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MADAGASCAR'S MESOZOIC SECRETS

THE WORLD'S FOURTH-LARGEST ISLAND DIVULGES FOSSILS THAT COULD REVOLUTIONIZE SCIENTIFIC VIEWS ON THE ORIGINS OF DINOSAURS AND MAMMALS

By John J. Flynn and André R. Wyss

THREE WEEKS INTO our first fossil-hunting expedition in Madagascar in 1996, we were beginning to worry that dust-choked laundry might be all we would have to show for our efforts. We had turned up only a few random teeth and bones—rough terrain and other logistical difficulties had encumbered our search. With our field season drawing rapidly to a close, we finally stumbled on an encouraging clue in the southwestern part of the island. A tourist map hanging in the visitor center of Isalo National Park marked a local site called "the place of animal bones." We asked two young men from a neighboring village to take us there right away.

Our high hopes faded quickly as we realized the bleached scraps of skeletons eroding out of the hillside belonged to cattle and other modern-day animals. This site, though potentially interesting to archaeologists, held no promise of harboring the much more ancient quarry we were after. Later that day another guide, accompanied by two dozen curious children from the village, led us to a second embankment similarly strewn with bones. With great excitement we spotted two thumb-size jaw fragments that were undoubtedly ancient. They belonged to long-extinct, parrot-beaked cousins of the dinosaurs called rhynchosaurs.

The rhynchosaur bones turned out to be a harbinger of a spectacular slew of prehistoric discoveries yet to come. Since then, the world's fourth-largest island has become a prolific source of new information about animals that walked the land during the Mesozoic era, the interval of the earth's history (from 250 million to 65 million years ago) when both dinosaurs and mammals were making their debut. We have unearthed the bones of primitive dinosaurs that we suspect are older than any found previously. We have also stirred up controversy with the discovery of a shrewlike creature that seems to defy a prominent theory of mammalian history by being in the "wrong" hemisphere. These exquisite specimens, among numerous others collected over five field seasons, have enabled us to begin painting a picture of ancient Madagascar and to shape our strategy for a sixth expedition this summer.

Much of our research over the past two decades has been aimed at unraveling the history of land-dwelling animals on the southern continents. Such questions have driven other paleontologists to fossil-rich locales in South Africa, Brazil, Antarctica and India. Rather than probing those established sites for additional finds, we were lured to Madagascar: the island embraces vast swaths of Mesozoic age rocks, but until recently only a handful of terrestrial vertebrate fossils from that time had been discovered there. Why? We had a hunch that no one had looked persistently enough to find them.

Persistence became our motto as we launched our 1996 expedition. Our team consisted of a dozen scientists and students from the U.S. and the University of Antananarivo in Madagascar. Among other benefits, our partnership with the country's leading university facilitated the acquisition of collecting and exporting permits—requisite components of all paleontological fieldwork. Before long, however, we ran headlong into logistical obstacles that surely contributed to earlier failures to find ancient fossils on the island. Mesozoic deposits in western Madagascar are spread over an area roughly the size of California. Generations of oxcarts and foot travel have carved the only trails into more remote areas, and most of them are impassable by even the brawniest four-wheel-drive vehicles. We had to haul most of our food, including hundreds of pounds of rice, beans and canned meats, from the capital. Fuel shortages sometimes seriously restricted mobility, and our work was even thwarted by wildfires, which occur frequently and rage unchecked. New challenges often arose unexpectedly, requiring us to adjust our plans on the spot.

Perhaps the most daunting obstacle we faced in prospecting such a large region was deciding where to begin. Fortunately, we were not planning our search blindly. The pioneering fieldwork of geologists such as Henri Besairie, who directed Madagascar's ministry of mines during the mid-1900s, provided us with large-scale maps of the island's Mesozoic rocks. From those studies we knew that a fortuitous combination of geologic factors had led to the accumulation of a thick blanket of sediments over most of Madagascar's western lowlands—and gave us good reason to believe that ancient bones and teeth might have been trapped and preserved there.

