, Yasuhiro Iba^{1*†}

Top predators drive changes in ecosystem structure. For the last ~370 million years, large-sized vertebrates have dominated the apex of the marine food chain, while invertebrates have served as smaller prey. Here we describe invertebrate top predators from this “age of vertebrates,” the earliest finned octopuses (Cirrata) from Late Cretaceous sediments (~100 to 72 million years ago), as identified based on huge, exceptionally well-preserved fossil jaws and their wear. This extensive wear suggests dynamic crushing of hard skeletons. Asymmetric wear patterns further indicate lateralized behavior, suggesting advanced intelligence. With a calculated total length of ~7 to 19 meters, these octopuses may represent the largest invertebrates thus described, rivaling contemporaneous giant marine reptiles. Our findings show that powerful jaws, and the loss of superficial skeletons, convergently transformed cephalopods and marine vertebrates into huge, intelligent predators.

Top predators impose strong top-down effects on biodiversity and ecosystem structures (1, 2). Vertebrates have been top predators in marine ecosystems for more than 370 million years (3, 4). They have repeatedly evolved large body sizes, which have allowed them to have advanced hunting abilities through allometrically enhanced physical strength, mobility, and cognition (3–6). This pattern was reinforced by iterative adaptation of tetrapod vertebrates since the early Mesozoic (~250 Ma), as documented by the fossil record of marine reptiles and whales (4). In the late Mesozoic (~200 to 66 Ma), the radiation of durophagous vertebrates, namely shell-crushing predators, opened a new phase in predator-driven evolution, shaping the modern-type marine ecosystem (7–9). Invertebrates of this interval primarily served as small prey, evolving hard, mineralized shells for protection over time (8–11).

Octopuses (suborders Cirrata and Incirrata), which thrive as intelligent mid-level carnivores in present-day oceans, followed an exceptional evolutionary pathway among invertebrates (12–15). Octopuses and their stem groups comprise the superorder Octobranchia, a group that demineralized their protective shells (16–18). This group experienced multiple diversifications after the Late Triassic in which the external shell was reduced, and octopuses consequently have only vestigial or no shells (16–18). This evolution of octopuses into a soft-bodied form represents a key innovation that enhanced swimming ability and facilitated improved eyesight and intelligence (17–20).

Among fossil Octobranchia, several gigantic genera, of more than 2 m in total length, have been documented from Mesozoic sediments by their chitinous jaws and gladii (remnant of the shell) (16, 21, 22). These so-called “krakens” may have been high-level carnivores at the

time. Their position in the food chain, however, has remained completely unknown since direct evidence such as the stomach contents of these giants has not been found to date (23). In fossil and extant cephalopods, including octopuses, the arm morphology does not provide any evidence concerning prey type. The jaw morphology, exhibiting a pointed tip and sharp edges (figs. S1 and S2), is also not a reliable proxy of feeding habits as it varies considerably throughout cephalopod phylogeny (24, 25). Here we use a different approach, in which the wear of fossil jaws is documented and used to reconstruct their carnivorous feeding habits. The wear was caused by cracking skeletons of prey, which are harder than the jaws composed of stiffened chitin (26). This pronounced wear of the jaws is a common feature of durophagous modern cephalopods (fig. S3) (26, 27).

We revisited 15 large-sized fossil jaws of Octobranchia, previously reported from Cretaceous sediments of Japan and Vancouver Island (table S1) (21, 28–30). Distinctive wear features were observed on an exceptionally well-preserved specimen. Additionally, we discovered 12 jaws of finned octopuses (suborder Cirrata) from Cretaceous rocks of Japan through the digital fossil-mining method (table S2) (24, 31). This technique uses high-resolution grinding tomography and a zero-shot learning artificial intelligence (AI) model, developed here, to process large image datasets precisely (movie S1) (31). The pigmentation patterns of the digital jaws reflect ontogenetic change within species and enable interspecific comparisons of growth rate (31, 32). As all 27 specimens came from low-energy, outer-shelf deposits without wave or current influence, transport-induced abrasion is unlikely. Our technical approach, and the excellent preservation of the material, enabled a precise identification of the wear; artificial damage by fossil preparation can be excluded. The approach and material thus allowed for important aspects of the feeding habits of fossil Cirrata to be revealed. Investigations of their taxonomy, stratigraphic ranges, and body size further allow a reconstruction of the position of the Cirrata in Cretaceous marine ecosystems.

Taxonomic revisions

Five species of Octobranchia have been reported from Cretaceous sediments, based on fossil jaws in the past (21, 28–30). Here, these taxa are taxonomically reorganized as two species, *Nanaimoteuthis jeletzkyi* and *N. haggarti* (Fig. 1, supplementary text, and fig. S4). *Nanaimoteuthis*, which was previously assigned to the order Vampyromorpha (vampire squids) (30), is here included in the suborder Cirrata (finned octopuses) of the order Octopoda (supplementary text and fig. S5). The extant families of the suborder Cirrata have either an elongated body or a short body (12). In their jaw morphology, broad wings are characteristic of long-bodied forms, whereas the wings of short-bodied forms are narrow. *Nanaimoteuthis*, having broad wings, is assigned to the long-bodied group (supplementary text). The newly discovered specimens extend the stratigraphic range of *N. jeletzkyi* to the earliest Cenomanian–late Campanian (~100 to 72 Ma), and that of *N. haggarti* to the Santonian–late Campanian (~86 to 72 Ma) (tables S1 and S2).

