THE ORIGIN OF BIRDS

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The remains of *Archaeopteryx*—a feathered creature of the size of a crow, which lived about 145 mln years ago, were found in 1861 in Southern Bavaria. Many scientists believed that it was the ancestor of modern birds. But for more than a century, a gap between this creature and modern birds was not filled up by other findings in paleontology. Only during the recent 20-25 years, when numerous new feathered creatures of the Mesozoic had been discovered, it became clear that their world was rich and varied 140-110 mln years ago. However, different scientists interpret these findings differently. Which of the hypotheses is closest to the truth and hence, to understanding of the ways and regularities of evolution?

For the public at large paleontologists are people who find and study mammoths* and dinosaurs**. Huge skeletons of these creatures, exhibited in museums, really attract everybody's attention and impress visitors. However, well preserved skeletons are rare. More frequent findings in the terrestrial layers are separate bones, teeth, and skulls, and on the basis of these remains scientists study the animals which disappeared and their relations. Fossil giants mainly demonstrate final, highly spe-

* *See*: V. Bolshakov, P. Kosintsev, "Baby Mammoth Lyuba's Story"; A. Tikhonov, Yu. Burlakov, "Causes of Northern Giants' Extinction", *Science in Russia*, No. 2, 2008.—*Ed.*

** *See*: Yu. Avsyuk et al., "Did Dinosaurs Die Out Suddenly?", *Science in Russia*, No. 3, 2002.—*Ed.*

Reconstruction of the four-winged Microraptor in a gliding flight. It is most likely that it could just glide from one tree to another, but could not flap its fore-wings (and even less so its hind ones). Artist, I. Sergeenkova from reconstruction by E. Kurochkin, 2004.

Jeholornis
(JEHOLORNIS PRIMA Zhou et Zhang, 2002)
from the lower Cretaceous deposits
in the Liaoning province
has not yet found its place in the system
of feathered creatures known by today.
Its anatomy resembles
that of ARCHAEOPTERYX most of all.

cialized results of evolution. The origin of the majority of vertebrate groups is to be found among small inconspicuous creatures without any special anatomical features. In such a state they replaced each other for millions of years, then they either died out or found another free niche for life, where, according to specialists, their extensive adaptive radiation started, i.e. many new species emerged, adapted to modified environmental conditions.

ARCHAEOPTERYX

The history of birds and their flight remained a mystery for a long time, though science posed these questions even before the publication of Charles Darwin's work on the origin of species. *Archaeopteryx* was found in the mid-19th century, almost simultaneously with the publication of this celebrated work, and the naturalists considered it a triumph of the theory of evolution. It seemed to be a missing transitional link between reptiles and birds. Up to the present time we read in textbooks—school and university ones alike—that birds are flying feathered creatures with just one "legal" ancestor, *Archaeopteryx*.

Directly after the first specimen had been found (at present there are 10 findings of this fossil), some scientists doubted that *Archaeopteryx* was really the ancestor of other birds. If we assume that all creatures with wings, feathers, with ability for flight, are birds, well, it can be a sparrow's grand-grand-grandfather. If we properly study the anatomy, it cannot be the sparrow: functionally it is a bird, but structurally it is a pure reptile. Except the feather, it has nothing in common with true birds: the structure of the skull and vertebrae are different, the fore-limbs, though transformed into wings, have different details of skeletal structure; the same is true of their hind limbs.

The scientists were not unanimous in their views. Some proved that birds originated from ancient thecodont reptiles, resembling lizards, while others believed that *Archaeopteryx* and all other birds after it originated from carnivorous (Theropod) dinosaurs.

The fundamental book by the Danish scientist Gerhard Heilmann *The Origin of Birds* (in English) was published in 1926. The author's conclusions are unambiguous: birds originated from thecodont reptiles, but not from raptorial dinosaurs. It is assumed that Theropods (carnivorous dinosaurs) also originate from Thecodonts.

Archaeopteryx really has much in common with Theropods. Their close relationship was analyzed in detail and confirmed in the 1970s by John Ostrom, an American paleontologist. But he considered *Archaeopteryx* to be the most ancient bird. This hypothesis is now supported by many scientists considering that birds originated from Theropods, and their opponents, also considering that *Archaeopteryx* originated from Archosauromorphs (carnivorous reptiles), more ancient than Theropods. If it is so, we have to assume for both hypotheses that evolution is a straightforward process from simple to complex. But it is never so in nature. The experience gained in paleontological and modern molecular-genetic studies of the recent decades shows that it is advancing through trials, achievements, and errors, by bundles of parallel lines of development. And the new data on the historical development of birds illustrate this type of evolutionary regularities. That is why speculations about feathers and bones become a key to understanding the basic problems of its theory.

