



42



**IER**

Instituto  
de Estudios  
Riojanos

ZUBÍA

REVISTA DE CIENCIAS.

Nº 42 (2024). Logroño (España).

P. 1-429, ISSN: 0213-4306

PRELIMINARY ANALYSIS OF A NEW DICYNODONT SPECIMEN REPORTED FOR THE METANGULA GRABEN (MOZAMBIQUE) FROM THE K5 FORMATION (LATE PERMIAN)

**ANA SORAYA MARQUES<sup>1,2\*</sup>,  
LÍGIA CASTRO<sup>1,3</sup>,  
TERESA CRUZ<sup>2,4</sup>,  
KATHLEEN DOLLMAN<sup>5</sup>,  
ZANILDO MACUNGO<sup>6</sup>,  
JULIEN BENOIT<sup>7</sup>,  
RICARDO ARAÚJO<sup>8</sup>**

ABSTRACT

Mozambique has become a focal point for numerous new discoveries of dicynodont remains, contributing significantly to our knowledge on the anatomy and phylogeny of Dicynodontia of the Late Permian. Here we present a new dicynodont skull from the Metangula Graben in Northern Mozambique, collected in 2019, which has been subjected to synchrotron scanning and segmentation for anatomical description and future phylogenetic analyses.

*Keywords:* Dicynodont, Metangula Graben, Permian, Synchrotron, Mozambique.

- 
1. NOVA School of Science and Technology, Department of Earth Sciences (DCT, FCT-NOVA), Caparica, Portugal. \*asr.marques@campus.fct.unl.pt
  2. Departamento de Biologia, Escola de Ciências e Tecnologia, Universidade de Évora, Évora, Portugal.
  3. Geobiosciences, Geotechnologies and Geoengineering (GeoBioTec), FCT-NOVA, Campus da Caparica, Caparica, Portugal.
  4. Marine and Environmental Sciences Centre (MARE)/Aquatic Research Network (ARNET), Laboratório de Ciências do Mar, Universidade de Évora, Sines, Portugal.
  5. European Synchrotron Radiation Facility, Grenoble, France.
  6. Museu Nacional de Geologia, Maputo, Mozambique.
  7. University of the Witwatersrand, Johannesburg, South Africa.
  8. Instituto de Plasmas e Fusão Nuclear & CERENA, Instituto Superior Técnico, Campus Tecnológico e Nuclear, Universidade de Lisboa, Lisboa, Portugal.

## 1. INTRODUCTION

In the Late Permian, dicynodonts were mostly herbivores that dominated the terrestrial ecosystems and subsequently survived the End-Permian Mass Extinction (Macungo *et al.*, 2023). A growing number of dicynodont findings in the Mozambique Karoo Basin have turned the Metangula Graben an important location to understand dicynodonts in recent years (e.g., Kammerer *et al.*, 2022, Araújo *et al.*, 2020). These recent studies have provided new information on the anatomy of the brain and other soft-tissues revealed by non-destructive techniques such as synchrotron radiation and segmentation. Here we present and describe a preliminarily study of a new dicynodont skull from the Metangula Graben, a fossil-rich geological formation of the Karoo Supergroup in Northern Mozambique, collected by PaleoMoz Project in 2019.

## 2. LOCALITY

Mozambique holds record of dicynodont remains from the Lopingian (254–251 Ma) mudstones and sandstones of the Metangula Graben, located in the Niassa Province, northwest of the country (Macungo *et al.*, 2020). The Metangula Graben is the southwestern-most tip of a large graben system that extends northwards to Tanzania (Verniers *et al.*, 1989).

## 3. GEOLOGICAL CONTEXT

The fossil skull under study was collected in the K5 Formation of the Middle Karoo Units. The fossiliferous strata are in the Lago District, Niassa Province (Macungo *et al.*, 2020). The K5 Formation can be subdivided into three members because of their distinct lithological differences (*i.e.*, K5a to K5c Mb, *sensu* Verniers *et al.*, 1989). The lower Member K5a is made up of reddish and fine-grained siltstones and sandstones with frequent carbonaceous levels. The middle member K5b consists mainly of red mudstones with several levels yielding reptilian bones. The upper Member K5c also hosts a vast number of reptile bones and consists primarily of sandstones and siltstones with occasional clay-mudstones and conglomerates (Araújo *et al.*, 2022, Verniers *et al.*, 1989).