Body size estimations and growth

The ontogenetic growth of jaws and soft body is allometric (32–34), thereby allowing reliable body size calculations (31). This study quantifies the maximum mantle length of *N. jeletzkyi* and *N. haggarti* based on the largest jaws observed for each species, using the comprehensive size data of modern long-bodied forms (tables S3 and S4) (31). The largest jaw of *N. jeletzkyi* was discovered here through the digital fossil-mining method (Fig. 1A), and that of *N. haggarti* is a nondigital specimen previously reported (Fig. 1B) (21). The maximum mantle length calculated based on jaws is ~0.67 to 1.84 m for *N. jeletzkyi* and ~1.58 to 4.43 m for *N. haggarti* (table S4). The pigmentation patterns of juvenile jaws indicate that *N. haggarti* is larger than *N. jeletzkyi* at the same growth stage (fig. S6).

¹Department of Earth and Planetary Sciences, Hokkaido University, Sapporo, Japan.

²Department of Geosciences, Ruhr University Bochum, Bochum, Germany. ³Spectroscopy and Imaging Division, Japan Synchrotron Radiation Research Institute, Sayo, Japan.

⁴Morgenrot Inc., Tokyo, Japan. ⁵Department of Geosciences, Osaka Metropolitan University, Osaka, Japan. ⁶Brain Research Institute, Niigata University, Niigata, Japan. ⁷Department of Biological Sciences, Chuo University, Tokyo, Japan. *Corresponding author. Email: iba@sci.hokudai.ac.jp †These authors contributed equally to this work.

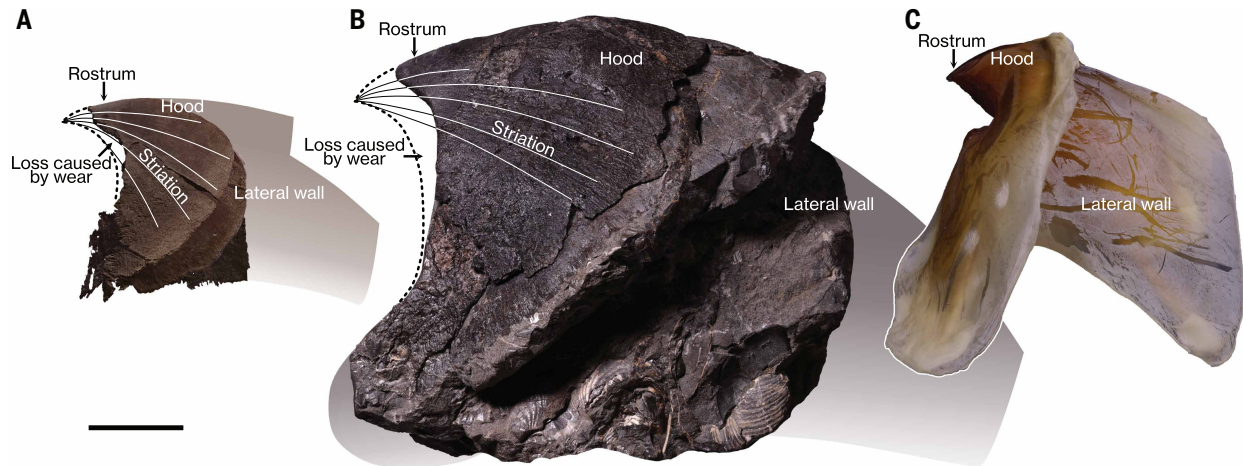


Fig. 1. Huge lower jaws of fossil octopuses and of an extant giant squid. (A and B) The largest lower jaws of the Late Cretaceous finned octopus species *N. jeletzkyi* [(A) NMNS DS00042 3LmvTpM] and *N. haggarti* [(B) KMNH IvP 902001]. Both specimens show extensive loss of jaw material caused by wear. (C) A lower jaw of the extant giant squid *Architeuthis dux* (NSMT-Mo 85956), a species having the largest jaw among modern cephalopods. (A) is a digital fossil jaw visualized as a 3D model; (B) is an exceptionally well-preserved nondigital fossil jaw; and (C) is a modern jaw dissected from a carcass of ~10 m total body length. Solid lines indicate the extension of striation on the outer surface of the hood and broken lines show the estimated outline of the rostrum without wear. The hood and lateral walls lost by weathering, shown as shadowed areas, are reconstructed based on the holotype and specimens in fig. S4. (A) and (C) are exhibited in a mirrored position. Scale bar, 20 mm.