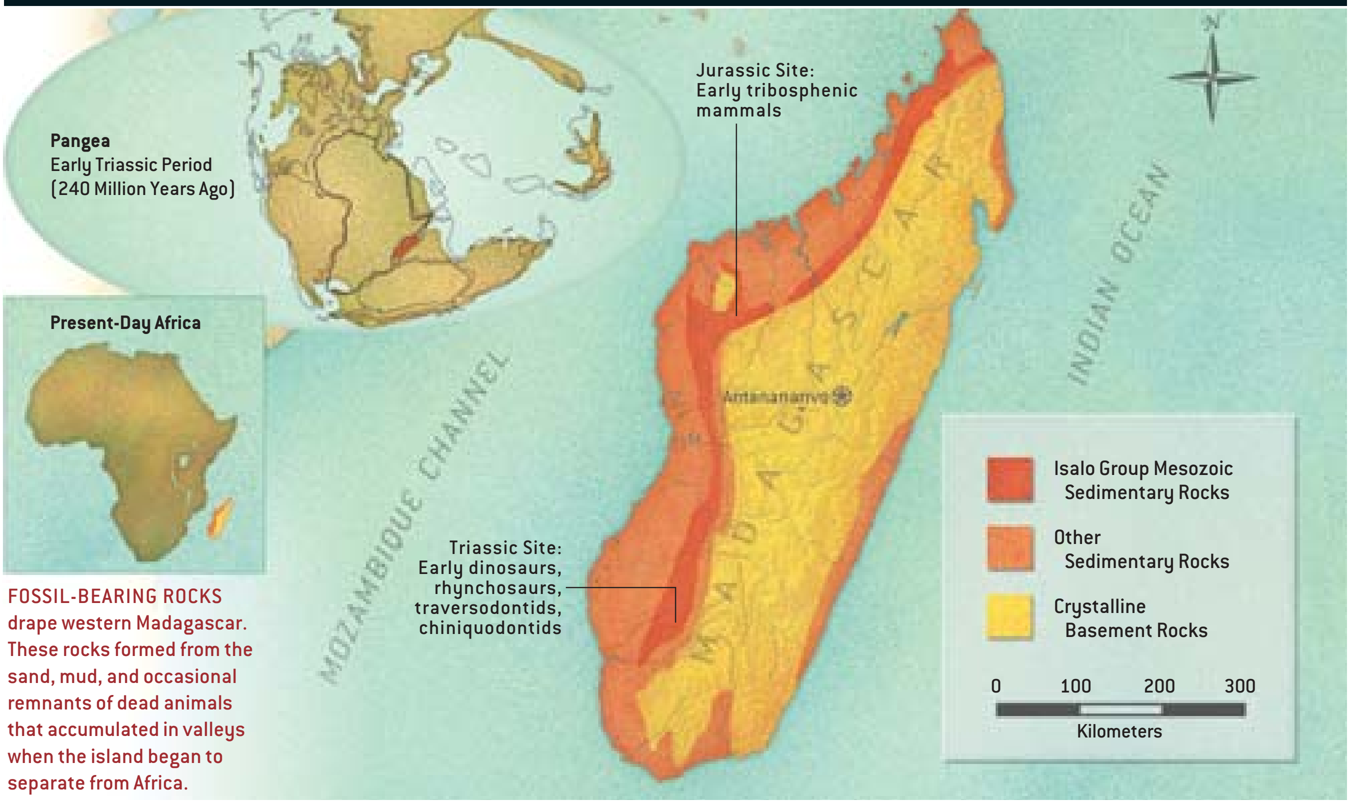
Mostly Mammals

AT THE DAWN OF THE MESOZOIC ERA 250 million years ago, it would have been possible to walk from Madagascar to almost anywhere else in the world. All of the planet's landmasses were united in the supercontinent Pangea, and Madagascar was nestled between the west coast of what is now India and the east coast of present-day Africa (*see map*). The world was a good deal warmer than at present—even the poles were free of ice. In the supercontinent's southern region, called Gondwana, enormous rivers coursed into lowland basins that would eventually become the Mozambique Channel, which today spans the 250 miles between Madagascar and eastern Africa.