NEW FACTS

For almost 150 years the hypotheses on the origin and relationships of birds were based almost exclusively on the data of studies of *Archaeopteryx*. The history of Cainozoic* birds (to which all modern birds belong) over

* The Cainozoic is the latest era of geological history, including also the modern epoque; it started about 65 mln years ago.—*Auth.*

Microraptor (MICRORAPTOR GUI Xu et al., 2003) is a four-winged dromeosaur from the early Cretaceous in China. Flying feathers with an aerodynamic profile are formed not only on the fore-limbs (wings), but also on the hind limbs, the longest feathers seen on the authopodium.

the last 65 mln years has been studied rather well. But the Mesozoic* birds can be studied only by scanty findings, which do not reveal a complete picture. And a hitch occurred all of a sudden.

At first *Enanthiornithes* were described from Argentina in 1981. Soon they were found in all continents in the Cretaceous deposits. It turned out that they inhabited the Earth at that time, i.e. between 145 and 65 mln years ago. They resembled true birds–completely feathered, with well developed wings and with seemingly the same legs and tails as in modern birds, but the details of the skeletal structure were quite different: they had much in common with *Archaeopteryx*. Therefore, they can be referred to the so-called Sauriurae, in contrast to the Ornithurae (fan-tailed birds), including all modern birds.

Then quite unusual feathered creatures had been discovered, which were called *Confuciusornithidae*. Their skeleton has many primitive and original structural features, while by other features they resemble modern birds. For example, their beak was covered by a horny cover and had no teeth; a large hole of unknown designation was seen in the humerus crest.

It was assumed that the true fan-tailed birds came into the world and lived almost exclusively during the Cainozoic. But unexpectedly they were found in the Cretaceous deposits, the last period in the Mesozoic, which lasted for about 80 mln years (longer than the entire Cainozoic). The first reliable finding–a bird called *Ambiortus dementjevi*, from the early Cretaceous of Mongolia was described by us at the beginning of the 1980s. At that time it seemed so uncommon, that some paleontologists did not believe it really ever existed.

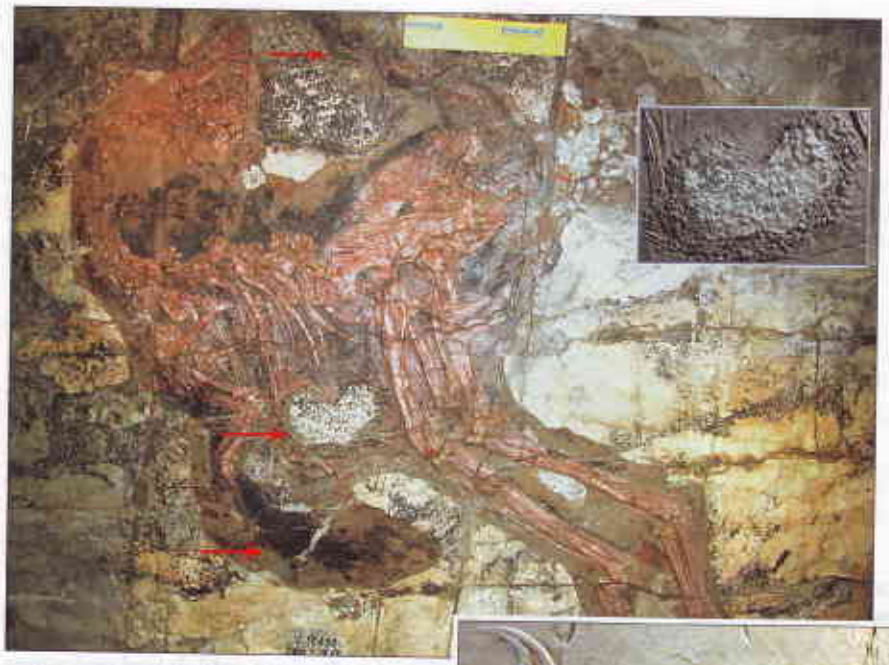
And, finally, a variety of feathered Theropod dinosaurs were found in China. Some of them had a sort of down-like covering, others had long feathers only at the tips of the wings and tail, still others were completely covered by small feathers. And suddenly the scientists found a small dinosaur, just the size of a pheasant, which had real wings with corresponding feathers and with feathers of the same kind on its hind limbs! A four-winged flier! Later it was found that different kinds of feathering were typical of dinosaurs from five different Theropod families (*Oviraptoridae, Avimimidae, Dromeosauridae, Therizinosauridae*, and *Troodontidae*), found in all continents except Antarctica. Moreover, even *Tyrannosauridae*, the "crown" of numerous carnivorous dinosaurs, were most likely feathered. What does it mean? The opinions of specialists were categorically divided. One group of scientists claims that some of these dinosaurs were in fact not dinosaurs, but birds without ability for flight, while in other dinosaurs collagen structures of the skin, modified in the fossil state, are taken for the down-like coating. Other scientists claim that these findings prove that true birds (including *Archaeopteryx*) originated from Theropod dinosaurs.