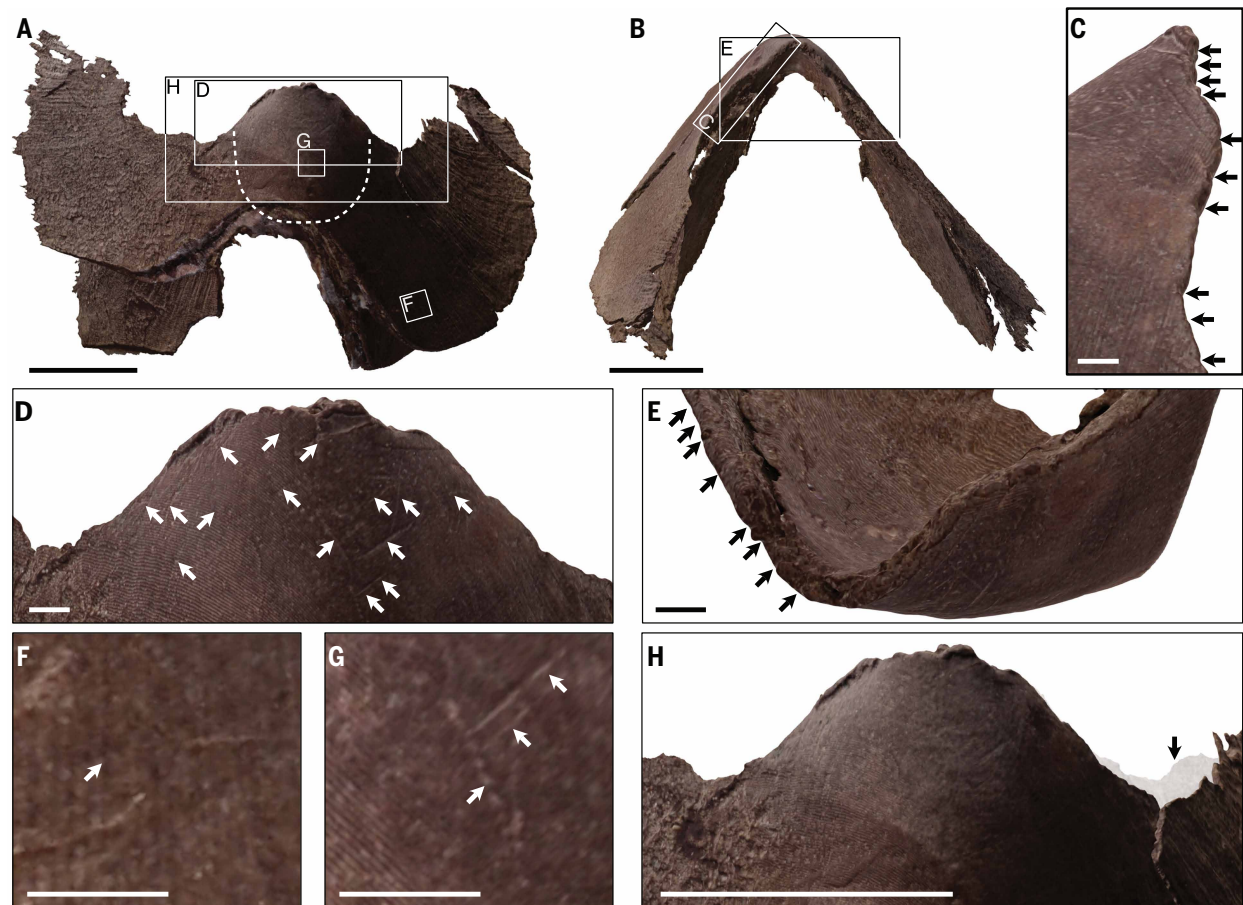


Fig. 2. Wear on the largest lower jaw of *N. jeletzkyi*. (A and B) The entire specimen [(A) dorsal view; (B) anterior view]. The broken line in (A) shows the boundary where striations become lost. (C to H) Close-ups of wear, of which the positions are indicated by boxes in (A) and (B). (C) Lateral view of the right jaw edge with chips (arrows). (D) Dorsal view of the rounded rostral part with scratches (arrows). (E) Oblique view of the rostral part with chips (arrows). (F) Area showing striations, which extends vertically in this figure (arrows). (G) Polished area where striation is lost, with scratches (arrows). (H) Asymmetric loss of the jaw edges (arrows), indicated by a mirrored image in 50% transparency overlaid beneath the original image. All panels show the specimen NMNS DS00042 3LmvTpM. Scale bars, 10 mm for (A), (B), and (H); 1 mm for (C) to (G).

Wear patterns

The largest specimens of *N. jeletzkyi* and *N. haggarti* have a blunt rostrum and rounded jaw edges as a result of intensive wear, both these jaw elements are sharp in juveniles (Figs. 1 to 3, supplementary text, and fig. S4). The rostral part, which has been lost by wear, was reconstructed from striations, original ornamentation of the jaw surface (Fig. 1) (31). The length of this lost part at the rostral tip is ~5.7 mm in *N. jeletzkyi* and ~10.6 mm in *N. haggarti*, which amounts to ~10% of the total jaw length for each species (Fig. 1). The right edge of the jaw is more worn than the left edge in both *N. jeletzkyi* and *N. haggarti* (Figs. 2H and 3K). The observed signs of wear include chips, scratches, and polish (Figs. 2 and 3). The chips and scratches in *N. jeletzkyi* were precisely visualized in the digital three-dimensional (3D) models (Fig. 2, C to E and G, and movie S1). Those in *N. haggarti* are filled with sediment, indicating that they were not caused by mechanical preparation (Fig. 3, C and D). In both species, many chips that surpass 1 mm in size are preserved on the jaw edges (Figs. 2, C and E, and 3, C and D). The outer surface of the rostrum is polished, obscuring primary striations (Figs. 2, A, F, and G, and 3, A, and G to J). It also shows numerous scratches up to 5 mm in length superposed on the polished part (Figs. 2, D and G, and 3, C to H). These scratches extend vertically or obliquely to the jaw edges. The inner surface of *N. jeletzkyi*, facing the oral cavity for chewing, is more worn than the outer surface (Fig. 2E). The rostrum of *N. haggarti* shows many transverse cracks up to 5 mm in length (Fig. 3, E to H).

