

Palaeontology

No consensus on *Archaeopteryx*

from Michael J. Benton

IN the last few years there has been a resurgence of interest in the oldest known fossil bird, *Archaeopteryx*. Contention has focused on its functional anatomy (could it fly?) and its relationships (is it the ancestral bird?; indeed, is it a bird?; did birds originate from dinosaurs or from some earlier stock?). The first specimen of *Archaeopteryx* was collected in 1861, and since then the total has risen to five specimens and a feather. All come from the Upper Jurassic (~150 million years ago) Solnhofen Plattenkalk of Franconia, West Germany. The most recent work on the 'London' specimen¹ reflects the inconclusive nature of the arguments surrounding this contentious creature.

Ostrom^{2,3} has expressed the view that *Archaeopteryx* was a cursorial terrestrial predator that could not fly, primarily because it lacked the deep breast-bone that provides an anchor for the powerful flight muscles in living birds. However, Olson and Feduccia⁴ have argued that this is not the case, and that the important downstroke muscles in *Archaeopteryx* attached to its well developed furcula ('wish-bone').

The feathers offer further evidence. They are excellently preserved as impressions in fine limestone and this has permitted a detailed description of those of the 'Berlin' specimen (ref. 5 and see the figure). The feathers are asymmetrical⁶, with longer hairs on one side of the quill than on the other. This asymmetry has an aerodynamic function and is characteristic of flying birds: flightless birds have symmetrical feathers.

In the new work that has recently been done on the braincase of *Archaeopteryx* by Whetstone¹, the cranium of the 'London' specimen has been removed from its limestone slab and painstakingly prepared by mechanical means. This has shown that the skull is much broader and more bird-like than had been thought⁷. Details of the braincase and associated bones at the back of the skull seem to suggest that *Archaeopteryx* is not the ancestral bird, but an offshoot from the early avian stem. The exact relationships of the quadrate and squamosal bones, which link the braincase with the jaw articulation, are uncertain, but they appear to be more primitive than modern birds in some respects. In other respects, *Archaeopteryx* is advanced: the top of the quadrate has a single articulation (rather than a double one, as in other archosaurs and in modern birds), the blade of the scapula (shoulder blade) attaches to one of the ribs and the metatarsals (foot bones) are fused in a transverse plane.

The relationships of *Archaeopteryx* and the origin of the birds are controversial. In a recent review, Thulborn and Hamley⁸

identified seven hypotheses concerning the affinities of *Archaeopteryx*, three of which appear to have supporters at present. The work of Whetstone¹ just described does not so far provide strong evidence for or against any of these ideas, and further analysis of the material is necessary.

Walker^{9,10} has suggested that crocodiles and birds (and thus *Archaeopteryx*) derived from a common ancestor among the thecodontians (the basal reptile stock that gave rise to crocodiles and dinosaurs). His evidence depends on resemblances between the braincase and skull of recent crocodiles and birds, as well as bird-like features of a possible early crocodile called *Sphenosuchus*. Whetstone and Martin¹¹ supported this view with further evidence from the braincase of birds and crocodiles. Both groups were said to share an homologous specialized opening in the wall of the inner ear region (the fenestra pseudo-rotunda) and homologous pneumatic spaces in the bones around the middle ear. Unfortunately, few of these features could be seen in *Archaeopteryx* and there is no

compelling evidence of an advanced character(s), shared between *Archaeopteryx* and some, or all, crocodiles, but absent in the thecodontians and dinosaurs^{8,12}.

Ostrom¹², on the other hand, has proposed the derivation of birds from the dinosaurs on the basis of many characters, of the limbs in particular, shared between *Archaeopteryx* and certain theropod dinosaurs (bipedal meat-eaters). He proposed an evolutionary sequence from thecodontian to theropod to *Archaeopteryx* to modern bird. Walker¹³ has argued that Ostrom's interpretation of the pelvis of *Archaeopteryx* is wrong and makes it seem more dinosaur-like than it really was. In modern birds, the pubis runs backwards below the other two pelvic bones, while in theropod dinosaurs the pubis points forwards. Ostrom¹² reconstructed the pubis of *Archaeopteryx* as pointing straight down — an intermediate position; while Walker¹³ reconstructed it in a more bird-like backward orientation. Further, Martin *et al.*¹⁴ have argued that the ankle and teeth of *Archaeopteryx* could not be derived from those of theropod dinosaurs. Theropod dinosaurs and birds have an ascending process from the ankle in front of the tibia (shin bone), but it is apparently not homologous in the two groups, and the teeth of primitive birds are more crocodile-like than dinosaur-like. Finally, Tarsitano



The Berlin specimen of *Archaeopteryx lithographica* found in 1877 near Eichstätt, Germany. Preservation of feather impressions established these as the remains of a true bird, despite the fact that the skeletal anatomy is more like that of theropod dinosaurs than that of modern birds. Scale bar, 100 mm.

and Hecht¹⁵ criticized various aspects of Ostrom's hypothesis, and they considered that he had misinterpreted the homologies of the limbs of *Archaeopteryx* and theropods. Thulborn and Hamley⁸, reviewing all the criticisms, however, have concluded that they are without foundation (incorrect interpretations, inconclusive evidence, persistence of primitive characters), and that they do not "seriously weaken the hypothesis that *Archaeopteryx* is closely related to theropod dinosaurs".

