PALEONTOLOGY

On Giant Filter Feeders

Lionel Cavin

Massive filter-feeding vertebrates have roamed the world's oceans for the past 170 million years.

The largest living marine vertebrates—baleen whales and several lineages of sharks and rays—feed directly on very small organisms (such as plankton and small fishes). Planktivorous sharks and rays collect food by filtering seawater through gill rakers (fingerlike projections on gill arches), whereas mysticete whales sieve small animals from seawater through whalebone or baleen (comblike keratin structures in their upper jaws) (*1*, *2*). On page 990 of this issue, Friedman *et al*. show that the first known large pelagic filter feeders, a group of ray-finned fishes, persisted between 170 and 65 million years ago (*3*). And on page 993, Marx and Uhen show that in the Tertiary (65 to 2.5 million years ago), the diversity of mysticete whales was linked to the diversity of diatoms and to climatic variations (*4*).

In the Jurassic (200 to 145 million years ago) and the Cretaceous (145 to 65 million years ago), ray-finned fishes called pachycormiforms lived in the oceans. These extinct fishes are regarded as primitive teleosts, the group to which most living bony fishes belong (*5*). A giant representative from the Middle Jurassic, *Leedsichthys*, was up to 9 m long and has been interpreted as a filter feeder (*6*). This massive filter-feeding fish has been regarded as an isolated and fleeting evolutionary experiment. By reinterpreting old findings, analyzing new fossils, and running phylogenetic analyses, Friedman *et al.* show that this and other fossil fishes form a clade of massive marine filter feeders that lived from 170 to 65 million years ago. As today's planktivorous sharks and rays do (*1*), these fishes engulfed water by swimming with an open mouth and sieved food while water escaped through the gill arches.

Giant reptiles roamed the Jurassic and Cretaceous oceans, and some huge ray-finned fishes—the ichthyodectiforms (bulldog fish and relatives)—emerged at the end of the Cretaceous. But all these beasts were apex predators that fed on large preys, and none had a filter-feeding diet. The newly discovered clade of massive filter-feeding fishes thus fills a large ecological niche.

Marx and Uhen reveal how the taxonomic diversity of another, younger type of massive filter feeder, the Tertiary baleen whales, was controlled by biological and environmental factors, rather than by the amount of rock in which we might find their fossils. Modern cetaceans (whales, dolphins, and porpoises) fall into two groups: the baleen whales (Mysteceti) and the toothed whales