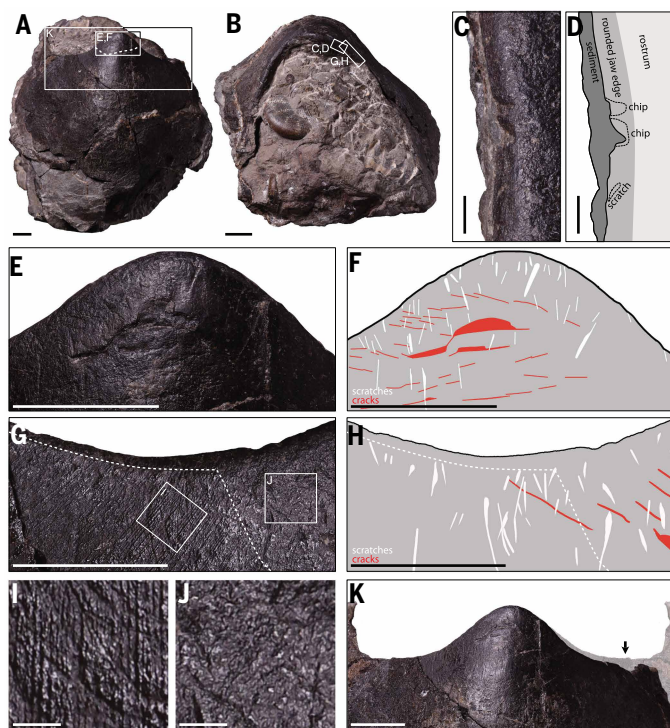


Fig. 3. Wear on the largest lower jaw of *N. haggarti*. (A and B) The entire specimen [(A) dorsal view; (B) anterior view]. (C to K) Close-ups of the wear, of which the accurate positions are indicated by boxes in (A), (B), and (G). (C) and (G) Lateral view of the right jaw edge with chips, scratches, and cracks. (E) Dorsal view of the rounded rostral part with scratches and cracks. Schematic drawings of (C), (E), and (G) are shown in (D), (F), and (H), respectively. (I) Area showing striation, which extends vertically in this figure. (J) Polished area where striation is lost. (K) Asymmetric loss of the jaw edges (arrows), indicated by a mirrored image in 50% transparency overlaid beneath the original image. All panels show the specimen KMNH IVP 902001. The broken line in (A), (G), and (H) shows the boundary where striation becomes lost. Scale bars: 10 mm for (A), (B), (E) to (H), and (K); 1 mm for (C), (D), (I), and (J).

Finned octopuses: Possibly the largest animals in Cretaceous oceans

Octopuses are classified into two suborders, the Cirrata (finned octopuses) and the Incirrata (finless octopuses) (12). In modern oceans, the Cirrata primarily inhabit deep-sea environments, and the Incirrata are mainly found in coastal areas (12). The specimens of *N. jeletzkyi*, newly discovered here, extend the oldest record of Cirrata (30) by ~15 million years and that of octopuses (16) by ~5 million years to the earliest Cenomanian (~100 Ma). The Cirrata extensively inhabited the shelf seas of the circum-North Pacific, the largest ocean during the Late Cretaceous.

The extant suborder Cirrata consists of two morphologically different groups, the long-bodied forms including four families (Cirroctopodidae, Cirroteuthidae, Grimpoteuthidae, and Stauroteuthidae), and the short-bodied forms comprising one family (Opisthoteuthidae) (12). We revealed here that *Nanaimoteuthis* had an elongated body, which is supported by previously reported fossils and molecular phylogeny. Numerous soft-body imprints of Mesozoic Octobranchia are known and so far more than 50 genera have been described based on these fossils (16). All of these taxa, such as *Trachyteuthis* and *Enchoteuthis*, have an elongated mantle (16). Molecular phylogenetic analyses covering all extant families of Cirrata show that the long-bodied form is ancestral to the short-bodied (35). In modern long-bodied Cirrata, the total length including the arms is on average ~4.2 times the mantle length

