

Hatching in Portugal: a new look to old eggs

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The outcrops of Portugal have provided a rich and diverse fauna of Late Jurassic tetrapods. Osteological remains of testudines, crocodylomorphs, pterosaurs, dinosaurs, squamates, lissamphibians and mammals, and ichnofossils of crocodylomorphs, pterosaurs and dinosaurs have drawn a comprehensive picture of a Late Jurassic ecosystem. Despite being largely based on incomplete specimens, this fossil ecosystem has been compared with similarly dated faunal assemblages from Africa and North America. Nevertheless, the fossil record of Portugal stands out among others due to the impressive fossils of archosaur reproduction and development. Eggs and eggshells of dinosaurs have been found in the Lourinhã formation since the late eighties. Among them, the “Paimogo clutch”, an assemblage of over a hundred theropod eggs, some of them containing embryos attributable to the theropod *Lourinhanosaurus antunesi*, is the most significative. The Paimogo eggs are amongst the oldest theropod eggs in the fossil record, represent one of the two instances of associated allosauroid osteological and oological remains, and the presence of three crocodylomorph eggs mixed in the assemblage has been postulated as evidence of symbiotic or commensalism relationship between crocodylomorphs and dinosaurs. Recent studies carried by our team have shown that the biological and taphonomic history of this egg assemblage is much more complex than previously thought. Untangling the formation of this assemblage has required a highly innovative holistic approach, which includes detailed oological and sedimentological studies, coupled with a geochemistry survey of each of the eggs on the assemblage and a study of the anisotropy of magnetic susceptibility of the encasing rock. With this new evidence, we have concluded that the “Paimogo clutch” was laid by at least two different theropod females, or the same female in different breeding seasons, and that at least a moderate amount of time passed between the independent laying episodes. Finally, some taphonomic remodelling of the assemblage occurred before fossilization. The oological record of the Lourinhã extends beyond the “Paimogo clutch”, with at least three other true clutches that can be attributed to the same ootaxon, collected in the beaches of, Peralta and Caniçal, and several other localities that have provided eggs and eggshell fragments of the same ootaxon. In addition, a clutch containing Dendroolithidae eggs associated with *Torvosaurus* embryos is known, with several localities providing eggs and eggshells of this second ootaxon. Electron Backscattered Diffraction (EBSD) analysis of the eggshell architecture of two coeval theropods with very different eggshell morphotypes provides a unique opportunity to see a snapshot of the early stages of evolution of the theropod eggshell, which would lead to the avian eggshell, one of the most sophisticated vertebrate segregated biomaterials. Finally, two crocodylomorph ootaxa have been described for the Lourinhã Formation, *Krokolithes dinophilus*, for the crocodylomorph eggs found together with the “Paimogo clutch”, and *Suchoolithus portucalensis*, which refers to a clutch of up to eleven eggs found in the proximity of Cambelas. Eggshell fragments referable to Krokolithidae are common in several microfossil assemblages across the Lourinhã Formation. At last, it is worth to mention the presence of testudines eggshells in the Guimarota mine, attributed to the oogenus *Testudoolithus*. Sadly, these specimens are currently lost. It is difficult to emphasize the worldwide importance of the Portuguese oological fossil record. Not only the main clades of amniotes with hard shelled eggs are represented, but also fossil embryos, one of the rarest fossils in the world, with a few dozens of instances, are preserved in multiple clutches. This palaeontological heritage not only raises Portugal as a global reference for studying the evolution of archosaur evolution but is also the egg from where many of the ongoing geotourism initiatives in the Região Oeste have hatched. *Acknowledgements.* This research was funded by the Fundação para a Ciência e a Tecnologia, project PTDC/CTA-PAL/31656/2017 and GeoBioTec, project (UIDB/04035/2020); by the Spanish Ministry of Science and Innovation, the European Regional Development Fund, the Government of Aragón (Grupo Aragosaurus: Recursos geológicos y Paleoambientes), project CGL2017-85038-P. M.M-A is supported by postdoctoral grants funded by the Fundação para a Ciência e a Tecnologia, Portugal (Grant number SFRH/BPD/113130/2015)

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