

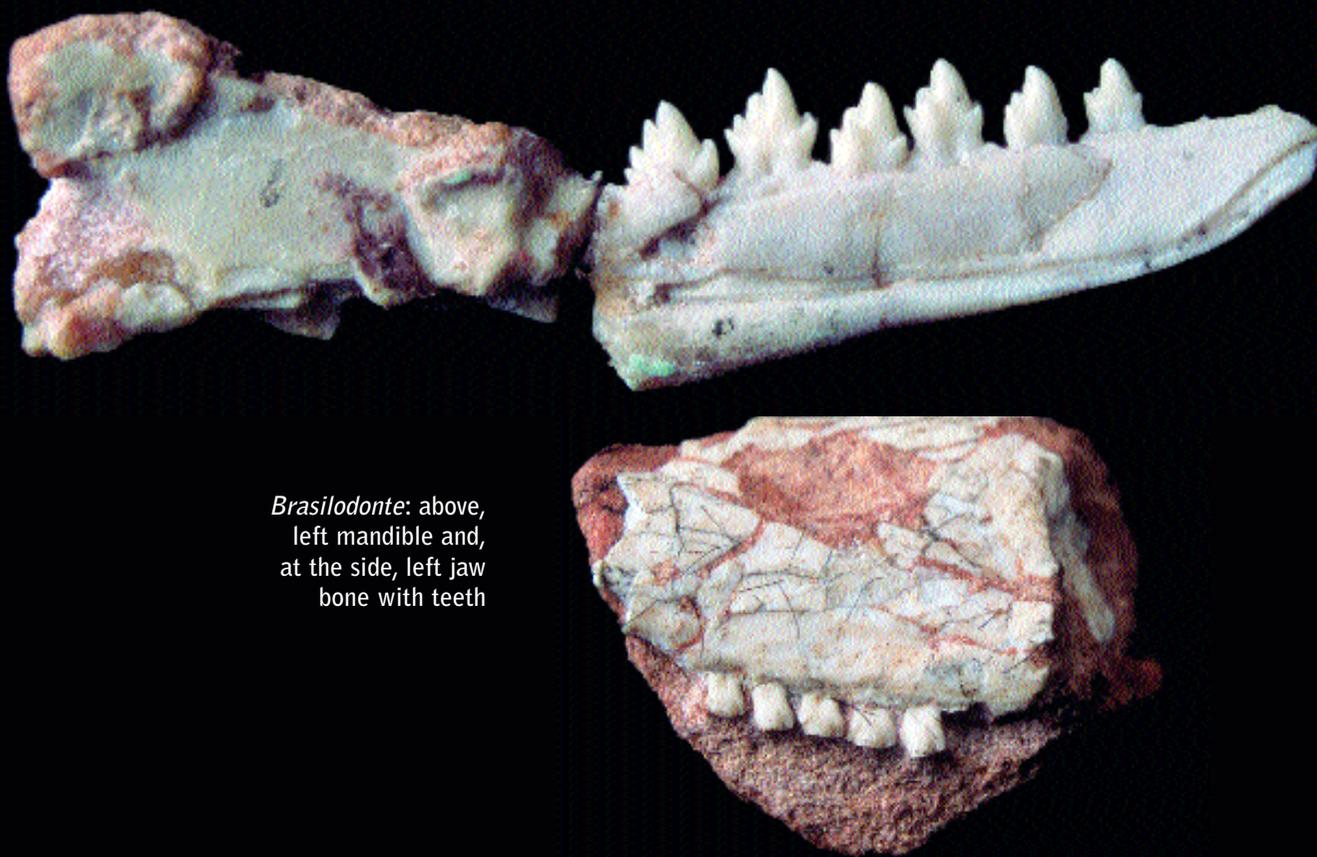
The origin of mammals

Fossils of small species discovered
in Rio Grande do Sul could be the closest
ancestors to the larger animals of today

MARCOS PIVETTA



Rocks from the Triassic period, with fossils of animals that lived around 210 million years ago: relatives of the mammals