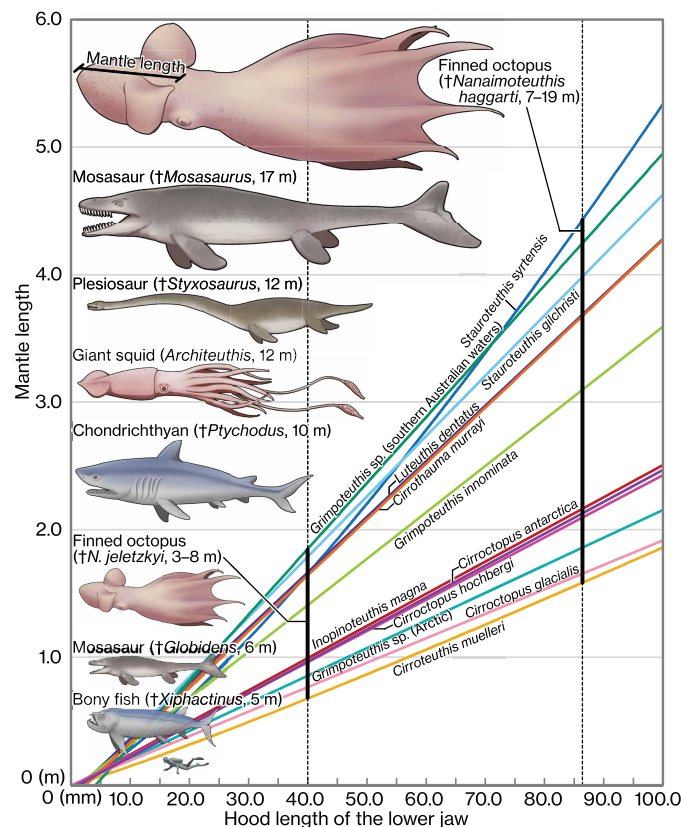


Fig. 4. Body size estimation of Late Cretaceous octopuses. The graph shows an allometric relationship between the length of the jaw and mantle in long-bodied species of extant finned octopus (tables S3 and S4) (31). The name of the corresponding species is shown along each growth curve. The sizes of *N. jeletzkyi* and *N. haggarti* based on their largest specimen are indicated by black vertical lines. Reconstruction of these two species, the extant giant squid (36), and gigantic vertebrate predators (37–40) in the Late Cretaceous are shown with their maximum total length.

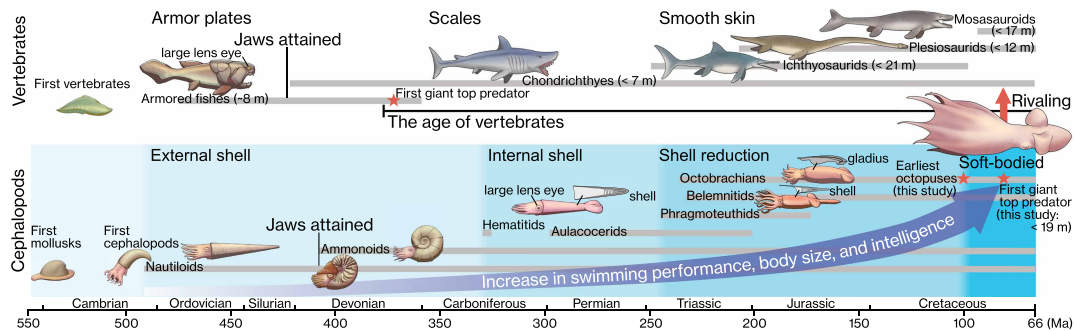


Fig. 5. Convergent evolution among marine top predators in the Paleozoic–Mesozoic. This model shows the acquisition of jaws and the reduction of superficial skeletons in the evolutionary history of marine vertebrates (top) and cephalopods (bottom) to become top predators. The gray horizontal bars show the chronological range of some selected groups of vertebrates and cephalopods (3, 4, 18). For cephalopods, stepwise reductions of skeletons are indicated by the blue background.

(table S5) (12). Based on this ratio, *N. jeletzkyi* with a mantle length of ~0.67 to 1.84 m reached a total length of ~2.8 to 7.7 m, and *N. haggarti* with a mantle length of ~1.58 to 4.43 m reached a total length of ~6.6 to 18.6 m (Fig. 4 and table S6). This difference in maximum body size (Fig. 4), together with that in growth rates shown by pigmentation patterns (fig. S6), suggests that *N. haggarti* grew larger and faster than *N. jeletzkyi*. As *N. haggarti* occurs from stratigraphically younger sediments (~86 to 72 Ma) than *N. jeletzkyi* (~100 to 72 Ma), these differences indicate that the Cirrata became more gigantic ~15 Myr after their origin toward the end of the Cretaceous.

N. haggarti is characterized by its extremely large size (Figs. 1 and 4). Its jaw size surpasses that of the giant squid, which has the largest jaw among extant cephalopods (Fig. 1C; ~80 mm maximum length) (34) by a factor of ~1.5. The giant squid, with a mantle length of 2.5 m and a total length of ~12 m, is the biggest species among all fossil and living invertebrates so far known (22, 36). Our calculations show that *N. haggarti* is comparable to the giant squid in both mantle and total length (Fig. 4). *N. haggarti* also rivals the dimensions of the largest bony fish (*Xiphactinus audax*, ~5 m) (37), chondrichthyans (*Ptychodus mortoni*, ~10 m) (38), plesiosaurs (*Styxosaurus* sp., ~12 m) (39), and mosasaurs (*Mosasaurus hoffmannii*, ~17 m) (40) known from the Cretaceous (Fig. 4). The Cirrata thus had among the largest body sizes of all organisms in the Cretaceous oceans.