These giant basins represent the edge of the geologic gash created as Madagascar began pulling away from Africa more than 240 million years ago. This seemingly destructive process, called rifting, is an extremely effective way to accumulate fossils. (Indeed, many of the world's most important fossil vertebrate localities occur in ancient rift settings—including the famous record of early human evolution in the much younger rift basins of east Africa.) The rivers flowing into the basins carried with them mud, sand, and occasionally the carcasses or bones of dead animals. Over time the rivers deposited this material as a sequence of vast layers. Continued rifting and the growing mass of sediment caused the floors of the basins to sink ever deeper. This depositional process persisted for nearly 100 million years, until the basin floors thinned to the breaking point and molten rock ascended from the planet's interior to fill the gap as new ocean crust.

Up to that point nature had afforded Madagascar three crucial ingredients required for fossil preservation: dead organisms, holes in which to bury them (rift basins), and material to cover them (sand and mud). But special conditions were also needed to ensure that the fossils were not destroyed during the subsequent 160 million years. Again, geologic circumstances proved fortuitous. As the newly separated landmasses of Africa and Madagascar drifted farther apart, their sediment-laden coastlines rarely experienced volcanic eruptions or other events that could have destroyed buried fossils. Also key for fossil preservation is that the ancient rift basins ended up on the western side of the island, which today is dotted with dry forests, grasslands and desert scrub. In a more humid environment, such deposits would have eroded

MADAGASCAR THEN AND NOW



FOSSIL-BEARING ROCKS drape western Madagascar. These rocks formed from the sand, mud, and occasional remnants of dead animals that accumulated in valleys when the island began to separate from Africa.

SARA CHEN

away or would be hidden under dense vegetation like the kind that hugs much of the island's eastern coast.

Initially Madagascar remained attached to the other Gondwanan landmasses: India, Australia, Antarctica and South America. It did not attain islandhood until it split from India about 90 million years ago. Sometime since then, the island acquired its suite of bizarre modern creatures, of which lemurs are the best known. For more than a century, researchers have wondered how long these modern creatures and their ancestors have inhabited the island. Illuminating discoveries by another team of paleontologists indicate that almost all major groups of living vertebrates arrived on Madagascar since sometime near the end of the Mesozoic era 65 million years ago [see "Modern-Day Mystery," on page 17]. Our own probing has focused on a more ancient interval of Madagascar's history—the first two periods of the Mesozoic era.

Pay Dirt

ONE OF THE JOYS OF WORKING in little-charted terrain has been that if we manage to find anything, its scientific significance is virtually assured. That's why our first discoveries near Isalo National Park were so exciting. The same evening in 1996 that we found the rhynchosaur jaw fragments, University of Antananarivo student Léon Razafimanantsoa spotted the six-inch-long skull of another interesting creature. We immediately identified the animal as a peculiar plant eater, neither mammal nor reptile, called a traversodontid cynodont.

The rhynchosaur jaws and the exquisite traversodontid skull—the first significant discoveries of our ongoing U.S.-Malagasy project—invigorated our expedition. The first fossil is always the hardest one to find; now we could hunker down and do the detailed collecting work necessary to begin piecing together an image of the past. The white sandstones we were excavating had formed from the sand carried by the rivers that poured into lowlands as Madagascar unhinged from Africa. Within these prehistoric valleys rhynchosaurs and traversodontids, both four-legged creatures ranging from three to 10 feet in length, probably grazed together much the same way zebras and wildebeests do in Africa today. The presence of rhynchosaurs, which are relatively common in coeval rocks around the world, narrowed the date of this picture to sometime within the Triassic period (the first of three Mesozoic time intervals), which spans from 250 million to 205 million years ago. And because traversodontids were much more diverse and abundant during the first half of the Triassic

THE AUTHORS

JOHN J. FLYNN and *ANDRÉ R. WYSS* have collaborated for nearly 20 years. Their expeditions have taken them to the Rocky Mountains, Baja California, the Andes of Chile, and Madagascar. Together they also study the evolutionary history of carnivores, including dogs, cats, seals, and their living and fossil relatives. Flynn is MacArthur Curator of Fossil Mammals at the Field Museum in Chicago, associate chair of the University of Chicago's committee on evolutionary biology doctoral program, and adjunct professor at the University of Illinois at Chicago. Wyss is a professor of geological sciences at the University of California, Santa Barbara, and a research associate at the Field Museum. The authors thank the National Geographic Society, the John C. Meeker family and the World Wildlife Fund for their exceptional support of this research.

than during the second, we thought initially that this scene played out sometime before about 230 million years ago.