Brasilodonte: above, left mandible and, at the side, left jaw bone with teeth

Any paleontologist will tell you that the mammals descended from some form of cynodont, a vast group of animals – extinct, just like the dinosaurs – characterized by having craniums and teeth similar to those of our current dogs. The cynodonts belong to the group of synapsids, which served as the transition between the reptiles and the mammals. What has been missing is to know what lineage of the cynodont generated, around 210 million years ago (more or less during the time that the dinosaurs came into being), the first beings with the bone characteristics that define a mammal today: four types of teeth functionally and anatomically differentiated, middle ear with three sound conducting ossicles and a larger more protruding cranium. As pioneers of bringing together these bone traits and probably being warm blooded, as well as having a hairy body and glands for the production of milk for their offspring, these animals were the primordial examples of the future mammals, among them man. Perhaps it will never be precisely determined which species of cynodont took the final step in the direc-

tion of mammals, but paleontologists from the Federal University of Rio Grande do Sul (UFRGS) and the Argentinean Museum of Natural Sciences believe that they have found important pieces to this phylogenetic puzzle.

Starting from the analysis of various fossil fragments of small reptiles – of the size of a pen and similar to rats

or wild squirrels – recovered over the last two years in the region of Santa Maria, at around 200 kilometers from the city of Porto Alegre, the capital of state of Rio Grande do Sul, the researchers have identified two new cynodonts – which they have provisionally named *Brasiliterio* and *Brasilodonte* – with anatomical characteristics that



SIRIO J. B. CANCADO



Cranium and mandible of *Brasiliterio*: the second species to have been discovered



Rock with the teeth of the *Brasiliterio*: white marks to the right



MARK A. KLINGER/CMNH

Hadrocodium and its cranium: the oldest representative of today's mammals

would place them as the ancestors closest to the primordial mammals. “These pre-mammalian reptiles from Brazil could be a sister group to the mammals”, says the renowned Argentinean paleontologist José Bonaparte, 73 years of age, who discovered the petrified bones of the two species together with researchers from the Institute of Geosciences of UFRGS, at which the researcher is a visitor with a scholarship from the National Council for Scientific and Technological Development (CNPq). “These animals, removed from the rocks of the Upper Triassic period – with a geological age estimated at between 230 and 205 million of years ago –, were not mammals, but their evolution was clearly in that direction.” For this reason they received names that place them in this animal group. *Brasiliterio* means “mammal from Brazil”, whilst the *Brasilodonte* has the teeth (odon) of a mammal and its post-canines, used for crushing, form four right angles.

The majority of the fossils found are complete or partial craniums, with preserved mandibles and teeth. Other bones have been rescued, but not an entire skeleton. Just this month, researchers from UFRGS and technicians

from the Argentinean museum returned to the region of Santa Maria in search of more fossils.

The comparison of the forms of the cranium, mandible and teeth of these animals with those of the *Morganucodon* – one of the oldest known mammals (close to 200 million years) with fossil material of good quality and that had fifteen centimeters in length and looked like a wild rat – has turned the southern Brazilian findings into strong candidates of being the best representatives of the cynodonts lineage that ended up in mammals. “The cynodonts of Rio Grande do Sul show a type of carnivore-insectivore dentition, above all in the mandible, comparable to the first mammals”, says Bonaparte. He believes that the *Brasiliterio* produced descendants which, generation later, could have led both to the primordial mam-

mal *Morganucodon* and to the *Brasilodonte*, an animal with a greater number of characteristics of a mammal. In other words, the lineage of the *Brasiliterio* could have been the ancestor both of synapsids very close to the mammals, and to the first mammals themselves.

Brother group - For now, the fossils of the *Brasiliterio* do not appear to be sensitive to the analyses as profound as those carried out on the *Brasilodonte*, and the researchers have not gone as far as labeling the mini cynodonts from Rio de Grande do Sul as the father of all the mammals. Instead of emphasizing the notion of a paternal and filial lineage, they prefer a concept more precise from the scientific point of view: that of a brother group. If their theories prove to be correct, the *Brasilodonte* and the *Brasiliterio* should take the place of two families of small cynodonts, the tritylodontids and the tritheledontids (also called ictidosaur), found in various parts of

The *tecodino* of Santa Maria

The region of Santa Maria, in the center of the State of Rio Grande do Sul, does not only provide interesting fossils of mini cynodonts that can help to explain the origin of the mammals. From there, there has also come vestiges of the bones of extinct animals of the Triassic period that inhabited the earth between 250 and 205 million years ago. A famous fossil removed from the rocks of the region, for example, is named *Staurikosaurus pricei*, one of the oldest dinosaurs recovered in the world, whose skeleton, discovered in 1937, is on exhibition at the Museum of Comparable Zoology of Harvard in the United States.