Earliest octopuses: Intelligent top predators

Most extant octopuses and cuttlefishes are generalist carnivores that consume both soft and hard prey, mainly crustaceans, shelled mollusks, other cephalopods, and bony fishes (41). Frequent durophagous predation on hard-shelled prey causes wear of their jaw tips and jaw edges, which is absent in nondurophagous cephalopods such as squids (fig. S3) (26, 27). This wear provides reliable evidence of durophagy, in a broader sense carnivory, in fossil cephalopods. The wear was found on adult jaws of Late Cretaceous Cirrata, but not on their juvenile jaws (fig. S4). It is also absent in co-occurring fossil squid jaws, including both juveniles and adults (24). In the largest specimens of *N. jeletzkyi* and *N. haggarti*, the loss of jaw material caused by the accumulated wear reaches ~10% of the total jaw length (Fig. 1), which is more severe than in modern durophagous cephalopods (26, 27). These wear patterns suggest that Late Cretaceous giant Cirrata were active carnivores that frequently crushed hard shells and bones. The long scratches distributed on wide areas of their jaw (Figs. 2, D and G, and 3, C to H) reflect the dynamic use of the entire jaw for dismantling prey. Asymmetric loss of the jaw edges suggests lateralized behavior (Figs. 2H and 3K), which has been linked to a highly developed brain and cognition (42). This, in turn, suggests that the earliest octopuses already possessed advanced intelligence. Laterality is known

in modern octopuses, whose high intelligence matches that of vertebrates (42, 43). The exceptionally large jaws of adult *N. jeletzkyi* and *N. haggarti* (Fig. 1) suggest a strong bite force because cephalopod jaw muscles enlarge as the jaw size increases (26). The long lateral walls in their jaws revealed by the new digital specimens reported here show that *Nanaimoteuthis* had large jaw muscles (Fig. 1 and fig. S4). The chipping on both the rostrum and jaw edge (Figs. 2, C and E, and 3, C and D) was caused by strong shear stress beyond the yield point of the most robust part of the jaw. The transverse cracks in *N. haggarti* (Fig. 3, E to H) are probably a trace of larger shear failures. These large fractures thus suggest a powerful bite. In giant Cirrata, the jaws are smaller than those of contemporaneous Cretaceous vertebrate top predators, which measure ~1.7 m in length (40). Instead of using a large mouth, the long and flexible arms of octopuses serve for catching large prey (fig. S1A) (13). The giant Cirrata probably consumed large prey with their long arms and jaws, playing the role of top predators in Cretaceous marine ecosystems.

Octopuses competed with large vertebrates

The marine ecosystem has evolved with vertebrates as top predators for the past ~370 Myr (3, 4, 44, 45). In the late Mesozoic, the increase of durophagous predation enhanced both taxonomic and ecological diversity, shaping the modern-type marine ecosystem (8–11). The Cretaceous, the final period of this interval, saw a peak of this predator-prey arms race (8–11). Previous studies have recognized only large vertebrates as durophagous top predators that drove this coevolution, represented by chondrichthyans (e.g., *Ptychodus* and *Coupatetia*) and mosasaurs (e.g., *Globidens* and *Carinodens*) (Fig. 4) (7–9, 40). By contrast, Cretaceous invertebrates have been primarily regarded as prey that underwent protective adaptations (8–11). This study shows that the earliest, gigantic octopuses were exceptional invertebrates that invaded a position in the top tier of the Cretaceous food webs (Fig. 5).

Vertebrates and cephalopods evolved jaws contemporaneously between 423 to 407 Ma, an innovation that improved feeding efficiency (Fig. 5) (45–48). Vertebrate top predators have since lost their armor plates and reduced scales to evolve smooth skin (3, 49), whereas cephalopods have internalized, demineralized, and reduced their external shell to become soft-bodied (Fig. 5) (17, 18, 50). Through these changes, both groups increased swimming performance, body size, and intelligence at the expense of defensive hard parts (Fig. 5) (3, 4, 17–20, 51). Long after the rise of vertebrate top predators, octopuses evolved body plans capable of rivaling them, as demonstrated here (Fig. 5). Our discovery of octopus top predators highlights that this convergent evolution of robust jaws and the reduction of superficial skeletons in cephalopods and vertebrates is essential for becoming a large, intelligent marine top predator.

