= Kimberella =

Kimberella is a monospecific genus of bilaterian known only from rocks of the Ediacaran period . The slug @-@ like organism fed by scratching the microbial surface on which it dwelt in a manner similar to the molluscs , although its affinity with this group is contentious .

Specimens were first found in Australia 's Ediacara Hills , but recent research has concentrated on the numerous finds near the White Sea in Russia , which cover an interval of time from 555 to 558 million years ago . As with many fossils from this time , its evolutionary relationships to other organisms are hotly debated . Paleontologists initially classified Kimberella as a type of jellyfish , but since 1997 features of its anatomy and its association with scratch marks resembling those made by a radula have been interpreted as signs that it may have been a mollusc . Although some paleontologists dispute its classification as a mollusc , it is generally accepted as being at least a bilaterian .

The classification of Kimberella is important for scientific understanding of the Cambrian explosion : if it was a mollusc or at least a protostome , the protostome and deuterostome lineages must have diverged significantly before 555 million years ago . Even if it was a bilaterian but not a mollusc , its age would indicate that animals were diversifying well before the start of the Cambrian .

= = Etymology = =

The genus is named after Mr. John Kimber , student , teacher , and collector who lost his life during an expedition to Central Australia in 1964 . Originally it was described with the name Kimberia . Dr. N. H. Ludbrook drew attention to the fact that the name Kimberia is preoccupied by Kimberia Cotton and Woods , a turtle subgenus . Accordingly , the new name Kimberella was proposed by Mary Wade in 1972 .

= = Occurrence = =

Kimberella has been found both in the Ediacara Hills of South Australia and in the Ust ? Pinega Formation in the White Sea region of Russia . The White Sea fossils are often associated with the Ediacaran " animals " Tribrachidium and Dickinsonia ; meandering trace fossil trails , possibly made by Kimberella ; and algae . Beds in the White Sea succession have been dated to 555 @.@ 3 ± 0 @.@ 3 million years ago and 558 million years ago by radiometric dating , using uranium @-@ lead ratios in zircons found in volcanic ash layers that are sandwiched between layers that contain Kimberella fossils . Kimberella fossils are also known from beds older and younger than this precisely dated range . The fossils from the Ediacara Hills have not been dated precisely .

= = Description = =

Over 1000 specimens , representing organisms of all stages of maturity , have now been found in the White Sea area at the bottom of fine @-@ grained sandstone layers . The large number of specimens , the small grain @-@ size of the sediments and the variety of circumstances in which specimens were preserved provide detailed information about Kimberella ? s external form , internal anatomy , locomotion and feeding style .

All of the fossils are oval in outline . Elongated specimens illustrate that the organism was capable of stretching in an anterior @-@ posterior direction , perhaps by as much as a factor of two . The only type of symmetry visible in the White Sea specimens is bilateral ; there is no sign of any of the kinds of radial symmetry that are normal in the Cnidaria , the group that includes jellyfish , sea anemones and hydras . The Australian fossils were originally described as a type of jellyfish , but this is inconsistent with the bilateral symmetry in the fossils . The White Sea fossils and the surrounding sediments also show that Kimberella lived on the surface of the sea @-@ floor .

Kimberella had a dorsal integument that has been described as a non @-@ mineralized " shell " ; in the larger specimens this reached up to 15 cm in length , 5 to 7 cm in width , and was 3 to 4 cm high

; the smallest specimens are only about 2 ? 3 mm long . The shell was stiff but flexible , and appears to have been non @-@ mineralized , becoming tougher as it grew larger (and presumably thicker) in more mature specimens . The deformation observed in elongated and folded specimens illustrates that the shell was highly malleable ; perhaps , rather than a single integument , it consisted of an aggregation of (mineralized ?) sclerites . At its highest point was a hood @-@ like structure , forming what is thought to be the front . In some specimens , the inner surface of the shell bears stripes spanning the width of the creature ; these may represent the attachment sites of muscles . Similar stripes around the edge of the shell may have been connected to muscles involved in retracting the muscular foot into the shell .

The long axis of the organism is marked by a raised ridge ; the middle axis is slightly humped . Kimberella ? s body had no visible segmentation but had a series of repeated " modules " . Each module included a well @-@ developed band of dorso @-@ ventral muscles running from the top to the single , broad , muscular " foot " , and smaller transverse ventral muscles from side to side on the underside of the body . The combination of the bands of dorso @-@ ventral and transverse ventral muscles enabled Kimberella to move by making the foot ripple .

The body also had a frilled fringe that may have been part of the animal 's respiratory system , performing a function similar to that of gills . The fact that the fringe extended well beyond the shell may indicate that Kimberella ? s " gills " were inefficient and needed a large area , or that there were no effective predators on Kimberella and the shell 's main function was to provide a platform for the muscles .

= = Ecology = =

Kimberella dwelt in shallow waters (up to tens of meters in depth) , sharing the calm , well @-@ oxygenated sea floor with photosynthetic organisms and microbial mats . Assemblages bearing Kimberella often also bear fossils of Yorgia , Dickinsonia , Tribrachidium and Charniodiscus , suggesting that it lived alongside these organisms .