More recently, paleontologists from a state institution – the Mu-

seum of Natural Sciences of the Zoobotany Foundation of Rio Grande do Sul –, which in 1998 had already participated in the discovery of the first pre-mammal mini cynodonts in the hinterland of Santa Maria, made another startling discovery: they found rich fossil material of a mysterious animal, informally called for now the *tecodino*.

What could this creature have been? The paleontologist Jorge Ferigolo, from the Foundation, still does not know precisely if the petrified bones found in the municipality of Dona Francisca – a complete skeleton, two entire craniums, two partially preserved craniums and four backbones almost intact, as well as parts of a skele-

ton that seems to be a young example of an enigmatic animal – belonging to the thecodonts, ancestors of the dinosaurs or to the dinosaurs themselves. Or perhaps of an animal that was a transition between two types of reptiles, a hypothesis that inspired the provisional name of *tecodino*. “We still have to prepare the majority of the fossils – to clean and to separate out the petrified bones encrusted in the rock – and to study them with care”, advised Ferigolo.

Though little material has so far been prepared, the fossil fragments of the *tecodino* that have already been cleaned, reinforce the hypothesis that they are dealing with a hybrid species, with some characteristics of the thecodont and others of the dinosaur. The mysterious animal – that lived some 235 million years ago and should be a

Schultz (left) and Bonaparte (with tie) with UFRGS paleontologists; fertile land

the world and that have battled for some time the elite position of being the brother group closest to animals with hair and warm blood. “Our findings could assist in better understanding the origin of the mammals and to show which lineages of the cynodonts participated in the process of transition of the synapsids in the direction towards this type of animal”, comments the paleontologist Cesar Schultz, of UFRGS, co-author of Bonaparte’s studies on the Gaucho pre-mammal mini synapsids.

With an appearance and dimensions similar to those of the *Morganucodon*, the new cynodonts measured between 9 and 15 centimeters from head to the end of their tail and the length of its cranium varied between 18 and 22 millimeters. Their weight would not have been more than a few hundred grams. The Brasilodonte was about 40% larger than the Brasiliterio. “These animals probably ate insects



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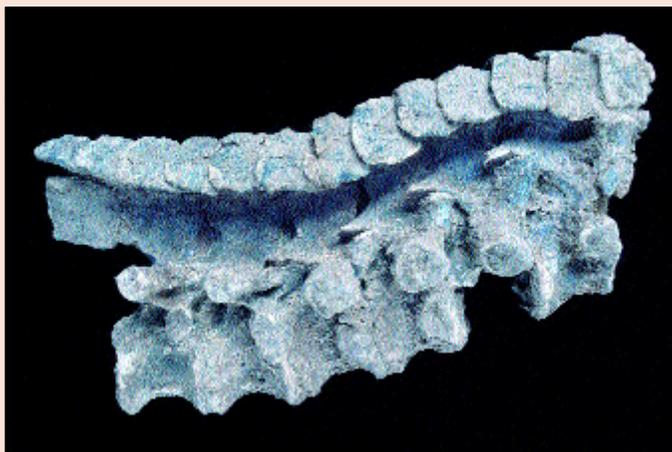
and other smaller animals, lived in burrows and had night habits”, says Schultz. They must already have had its body covered with hair, and its paws were strong enough for it to open up burrows in the ground where it sheltered from predators such as the first dinosaurs and other reptiles. The remains of this as yet poorly known mini-fauna

were removed from rocks in paleontologist sites in the Gaucho municipalities of Faxinal do Soturno and Candelária, belonging to the Santa Maria Formation, one of the areas in the State with Triassic sedimentary rocks – an agitated geological period of little more than 40 million years, that occurred between 250 and 205 million years ago.

biped of around 2.5 meters in total length – reveals lots of characteristics of having had a backbone that is more or less typical of the dinosaurs. However, they have not as yet been able to determine if its articulation with the femur, in the pelvis, is perforated, a trait characteristic of the dinosaurs.

The thecodont side of the animal shows itself in the bone plates that seem to have existed below its skin, more or less as it occurs today in the crocodiles, called osteoderms. Although it had been hoped that they would show these bone plates, so as to place in on

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Bone plates of the backbone of the *tecodino*: a transition species

the evolutionary scale close to the thecodonts, the oldest types of dinosaurs, of the age of the *tecodino*, apparently don't have them. The osteoderms became more common in later dinosaurs.