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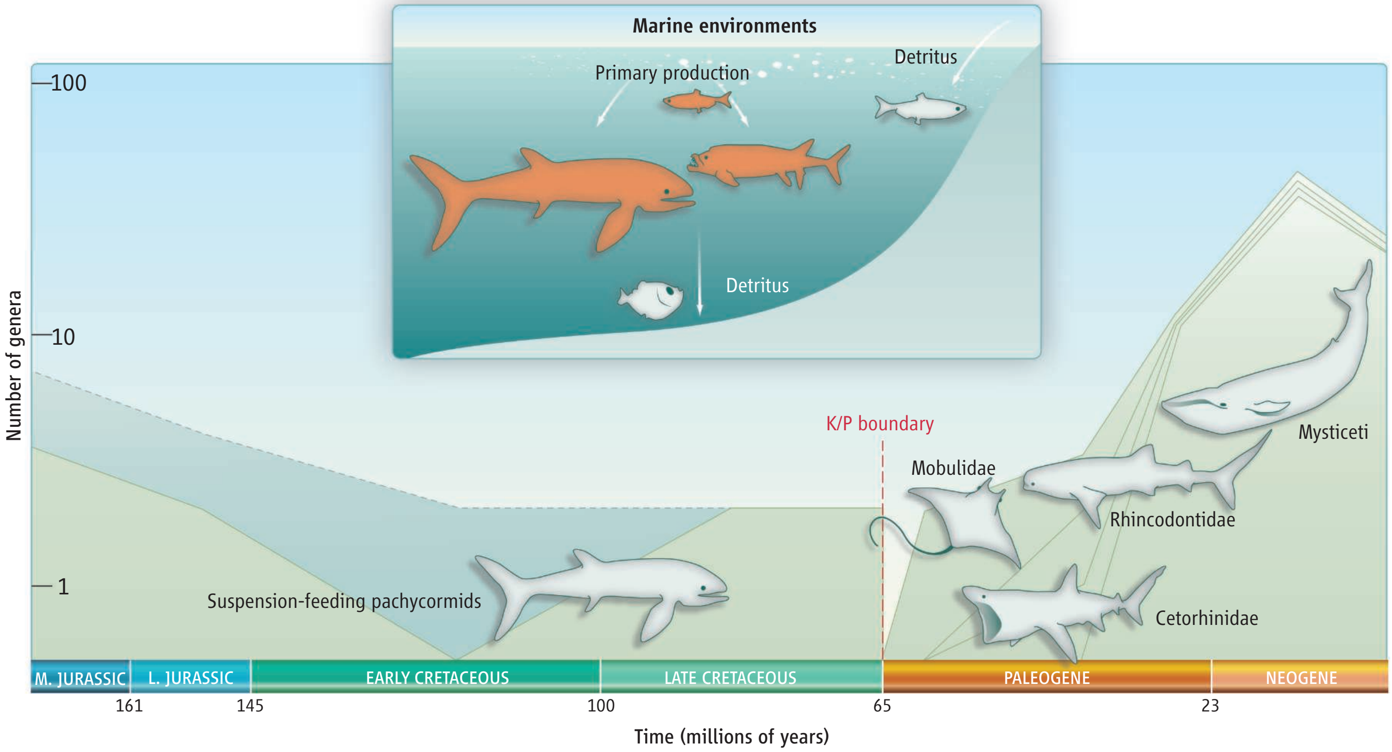

Past diversity of large filter feeders. The diversity of filter-feeding pachycormids is from (*3*); the dotted line shows the diversity, including ghost lineages (which have no fossil record but are inferred to exist to comply with a phylogenetic tree) [see supporting online material of (*3*)]. The diversity of rays and sharks (Mobulidae, Cetorhinidae, Rhincodontidae) is from (*10*) and that of mysticete whales from (*4*). **(Inset)** At the Cretaceous–Paleogene boundary, the food chains based on primary production collapsed, leading to the extinction of large suspension feeders and large fish-eating fishes (red), whereas costal and deep-ocean fishes that relied more on detritus survived.

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(Odontoceti). The authors show that the diversity of both groups can be explained by diatom diversity in conjunction with variations in climate, as indicated by oxygen stable isotope records. The results add to previous observations that have stressed the importance of environmental parameters (both geographic and oceanographic) in the evolution of modern cetaceans (*7*).

The two papers change our view of the natural history of these evolutionary distant organisms, which share similar trophic resources (see the figure), and raise new questions about their evolutionary drivers. For instance, it has been shown that marine ray-finned fish diversity was positively correlated with sea surface temperature in the Cretaceous, and that the Cretaceous fossil fish record corresponds to a genuine biological radiation (*8*). Further evolutionary studies will help to determine whether the diversity of the Jurassic/Cretaceous filter-feeder clade was related to climatic factors and the diversity of primary producers, and/or whether it was controlled by paleogeographical factors.

What caused the gap between the Jurassic/Cretaceous and the Tertiary episodes of the natural history of giant filter feeders? It is probably linked with the same event that caused a mass extinction at the Cretaceous-Paleogene boundary on land. This event affected only specific food chains, mainly those based on fresh plants (*9*). In the oceans, the phytoplankton-based food chains collapsed, whereas coastal and deep-ocean organisms that fed more on detritus survived (see the figure, inset). The filter-feeding pachycormiforms, relying for food on small organisms low in the trophic chain, had the perfect profile of a victim and became extinct. The trophic niche was later refilled, first with sharks and rays from ~56 million years ago and then with modern cetaceans from ~34 million years ago (see the figure).