REFERENCES AND NOTES

- J. L. Atkins *et al.*, *Science* **364**, 173–177 (2019).
- A. G. Rossberg, U. Gaedke, P. Kratina, *Nat. Commun.* **10**, 4396 (2019).
- C. E. Brett, S. E. Walker, *Paleontol. Soc. Pap.* **8**, 93–118 (2002).
- N. P. Kelley, N. D. Pyenson, *Science* **348**, aaa3716 (2015).
- K. H. Andersen *et al.*, *Annu. Rev. Mar. Sci.* **8**, 217–241 (2016).
- U. Brose *et al.*, *Nat. Ecol. Evol.* **3**, 919–927 (2019).
- G. Guinot, F. L. Condamine, *Science* **379**, 802–806 (2023).
- G. J. Vermeij, *Paleobiology* **3**, 245–258 (1977).
- M. Zuschin, M. Stachowitsch, R. J. Stanton Jr., *Earth Sci. Rev.* **63**, 33–82 (2003).
- J. Alroy, *Science* **329**, 1191–1194 (2010).
- A. A. Klompmaker, M. Kowalewski, J. W. Huntley, S. Finnegan, *Science* **356**, 1178–1180 (2017).
- P. Jereb, C. F. E. Roper, M. D. Norman, J. K. Finn, *Cephalopods of the World*. (FAO Species Catalogue for Fishery Purposes, no. 4, 2016); Vol. 3.
- A. Packard, *Biol. Rev.* **47**, 241–307 (1972).
- D. P. Tittensor *et al.*, *Nature* **466**, 1098–1101 (2010).
- G. Zolotarov *et al.*, *Sci. Adv.* **8**, eadd9938 (2022).
- D. Fuchs, M. Part, Treatise Online no. 138: Part M, Chapter 23G: Systematic Descriptions: Octobranchia. *Treatise Online* **138**, 1–52 (2020).
- D. Fuchs, Y. Iba, H. Tischlinger, H. Keupp, C. Klug, *Lethaia* **49**, 433–454 (2016).
- B. Kröger, J. Vinther, D. Fuchs, *BioEssays* **33**, 602–613 (2011).
- P. Amodio *et al.*, *Trends Ecol. Evol.* **34**, 45–56 (2019).
- C. B. Albertin *et al.*, *Nature* **524**, 220–224 (2015).
- K. Tanabe, A. Misaki, T. Ubukata, *Acta Paleontol. Pol.* **60**, 27–38 (2015).
- C. Klug *et al.*, *Sci. Rep.* **15**, 30736 (2025).
- R. Hoffmann, K. Stevens, H. Keupp, S. Simonsen, G. Schweigert, *J. Geol. Soc. London* **177**, 82–102 (2020).
- S. Ikegami, Y. Takeda, J. Mutterlose, Y. Iba, *Science* **388**, 1406–1409 (2025).
- A. Sánchez-Márquez *et al.*, *Rev. Fish Biol. Fish.* **33**, 221–239 (2023).
- L. Souquet *et al.*, *Mar. Biol.* **170**, 82 (2023).
- M. R. Clarke, *Bull. Br. Mus. Nat. Hist. Zool.* **8**, 419–480 (1962).
- K. Tanabe, P. Trask, R. Ross, Y. Hikida, *J. Paleontol.* **82**, 398–408 (2008).
- K. Tanabe, Y. Hikida, *Paleontol. Res.* **14**, 145–150 (2010).
- K. Tanabe, A. Misaki, Y. Hikida, T. Nishimura, *Cretac. Res.* **70**, 128–141 (2017).
- Materials and methods are available as supplementary materials.
- E. Lefkaditou, P. Bekas, *Mediterr. Mar. Sci.* **5**, 143–150 (2004).
- M. R. Clarke, *Nature* **193**, 560–561 (1962).
- M. R. Clarke, *A Handbook for the Identification of Cephalopod Beaks* (Clarendon Press, 1986).
- M. Taite *et al.*, *Mol. Phylogenet. Evol.* **182**, 107729 (2023).
- C. R. McClain *et al.*, *PeerJ* **3**, e715 (2015).
- H. G. Ferrón, *J. Vertebr. Paleontol.* **39**, e1724123 (2019).
- K. Shimada, M. J. Everhart, R. Decker, P. D. Decker, *Cretac. Res.* **31**, 249–254 (2010).
- S. Gutarra, T. L. Stubbs, B. C. Moon, C. Palmer, M. J. Benton, *Commun. Biol.* **5**, 1–12 (2022).
- M. J. Polcyn, L. L. Jacobs, R. Araújo, A. S. Schulp, O. Mateus, *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **400**, 17–27 (2014).
- R. Villanueva, V. Perricone, G. Fiorito, *Front. Physiol.* **8**, 598 (2017).
- O. Güntürkün, F. Ströckens, S. Ocklenburg, *Physiol. Rev.* **100**, 1019–1063 (2020).
- E. Frasnelli, G. Ponte, G. Vallortigara, G. Fiorito, *Symmetry* **11**, 1121 (2019).
- R. K. Engelman, *Palaeontol. Electronica* **27**, 1–79 (2024).
- J. A. Long, *Science* **354**, 280–281 (2016).
- C. Klug, L. Frey, D. Korn, R. Jattiot, M. Rücklin, *Palaeontology* **59**, 611–629 (2016).
- C. Klug, L. Frey, A. Pohle, K. De Baets, D. Korn, *Bull. Geosci.* **92**, 439–442 (2017).
- X. Cui, M. Friedman, Y. Yu, Y. A. Zhu, M. Zhu, *Nat. Commun.* **14**, 7622 (2023).
- S. Gutarra, I. A. Rahman, *Biol. Rev.* **97**, 67–98 (2022).
- C. Klug *et al.*, *Commun. Biol.* **2**, 280 (2019).
- J. D. Currey, *J. Morphol.* **123**, 1–16 (1967).
- S. Ikegami *et al.*, Fossil lower jaws of the Cretaceous finned octopuses, version 1, Figshare (2026); <https://doi.org/10.6084/m9.figshare.27933759>.
- Y. Iba *et al.*, Animations of cross-sectional images of carbonate concretions including octopus jaw fossils (Cenomanian–Campanian), version 1, Figshare (2026); <https://doi.org/10.6084/m9.figshare.27935904>.
- M. O. Derin *et al.*, CPU-enabled AI segmentation for annotating large-scale tomographic data, version 1, Zenodo (2026); <https://doi.org/10.5281/zenodo.15176344>.
- S. Ikegami *et al.*, Morphological disparity analyses of modern and Cretaceous octobranchian jaws, version 1, Figshare (2026); <https://doi.org/10.6084/m9.figshare.29561630>.

