[chime plays]

[music plays]

[CLARKE (narration):] The animal kingdom is made up of major groups, recognized by key traits. Fish have fins. Some land animals have four legs, others six, and several different groups have wings. Biologists have long sought to discover how groups of animals, and their key features, evolved. And one of the greatest mysteries has been the origin of birds. Our world has more than 10,000 species of birds with feathered wings. Where did birds come from, and how did wings and feathers first arise? To find out, scientists have scoured the fossil record. … And they have uncovered surprising twists in the evolution of birds from their flightless ancestors.

[CLARKE (to camera):] In the past 30 years we've found a treasure trove of new fossil discoveries. They've made the origin of birds one of the best-documented transitions in the history of life.

[music plays]

[birds call]

[CLARKE (narration):] I am fascinated by birds. And as a paleontologist, I've spent my career chasing their evolutionary origins in the fossil record.

[CLARKE (to camera):] Above all else, what makes birds unique are their wings. They're made of feathers that are stiff yet flexible. And bird wings are even more remarkable than airplane wings, because they can flap, which allows them to maneuver rapidly and ultimately defy gravity.

[CLARKE (narration):] The quest to understand the origin of birds and other animals began in earnest over 150 years ago. When Charles Darwin wrote "The Origin of Species," he argued that every major group of animals evolved from a pre-existing one. He predicted that we would find fossils with features that linked one major group to another. In fact, he staked his theory of evolution on the existence of these intermediates. But no fossils were yet known that revealed these transitions. Then, just two years later, a marvelous creature was unearthed from a limestone quarry in Germany. The 150-million-year-old fossil, named *Archaeopteryx*, rocked the scientific world.

[CLARKE (to camera):] This *Archaeopteryx* fossil is truly remarkable. It preserves in fine detail feathers along the wing—just like those we see in living birds—and feathers along the tail. But the bony features tell a very different story. We look closely, we'll see teeth in the jaw, tiny claws preserved in a hand, and a long bony tail, lacking in living birds, but present in things we think of as traditionally reptilian. For Darwin, it must have been an incredible vindication. He predicted that we would find forms like these.

[CLARKE (narration):] *Archaeopteryx* pointed to a close link between birds and reptiles. But which group of reptiles? Flying pterosaurs had been discovered with light hollow bones. But their wings are constructed very differently than the wings of *Archaeopteryx* and birds.

[CLARKE (to camera):] Here is a tiny pterosaur, and if we take a closer look at its arm, we'll make out 3 small digits, and a fourth, which is really, really long.

[CLARKE (narration):] The membrane of a pterosaur's wing attaches to this fourth digit and along its body and hind limb. In contrast, the wings of Archaeopteryx and birds have only three digits. And their feathers attach individually along their arm and hand bones. These differences tell us that pterosaurs and *Archaeopteryx* evolved flight independently. *Archaeopteryx* must have descended from different reptiles. Thomas Huxley, Darwin's champion, was astonished by *Archaeopteryx*'s resemblance to a turkey-sized dinosaur called *Compsognathus*. *Compsognathus*' hand also had three digits. It had hollow bones and stood on two legs. Similarities like these led Huxley to propose that birds are related to the branch of reptiles called dinosaurs. But other scientists questioned this conclusion. Birds appeared so different from dinosaurs, and some characteristic features of birds—like wishbones—seemed to be missing from dinosaurs, but were present in other reptiles.

[HORNER:] We found an articulated foot …

[CLARKE (narration):] When paleontologist Jack Horner began his career, few thought that birds could have come from dinosaurs.

[CLARKE:] So Jack, why was it so hard to believe that birds and dinosaurs were related?

[HORNER:] Most of the dinosaurs that the public knew about were really big. Like, you know, this is a shoulder blade of a sauropod. And sauropods were gigantic.

[CLARKE (narration):] Scientists thought that dinosaurs were cold-blooded and slow-moving, like other reptiles.

[HORNER:] People couldn't imagine dinosaurs being agile and hopping around. They look at these big giant things and they lumber. There's no way to relate them to birds.

[music plays]

[CLARKE (narration):] Then, in 1963, John Ostrom discovered a fossil in the badlands of Montana that challenged that view.

[HORNER:] What John Ostrom first found was … was this claw. Obviously goes to a foot. It was not a claw for walking on. This dinosaur actually used that claw for slashing.

[CLARKE (narration):] *Deinonychus* was small with a delicate build. It ran upright on two legs. It had a long, stiff tail for balance. Not all dinosaurs were big and lumbering.

[HORNER:] Ostrom hypothesized that the animal would scale its prey and start using its slashing claw and probably eating the animal while it was alive.

[CLARKE (to camera):] Ostrom's discovery set off a revolution. What if dinosaurs weren't slow, but warm-blooded and fast-moving, like birds?