The two studies also show that phylogenetic reconstructions can be the starting point for investigating major events in the history of life (*3*)—and not only an aim per se, as happens too often with fossil fish studies—and that variations in the diversity of life can be read directly from the fossil record if precautions are taken (*4*).

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PHYSICS

The Lowdown on Heavy Fermions

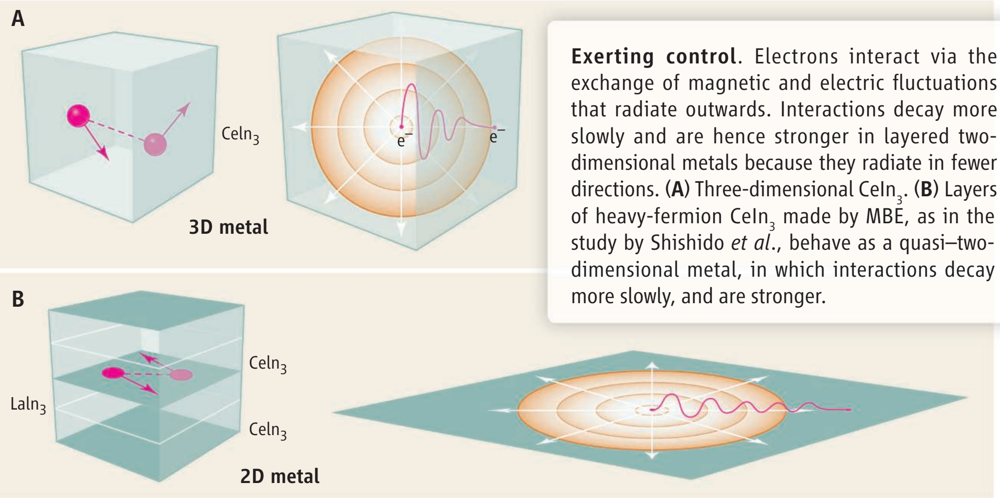
Layer-by-layer growth provides a route to control the properties of complex interacting electron systems.

Piers Coleman

One of the quests of condensed matter physics is to discover materials with new types of collective electronic properties, such as the giant magnetoresistance materials (*1*) now used for memory storage or high-temperature superconductors (*2*). Such "strongly correlated electron" materials challenge our understanding and provide the grist for future technologies. However, identifying new kinds of electronic behavior is still serendipitous, largely because the materials structures of greatest interest do not crystallize to order. On page 980 of this issue, Shishido *et al.* (*3*) introduce a systematic approach based on molecular beam epitaxy for the preparation of complex interacting electron materials, thus opening up the possibility of making available many new structures not currently accessible to direct chemical synthesis.

It is the Coulomb repulsion between electrons that drives the development of new kinds of electronic behavior. When the repulsion energy between electrons is small compared with their kinetic energy, electrons move independently, but when the interactions are large, electron motions become highly correlated, and may develop unexpectedly new types of collective behavior in order to try and lower the Coulomb energy.

Two strategies have proven particularly successful in preparing strongly correlated electron materials. The first is to find layered materials where the confinement of electrons to two dimensions enhances their interactions. The other is to tune the material by some external parameter (e.g., pressure, magnetic or electric field) to the brink of magnetic instability, a point in the phase diagram called a "quantum phase transition" (*4*, *5*). Interactions between electrons inside materials are



Exerting control. Electrons interact via the exchange of magnetic and electric fluctuations that radiate outwards. Interactions decay more slowly and are hence stronger in layered two-dimensional metals because they radiate in fewer directions. (**A**) Three-dimensional $CeIn_3$. (**B**) Layers of heavy-fermion $CeIn_3$ made by MBE, as in the study by Shishido *et al.*, behave as a quasi–two-dimensional metal, in which interactions decay more slowly, and are stronger.

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