ACKNOWLEDGMENTS

We thank Y. Ikeda and B. T. Breeden for the critical discussion; T. Sasaki, A. Misaki, Y. Hikida, T. Haga, K. Hasegawa, T. Nishimura, C.-C. Lu, S. Mills, and D. Macpherson for facilitating the observation of specimens; S. Sasaki, T. Ishii, S. Hosokawa, H. Kamata, Y. Usuda, Y. Kamikubo, T. Sano, Y. Yamazaki, Y. Kanno, T. Tajima, H. Oguri, T. Kawase, A. Shikakura, T. Ohno, M. Nishimoto, M. Nakamura, H. Inoue, N. Tsuchiya, T. Kaneko, Y. Okuyama, Y. Ito, Y. Sato, T. Chigai, Y. Chikarashi, M. Takei, M. Kusuzaki, R. Sasaki, K. Nakamura, and M. Endo for assistance in the imaging through the grinding tomography; M. Manabe, C. Sakata, E. Kosugi, H. Ito, A. Koshimizu, R. Nozaki, and A. Togashi for archiving the data. **Funding:** This work was supported by the following: Japan Society for the Promotion of Science grant 22J13936 (to S.I.); Japan Society for the Promotion of Science grant 23K17274 (to Y.T.); Japan Society for the Promotion of Science grant 19H0210 (to Y.I.); Japan Society for the Promotion of Science grant 22H02937 (to K.T.); Japan Society for the Promotion of Science grant 23H02544 (to A.K., H.N., and Y.I.); Japan Society for the Promotion of Science grant 25K22459 (to Y.T., K.T., and Y.I.); Japan Society for the Promotion of Science grant 26K00821 (to Y.I.); Japan Aerospace Exploration Agency grant JX-PSPC-540452 (to T.H. and Y.I.); The Canon Foundation 2019 (to Y.I.). **Author contributions:** Conceptualization: Y.I. Methodology: S.I., K.S., Y.T., M.O.D., A.K., K.T., T.H., H.N., and Y.I. Software: S.I., J.M., K.S., Y.T., M.O.D., A.K., K.T., T.H., H.N., and Y.I. Resources: S.I., Y.T., M.O.D., T.H., and Y.I. Investigation: S.I., Y.I. Visualization: S.I., K.S., Y.T., M.O.D., and Y.I. Validation: J.M., Y.T., M.O.D., A.K., K.T., T.H., H.N., and Y.I. Data curation: S.I., K.S., Y.T., and Y.I. Funding acquisition: S.I., Y.T., A.K., K.T., T.H., H.N., and Y.I. Project administration: Y.I. Supervision: Y.I. Writing – original draft: S.I., J.M., and Y.I. Writing – review & editing: S.I., J.M., K.S., Y.T., M.O.D., A.K., K.T., T.H., H.N., and Y.I. **Competing interests:** Authors declare that they have no competing interests. **Data, code, and materials availability:** The image datasets of octopus jaws discovered here and the original tomographic images of carbonate concretions are archived in the National Museum of Nature and Science, Tokyo. Those images are listed in table S2. The image datasets of octopus jaws include 3D models, mask data, and cross-sectional images that were cropped for annotation. These data are available from Figshare (52). The animations of the original tomographic images are also available from Figshare (53). The source code of the CPU-enabled DEVA for large-scale tomographic data is available at Zenodo (54). The character matrices and R codes used for morphological disparity analyses are available from Figshare (55). All other data supporting the findings of this study are provided in this paper and/or the supplementary materials. **License information:** Copyright © 2026 the authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original US government works. <https://www.science.org/content/page/science-licenses-journal-article-reuse>

SUPPLEMENTARY MATERIALS

[science.org/doi/10.1126/science.aea6285](https://www.science.org/doi/10.1126/science.aea6285)
Materials and Methods; Supplementary Text; Figs. S1 to S6; Tables S1 to S6;
References (56–74); MDAR Reproducibility Checklist; Movie S1

Submitted 15 July 2025; accepted 25 February 2026

10.1126/science.aea6285



Earliest octopuses were giant top predators in Cretaceous oceans

Shin Ikegami, Jörg Mutterlose, Kanta Sugiura, Yusuke Takeda, Mehmet Oguz Derin, Aya Kubota, Kazuki Tainaka, Takahiro Harada, Harufumi Nishida, and Yasuhiro Iba

Science **392** (6796), . DOI: 10.1126/science.aea6285

Editor's summary

The Kraken, the giant cephalopod of legend, was feared by sailors for centuries. Later interpretations suggested that it may have been based on sightings of the giant squid, which can be 10 meters long. Although they lived far too early to have been the source of the legend, Ikegami *et al.* describe fossil octopods from the late Cretaceous that truly would have fit the description of the monster, reaching up to 19 meters in length. Wear patterns on their jaws suggest that these octopods preyed upon the large reptiles present at the time, including plesiosaurs and mosasaurs. The authors interpret asymmetry in these wear patterns as an indication of corresponding asymmetry in behavior, suggesting complex brain development and, potentially, high intelligence. —Sacha Vignieri

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