The region of Santa Maria is so rich in fossil remains that the government of Rio Grande do Sul, by way of the Pro-Guaíba Program, which is carrying out a survey of the potential of this hydrographic basin, has already proposed the creation of a Paleontology Park in the surroundings of the town of Candelária. "The chosen area is already in the phase of being bought over", explains the paleontologist Ana Maria Ribeiro from the Foundation.

Besides making a comparison of the anatomy of the Rio de Grande do Sul cynodonts with the primordial mammal *Morganucodon*, the group confronted their findings with the morphology of the Chinese mammal *Hadrocodium wui*, which lived some 195 million years ago and was also similar to a small rat. Result: the upper teeth of the Brasilodonte and of the Brasiliterio resemble those of the Chinese fossil, whose lowermost teeth measure a total length of two centimeters. The feeling from the comparison comes from the fact that, though animals of the type of *Morganucodon* are considered to be the first mammals, one does not know with certainty if its descendants generated the current existing lineages. This origin, it would appear, is more probably related to a mammal of the type such as *Hadrocodium*.

The object of a cover article of the North American magazine *Science* in May of last year, this Asian little animal is considered the potential common ancestor of the three current groups of mammals (a fourth group, that of the multituberculates, has been extinct for 40 million years): the monotremes, which lay eggs and are represented by the duckbill platypus and by two speci-

es of echidna, similar to a hedgehog; the marsupials, such as the possum, the kangaroo and the koala bear, which house and feed their young in a skin pouch; and the placental, more numerous, which include the rodents and elephants, passing through the primates, amongst which there is man. To compare the new Rio Grande do Sul fossils with the *Hadrocodium*, the most distant descendant of all of the living mammals up until now localized, is a manner of asserting if the Brasiliterio and the Brasilodonte also do not guard some relationship, however remote, with the current animals of hair and warm blood.

The discoveries have not as yet been formally published, which should occur during this year. In April of 2001, at an informal meeting with researchers from North America at the Museum of Comparative Zoology of Harvard, Bonaparte demonstrated some of the fossils and discussed their peculiarities and the importance of these new species. He stated that the receptivity of his fellow colleagues was good. The proposal that the mini cynodonts from Rio Grande

do Sul are the closest parents known to the mammals might appear daring, but Bonaparte – who for the last seventeen years has had the financial support of the *North American National Geographic Society* for his field work – has the credentials to defend the hypothesis.

With more than four decades of research, Bonaparte is one of the best specialists on dinosaurs in the world. Thanks to his work, above all in the Argentinean Patagonia, more than twenty species of dinosaurs typical of the southern hemisphere have been discovered, among them the *Amargasaurus*, the *Argentinosaurus* (perhaps the largest in the world with up to twelve meters in height), the *Saltasaurus* and the *Carnotaurus*. This last one, a carnivore of 3.5 meters in height, 7.5 meters in length and with two horns, transformed itself into an animated movie personality – in the children's film *Dinosaur*, launched in 2000 by Disney.

More recently, and without abandoning the dinosaurs, Bonaparte began to study the ancestors of the mammals, which appeared on Earth at the time as these large reptiles and that lived discretely under their shadow for 160 million years. In the Argentine, he found fossils of small synapsids with

mammiferous traces, that could be labeled as distant cousins of *Morganucodon*. “However, these fossils were of the Lower to Middle Triassic era, between 250 and 230 million years ago”, he ponders. His hope of finding advanced cynodonts, which would make the link between reptiles and mammals, consequently made him move to the South of Brazil, more specifically to the Rio Grande do Sul rocks of the Upper Triassic period.

In the middle of 1997, Bonaparte came to work at the Museum of Natural Sciences of the Zoo-botany Foundation of Rio Grande do Sul, in Porto Alegre, famous by its research in the area of paleontology. One year later, at the side of two researchers from the foundation, Jorge Ferigolo and Ana Maria Ribeiro, he gathered together numerous fossil fragments of a new advanced cynodont, named *Riograndia guai-bensis*, in rocky outcrops of Candelária, and described the animal in a scientific paper published in 2001 on the British magazine *Palaeontology*.

