

The sediments are at their thickest (up to 3 km) towards the southern margin, where the current density is greatest. Taken together, these facts suggest that the current responsible for the magnetic variation anomaly is concentrated principally in the relatively conductive Carboniferous sedimentary rocks of the Northumberland Basin.

To the west of the Alston Block, in the Vale of Eden, is a similar sedimentary basin which runs in a north-south direction, and which contains up to 3 km of Carboniferous and Permo-Triassic sediment¹⁵. If these sedimentary basins responded to electromagnetic fields as isolated conductors, the maximum response of the Vale of Eden should occur when the regional current flow is north-south, that is the horizontal magnetic field is east-west. However, at 750 s period, the basin responds to neither azimuth of the field, in striking contrast to the Northumberland Basin. What differentiates the two basins are the links which the Northumberland Basin makes at either end to the laterally extensive conductors of the Irish and North seas, together with their own associated sedimentary basins. The Vale of Eden is isolated at its southern end, either by the postulated ridge connecting the Lake District and Weardale

granites¹⁵, or by the westward thinning of sediments in the Stainmore Trough.

It has been suggested that the Northumberland Basin marks the Iapetus suture, the line of closure of the proto-Atlantic Ocean⁷. Before it can be established that there is a deep conductive structure beneath the basin, it will be necessary to model the effects of the currents in the shallow sedimentary rocks, using the available data on their thickness. We believe that, if the response of the Basin to electromagnetic fields with periods of 750 s is to be correctly modelled, it will be essential to include the Irish and North Seas and their underlying sediments. Without the results from such modelling, all we can say at present is that a deep conductor beneath the basin does not seem essential. The only completely unexplained feature of the maps is the Southern Uplands anomaly, and, if we believe that the line of the suture must be marked by a conductivity anomaly, this must be reckoned the most likely candidate.

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The first fossil ctenophore from the Lower Devonian of West Germany

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Of the 21 or so generally accepted animal phyla, only one, the Ctenophora, has no fossil record¹. The Phylum Ctenophora or comb jellies, are typically globular, swimming marine organisms, widely distributed in today's oceans. They are small, delicate, mostly planktonic animals of a gelatinous nature² that were first considered to be coelenterates but later were recognized as a distinct group of phylum rank. We have now discovered the pyritized fossil remains of a small, globular, soft-bodied ctenophore. It comes from the Lower Devonian Hunsrück Slate of West Germany and provides the first tangible evidence for the existence of the group. Our discovery demonstrates that the basic ctenophore body plan has changed very little over the past 400 Myr and suggests that the origin of the phylum must extend even further back in time.

Although poorly preserved, the shape, symmetry and anatomical details of the fossil described below leave little doubt that it is a ctenophore. The specimen was discovered during radiographic study of a variety of fossils in the collection of Günther Brassel found in Hunsrück Slate from the Eschenbach Slate Mine, Bundenbach, FRG. Millions of fossils from this formation include over 370 different invertebrate taxa³. The use of X rays in the study of other Hunsrück fossils has greatly expanded the resolving power of palaeontological observations, revealing details as fine as 5 µm (refs 4, 5). The preservation of soft tissues frequently occurs through the conversion of organic sulphur compounds to iron sulphides^{5,6}. Jellyfish-like hydrozoans (Velellidae) with exquisite details of the tentacles,

organs and soft tissues are preserved in a similar manner^{7,8}. The discovery of a ctenophore in the Hunsrück Slate establishes the existence of this phylum over 400 Myr ago in the early Devonian.

Systematic description: *Paleoctenophora brasseli* Stanley and Stürmer, n. gen., n. sp. (Figs 1 and 2). The description of the specimen is based on stereoradiographs. It is biradially symmetrical, oval-shaped, 13 mm high and 9 mm in diameter. The wall is exceptionally thin and discontinuous and there is a slightly depressed apical (aboral) region, strongly differentiated into distinct spherical granules (0.20-0.54 mm diameter) from which extend at least seven or possibly eight radially disposed linear features. The longest extends three-quarters of the body length. Others are short and thicken away from the apex, gradually dissipating and losing integrity. Fibrous, irregular matter is distributed within the specimen. Opposite the apex, the wall of the oral region has slight but perceptible indentation. On opposite sides, two tentacular projections emerge through the wall. One is short and thick with possibly an internal sac, the other is longer, extending 50 mm outside the body, with a few short branches along its length.