EVOLUTION IS A MOST EXTRAVAGANT DREAMER

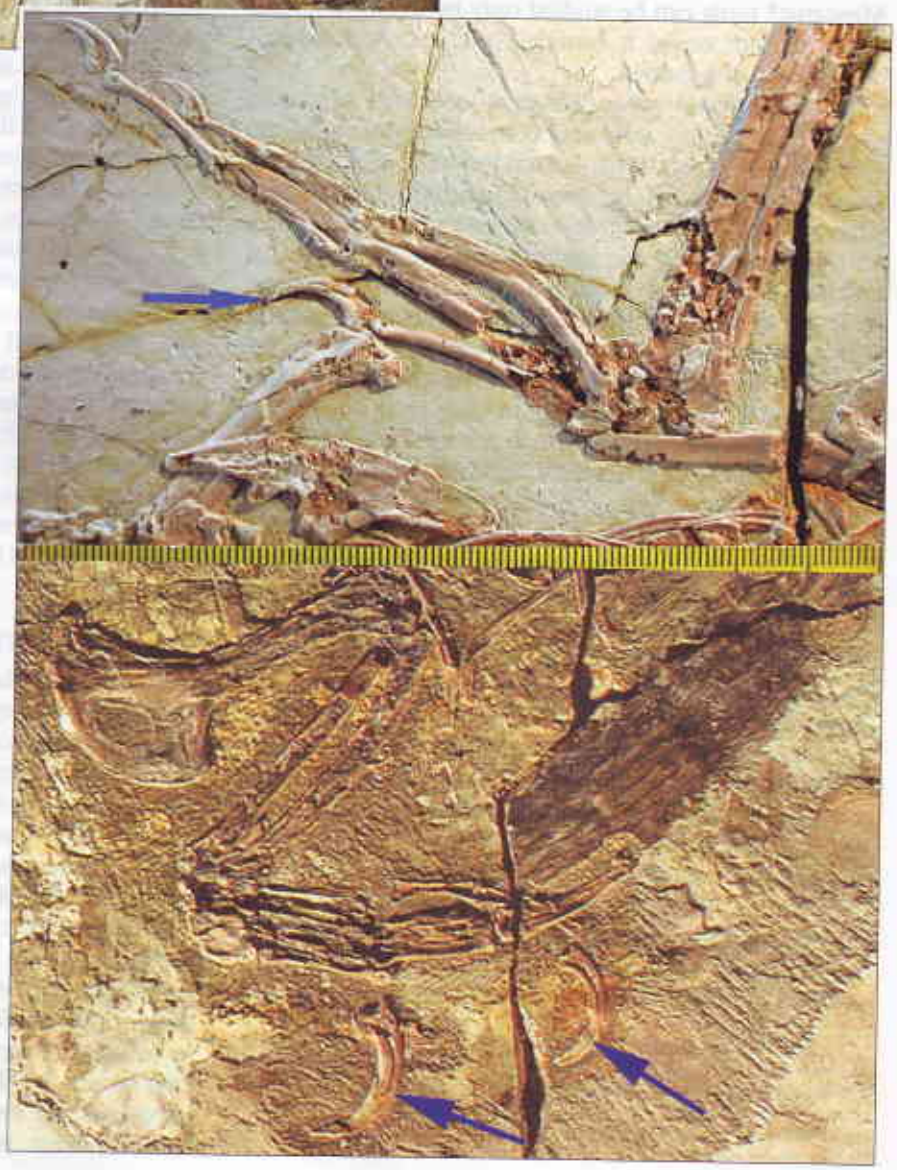
However, another interpretation of all new facts is possible. *Archaeopteryx* and enanthiornithines, which have many features common with the Theropod dinosaurs, most likely originated from them, crowning one of the attempts of these reptiles to conquer the air. Alas, it failed. *Archaeopteryx* disappeared as early as the Jurassic, while enanthiornithines could not compete with true birds and became extinct, living no descendants, together with the dinosaurs at the end of the Cretaceous.