## 4. MATERIALS AND METHODS

The skull is encased within a hematite concretion (Fig. 1). It was synchrotron-scanned to prevent potential damage during mechanical preparation, thus providing a non-destructive procedure to understand the anatomy of the bones within the concretion. This is due to the delicate nature of the specimen and dense matrix consisting of an iron-oxide concretion.



The sampled fossil skull was scanned at the European Synchrotron and Radiation Facility, Grenoble, France on the beamline BM18 (Duhamel *et al.*, 2025a), a new large field micro-tomography beamline at the ESRF (Tafoureau *et al.*, 2021). The beamline setup was for propagation phase-contrast synchrotron X-ray micro-computed tomography with a filtered white beam, with the voxel size and energy optimized on the skull diameter and density to achieve the optimal resolution for complete skull imaging. Furthermore, the fossil was imaged with a ‘tetra-acquisition’ setup; whereby the centre of rotation was shifted twice to create four overlapping radiograph images to increase the size of the final reconstructed images (Carlson *et al.*, 2011). PPM2019-105R was imaged on BM18 at an isotropic voxel size of 23.08  $\mu\text{m}$  at 148.8 keV (Cau *et al.*, 2017)

For the segmentation and image processing, we used the software Dragonfly (version 2022.2 Build 1409). The resulting three-dimensional model was segmented manually and colors were assigned to highlight different structures and volumes. Window Leveling was used to adjust the contrast, toggling Opacity was used for visualization of the matrix and fossil, Range to isolate the material for coloring, ROI where all layers were created and segmented, and utilizing the 2D Painter with Multi Slice interaction for efficient segmentation. This setting enables painting on multiple slice layers simultaneously with Multi Slice and correcting final parts with abrupt transitions using Single Slice.

## 5. PRELIMINARY ANATOMICAL RESULTS

Through the imaging techniques we were able to visualize and present the anatomical features of the skull hidden in the dense matrix (Fig. 2A and 2B).

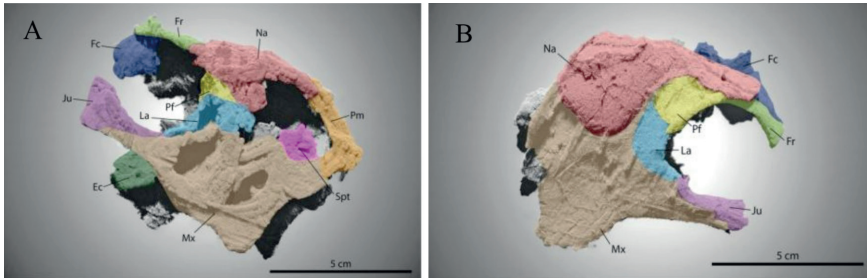


Figure 2. PPM2019-105R segmented specimen. A-right lateral view, B-left lateral view. Anatomical abbreviations: ec-ectopterygoid, fc-frontal crust, fr-frontal, ju-jugal, la-lacrimal, mx-maxilla, na-nasal, pf-prefrontal, pm-premaxilla, spt-septomaxilla.

PPM2019-105R comprises the anterior part of the skull. The premaxilla forms the most anterior part of the skull. It can only be seen in right lateral view and it contacts with the nasal posteriorly and the maxilla ventrally. On the anterodorsal margin of the left side the premaxilla contacts with the septomaxilla, following half of the nasal curvature inside of the nasal cavity only seen in right lateral view. The premaxilla contacts medially the lacrimal and the jugal at its posterior end. Both sides of the maxillae are preserved, although the left maxilla is sagittally sectioned. A major contact of the maxilla is with the nasal, only seen on the right side of the specimen. The nasal meets the premaxilla on the anterior side followed by the lacrimal and prefrontal medially and frontal on the dorsal side. The lacrimal contacts the maxilla ventrally, and the prefrontal and nasal dorsally. Along with prefrontal, the lacrimal can be viewed anteriorly and ventrally relative to the skull to form the orbit. The prefrontal forms the medial part of the orbit and contacts with the lacrimal anteriorly, with nasal dorsally, medially and posteriorly along with the frontal also posteriorly. The frontal meets the prefrontal anteriorly, the nasal dorsally posteriorly to also participate on the posterodorsal border of the orbit. Only the anterior process of the jugal is preserved and forms one of the lateral extremities of the skull and the anterior floor of the orbit. The jugal contacts the posterior process of the maxilla anteriorly. The ectopterygoid can be viewed in the right lateral view due to the way the skull was fractured and contacts the maxilla laterally.