The presence of tentacles and apparent tentacle sheaths place this ctenophore in the Class Tentaculata; the shape, symmetry and details of the tentacles allow its assignment to the Order Cydippida. Finer details are insufficient for assignment to a particular family but the resemblance to *Pleurobrachia* is striking. The specimen is in the Bavarian State Collection, Munich, FRG (BSP 1938 ROEM 134). Original radiographs (WS 1021) are with W.S.

Only two doubtful fossil ctenophores are known⁹. These are *Rangaea*¹⁰ and *Xenusion*¹¹. The former is now known to be a soft-bodied coelenterate of the Precambrian Ediacara fauna belonging to the Pennatulacea^{12,13}. The latter is undoubtedly a segmented Cambrian arthropod. The eight row combs of cydippids are very delicate external structures that are lightly attached to the gelatinous body. Each is composed of overlapping plates of fused cilia and their coordinated beating is the principal means of locomotion. Because of their delicate nature, it is not surprising to find the comb structures of *Paleoctenophora* in disarray. Relative to the body, they were more rigid,

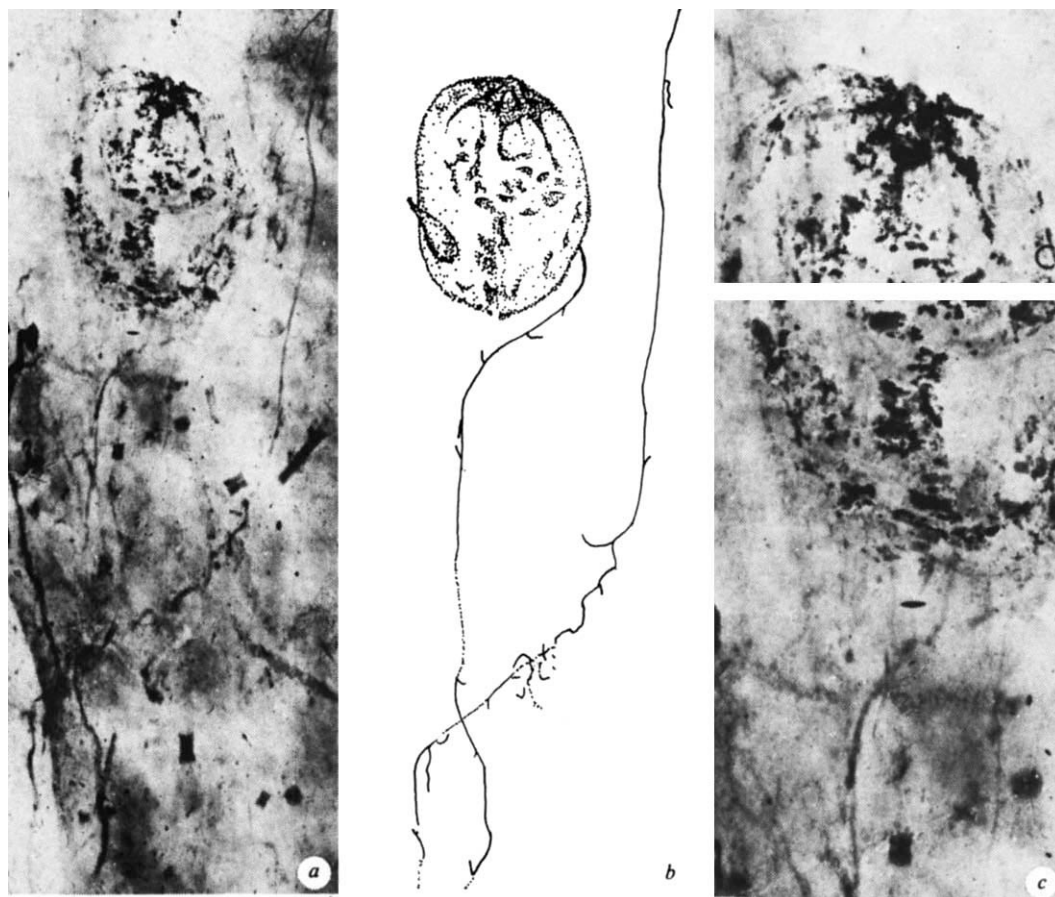
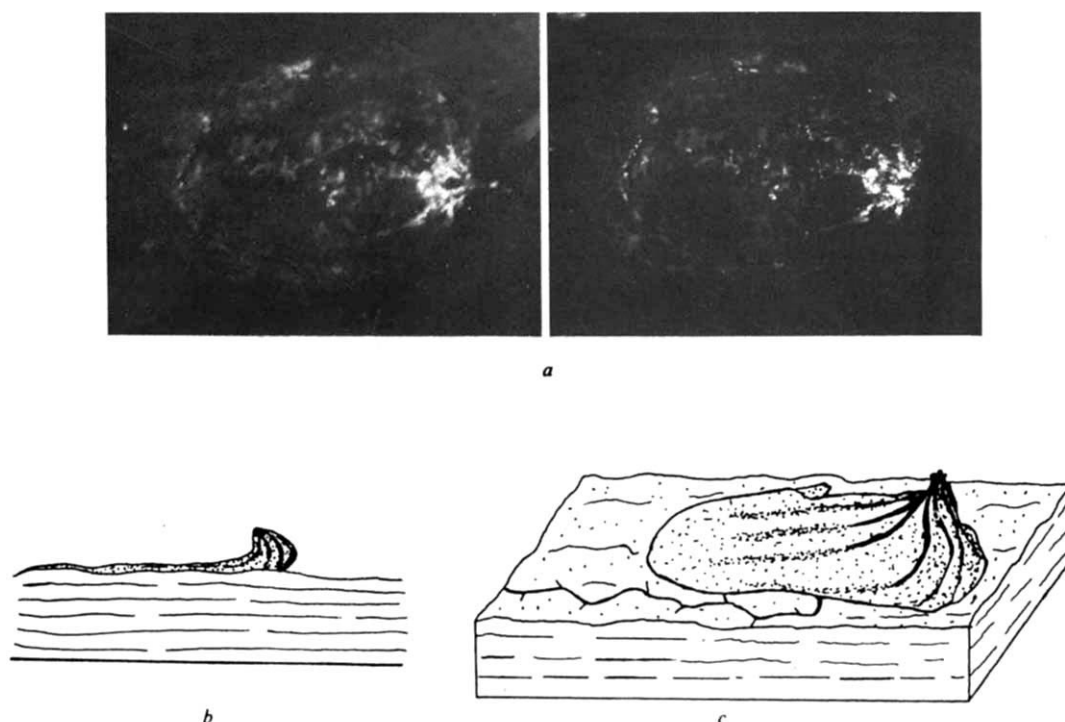