If so, then the true fan-tailed birds existed in parallel with these feathered dinosaurs for millions of years? And they originated from some primitive archosauromorphs (a subclass of reptiles, characteristic of early Mesozoic) long before the flying dinosaurs? A thing like that could happen at the end of the Triassic (about 220 mln years ago). Indirect proofs of this hypothesis are the late

* The Mesozoic era started about 250 mln years ago and lasted for about 185 mln years; it is subdivided into three periods: the Triassic (started 250 mln years ago and lasted for about 35 mln years), the Jurassic (started 213 mln years ago and lasted for about 70 mln years), and the Cretaceous periods (started 144 mln years ago and lasted for about 80 mln years).–*Auth.*



Caudipteryx (CAUDIPTERYX ZOUI Ji et al., 1998) from the early Cretaceous in China belongs to Theropod dinosaurs, but some scientists consider it to be a bird, which lost ability for flight. It has characteristic small feathers on the tail and on tips of the fore-limbs (shown by red arrows). Accumulation of gastroliths–gastric stones (shown by a red arrow) were found in the abdominal cavity of many specimens of caudipteryxes. These stones promoted grinding of coarse plant food (magnification: upper picture to the right).



The claws on the wing digits (blue arrows) are curved outwards in JEHOLORNIS (upper picture) and CONFUCIUSORNIS (lower picture); this was most likely for better clutching at the branches (photos from the book by L. Hou, Chinese paleontologist).

Saint Confuciusornis (CONFUCIUSORNIS SANCTUS Hou et al., 1995) is one of the first sensational findings of early Cretaceous birds in the Liaoning province in China. By the present time 6 species are described.

Longirostravis (LONGIROSTRAVIS HANI Hou et al., 2003) from the enanthiornithines. The size of a starling, with a long fine beak, its tip armed with small teeth, due to which it presumably could drag out the sheltered prey holding it surely.

Triassic and early Jurassic small bird footprints, found in South America, Africa, and Europe. Not a single bird skeleton of that period of millions of years is known. However, up to recently we knew nothing about their presence in the deposits of the early Cretaceous. Only footprints and numerous feathers were found, which permitted us hypothesize unknown evolution of feathered creatures throughout at least the Cretaceous.

Other feathered bird-like animals are known by separate findings; a detailed analysis does not allow to refer them to theropods, enanthiornithines, confuciusornithids, or true fan-tailed birds.

It seems that evolution has made not one attempt at raising the reptiles and their descendants into the air. For various reasons the majority of attempts failed and eventuated in extinction. Only fan-tailed birds in the end gave a bright outbreak of adaptive radiation and populated all the layers of the air environment. It turns out that evolution is not an economical housekeeper, but an extravagant dreamer.

TREASURES OF THE LIAONING PROVINCE

The majority of recent sensational paleontological discoveries were made in the Liaoning Province in North-Eastern China. Cretaceous localities in this region attracted the attention of specialists since the 1920s. Large number of fossil fishes, insects, and plants were found there previously. But at the end of the 20th century birds and feathered dinosaurs were unexpectedly found. The birds included true fan-tailed, enanthiornithines, confuciusornises, and some other kinds of birds, which still cannot be classified with any of the known groups. And almost all above-mentioned feathered dinosaurs have been described after the Liaoning findings. Later on they were detected in the early Cretaceous and even in Jurassic deposits in other Chinese provinces. By the way, in addition to a variety of feathered creatures, numerous unknown mammals, lizards, pterosaurs, dinosaurs, turtles, amphibians, various fishes, numerous insects, and abundant material on the flora, including the most ancient flowering plants, were found in this province. A total of 30 bird species, 20 dinosaurs, and 6 mammalian species are already described by the Liaoning findings.