During our second expedition, in 1997, a third type of animal challenged our sense of where we were in time. Shortly after we arrived in southwestern Madagascar, one of our field assistants, a local resident named Mena, showed us some bones that he had found across the river from our previous localities. We were struck by the fine-grained red rock adhering to the bones—everything we had found until that point was buried in the coarse white sandstone. Mena led us about half a mile north of the rhynchosaur and traversodontid site to the bottom of a deep gully. Within a few minutes we spotted the bone-producing layer from which his unusual specimens had rolled. A rich concentration of fossils was entombed within the three-foot-thick layer of red mudstones, which had formed in the floodplains of the same ancient rivers that deposited the white sands. Excavation yielded about two dozen specimens of what appeared to be dinosaurs. Our team found jaws, strings of vertebrae, hips, claws, an articulated forearm with some wrist bones, and other assorted skeletal elements. When we examined these and other bones more closely, we realized that we had uncovered remains of two different species of prosauropods (not yet formally named), one of which appears to resemble a species from Morocco called *Azendohsaurus*. These prosauropods, which typically appear in rocks between 225 million and 190 million years old, are smaller-bodied precursors of the long-necked sauropod dinosaurs, including such behemoths as *Brachiosaurus*.

When we discovered that dinosaurs were foraging among rhynchosaurs and traversodontids, it became clear that we had unearthed a collection of fossils not known to coexist anywhere else. In Africa, South America and other parts of the world, traversodontids are much less abundant and less diverse once dinosaurs appear. Similarly, the most common type of rhynchosaur we found, *Isalorhynchus*, lacks advanced characteristics and thus is inferred to be more ancient than the group of rhynchosaurs that is found with other early dinosaurs. What is more, the Malagasy fossil assemblage lacks remains of several younger reptile groups usually found with the earliest dinosaurs, including the heavily armored, crocodilelike phytosaurs and aetosaurs. The occurrence of dinosaurs with more ancient kinds of animals, plus the lack of younger groups, suggests that the Malagasy prosauropods are as old as any dinosaur ever discovered, if not older.

Only one early dinosaur site—at Ischigualasto, Argentina—contains a rock layer that has been dated directly; all other early dinosaur sites with similar fossils are thus estimated to be no older than its radioisotopic age of about 228 million years. (Reliable radioisotopic ages for fossils are obtainable only from rock layers produced by contemporaneous volcanoes. The Malagasy sediments accumulated in a rift basin with no volcanoes nearby.) Based on the fossils present, we have tentatively concluded that our dinosaur-bearing rocks slightly predate the Ischigualasto time span. And because prosauropods represent one of the major branches of the dinosaur evolu-

Tiny Bones to Pick

Paleontologists brave wildfires, parasites and scorching temperatures in search of ancient mammal fossils

By Kate Wong

THE THREE LAND ROVERS pause while John Flynn consults the device in his hand. "Is the GPS happy?" someone asks him. Flynn concludes that it is, and the caravan continues slowly through the bush, negotiating trails usually traversed by oxcart. We have been driving since seven this morning, when we left Madagascar's capital city, Antananarivo. Now, with the afternoon's azure sky melting into pink and mauve, the group is anxious to locate a suitable campsite. A small cluster of thatched huts comes into view, and Flynn sends an ambassador party on foot to ask the inhabitants whether we may camp in the area. By the time we reach the nearby clearing, the day's last light has disappeared and we pitch our tents in the dark. Tomorrow the real work begins.

The expedition team of seven Malagasies and six Americans, led by paleontologists Flynn and André Wyss of the Field Museum in Chicago and the University of California at Santa Barbara, respectively, has come to this remote part of northwestern Madagascar in search of fossils belonging to early mammals. Previous prospecting in the region had revealed red and buff-colored sediments dating back to the Jurassic period—the ancient span of time (roughly 205 million to 144 million years ago) during which mammals made their debut. Among the fossils unearthed was a tiny jaw fragment with big implications.