Fig. 1 *a*, *Paleoctenophora brasseli* n. gen., n. sp. Radiograph of fossil ctenophore (WS 1021) from the Hunsrück Slate of West Germany showing general shape of specimen and the associated structures lying in the matrix. A fine sinuous feature extending from the specimen is interpreted as the remains of a tentacle. A few short filaments branch off at various points along its length. To right of specimen, a similar structure is unattached but could also be the remains of a tentacle ($\times 2.3$). *b*, Sketch of specimen at left clarifying principal features. *c*, Top, enlarged details of apical region showing concentration of pyritic matter interpreted as remains of the statocyst and the radially extending comb rows ($\times 4.7$). *d*, Below, enlarged details of lower left part of specimen showing the protruding tentacle that emerges through the body wall. A trace of a sac-like structure, probably the remains of an internal tentacle sheath, is visible (upper left). Part of the right tentacle, showing indications of fine-branched extensions, is also present.

Fig. 2 *a*, Radiograph stereo-pair of *Paleoctenophora* showing flattened specimen entombed within the slate matrix ($\times 3.0$). Angle of stereo photographs accentuates slight three-dimensional details and emphasizes the relief in the apical region of the specimen. Original rigidity of comb rows may have reduced flattening in this area. *b*, Schematic drawing with proportions exaggerated showing a profile of the specimen and the raised apical region where comb row structures are present. *c*, Generalized sketch of the specimen based on stereo radiography giving orientation in the matrix.



