Study of Fossilized Massospondylus Dinosaur Embryos from South Africa (1978-2012) [1]

By: Madison, Paige Keywords: South Africa [2] James Kitching [3] Massospondylus [4] Prosauropod dinosaur [5]

In 1978, James Kitching discovered two dinosaur embryos in a road-cut talus at Roodraai (Red Bend) in Golden Gate Highlands National Park, South Africa. Kitching assigned the fossilized embryos to the species of long necked herbivores *Massospondylus carinatus* [6] (longer vertebra) from the Early Jurassic period, between 200 and 183 million years ago. The embryos were partially visible but surrounded by eggshell and rock, called matrix. Kitching said that the eggs were too delicate to remove from the matrix without damage. Twenty-seven years later in 2005, Diane Scott, a member of a team led by Robert Reisz from the University of Toronto in Toronto, Canada, uncovered the two almost complete, well-articulated embryos. Scientists have inferred information from the embryos about *Massospondylus* dinosaurs' growth, development, and behaviors including parental care, gait, and locomotion.

Kitching at the University of the Witwatersrand in Witwatersrand, South Africa, recovered the*Massospondylus* eggs in a layer of sediment in South Africa that had previously yielded many dinosaur fossils. Prior to his egg [7] discovery, Kitching had excavated many fossils from the *Massospondylus* genus in that particular layer. Upon his discovery of the eggs, Kitching collected the entire nest, called a clutch, which contained six eggs, and brought them to the Bernard Price Institute for Paleontological Research at the University of Witwatersrand.

In 1979, Kitching published a preliminary report on his find. In the paper, he described the size, shape, and characteristics of the eggs, including the partially visible fossilized embryonic remains. He described the eggshell as half a millimeter thick, and the eggs as sixty-five millimeters long and fifty-five millimeters wide. Kitching stated that of the six eggs, three were too incomplete to contain embryonic remains, and one egg [7] had already hatched, leaving only flattened eggshell. The remaining two eggs, however, each contained embryonic remains that Kitching could see through breaks in the eggshells. Kitching also described the reddish-brown mudstone matrix that surrounded each embryo inside the eggs.

Kitching noted that one of the eggs contained a partially visible skull. He stated that the skull was well preserved and measured ten millimeters from ear to ear, called the squamosal region on each side of the skull, and seven millimeters from nasal bones in the front of the skull to the squamosal bones at the back. Kitching stated that scientists were working to expose the rest of the embryos, but he stressed how difficult it was for scientists to expose such delicate bones from a hard fossil matrix without damaging the bones. He stated that visible skulls were dinosaurian, citing features such as a short braincase, and the position and shape of the eye socket, formed by the postorbital and lachrymal bones. Kitching stated that he could not assign the specimens to a specific dinosaurian genus and species yet. However, he noted that he had excavated a prosauropod dinosaur, *Massospondylus*, nearby in the same sediment layer, and that it was possible that these embryos belonged to that same genus.

Despite Kitching's note in the preliminary report that scientists would prepare and expose the embryos, he ultimately decided that The Bernard Price did not have the resources to remove the fossils from the rock without harming the delicate bones. Therefore, without the ability to further study the remains, Kitching shifted his focus to the eggshells of the specimens. He published a paper with Frederick E. Grine at the State University of New York at Stony Brook in Stony Brook, New York, in 1987. In the paper they described examinations of the eggshell under a scanning electron microscope [8]. They concluded that the structure of the eggshell appeared similar to crocodiles and birds [9], which they said were the closest living relatives of dinosaurs. Kitching further hypothesized that the eggs likely belonged to the *Massospondylus* genus because they were too large to have been laid by any of the other dinosaurs whose fossils Kitching had recovered from the same sediment layer.

However, as scientists could not thoroughly study the partially exposed embryos, many people questioned Kitching's assignment of the specimens as Massospondylus. Decades passed until scientists could settle the debate on these eggs' taxonomic status with further information from the embryonic remains. Some scientists argued that the eggs were not dinosaurian. In 2002, Darla Zelenitsky, a dinosaur egg [7] specialist at the University of Calgary in Calgary, Canada, published a paper with Sean Modesto from the Carnegie Museum of Natural History in Pittsburgh, Pennsylvania, in which they re-examined the eggshell of Kitching's eggs under a microscope [10]. They concluded that the microstructure of the eggshell displayed crocodilian, rather than dinosaurian, characteristics.