[CLARKE (narration):] When Ostrom compared *Deinonychus* to *Archaeopteryx*, he saw that they both had lightly-built, hollow bones. And they shared even more features, including long arms and similar hip and shoulder bones. Ostrom concluded that birds did descend from dinosaurs as Huxley had argued. Not from lumbering sauropods, but from another lineage called therapods that walked on two legs and included *T. rex* and agile predators like *Deinonychus*. While some scientists did not accept this idea at first, supporting evidence continued to accumulate, including the discovery that theropods had a feature of birds not previously found: a wishbone.

[HORNER:] People had sort of looked for them and really didn't know what it was going to look like. And then all of a sudden we started finding them. Here is the wishbone of *Tyrannosaurus rex*.

[CLARKE (narration):] When scientists analyzed the skeletons of theropods and birds, they found too many similarities for any explanation but common ancestry. Jack's collection at the Museum of the Rockies offers an opportunity to compare their features.

[HORNER:] Here is an Albertosaur tibia, and as you can see, it's hollow, just like a modern bird.

[CLARKE (to camera):] This is a *T. rex* foot. What we see here are three forward-facing digits that bear the weight of the animal, and in the back, a much smaller digit. If we take a look at this chicken foot, we'll see the same pattern. We've got three forward-facing digits and on the back, a much smaller one. All dinosaurs share an S-shaped neck. You can see it here and in living birds like this chicken.

[CLARKE (narration):] New kinds of evidence also emerged. In 1978, Jack made the surprising discovery of a vast dinosaur nesting ground.

[HORNER:] We discovered that dinosaurs nested in colonies, cared for their young, brought food to their babies. We also had evidence that they came back, probably over and over again, for many years to the same site.

[CLARKE (narration):] In a radical shift, by the 1980s, a consensus was finally building that birds descended from theropod dinosaurs—from active predators that walked on two legs. But scientists were about to discover the most startling evidence of all. In the mid-1990s, farmers in northeast China began unearthing dinosaurs 120 million years old. And these fossils preserved astonishing detail.

[CLARKE (to camera):] In 1996, I was a first-year graduate student at my first scientific meeting. They were passing around pictures of this dinosaur.

[CLARKE (narration):] This chicken-sized theropod, named *Sinosauropteryx*, did not have scales. It was covered in some primitive kind of feather.

[CLARKE (to camera):] To see those photos of a tiny, fuzzy dinosaur, … it just blew everybody's minds.

[CLARKE (narration):] This dinosaur was just the first of many fuzzy and feathered theropods to be uncovered. Another, called *Caudipteryx*, had feathers identical to living birds on its tail and hands, but lacked wings. With the discovery of these spectacular feathered finds, there was no longer any doubt that birds were related to theropods. But while feathered dinosaurs settled one question, they raised a new one: These animals could not fly. Why were they feathered?

[CLARKE (to camera):] It was long assumed that feathers evolved for flight. But what we found was that clearly feathers predate flight and arose for some other purpose.

[CLARKE (narration):] So why did the first feathers evolve? That's hard to tell from just the fossil evidence. But living birds may offer answers. Feathers provide insulation. So the first feathers might have helped keep dinosaurs warm. Birds also use colorful feathers in communication, in courtship and in territorial displays. Dinosaurs may have used feathers in the same way. Feathers likely played different roles at first, and then were modified for flight. The modification of an existing structure for a new use is called co-option. It is a common way that new structures and abilities evolve. Bird wings are modified forelimbs once used for grabbing and feeding. Just as the walking limbs of land animals are modified fins. And the turtle's shell is a modified ribcage. So the co-option of feathers for flight enabled Archaeopteryx and its relatives to take to the air. And other features also evolved.

[CLARKE (to camera):] When we look at evolution after the origin of flight, we see a lot of characteristics of living birds gradually accruing.

[CLARKE (narration):] But not in a simple linear sequence. Like other dinosaurs, this crow-sized bird had large claws on its hand, but like living birds, it had a toothless beak and a short bony tail. While this species had teeth, its hand bones were partially fused to form a stronger wing. And this bird had a large breastbone for well-developed flight muscles, like living birds. But it also had teeth.

[CLARKE (to camera):] We don't find forms that are somehow lock-step intermediate between *Archaeopteryx* and living birds; … we find a diversity of forms, forms we could not have predicted.

[CLARKE (narration):] For tens of millions of years, an assortment of scaly dinosaurs, feathered dinosaurs, and many types of birds lived together. Then, 66 million years ago, almost all of these creatures died out.

[rumble]

A six-mile wide asteroid slammed into the planet …

[explosion]

… and triggered a global mass extinction.

[music plays]

Only a small group of toothless birds survived, … and they evolved into the 10,000 species of birds we see today.

[bird calls, music]

We once might have said the dinosaurs all died out, but now we know that living birds are a lineage of theropod dinosaurs in the same way that we are a lineage of primates.

[HORNER:] Have dinosaurs gone extinct? Absolutely not. We separate dinosaurs into two groups now: the non-avian dinosaurs fortunately have gone extinct, and the avian dinosaurs are still alive, making it a beautiful world.

[music plays]

[CLARKE (to camera):] Dinosaurs are still with us. We just call them birds.

[music plays]

[bird calls]

[music plays]