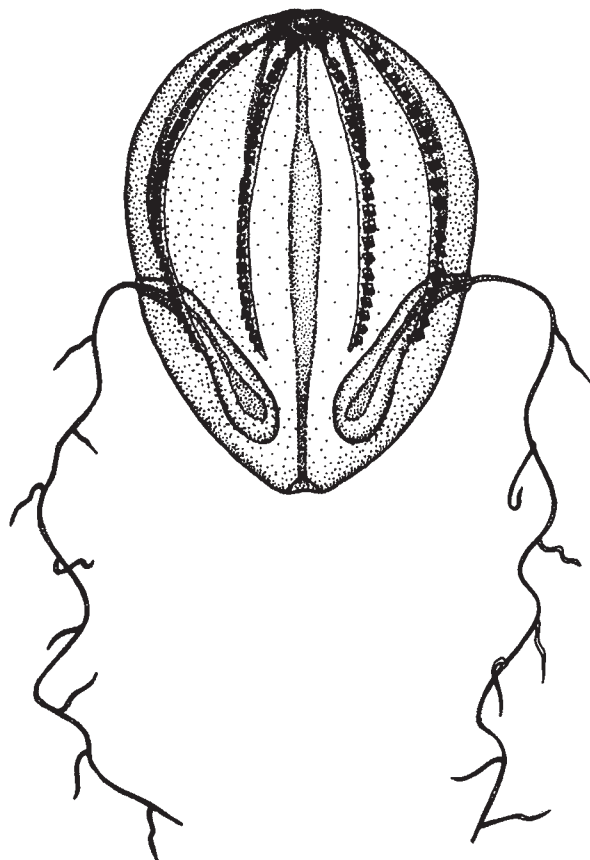


Fig. 3 Life reconstruction of *Paleoctenophora* showing principal anatomical features suggested by the fossil. Drawing illustrates the apical statocyst from which radiate eight longitudinal comb rows. Also shown are the paired, retractable tentacles with internal tentacle sheaths. In the centre, a part of the gastrovascular system runs through the body and terminates in the mouth. Many details of the internal anatomy, including much of the gastrovascular system, are not visible owing to lack of preservation in the fossil. Drawing illustrates the striking similarity with living cydippid ctenophores such as *Pleurobranchia*.

supporting the soft tissue (Fig. 2). The comb rows terminate in and attach to the aboral region (Fig. 2). Comparison with modern cydippids shows this to be the region of the statocyst or balance organ that in living ctenophores consists of minute calcareous spherules (statolith)¹⁴. Remains of such spherules are present in the specimen (Fig. 1c) and the opposite (oral) side reveals an indentation indicating a mouth (Fig. 1a). The fine, dark, pyritic matter scattered within the specimen (Fig. 1) could be degraded remains of muscle fibres, the pharynx and gastrovascular system.

Of the two tentacles indicated, one on the left side appears to be either broken off or retracted and is enclosed in a sac-like tentacle sheath (Fig. 1c). On the opposite side a tentacle emerges from the body and can be traced along a sinuous path for about 5 cm (Fig. 1a). Along its length, it displays several branched filaments. Other sinuous lines not connected with the specimen lie in different planes and are interpreted as worm burrows. Figure 3 illustrates a reconstruction of *Paleoctenophora*.

With only one fossil specimen representing an entire living phylum, *Paleoctenophora*, must be the rarest of all fossils. Very special conditions of burial account for the preservation of such a delicate, jelly-like organism. We have no idea how common ctenophores were in Devonian seas but today they are exceedingly abundant and diverse plankton feeders, forming an important component of oceanic marine ecosystems¹⁵.

The basic cydippid body plan of *Paleoctenophora* reinforces earlier evolutionary hypotheses based on embryological grounds. Since all ctenophores, including the most morphologi-

cally diverse, go through an early free-swimming cydippid larval stage, the Order Cydippida is postulated to be the ancestral form^{1,14}. *Paleoctenophora* therefore adds credence to this idea.

Although caution is necessary in a radiographic study, we judge the obvious similarities to living cydippid ctenophores convincing enough to justify our interpretations. The striking similarity of *Paleoctenophora* with living counterparts such as *Pleurobranchia* indicates the antiquity of the basic ctenophore body plan¹⁶. The presence of this grade of metazoan organization over 400 Myr ago, suggests that if ctenophores had a common origin with Cnidaria (Coelenterata) or any metazoans of the Radiata branch, it must extend even further back into the Palaeozoic, perhaps to the dramatic appearance of metazoans in the late Precambrian¹⁷.

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Controlling the duration of photosynthetic charge separation with microwave radiation

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Electron transfer reactions are commonplace in both chemical and biochemical transformations. These reactions generally involve the formation of transient radical ion pairs. Non-adiabatic electron transfer results in formation of a correlated radical ion pair¹. Only when the radical ions have separated to distances of the order of 10 Å are the internal magnetic fields in the radical ions able to perturb this correlation. Thus radical pairs initially born in a singlet state will develop triplet character as a function of time, and vice versa. Because the ensuing chemistry of the radicals is dependent on their spin state, external perturbations of the radical pair spin state may permit some control over the course of the chemistry. Microwave radiation can provide a strong internal magnetic field perturbation on a radical pair such as the one that results from photoinduced charge separation in bacterial reaction centres. We show here how this perturbation can be used to control the lifetime of the initially formed radical pair.

Photoexcitation of the reaction centre protein from purple photosynthetic bacteria results in rapid (<5 ps) formation of a radical pair, P[•] composed of an oxidized bacteriochlorophyll a dimer, P⁺ and a reduced bacteriopheophytin a molecule, I[•]