It is remarkable that many animals were presented not just by skeletons, but also by impressions of soft tissues, external integuments (skin, scales, fur, feathers), viscera, and even the contents of their gastrointestinal system. For example, accumulation of gastroliths (small stones), grinding the plant food, was found in area of stomach in

Caudipteryx, feathered dinosaurs (Oviraptoridae family), and *Sapeornis* (an ancient bird of vague origin). Remains of a fish were found in the oral cavity of *Yanornis* (an ancient fan-tailed bird), mammalian bones were found inside of the skeleton of *Sinosauropteryx* (a small carnivorous dinosaur), and remains of a small dinosaur were found in mammal *Repenomamus*. Hence, these Chinese findings present the biota of this part of the world in all its diversity and demonstrate the ecological features of some of its representatives. It received the name of Jechol biota.

The geological age of these sediments, determined by the argon, uranium, and plumbum isotopes, is estimated as 110-130 mln years before. It was formed in fresh-water lakes and the adjacent river beds and deltas. It is known that deposits of this kind are highly prevalent in the extensive territory in many parts of China, Mongolia, in Southern Siberia, Korea, and Japan. Then why only Liaoning became a paleontological treasure area? The matter is that intense volcanic activity emerged in this region during the early Cretaceous. Periodical eruptions with potent discharge of ashes and release of toxic gases killed all that was living, and whole animals were buried under ash in the lake sediments. For example, hundreds, even thousands of the so-called holy bird of Confucius (*Confuciusornis sanctus*) were collected. However, it seems that the majority of them were sold for private collections.

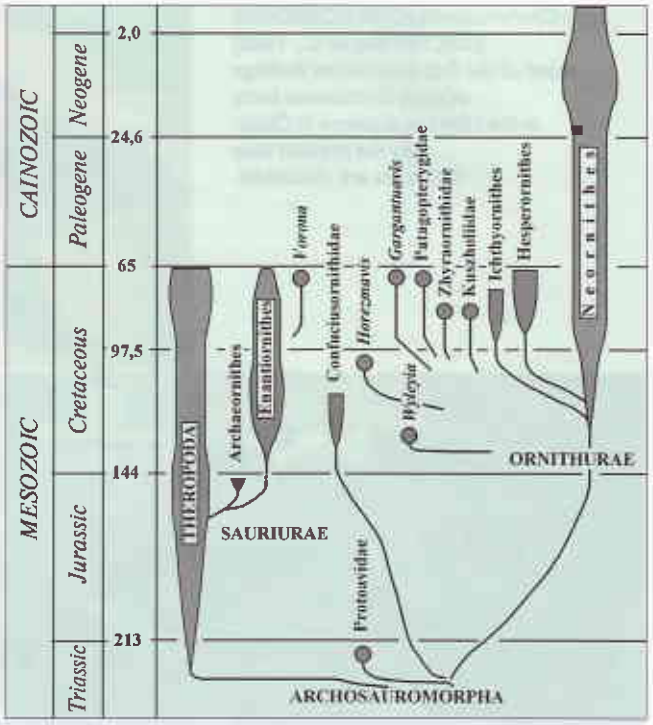


Chart of relationships between Theropod dinosaurs and various feathered creatures. It shows numerous attempts of archosauromorph descendants to conquer the air environment. Only one of them eventuated in flying for modern neornithine birds.

EVOLUTIONARY "GRASS-PLOT"

According to our hypothesis, various feathered creatures evolutionally transformed over tens of millions years in parallel, originating from various groups of reptiles (naturally, we inevitably simplify the evolutionary scheme, omitting the entire complex of actual facts published in scientific papers, but try to correctly present the essence of the hypothetical process). All this is supported by the data from other spheres of paleontology, as not only birds, but other main classes of vertebrates evolved according to a similar scheme.