The third current view of the relationships of *Archaeopteryx* has been given by Tarsitano and Hecht¹². They revived an old idea that *Archaeopteryx* is a member of a distinct lineage that arose from the thecodontians and has no direct relationships with crocodiles or dinosaurs. Their evidence consists of a resemblance between the coracoid (a bone of the shoulder girdle) of *Archaeopteryx* and some thecodontians, as well as arguments against the 'crocodile' and 'theropod' hypotheses. Thulborn and Hamley⁸ take the view that this hypothesis was selected merely by a process of elimination, but Hecht and Tarsitano have more recently reaffirmed their viewpoint¹⁶.

There are thus three strongly held views on the relationships of *Archaeopteryx* — that it is related to crocodiles^{9-11,13,14}, that it is related to theropod dinosaurs^{8,12} and that it is related to thecodontians^{15,16}. It might seem to be an easy question to solve in view of the relatively well preserved specimens of *Archaeopteryx* and of thecodontians and early dinosaurs and crocodiles. But the arguments rest on interpretations of the anatomy of *Archaeopteryx* and related forms, and on modes of interpreting the data — whether by seeking general resemblances and ancestors, or in attempting a strict cladistic analysis of sister-group relationships. A rumoured sixth skeleton of *Archaeopteryx*¹⁷ may offer new light on its anatomy. Interest in the 'early bird' or 'Urvogel' is so strong that a conference devoted to it is to be held in Eichstätt, West Germany, in September 1984. □

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Geophysics

Magnetic reversals from a submersible

from J. R. Cann

THE Vine-Matthews hypothesis¹ is 20 years old this year, and coincidentally a paper has just been published by Macdonald and co-workers² which represents a decisive step in the affirmation and development of the hypothesis. In case you need reminding, the hypothesis is that the lineations observed on magnetic anomaly maps of the ocean basins³ can be explained as corresponding to strips of alternately normally and reversely magnetized sea floor. These strips were formed, it is argued, in a narrow zone along the crests of the mid-ocean ridges as the ocean floor spread apart continuously while the Earth's magnetic field periodically reversed. The ocean crust created, and especially the upper part of it, made up of submarine basalt lava flows, thus acted as a record of the field reversals.

A large amount of evidence has now accumulated that this hypothesis is a good model for the ocean floor, but the evidence has always been essentially indirect, and some scientists have contrived still to maintain their disbelief. The new paper does two things. It provides concrete support for the Vine-Matthews hypothesis through direct observation of a magnetic reversal on the ocean floor, and it also contributes important evidence about the creation of crust at mid-ocean ridges. The latter topic is especially important at present given the great interest in the black smoker springs and ore deposits of very young ocean crust⁴.

Working from the US submersible *Alvin*, Macdonald and co-workers used a vertical magnetic gradiometer made from two vertical-component fluxgate magnetometers spaced 30 cm apart to find the polarity of magnetization of individual outcrops of basalt (usually single pillows) at nearly 300 places on several transects across a predicted reversal boundary on the sea floor. This boundary corresponds to the most recent major reversal of the Earth's field at 0.7 Myr (the Brunhes-Matuyama boundary). A previous survey with a near-bottom towed vehicle had enabled them to calculate where the reversal boundary was likely to occur. The submersible measurements found a sharp boundary as expected, on one side of which (the side nearer the mid-ocean ridge crust) the outcrops of basalt were all normally magnetized, and on the other all reversely magnetized. This is clearly the outcropping of a Vine-Matthews stripe edge. In places it was covered by a sediment pond, but in others it appeared as a flow front of normally magnetized lava overlying reversely magnetized lava (thus showing the normal-

ly magnetized lava to be younger, as indeed it ought to be). Near the boundary some of the outcrops are very weakly magnetized, and these may be of lava erupted while the magnetic field was in the course of reversing.

The experiment is a particularly elegant demonstration of the Vine-Matthews hypothesis because it is very direct and can be repeated in principle anywhere in the oceans where a reversal boundary is not covered by sediment.

But what about crustal formation? The important evidence here is that the reversal observed in the outcrops is systematically displaced 250–500 m away from that calculated from the near-bottom survey, in a direction opposite to that in which the mid-ocean ridge crest lies. This had been anticipated by some modellers⁵, who considered from the evidence of ophiolite complexes (slices of ocean crust thrust above sea level during mountain building) that the zone of fissures from which lava is erupted must be about 50 m wide, much less than the distance that lavas flow away from the fissures (0.5–1 km)⁴. Macdonald and co-workers point out that the reversal from the near-bottom survey should correspond approximately to the position where the reversal is about half-way buried in the lava pile. This line in turn, if the fissure zone is indeed very narrow, should be displaced from the outcrop of the reversal by half of the lava flow length in the direction towards the mid-ocean ridge crest, which corresponds well with the observations.

Other modellers^{6,7}, whose experience had been conditioned by magnetic observations in deep-sea drilled holes on the Mid-Atlantic Ridge, had expected a much more irregular relationship. Such an irregular structure may be characteristic of the highly rifted (and generally slower spreading) ridges such as the Mid-Atlantic Ridge, while the narrow zone of fissuring may only be found on the less rifted ridges such as the East Pacific Rise where the experiment was performed. It is clearly necessary to resolve this question by repeating the experiment in the Atlantic. □

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