Conventional wisdom holds that the precursors of modern placental and marsupial mammals arose toward the end of the Jurassic in the Northern Hemisphere, based on the ages and locations of the earliest remains of these shrewlike creatures, which are characterized by so-called tribosphenic molars. But the Malagasy jaw, which Flynn and Wyss have attributed to a new genus and species, Ambondro mahabo, possesses tribosphenic teeth and dates back some 167 million years to the Middle Jurassic. As such, their fossil suggests that tribosphenic mammals arose at least 25 million years earlier than previously thought and possibly

FOUR-INCH-LONG MAMMAL *Ambondro mahabo* lived in Madagascar about 167 million years ago.

in the south rather than the north.

No one has disputed the age of A. mahabo, but not everyone agrees that the finding indicates that tribosphenic mammals originated in the south. Fossil-mammal expert Zhexi Luo of the Carnegie Museum of Natural History in Pittsburgh and several of his colleagues recently suggested that A. mahabo and a similarly surprising fossil beast from Australia named Ausktribosphenos nyktos might instead represent a second line of tribosphenic mammals—one that gave rise to the egg-laying monotremes. But Flynn and Wyss counter that some of the features that those researchers use to link the Southern tribosphenic mammals to monotremes may be primitive resemblances and therefore not indicative of an especially close evolutionary relationship.

As with so many other debates in paleontology, much of the controversy over when and where these mammal groups first appeared stems from the fact that so few ancient bones have ever been found. With luck, this season's fieldwork will help fill in some of the gaps in the fossil record. And recovering more specimens of A. mahabo or remains of previously unknown mammals could bolster considerably Flynn and Wyss's case for a single, Southern origin for the ancestors of modern placentals and marsupials.

The next morning, after a quick breakfast of bread, peanut butter and coffee, we are back in the vehicles, following the GPS's trail of electronic bread crumbs across the grassland to a fossil locality the team found at the end of last year's expedition. Stands of doum palms and thorny Mokonazy trees dot the landscape, which the dry season has left largely parched. By the time we reach our destination, the morning's pleasant coolness has given way to a rather toastier temperature. "When the wind stops, it cooks," remarks William Simpson, a collections manager for the Field Museum, coating his face with sunscreen. Indeed, noontime temperatures often exceed 90 humid degrees Fahrenheit.

Flynn instructs the group to start at the base of the hillside and work up. Meanwhile he and Wyss will survey the surrounding area, looking for additional exposures of the fossil-bearing horizon. "If it's something interesting, come back and get me," he calls. Awls in hand and eyes inches from the ground, the workers begin to scour the gravel-strewn surface for small bones, clues that delicate mammal fossils are preserved below. They crawl and slither in pursuit of their quarry, stopping only to swig water from sun-warmed bottles. Because early mammal remains are so minute (A. mahabo's jaw fragment, for example, measures a mere 3.6 millimeters in length), such sleuthing rarely leads to instant gratification. Rather the team collects sediments likely to contain such fossils and ships that material back to the U.S. for closer inspection. Within a few hours, a Lilliputian vertebra and femur fragment turn up—the first indications that the fossil hunters have hit pay dirt. "It's a big Easter egg hunt," Wyss quips. "The eggs are hidden pretty well, but we know they're out there."

By the third day the crew has identified a number of promising sites and bagged nearly a ton of sediment for screen washing. Members head for a dammed-up stream that locals use to water their animals. Despite the scorching heat, those working in the water must don heavy rubber boots and gloves to protect against the parasites that probably populate the murky green pool. They spend the next few hours sifting the sediments through screen-bottomed baskets and buckets. Wyss spreads the resulting concentrate on a big blue plastic tarp to dry. Volunteers at the Field Museum will eventually look for fossils in this concentrate under a microscope, one spoonful at a time, but Wyss has a good feeling about the washed remains already. "You can actually see bone in the mix," he observes. The haul that yielded A. mahabo, in contrast, offered no such hints to the naked eye.