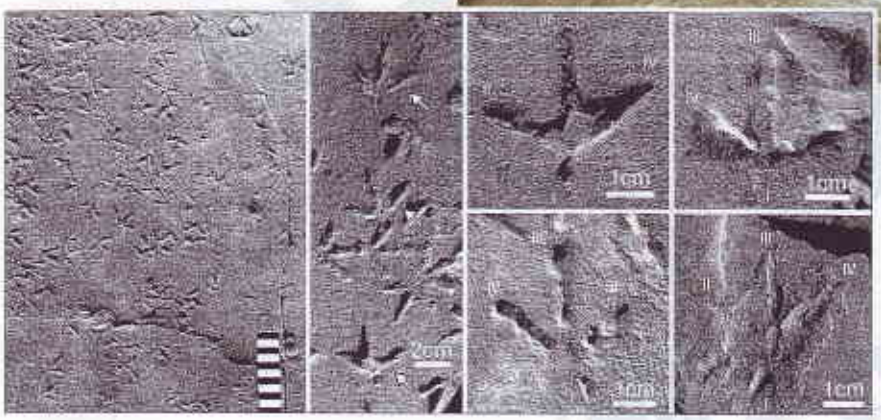
In the 1970s Leonid Tatarinov from our Institute (Academician since 1981) demonstrated at least 7 attempts of reptiles to transform into mammals; only one or two of these attempts were effective. For many millions of years, there existed several evolutionary lineages of mammals; Alexander Agadzhanyan, Dr. Sc. (Biol.) from our Institute, showed that only three of them survived till today: placental, marsupials, and monotremats. Studies headed by Academician Emilia Vorobyova (Severtsov Institute of Problems of Ecology and Evolution, Russian Academy of Sciences) in 1970-1990 showed that the ancient fishes not once attempted to come out from water to land. However, such attempts were characteristic of not only vertebrates. Various invertebrates also tried to become arthropods, which was shown in recent publications by Alexander Ponomarenko, Dr. Sc. (Biol.) from the Paleontological Institute. One more scientist from our Institute, Valentin Krasilov, Dr. Sc. (Geol. & Mineral.), showed in 1989 that proangiosperms* had made at least six attempts to transform into flowering plants, the majority of which can be seen today.

My colleague Ponomarenko called this evolution picture an evolutionary "grass-plot". Numerous separate stems develop in parallel on this "grass-plot". The majority of them disappear, being "cut away" by ecological and evolutionary mechanisms. And only some of them, usually situated at the periphery of evolving space, are retained, mature, give a "seed brush", and develop further.

But why, say, enanthiornithines became extinct, while the true fan-tailed birds progressively developed? Presumably, because enanthiornithines were too much in a hurry to become birds. We know the skeletons of their embryos from deposits of the upper Cretaceous in Mongolia, aged about 70 mln years. The skeleton was completely formed already in the egg. And the chickens pecked out as absolute copies of adult specimens. The only thing left for them was to grow up to full size, and they grew throughout their whole life. By contrast, in true fan-tailed birds, the nestlings, just like now, hatched out from eggs with a half-cartilaginous skeleton. Then it rapidly (within 2-4 months) ossified and its growth

* Proangiosperms are gymnospermous plants with elements of flowering plants.—*Ed.*

Footprint of Plesiornis (PLESIORNIS PILULATUS Hitchcock, 1858) from the lower Jurassic deposits in Poland.



Footprints and footprint tracks of small birds from the upper Triassic deposits in Argentina (Melchor et al., 2002).

ceased. Thus, enanthiornithines hatched out from eggs as fully formed feathered creatures and later lived the life of birds, sometimes, presumably, not utilizing all the possibilities offered by flight.

True birds rapidly attained the perfection of flying creatures during the postembryonal period and retained it throughout their whole life. Perhaps this was the main reason for which enanthiornithines lost the air space, while fan-tailed birds conquered it? Recently we described a unique finding: fossilized bird brain from the Senoman deposits (aged about 93 mln years) in the Volgograd Region. Sergei Savelyev, Dr. Sc. (Biol.), a specialist in animal central nervous system from the Institute of Human Morphology, Russian Academy of Medical Sciences, showed that the brain compartments responsible for mobility, intellectual activity, etc., were less developed in comparison with the respective compartments of modern birds. According to indirect data, such brain could belong to an enanthiornithine. Was it one more reason for their loss in competition with true birds?

HOW DID THEY FLY?

It was assumed previously that the origination of a feather and flight proper were inseparably linked together. Today, after discovery of various feathered Theropod dinosaurs and ancient birds we have to abandon this hypothesis. Hence, acquisition of feathering was due to some other reasons. Presumably, at first feathers protected the animals from cold or shielded their owners from strong ultraviolet solar radiation. It is impossible to fly having just soft covert feathers. Then, what is the origin of wiry long feathers on wings and tail? It is hypothesized that their initial elongation and enlargement in the precursors of birds and flying dinosaurs was caused by the formation of decorative structures, essential for mating demonstrations.