In 2004, Reisz and Scott at the University of Toronto began to reexamine the eggs. Reisz attempted to analyze the eggs with Computed Assisted Tomography (CAT scan), in which X-ray images or virtual slices are taken through the object and are then rendered in a three-dimensional image by a computer. However, the scans were inconclusive because the researches could not distinguish the bones from the rock matrix, which encased the eggs. Scott then exposed the material inside the egg [7] with tools like tiny air-driven jackhammers and thin needles to remove the rock by hand. She spent the next year preparing both eggs under a high-powered light microscope [10] to catch every detail. When she finished, she had exposed two dinosaur embryos that were fully articulated in the fetal position.

Once Scott exposed the embryos, Reisz and Scott published a paper in 2005 in which they confirmed Kitching's original taxonomic classification of the eggs as members of the genus *Massospondylus*. They further argued that, based on comparisons between the embryos and existing adult *Massospondylus* fossils, the embryos belong to the species *Massospondylus carinatus*. To support their taxonomic placement, the authors highlighted some*Massospondylus* features present in the embryos, such as a slightly expanded inner ear bone, called the stapes, and the same ratio of width-to-height measurement as adults in the species. The authors found that the proportions of other skeletal elements differed from those in *Massospondylus* adults, such as the proportional length of the forelimbs. They argued that the differences were due to incremental growth, a normal process for any developing vertebrate.

In their 2005 publication, Scott and Reisz described the two embryonic individuals in detail. They described the visible cervical or neck vertebrae, and the sacral vertebrae in the lower back as shorter and more delicate than those of adult *Massospondylus*, although the position of the ribs remains constant. They noted that the shoulder bone (scapula) was tall and thin, and that it was associated with notably longer forelimbs than in adults. In this paper, the researchers graphed the size of the embryo bones such as at upper arm (humerus), lower arm (radius and ulna), and the skull, comparing them with the size of seven other *Massospondylus* fossils of different ages, both adults and juveniles. The graph showed how the forearms would lengthen as the Massospondylus dinosaurs aged, information from which Reisz inferred about gait and locomotion.

Based on the features of the*Massospondylus* embryos' forelimbs, as well as a combination of features of the head, neck, and spine, Reisz and his team argued that the embryos indicate that *Massospondylus* babies walked on all four legs, making them quadrupeds. To substantiate that claim, Reisz noted the large skull of the embryos, the horizontal position of the neck, the long forelimbs, and the weak ribs and spine. Those features were juxtaposed against the adult *Massospondylus*, which is bipedal and walks on two legs, with a smaller head, shorter forelimbs, and a more robust spine. Reisz argued that those proportional differences in the skeletons suggested a potential shift from quadrupedal to bipedal posture and locomotion in early development of young *Massospondylus* dinosaurs.

In the 2005 article, Reisz also estimated the age of the embryos at their time of death. Although the exact age cannot be determined, Reisz argued that indicators such as the fossils' well-developed bones, in addition to how the bones completely filled the space inside the egg [7], indicated that the embryos were in advanced stages of embryonic development and possibly close to hatching. Reisz argued that the conclusion was consistent with Kitching's suggestion that the sixth egg [7] may have hatched.

Reisz's team inferred how dinosaur parents cared for their young based on the*Massospondylus* embryos. Based on the large size of the head of the embryos, combined with a small pelvic girdle and underdeveloped caudal vertebrae in the tail, Reisz said that these dinosaurs likely moved around little after they hatched. Additionally, the embryonic remains show underdeveloped teeth, which would have made eating difficult for *Massospondylus* young. Therefore, Reisz concluded that these young would have struggled to survive on their own, and that *Massospondylus* adults may have cared for the young.

In 2006, Reisz led a team to conduct further excavations at the site where Kitching had discovered the eggs. The team excavated additional *Massospondylus* egg [7] clutches. In 2012, Reisz's team published a paper stating that the presence of multiple egg [7] clutches indicates that Rooidraai was a nesting site for these creatures.

The *Massospondylus* eggs excavated by Kitching and prepared by Reisz and Scott provided researchers with a wide range of information about dinosaurs and embryos, from parental care to growth and development, and the evolution [11] of bipedal gait. The *Massospondylus* embryos indicated that juveniles first walked on four limbs and transitioned to bipedalism as adults, and that the genus provided parental care both prior to and after the eggs hatched.

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Subject

Dinosaurs [18] Dinosaurs--Eggs [19] Massospondylus carinatus [20] Massospondylus [21] Paleobiology [22] Fossils [23] Embryology [24] Embryos [25] Kitching, James William [26] Golden Gate Highlands National Park (South Africa) [27] Embryological development [28]

Topic

Theories [29] Organisms [30]

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- Contact Us

- The Embryo Project at Arizona State University, 1711 South Rural Road, Tempe Arizona 85287, United States

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