Hot and weary from the screen washing, the researchers eagerly break for lunch. Under the shade of a Mokonazy tree, they munch their sardine, Gouda and jalapeño sandwiches, joking about the bread, which, four days after leaving its bakery in Antananarivo, has turned rather tough. Wyss ceremoniously deposits a ration of jelly beans into each pair of upturned palms. Some pocket the treats for later, others trade for favorite flavors, and a few ruefully relinquish their sweets, having lost friendly wagers made earlier.

Usually lunch is followed by a short repose, but today nature has a surprise in store. A brushfire that had been burning off in the distance several hours ago is now moving rapidly toward us from the northeast, propelled by an energetic wind. The crackling sound of flames licking bone-dry grass crescendos, and ashen leaf remnants drift down around us. We look on, spellbound, as cattle egrets collect in the fire's wake to feast on toasted insects, and birds of prey circle overhead to watch for rodents flushed out by the flames. Only the stream separates us from the blaze, but reluctant to abandon the screen washing, Flynn and Wyss decide to wait it out. Such fires plague Madagascar. Often set by farmers to encourage new grass growth, they sometimes spread out of control, especially in the tinderbox regions of the northwest. Indeed, the explorers will face other fires that season, including one that nearly consumes their campsite.

An hour later the flames have subsided, and the team returns to the stream to finish the screening quickly. Banks once thick with dry grass now appear naked and charred. Worried that the winds might pick up again, we pack up and go to one of the team's other fossil localities to dig for the rest of the afternoon.

Following what has already become the routine, we return to camp by six. Several people attend to the filtering of the drinking water, while the rest help to prepare dinner. During the "cocktail hour" of warm beer and a shared plate of peanuts, Flynn and Wyss log the day's events and catalogue any interesting specimens they've collected. Others write field notes and letters home by the light of their headlamps. By nine, bellies full and dishes washed, people have retired to their tents. Camp is silent, the end of another day's efforts to uncover the past.

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FRANK IPPOLITO (*opposite page*)

tionary tree, we know that the common ancestor of all dinosaurs must be older still. Rocks from before about 245 million years ago have been moderately well sampled around the world, but none of them has yet yielded dinosaurs. That means the search for the common ancestor of all dinosaurs must focus on a relatively poorly known and ever narrowing interval of Middle Triassic rocks, between about 240 million and 230 million years old.

Mostly Mammals

DINOSAURS NATURALLY ATTRACT considerable attention, being the most conspicuous land animals of the Mesozoic. Less widely appreciated is the fact that mammals and dinosaurs sprang onto the evolutionary stage at nearly the same time. At least two factors account for the popular misconception that mammals arose only after dinosaurs became extinct: Early mammals all were chipmunk-size or smaller, so they don't grab the popular imagination in the way their giant Mesozoic contemporaries do. In addition, the fossil record of early mammals is quite sparse, apart from very late in the Mesozoic. To our delight, Madagascar has once again filled in two mysterious gaps in the fossil record. The traversodontid cynodonts from the Isalo deposits reveal new details about close mammalian relatives, and a younger fossil from the northwest side of the island poses some controversial questions about where and when a key advanced group of mammals got its start.

The Malagasy traversodontids, the first known from the island, include some of the best-preserved representatives of early cynodonts ever discovered. ("Cynodontia" is the name applied to a broad group of land animals that includes mammals and their nearest relatives.) Accordingly, these bones provide a wealth of anatomical information previously undocumented for these creatures. These cynodonts are identified by, among other diagnostic features, a simplified lower jaw that is dominated by a single bone, the dentary. Some specimens include both skulls and skeletons. Understanding the complete morphology of these animals is crucial for resolving the complex evolutionary transition from the large cold-blooded, scale-covered animals with sprawling limbs (which dominated the continents prior to the Mesozoic) to the much smaller warm-blooded, furry animals with an erect posture that are so plentiful today.

Many kinds of mammals, with many anatomical variations, now inhabit the planet. But they all share a common ancestor marked by a single, distinctive suite of features. To determine what these first mammals looked like, paleontologists must examine their closest evolutionary relatives within the Cynodontia, which include the traversodontids and their much rarer cousins, the chiniquodontids (also known as probainognathians), both of which we have found in southwestern Madagascar. Traversodontids almost certainly were herbivorous, because their wide cheek teeth are designed for grinding. One of our four new Malagasy traversodontid species also has large, stout, forward-projecting incisors for grasping vegetation. The chiniquodontids, in contrast, were undoubtedly carnivorous, with sharp, pointed teeth. Most paleontologists agree that some chiniquodontids share a more recent common ancestor with mammals than the herbivorous traversodontids do. The chiniquodontid skulls and skeletons we found in Madagascar will help reconstruct the bridge between early cynodonts and true mammals.