A possible ancestor of Brasiliterio and Brasilodonte, the *Riograndia* could not have mammals as its descendants. “Its teeth are different”, explains the paleontologist Marina Bento Soares from UFRGS. Nevertheless, the localization of lots of petrified remains of this species confirmed the clues that it was worth while exploring the soil of Candelária and of its surroundings. “The fossil potential of the region is extremely high”, comments Ana Maria Ribeiro, who continues to study the pre-mammals of the Rio Grande do Sul Triassic period parallel to the work of Bonaparte, today based at UFRGS. Encrusted and sometimes found in the middle of the reddened rocky sediments of the Santa Maria Formation, the bony remains of these diminutive pre-mammal reptiles are difficult to locate by the untrained eye.

Privileged location - The clue to a petrified bone generally does not go beyond a white point – as it contains calcium which is of this color – of the size of a match head on the surface of the



MIGUEL BOYVAN

Cleaning a Fossil: care and patience

rock. “We were used to looking for fossils of larger reptiles such as dinosaurs and even cynodonts of larger size”, tells Cesar Schultz. “We had to learn to look at the rock in a different way in the search for these small pre-mammals.” As it is the only place in the country with sedimentary rocks containing fossils of terrestrial vertebrates from the Triassic period, when both the dinosaurs and the mammals came into being, Rio Grande do Sul is a privileged land for prospecting.

One of the largest difficulties for studying animals of the transition era is exactly how to classify each fossil into a categorized date – cynodont or mammal, dinosaur or bird. It is common to find nothing more than teeth or fragments of cranium, of difficult identification. In the case of the pre-mammalian reptiles from Rio Grande do Sul, until the fossils found are reasonable abundant and rich in detail. Even though there are well accepted conventions for dealing with the dividing line between species, it is difficult to have unanimity. “The classifications reflect more or less the preferences of each author and are, in some measures, arbitrary”, Schultz says.

During the Triassic era, the solid earth was unified in the super continent named Pangaea, whose center was an immense desert. The ice of the polar caps had been melted. In this arid environment, around about 230 to 220 million years ago, the dinosaurs came about, descendants of reptiles of the

group of the thecodonts. Until the end of the Triassic era, in a movement of the renovation of the fauna almost simultaneous to the appearance the dinosaurs, the first mammals, crocodiles and turtles appeared as well as the pterosaurs, flying reptiles also extinct. At this point in time, the fauna and flora were very similar in all places, since there was only one continent. “Animals similar to the mini-cynodonts of Rio Grande do Sul must have existed in other parts of the planet”, comments Bonaparte.

It is within this lost world of the Triassic period, more than 200 million years ago, which the researchers are making their efforts to find the most adequate place for the Brasiliterio and the Brasilodonte in the evolutionary tree. How close to the first mammals to these reptiles that remind one of rats? There are two anatomical parameters in the bones that help to demonstrate the distance of one animal in relation to the mammals: the construction of the teeth and of the mandible and the bone composition of the middle ear. Mammals change their teeth only once during their life and have four types of well defined teeth: incisors to bite or to gnaw, canine to tear and molars and pre-molars to chew and to crush. In the reptiles, the substitution of teeth is continuous and lasts the life time and it is impossible to differentiate between pre-Brasilodonte and the Brasiliterio, the distinction between molars and pre-molars is as yet not clear and the changing of teeth seems to obey the standard of the reptiles”, comments Bonaparte. In spite of this, the sharp points of the canines resemble those of the primordial mammals, which reinforces the thesis that they have the potential to generate, in lineages yet to come, some form of mammal.

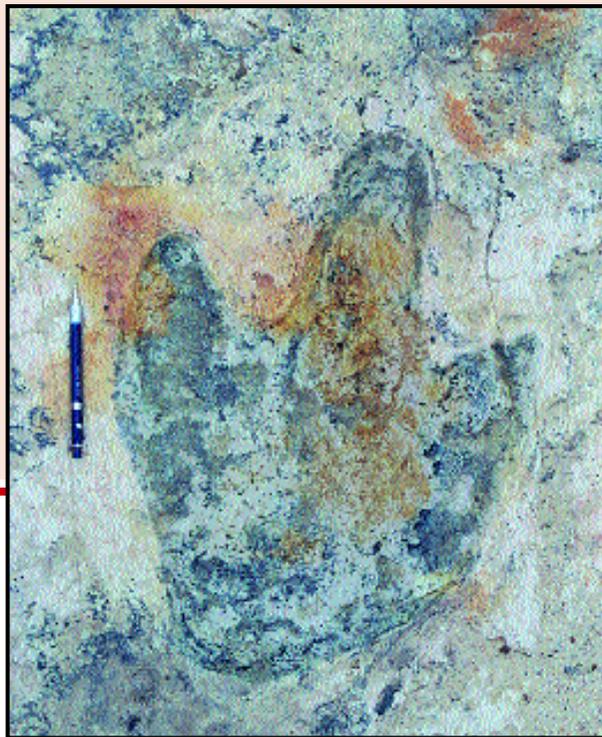
The hearing system shows that they were on the correct path, but there were not yet mammals. This is because in the mammals the middle ear, an internal cavity full of air, is composed of three small interconnecting bones: the hammer, the anvil and the stirrup. The middle ear of the cynodonts, among