## 6. CONCLUSION

This method offers significant benefits, including a comprehensive understanding of anatomy at scales from microscopic to mesoscale, and facilitates non-destructive analysis of fossils. It allows for detailed observation of bone structure and fossilization processes, distinguishing between adult and juvenile specimens based on specific markers. PPM2019-105R is an anterior skull of a dicynodont with several internal bones preserved and clear sutures in some sections of the skull. Further analysis will reveal the taxonomic affinities of the specimen.

## REFERENCES

- Araújo, R., Macungo, Z., Fernandez, V., Chindebvu, E.G., Jacobs, L.L. (2022). *Kembawacela yajuwayeni* n. sp., a new cistecephalid species (Dicynodontia: Emydopoidea) from the Upper Permian of Malawi. *Journal of African Earth Sciences*, 196, 1040726.
- Araújo, R., Macungo, Z., Smith, R.M., Tolan, S., Angielczyk, K.D., Crowley, J., Milisse, D., Mugabe, J. (2020). Biostratigraphic refinement of tetrapod-bearing beds from the Metangula Graben (Niassa Province, Mozambique). New radiometric dating and the first Lower Triassic tetrapod fossils from Mozambique. *Paleontologia africana*, 54, 56-68.
- Carlson, K.J., Stout, D., Jashashvili, T., De Ruiter, D.J., Tafforeau, P., Carlson, K., & Berger, L.R. (2011). O endocast de MH1, *Australopithecus sediba*. *Ciência*, 333(6048), 1402-1407.
- Cau, A., Beyrand, V., Voeten, D.F., Fernandez, V., Tafforeau, P., Stein, K., Barsbold, R., Tsogtbaatar, K., Currie, P.J., & Godefroit, P. (2017). Synchrotron scanning reveals amphibious ecomorphology in a new clade of bird-like dinosaurs. *Nature*, 552(7685), 395-399.
- Duhamel, A., Benoit, J., Araújo, R., & Macumbo, Z. (2025). PaleoMoz Project: new fossils from Mozambique and South Africa help elucidate the origins of endothermy. *European Synchrotron Radiation Facility*. <https://doi.org/10.1515/ESRF-ES-781826130>
- Kammerer, C.F., Araújo, R., Cumbane, K., Macungo, Z., Smith, R.M., & Angielczyk, K.D. (2021). New material of *Dicynodon angielczyki* (Synapsida: Anomodontia) from Mozambique and Zambia with biostratigraphic implications for African Permo-Triassic basins. *Journal of Vertebrate Paleontology*, 41(6), e2041652.
- Macungo, Z., Benoit, J., Fernandez, V., & Araújo, R.M. (2023). X-ray micro-computed and synchrotron tomographic analysis of the basicranial axis of emydopoid dicynodonts: implications for fossoriality and phylogeny. *Zoological Journal of the Linnean Society*, 198(1), 1-46.
- Macungo, Z., Loide, I., Zunguza, S., Nhamutole, N., Maharaj, I.E.M., Mugabe, J., Angielczyk, K.D & Araújo, R. (2020). Endothiodon (Therapsida, Anomodontia) specimens from the middle/late Permian of the Metangula Graben (Niassa Province, Mozambique) increase complexity to the taxonomy of the genus. *Journal of African Earth Sciences*, 163, 103647.
- Mirone, A., Brun, E., Gouillart, E., Tafforeau, P., & Kieffer, J. (2014). The PyHST2 hybrid distributed code for high speed tomographic reconstruction with iterative reconstruction and a priori knowledge capabilities. Nuclear Instruments and Methods in Physics Research Section B: *Beam Interactions with Materials and Atoms*, 324, 41-48.
- Walsh, C.L., Tafforeau, P., Wagner, W.L., Jafree, D.J., Bellier, A., Werlein, C., Kuhnel, M.P., Bollers, E., Walker-Samuel, S., Robertus, J.L., Long, D.A., Jacobs, J., Marussi, S., Brown, E., Holroyd, N., Jonigk, D.D., Ackermann, M.,

& Lee, P.D. (2021). Imagem de órgãos humanos intactos com resolução local de estruturas celulares usando tomografia hierárquica de contraste de fase. *Métodos naturais*, 18(12), 1532-1541.

Verniers, J., Jourdan, P.P., Paulis, R.V., Frasca-Spada, L., & De Bock, F.R. (1989). The Karoo Graben of Metangula Northern Mozambique. *Journal of African Earth Sciences (and the Middle East)*, 9(1), 137-158.



# ZUBÍA

42



**IER**

Instituto de  
Estudios Riojanos