Not only are Madagascar's Triassic cynodonts among the best preserved in the world, they also sample a time period that is poorly known elsewhere. The same is true for the

Modern-Day Mystery

MADAGASCAR IS FAMOUS for its 40 species of lemurs, none of which occurs anywhere else in the world. The same is true for 80 percent of the island's plants and other animals. This biotic peculiarity reflects the island's lengthy geographic isolation. (Madagascar has not been connected to another major landmass since it separated from India nearly 90 million years ago, and it has not been joined with its nearest modern neighbor, Africa, since about 160 million years ago.) But for decades the scant fossil evidence of land-dwelling animals from the island meant that little was known about the origin and evolution of these unique creatures.

While our research group was probing Madagascar's Triassic and Jurassic age rocks, teams led by David W. Krause of the State University of New York at Stony Brook were unearthing a wealth of younger fossils in the island's northwestern region. These specimens, which date back some 70 million years, include more than three dozen species, none of which is closely related to the island's modern animals. This evidence implies that most modern vertebrate groups must have immigrated to Madagascar after this point.

The best candidate for a Malagasy motherland is Africa, and yet the modern faunas of the two landmasses are markedly distinct. Elephants, cats, antelope, zebras, monkeys and many other modern African mammals apparently never reached Madagascar. The four kinds of terrestrial mammals that inhabit the island today—rodents, lemurs, carnivores and the hedgehoglike tenrecs—all appear to be descendants of more ancient African beasts. The route these immigrants took from the mainland remains unclear, however. Small clinging animals could have floated from Africa across the Mozambique Channel on "rafts" of vegetation that broke free during severe storms. Alternatively, when sea level was lower these pioneers might have traveled by land and sea along a chain of currently submerged highlands northwest of the island.

Together with Anne D. Yoder of Northwestern University Medical School and others, we are using the DNA structure of modern Malagasy mammals to address this question. These analyses have the potential to reveal whether the ancestors of Madagascar's modern mammals arrived in multiple, long-distance dispersal events or in a single episode of "island hopping." —*J.J.F. and A.R.W.*

FRANK IPPOLITO (*opposite page*)

LIVING IN MIXED COMPANY

PALEONTOLOGISTS DID NOT KNOW until recently that the unusual group of ancient animals shown above—prosauropods (*1*), traversodontids (*2*), rhynchosaurs (*3*) and chiniquodontids (*4*)—once foraged together. In the past six years, southwestern Madagascar has become the first place where bones of each particular type of animal have been unearthed alongside the others, in this case from Triassic rocks about 230 million years old. Then the region was a lush, lowland basin that was forming as the supercontinent Pangea began to break up. The long-necked prosauropods here, which represent some of the oldest dinosaurs yet discovered, browse on conifers while a parrot-beaked rhynchosaur prepares to sip from a nearby pool. The prosauropod teeth were spear-shaped and serrated—good for slicing vegetation; rhynchosaurs were perhaps the most common group of plant eaters in the area at that time. Foraging among these large reptiles are the peculiar traversodontids and chiniquodontids. Both types of creatures are early members of the Cynodontia, a broad group that includes today's mammals. The grinding cheek teeth of the traversodontids suggest they were herbivores; the chiniquodontids sport the sharp, pointed teeth of carnivores. —*J.J.F. and A.R.W.*

youngest fossils our expeditions have uncovered—those from a region of the northwest where the sediments are about 165 million years in age. (That date falls within the middle of the Jurassic, the second of the Mesozoic's three periods.) Because these sediments were considerably younger than our Triassic rocks, we allowed ourselves the hope that we might find remains of an ancient mammal. Not a single mammal had been recorded from Jurassic rocks of a southern landmass at that point, but this did nothing to thwart our motivation.

