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Expressive Record of a Cenozoic Brazilian Palaeolagoon

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The B-17 Mine palaeontological and paleoenvironmental site, located in the Capanema district, northeastern of Pará State, guards the most expressive occurrence of the Brazilian Cenozoic paleolagoon. It can be considered similar as part of the recent depositional system, found in the equatorial margin among the Amapá and Maranhão states. The stratigraphic section has about 20m of thickness and is composed by alternance of the gray carbonatic lithofacies and sandstones, deposited in lagoonal environment, with low energy and fluctuations of sea level, connected with open sea and an estuarine system. The faunistic abundance suggests eutrophic and well oxygenated environment with clear and calm waters, low sedimentation rate, affected by waves. The most important data concerning the paleofauna is the record of the balanoid biome, constituted by four species, whose specimens are 3D preserved in life position and with biocrome vestiges. This is the only fossiliferous record of the balanomorph cirripedia of the South America. Taking in consideration that the limestone mine activities in the area continuously reveals new data, it is developed rescue actions to avoid the loss of the paleontological heritage, such as frequent specific fieldtrips and new paleontological researches.

Keywords: palaeontologic site; balanomorph cirripedia; Cenozoic; Pirabas formation; palaeolagoon

INTRODUCTION

The Pirabas Formation (Maury, 1925) outcrops discontinuously in the Pará, Maranhão and Piauí states, representing one of the best marine cenozoic paleontological exposures in Brazil. This unit consists predominantly of limestones, deposited under warm shallow marine conditions with normal salinity, during the Early Miocene. The diverse and abundant fossil content suggest that three ecological facies occur in the Pirabas Formation: Castelo, Capanema and Baunilha Grande, representing open sea, lagoon and mangrove environments respectively. The more expressive exposures of ecological facies is Fortaleza island (Castelo), B-17 Mine (Capanema) and Baunilha island (Baunilha Grande). The facies architecture within individual units revealed a dominant progradational domain, reflected by the upward progressive increase in relatively more landward facies associations, that contains barrier islands.

The Capanema ecofacies occurs in the northeastern of Pará state and northwestern of Maranhão state, with more expressive record at Capanema district, where the B-17 Mine paleontological and paleoenvironmental site is more complete Brazilian Cenozoic marine paleolagoon, whose rich and diverse fossiliferous content includes microfossils, invertebrates and vertebrates. The stratigraphical section of the B-17 Mine has about 20m thickness with great lithological and biotic content variety, that characterize wave-influenced restricted shelf/lagoon environment with fluctuations

of depth, salinity, substrate and organic matter content. The fluctuations of sea level in Pirabas sea are marked by micro and macrofossiliferous content variations as studied in outcrops and drill holes located at Fortaleza island and Atalaia/Maçarico beaches (Góes *et al.*, 1990; Távora *et al.*, 2002), Aricuru locality- Maracanã district (Távora & Fernandes, 1999), Nova Canindé and Bragança (Araújo, 2003; Silva, 2004)- Pará state, as well as Alcântara-Guimarães region in Maranhão state (Rossetti, 2000). These deposits show a variety of depositional settings transitional from shallow marine to estuarine low coast including a incised valley system, similar as part of the recent depositional system found in the equatorial margin among the Pará and Maranhão states (Rossetti *et al.*, 1990; Rossetti, 2000; Rossetti & Góes, 2004).

The paleobiotic content confirms the affinity of the Pirabas Formation with others synchronous lithostratigraphic units of the Central America, north of the South America (Venezuela and Colombia) and south of the USA, included at Caribbean Biogeographic Province (Woodring 1966, 1974, 1978). The most important data concerning the paleofauna of the Capanema paleolagoon is the record of the balanoid biome, the only fossiliferous record of this group in the South America. Were collected 89 specimens, 3D preserved in life position and with biocrome vestiges.

The exploration and exploitation activities in B-17 Mine was started in 1996, when were exposed the first sedimentary sequences of the Capanema ecofacies. At

this occurrence the strata are more thick than expositions in others mines explored by Cimentos do Brasil S/A at Capanema district. The paleontological research has been developed by paleontologists of the Universidade Federal do Pará and Museu Paraense Emílio Goeldi since 1998. These scientists found here a very important source of research about the Brazilian Cenozoic geology and paleontology. The knowledge of the historical geology of the Capanema ecofacies increase continuously due the exploration activity, that reveals complete stratigraphic sequences, anteriorly in subsurface level.