Kimberella probably grazed on microbial mats , but a selective predatory habit cannot be ruled out . Fedonkin reckons that as it ate , it moved " backwards " ; the trail thus created was destroyed by the subsequent grazing activity . Conversely , Gehling et al. claim that it moved ' forwards ' . Fans of grooves are often found radiating from the " head " end of the organism ; these indicate that the organism stayed in one place , and raked the surface of the microbial mat towards it by extension of its head , which bore two " teeth " . Gehling et al. reconstruct Kimberella as having a long neck that operated like the arm of a digger , rotating about an axis perpendicular to the sea floor in order to produce the sweep of the fan , and rotating towards and away from the animal to scrape food from the substrate to the mouth .

The lack of evidence to the contrary suggests that the organisms reproduced sexually .

The waters in which Kimberella dwelt were occasionally disturbed by sandy currents , caused when sediments were whipped up by storms or meltwater discharge , and washed over the creatures . In response to this stress , the organisms appear to have retracted their soft parts into their shells ; apparently they could not move fast enough to outrun the currents . Some organisms survived the current , and attempted to burrow out of the sand that had been deposited above them ; some unsuccessful attempts can be seen where juveniles were fossilised at the end of a burrow a few centimetres long .

= = Preservation = =

Kimberella fossils are generally preserved on top of a clay @-@ rich bed and beneath a sandy bed . All fossils are preserved as depressions in the bases of beds , implying that the organism , although not mineralised , was firm enough to resist being crushed as sediment accumulated above it ; as the soft parts of the organism decayed , the soft muds underneath would be squeezed up into the shell , preserving the shape of the organism .

Preservation of most specimens was made possible by the fast sedimentation that quickly cut the

organism off from seawater ; it may also have been enhanced by the decay products of the rotting organism , which could have helped the overlying sediment to mineralise and harden . It has been suggested that a mucus trail produced by the organism may have assisted its preservation , but experiments suggest that mucus disintegrates too easily to play a role in binding sediment together .

= = Classification = =

All the Kimberella fossils found so far are assigned to one species , K. quadrata . The first specimens were discovered in Australia in 1959 . They were originally classified as jellyfish by Martin Glaessner and Mary Wade in 1966 , and then as box jellyfish by Wade in 1972 , a view that remained popular until the fossils of the White sea region were discovered ; these prompted a reinterpretation . Research on these specimens by Mikhail A. Fedonkin , initially with Benjamin M. Waggoner in 1997 , led to Kimberella being recognised as the oldest well @-@ documented triploblastic bilaterian organism ? not a jellyfish at all .

So far Kimberella fossils show no sign of a radula , the toothed chitinous " tongue " that is the diagnostic feature of modern molluscs , excluding bivalves . Since radulae are very rarely preserved in fossil molluscs , its absence does not necessarily mean that K. quadrata did not have one . The rocks in the immediate vicinity of Kimberella fossils bear scratch marks that have been compared to those made by the radulae of molluscs as they graze on microbial mats . These traces , named Radulichnus and Kimberichnus , have been interpreted as circumstantial evidence for the presence of a radula . In conjunction with the univalve shell , this has been taken to indicate Kimberella was a mollusc or very closely related to molluscs . In 2001 and 2007 Fedonkin suggested that the feeding mechanism might be a retractable proboscis with hook @-@ like organs at its end . Kimberella ? s feeding apparatus appears to differ significantly from the typical mollusc radula , and this demonstrates that Kimberella is at best a stem @-@ group mollusc . Notably , the scratch marks indicate that the ' teeth ' were dragged towards the organism , not pushed away as in molluscs , and that the maximum impact on the sediment was when the mouthpart was furthest from the organism . The direction of grazing is also backwards , as opposed to forwards as in molluscs . Furthermore , the constant width of grooves implies stereoglossy ? a trait that is very derived in molluscs . It has been argued that the shape of the feeding traces is incompatible with a radula , and that despite the molluscan body form , the lack of a radula places Kimberella well outside the molluscan crown group . Butterfield points out that plenty of other groups of organisms bear structures capable of making similar marks .

Taken together , sceptics doubt that the available evidence is enough to reliably identify Kimberella as a mollusc or near @-@ mollusc , and suggest that it is presumptuous to call it anything more than a " possible " mollusc , or even just a " probable bilaterian " .

= = Theoretical importance = =

The Cambrian explosion is an apparently rapid increase in the variety of basic body structures of animals in the Early Cambrian period , starting after 543 million years ago and finishing before 518 million years ago . A few of the Early Cambrian fossils were already known in the mid @-@ 19th century , and Charles Darwin saw the apparently sudden appearance and diversification of animals as one of the main objections that could be made against his theory of evolution by natural selection .

The majority of animals more complex than jellyfish and other Cnidarians are split into two groups , the protostomes and deuterostomes . The mollusc @-@ like features of Kimberella strongly suggest that it was a member of the protostomes . If so , this means that the protostome and deuterostome lineages must have split some time before Kimberella appeared ? at least 558 million years ago , and hence well before the start of the Cambrian 541 million years ago . Even if it is not a protostome , it is widely accepted as a member of the more inclusive bilaterian clade . Since fossils of rather modern @-@ looking Cnidarians have been found in the Doushantuo lagerstätte , the Cnidarian and

bilaterian lineages would have diverged well over 580 million years ago .