Frontier dinosaurs

A new archeological site is gaining fame in the state of Rio Grande do Sul: the municipality of Santana do Livramento, in the west, on the frontier with Uruguay. Here, some 500 kilometers from the city of Porto Alegre, researchers from the Federal University of Rio Grande do Sul (UFRGS) and from the University of the Vale do Rio dos Sinos (Unisinos) found during 2001 and in January of this year various types of dinosaurs at the side of a road where the earth was being moved and leveled. By their format, they belong to two forms that must have lived between 144 and 137 millions of years ago, at the end of the Jurassic era the beginning of the Cretaceous era, when the dinosaurs dominated the scenario.

A type of footprint, which went as far as leaving trails, resembling elephant tracks, each one of 40 centimeters on average. "These tracks must have come from a sau-

ropod, a large herbivore with a long neck that may well have been more than 13 meters in length", says Cesar Schultz from UFRGS, who is studying the recently discovered vestiges near the frontier. Another type of footprint was made by paws with three toes, which could have belonged to the carnivorous dinosaurs or to a herbivorous group of the hadrosaurus: in either of the cases, by the size of the footprints, they must have been biped dinosaurs of around three meters in height.



CLAYTON SCHERER

Footprint with marks of three toes: probably a teropod (carnivore) or a hadrosaurus (herbivore)

them the Brasiliterio and the Brasilodonte, do not have these bones. Through evolution, the hammer, anvil and stirrup of the middle ear of the mammals were constructed beginning with the bones originally situated in the mandible and in the region of the articulation of the cranium of ancestral reptiles. The mammals always have only a large bone in the mandible and three in the middle ear. It so happens that the reptiles have an articulated mandible on top of various bones and the middle ear is without a hammer, anvil and stirrup. The cynodonts show exactly a transitional standard between these two extremes. "The smaller the number of bones in the mandible of an animal, the closer this animal is to the condition of a ma-

mmal", compares Schultz. The fossils from Rio de Grande do Sul still have more than one bone in the mandible, denoting their pre-mammal character.

The discovery of the new brothers of the warm blooded animals also puts in check a common idea about the animals which made up the bridge between the cynodonts and the mammals: that there had been a miniaturization of this group of reptiles before the first mammals were derived. Based on the evidence of the fossils from Rio de

In Uruguay, fossils of fish and dinosaurs have been found in the same rocky layer in which now flourish the remains of reptiles on the Brazilian side of the division. For this reason the researchers are going to make exploratory expeditions into the region, in the hope of rescuing the bones of the authors of the footprints. The rocky layer that preserves the tracks is below the type of rock that forms the Botucatu sandstone, whose top layer is dated at 134 million years ago, back in the Cretaceous period, nonetheless, whose base could still be placed at the end of the Jurassic era. It is possible that we are dealing with a sedimentary block of the last stage of the Jurassic period or the first stage of the Cretaceous era, a period that did not have known layers in Rio Grande do Sul.

Grande do Sul, Bonaparte disagrees: the fauna of the cynodonts, even before the origin of the *Morganucodon* and other primordial mammals, were already of various sizes, some with more than 1.5 meters in length and

others with only a few centimeters as in the case of the Brasilodonte and the Brasiliterio. Therefore, there was no need to diminish in size in order to become mammals. For him, something distinctive occurred: there were large and small cynodonts, but only one of these small ones evolved into the mammals. "With these Gaucho fossils, we can better understand this process of transition", emphasizes Bonaparte. "And, in many cases, better understand and substitute theories."