Thus, the B-17 Mine paleontological and paleoenvironmental site has great scientific importance justified by the most expressive record of the Cenozoic marine paleolagoon, whose quantitative and qualitative variations as well as terrigenous content characterize sea level fluctuations in similar depositional setting related to the actual estuarine system. Also the unique in South America record of the balanomorph cirripedia taphocoenosis, justify the formalization of the Mine as Brazilian scientific reference.

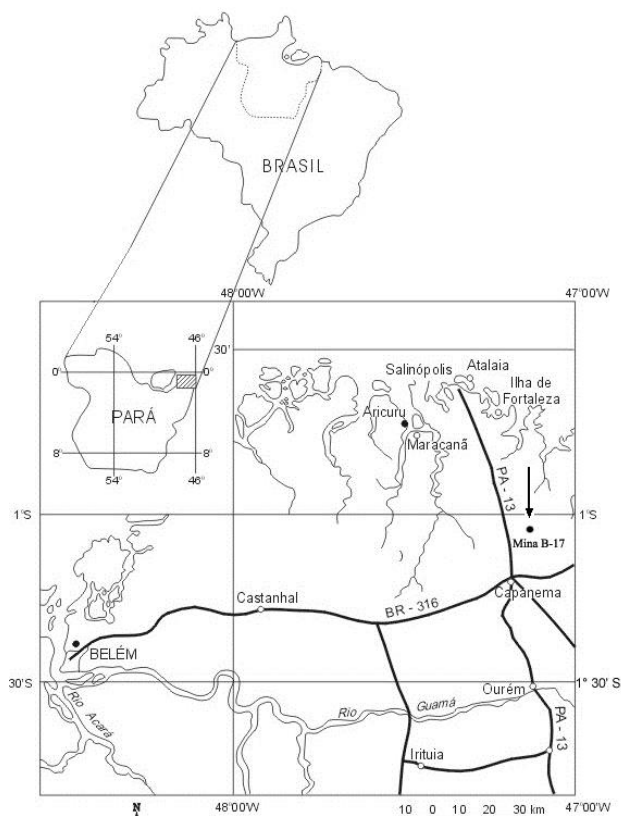


Figure 1 – Location map of Mine B-17.

LOCATION

The B-17 Mine (01°02'48"S-47°09'18"W) is located at the Capanema district, northeastern of Pará State (Fig. 1). The access is granted through the road BR-316 which connects Belém city to the Capanema

county. From this city one turns to the north by 17 km through of the PA-124, and enter to right accordingly the direction indicated by a road mark point to CIBRASA Mine, which owns the rights to explore the quarry.

SITE DESCRIPTION

The B-17 Mine is a limestone mining with exploitation since 1996. There are various benches opened for calcareous exploitation in Capanema ecofacies of the Pirabas Formation (Figs. 2 and 3). The B-17 Mine is one the major Brazilian deposit that exploits the rocks for cement production. The quarry has 20 m of thickness, close to the contact zone with 3 m of the Barreiras Formation.

During the late Oligocene to early Miocene, sea level rose and produced transgressive to highstand mixed siliciclastic and carbonatic deposits, that were deposited in environments range from transitional from shallow marine to wave-deposited estuarine setting, comprising the sequence Pirabas/Barreiras, accumulated in a NW-SE asymmetrical and elongated basin. The lower sequence comprises limestones interbedded with mudstones and calcareous sandstones, that grade laterally and upward into mudstones and sandstones attributed to outer shelf, restricted shelf/lagoon and mangrove/tidal flat depositional settings. The upper sequence includes conglomerates, sandstones and claystones, which were formed in an estuarine environment. These deposits reveal a dominant prograding character reflected by the upward progressive increase in relatively more landward facies associations (Rossetti, 2000). The development of the Pirabas/Barreiras sequence was controlled by NW-SE normal faults and NE-SW strike-slip faults, considered as last manifestation of the movements established during the final stages of the Gondwana break-up. (Costa *et al.*, 1993).

The geologic section of B-17 Mine is composed by alternance of gray carbonatic lithofacies interbedded including marges, calcilutites, biocalcarenites no stratified, biocalcirudites and mudstones, as well as massive sandstones in the top of the section (Fig. 4). This lithological variety distinguish two categories of substrate firmness, firmgrounds and softgrounds and the shelled benthic fauna were adapted very good to this changes. The sessile benthic (Pectinidae, Ostreidae and Plicatulidae families of Bivalvia and encrusting bryozoans) are typical of firmgrounds. On other hand the decapod crustaceans, vagile epifaunal and infaunal bivalvs and gastropods live in soft substrates (softgrounds). The lithology and the dominance and diversity of paleoinvertebrates characterize the depositional environment of the Capanema ecofacies as tropical and restricted shelf/lagoonal, with low energy and fluctuations of the sea level connected with open sea

and estuarine system. The connection with open sea is suggest by planktonic foraminifera, centric diatoms,

calcareous nanofossils and shark's teeth, typical of the outer shelf environments.