Once again, persistence paid off. During our 1996 field season, we had visited the village of Ambondromahabo after hearing local reports of abundant large fossils of the sauropod dinosaur *Lapperentosaurus*. Sometimes where large animals are preserved, the remains of smaller animals can also be found—though not as easily. We crawled over the landscape, eyes held a few inches from the ground. This uncomfortable but time-tested strategy turned up a few small theropod dinosaur teeth, fish scales and other bone fragments, which had accumulated at the surface of a small mound of sediment near the village.

These unprepossessing fossils hinted that more significant items might be buried in the sediment beneath. We bagged about 200 pounds of sediment and washed it through mosquito-net hats back in the capital, Antananarivo, while waiting to be granted permits for the second leg of our trip—the leg to the southwest that turned up our first rhynchosaur jaws and traversodontid skull.

During the subsequent years back in the U.S., while our studies focused on the exceptional Triassic material, the tedious process of sorting the Jurassic sediment took place. A dedicated team of volunteers at the Field Museum in Chicago—Dennis Kinzig, Ross Chisholm and Warren Valsa—spent many a weekend sifting through the concentrated sediment under a microscope in search of valuable flecks of bone or teeth. We didn't think much about that sediment again until 1998, when Kinzig relayed the news that they had uncovered the partial jawbone of a tiny mammal with three grinding teeth still in place. We were startled not only by the jaw's existence but also by its remarkably advanced cheek teeth. The shapes of the teeth document the earliest occurrence of Tribosphenida, a group encompassing the vast majority of living mammals. We named the new species *Ambondro mahabo*, after its place of origin.

The discovery pushes back the geologic range of this group of mammals by more than 25 million years and offers the first glimpse of mammalian evolution on the southern continents during the last half of the Jurassic period. It shows that this subgroup of mammals may have evolved in the Southern Hemisphere rather than the Northern, as is commonly supposed. Although the available information does not conclusively resolve the debate, this important addition to the record of early fossil mammals does point out the precarious nature of long-standing assumptions rooted in a fossil record historically biased toward the Northern Hemisphere [see "Tiny Bones to Pick," by Kate Wong, on page 13].

Although our team has recovered a broad spectrum of fossils in Madagascar, scientists are only beginning to describe the Mesozoic history of the Southern continents. The number of species of Mesozoic land vertebrates known from Australia, Antarctica, Africa and South America is probably an order of magnitude smaller than the number of contemporaneous findings from the Northern Hemisphere. Clearly, Madagascar now ranks as one of the world's top prospects for adding important insight to paleontologists' knowledge of the creatures that once roamed Gondwana.

Planning Persistently

OFTEN THE MOST SIGNIFICANT HYPOTHESES about ancient life on the earth can be suggested only after these kinds of new fossil discoveries are made. Our team's explorations provide two cases in point: the fossils found alongside the Triassic prosauropods indicate that dinosaurs debuted earlier than previously recorded, and the existence of the tiny mammal at our Jurassic site implies that tribosphenic mammals may have originated in the Southern, rather than Northern, Hemisphere. The best way to bolster these proposals (or to prove them wrong) is to go out and uncover more bones. That is why our primary goal this summer will be the same as it has been for our past five expeditions: find as many fossils as possible.

Our agenda includes digging deeper into known sites and surveying new regions, blending risky efforts with sure bets. No matter how carefully formulated, however, our plans will be subject to last-minute changes, dictated by such things as road closures and our most daunting challenge to date, the appearance of frenzied boomtowns.

During our first three expeditions, we never gave a second thought to the gravels that overlay the Triassic rock outcrops in the southwestern part of the island. Little did we know that those gravels contain sapphires. By 1999 tens of thousands of people were scouring the landscape in search of these gems. The next year all our Triassic sites fell within sapphire-mining claims. Those areas are now off limits to everyone, including paleontologists, unless they get permission from both the claim holder and the government. Leaping that extra set of hurdles will be one of our foremost tasks this year.

Even without such logistical obstacles slowing our progress, it would require uncountable lifetimes to carefully survey all the island's untouched rock exposures. But now that we have seen a few of Madagascar's treasures, we are inspired to keep digging—and to reveal new secrets.

MORE TO EXPLORE

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