But how did they fly? Up to the present time, two hypotheses predominated. According to one, the "arboreal" one (with the direction "trees down"), the first flights were realized by the archosauromorphic ancestors of birds, living on the trees; the animals climbed up the trees, clutching to them with their fore-limbs, and then jumped down, after which started flying. According to the other hypothesis, "terrestrial", closely related to bird origination from dinosaurs, the vector of the flight was different: "Ground up!": they ran and ran, faster and faster, then jumped, and, finally flew. In any case, these were two-legged ancestors (bipedal, as we call them), moving solely on their hind limbs, while their fore-limbs were free from the supporting function. However, both hypotheses left much questions and misunderstanding, and hence, none could be adopted without amendments. For example, the claws on the fore-limbs (wings) of *Archaeopteryx*, enanthiornithines, and *Confuciusornis* are for some reason curved outwards. How could they hold to the tree with these claws? Their claws should have been curved inwards, so that they could clutch to the trunk.

Together with Igor Bogdanovich, Cand. Sc. (Biol.) from Shmalghausen Institute of Zoology (National

The succession of hypothetical stages of flight learning by modern birds:
I–bipedal terrestrial archosauromorph;
II–development of anisodactylia in an archosauromorphic ancestor of modern birds:
III–jumping to the lower branches of trees and bushes;
IV–steady sitting on roost during final formation of anisodactylia and initial reduction of long tail;
V and VI–emergence of feathers with symmetrical vanes on the distal segments of the fore-limbs and tail for mating demonstrations;
VII–formation of asymmetrical aerodynamic feathers on the wings and reduction of long tail;
VIII–transition to proper flapping flight.
Artist, O. Orekhova-Sokolova from reconstruction by E. Kurochkin, 2007.

An embryo of an enanthiornithine bird, detached from a fossil egg of the late Cretaceous age (Mongolia). It is clearly seen that its wing bones, scapulas, and skull were completely ossified, without cartilaginous fragments characteristic of true birds.

Academy of Sciences of Ukraine), we developed a compromise hypothesis on the origin of flight. The key factor (in addition to bipedalism) was the foot structure in birds and Theropod dinosaurs. The very first known early Cretaceous true birds had hind limbs of the anisodactylous type: with three fore-digits directed forward, while the right inner one opposite to them and directed backward. By the way, though no bird skeletons of the Triassic and Jurassic were found up to the present time, their footprints from late Triassic in Argentina and early Jurassic in Africa and Europe show this structure of the foot.

Next. The earliest known birds from the lower Cretaceous deposits had a fan-like tail: a short vertebral compartment with a short pigostyle (a series of terminal tail vertebrae grown together) with a fan of feathers on it. What did it offer to the early bird precursors or to birds? Having feet with this position of the digits, they could tightly clutch to the branches and support themselves without need to keep balance by the long tail. And gradually it disappeared, as there was no need in this posterior balancer, as in *Archaeopteryx* or feathered Theropod dinosaurs, which could not clutch to the branches tightly. The first digit in these creatures never reached a completely opposite position, and hence, they had to support themselves on the branches by balancing with their long tail. And, surely, they could not climb the trees by clutching to the trunks with their fore-limbs, as the claws on their digits were curved outwards. And what was the use of the claws directed in this way? We think, they were for clutching to the adjacent branches when the hind limbs support was unreliable, as the digits failed to encircle the branch completely. It is noteworthy that the earliest true fan-tailed birds had claws on the wing digits, but they were small and almost straight (not curved).

And how these early birds and Theropod dinosaurs, which strove to fly, got to trees? Presumably, they jumped to the lower branches and then moved up higher and higher. The former clung to the branches by their anisodactylous feet, while the latter assisted themselves by long wing digits with claws curved outwards.

Why both kind of creatures needed the trees? First of all, not for learning to fly. Flights started later, as a result of assimilation of the above-ground synfolium. Presumably, they started getting up in order to find new food sources. Or, maybe, escape from terrestrial predators during nights. Maybe, to build their nests there and thus save their clutches and breed from predators. Or for all these reasons.

With their short light tail and light skeleton, true birds, going down from the trees to the ground, fluttering with their primordial feathered wings, eventually flew properly, by flapping flight. Feathered dinosaurs, though they had long feathers on the wings and similar feathers on their hind limbs, most likely, failed to master a true flight, though became rather skilled "gliders".