Figure 2 - General view of Mine B-17, showing part of the carbonatic section and sandstones (top, on the back). The pale gray levels correspond to different carbonatic lithofacies from the 20m section left.



Figure 3 - Mine B-17: part of the geologic section on the mine walls opened to limestone exploration, exposing massive fossiliferous carbonatic sandstones fine-grain sandstones and limestones.

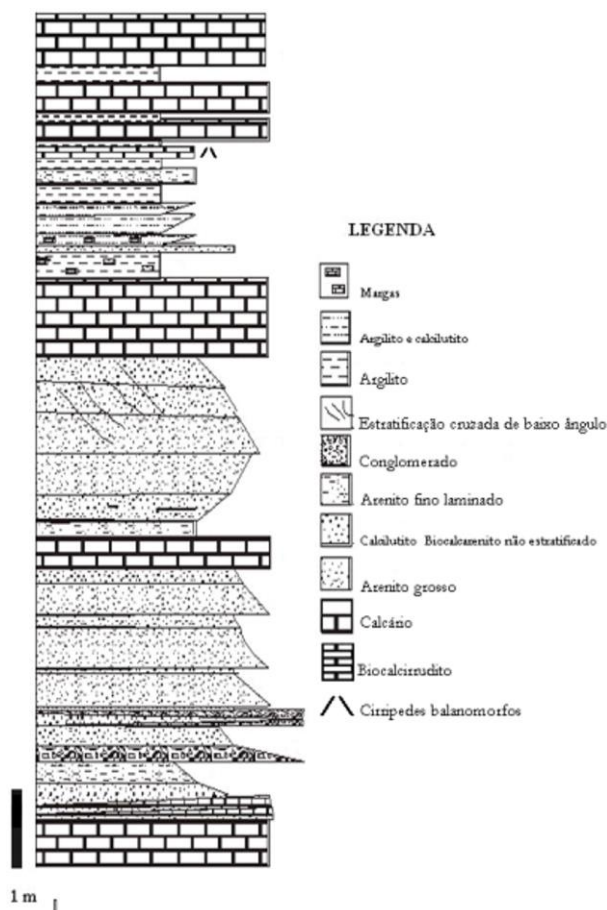


Figure 4 – Geological section of the Mine B-17 (modified from Costa, 2004).

The great faunistic abundance of paleoinvertebrates in Capanema ecofacies of the Pirabas Formation, constituted by anermatypic corals, bivalvs, gastropods, decapod crustaceans, balanomorph cirripedia and echinoids suggests eutrophic and well oxygenated environment with warm, clear and calm waters, low sedimentation rate, affected by waves (Fernandes, 1981; Ryland, 1970; Távora *et al.*, 2002).

The mollusks, decapod crustaceans, echinoids, benthic foraminífera and ostracods are generally euryhaline that support salinity fluctuations. The taxonomic composition of the stenohaline species of the systematic groups in Capanema ecofacies, indicate oscilations in the salinity values to normal, low and high. The fossils that attest these oscilations are the benthic foraminífera associated with bivalvs pectinids e heterodontids, that in different surface and subsurface geologic sections show oscilations between normal to high. In some stratigraphical levels were identified conditions of the low salinity, based on anermatypic corals (Fernandes, 1981) and decapod crustaceans and specially the *Balanus eburneus* and *B. improvisus*, balanomorph cirripedia with little size and that support absolute values between 16 and 18‰ (Távora & Pontes, 2002).

Balanoid Biome

The balanomorph cirripedia faune of the Capanema ecofacies of the Pirabas Formation is composed by four species, all living actually in transitional marine environments of the shallow depths (Fig.5). This fact confirms the data obtained with the other systematic groups recorded in the Pirabas Formation, where the paleofauna has a modern aspect, related with the recent marine fauna found in Brazilian coast. In this study were confirmed the species *Balanus eburneus* Gould and *B. improvisus* Darwin, recognized by Brito (1977). The species *M. tintinnabulum* (Linnaeus) were confirmed, but characterized in the *Megabalanus* genus. Also, was recorded to first time in the Pirabas Formation and like fossil in Brazil, *Balanus dentinarians* Henry, that occur in west Central America and Mexico until Ecuador in South America (Henry & McLaughlin, 1975).