And now we have to wait for just one finding: a little bird with an anisodactylous foot and a fan-tail in the Jurassic or, better, in late Triassic deposits. And there were such birds, but due to many reasons we have not found them yet. Remember: quite recently we knew almost nothing about the early Cretaceous stage in the history of birds. Let us admit, not only knew nothing. Some of the experts even did not believe that the true fan-tailed creatures existed at that time.

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Photos by the author

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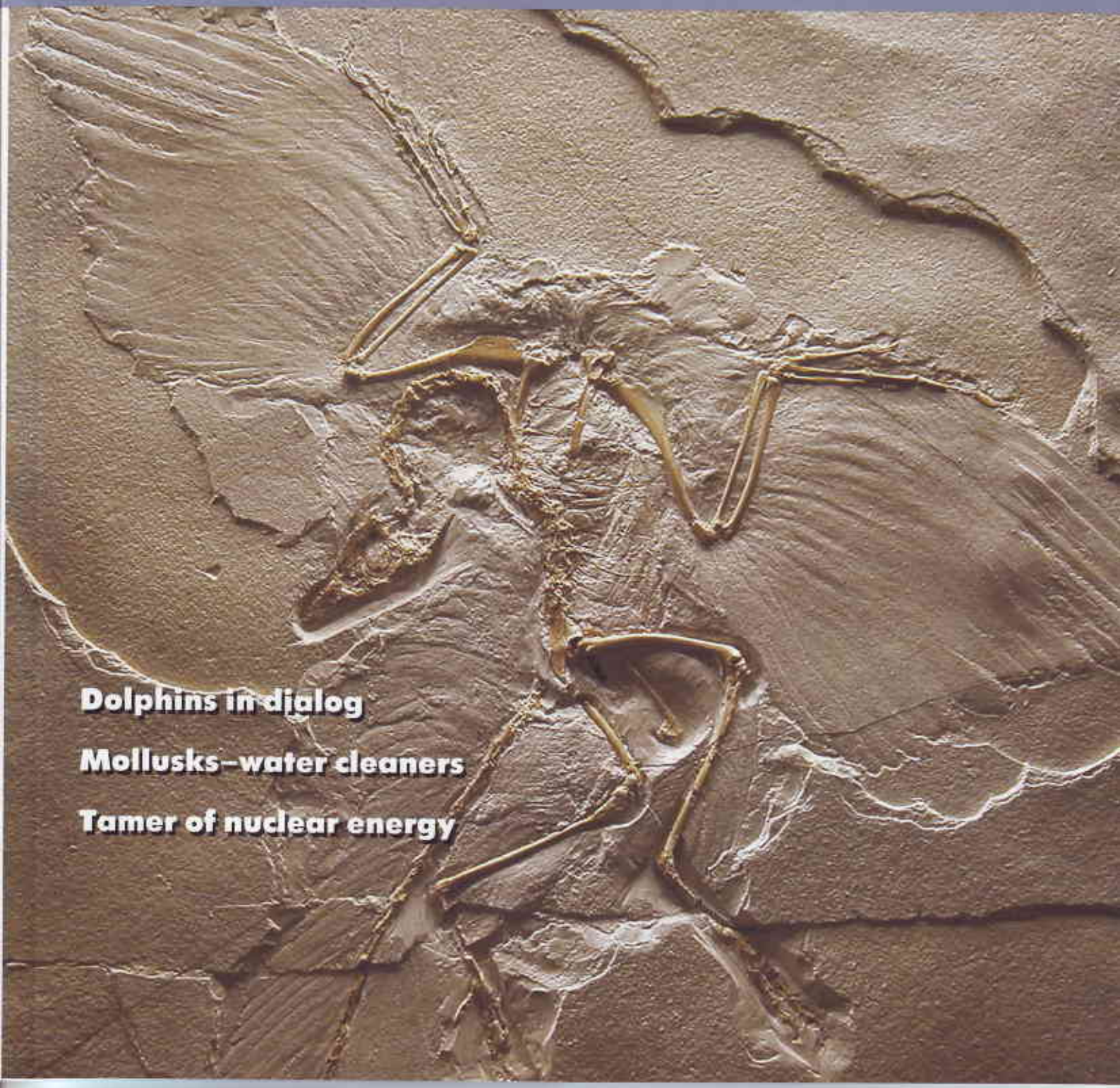

Dolphins in dialog

Mollusks–water cleaners

Tamer of nuclear energy