The balanomorph cirripedia occur in a layer of biocalcirudite with 32 cm of thickness, a three-dimensional feature, internally simple (Kidwell *et al.*, 1986), sharp lower and upper contact, with marges fossiliferous also massives. The paleoinvertebrates are very abundant principally anermatypic corals, bryozoans and decapoda crustaceans. The fossil concentration is monotypic, usually loosely packed, shell orientation primarily concordant (Kidwell & Holland, 1991).

The 94% of the studied cirripedia taphocoenosis presents vertical position related to the substrate, suggesting sudden burial, and 6% cirripedia are flattened and horizontally oriented, representing ancient bioclasts, remains of the dead cirripedia available in the substrate that were buried together with the alive, since all of them occur in the same stratigraphic level. The preservation in life position suggest that were buried alive by fast sedimentary deposition in the unique event by the sudden increase in the sedimentary rate, associated with storm events (Rodrigues *et al.*, 2003). The variations of size of the fossiliferous concentration elements are related with distinct ontogenetic stages also suggesting mass mortality event.

BIOCHROME

The organic pigments that provide the colour on shells of the invertebrates are called biochromes, and occur within the outer shell and periostracum. Apparently the pigmentations are frequently attributed to the degradation of hormones or the storage of waste products of digestion or can be established as an accumulation of carotenoids as a byproduct of metabolic processes (Hollingworth & Barker, 1991).



Figure 5 – Cirripedia biome of the Capanema ecofacies of the Pirabas Formation, preserved in 3D, life position and biochrome vestiges. (a) *Balanus dentivarians*; (b) *B. eburneus*; (c) *B. improvisus*; (d) *Megabalanus tintinnabulum*.

The biochromes in hard parts are melanine, tetrapyrole, ommochromes, pterins, quinones and pigmentos naphthazarins pigments. The melanins and tetrapyrole are stables and have generally a higher preservation potential. The melanin is produced by oxidation and subsequent polymerization of the amino acid tyrosine, and are generally insoluble in organic and acid-based solvents, frequently attached to a protein. Depending upon the concentration it produces colours ranging from black-brown-red to yellow. Melanin is widely distributed in animal kingdom both in hard and soft tissues. The tetrapyroles have thermodynamical stability, but are usually soluble in most percolant liquids during the fossilization. Thus the preservation of colour occur in species with stability in the original shell mineralogy (Hollingworth & Barker, 1991). The colour layer represents a residual organic compound. The controlling factors that affect the preservation potential of colour patterns are the chemistry and stability of colour pigment, the taphonomic processes leading to colour pattern preservation, the original shell mineralogy and any post-burial diagenetic effects (Hollingworth & Barker, 1991). Pigments are degraded by transportation, bacterial action and boring by endolithic algae or by prolonged exposure of the shells to sunlight that results in loss of pigment through breakdown by ultraviolet light. The preservation of original colour in fossils attest rapidity

of burial and subsequent diagenetic history (Hollingworth & Barker, 1991). In majority of the specimens of the studied thanatocoenosis were identified biochrome vestiges, probably melanin, situated in the radii (reddish stains) and parietes (purples stains). The preservation of original colour suggests rapidity of burial of these balanomorphs remains by episodic sedimentation event.

The sedimentological, stratigraphical and taphonomic features as well as the original colour in the majority of specimens suggest that fossiliferous concentration is parautochthonous and was formed by storm waves that causes a catastrophic event. The specimens are 3D preserved in life position, have low degree of fragmentation, three ontogenetic stages, no evidence of transportation, abrasion, bioerosion and incrustation as well as biochrome vestiges confirms this hypothesis. The preservation in life position suggest that the burial occurred below the base level of storm waves, because the cirripedia have benthonic sessile life mode, whose *in situ* preservation implies necessarily in the absence of current flows under the substrate.

SITE PROTECTION

The rocks of B-17 Mine constitutes the important mine of the limestone and presently is exploited to the quarry industry by Cimentos do Brasil S/A (CIBRASA). The mining activity brings a lot of

social and economic benefits for the region where situates. In the São José de Itaboraí (RJ) and Pernambuco-Paraíba (PE) basins, limestones and evaporites mines respectively are in this present flooded by rain waters, covers most of benches excavated that obstruct the continuity of the geological and paleontological researches in these geotectonic units. Thus the site protection would be the isolation of a part of B-17 Mine, to the reference of the most expressive Brazilian Cenozoic paleolagoon. However is distinct the reality of this mine, because perhaps it will have fifty years for active exploration, that has revealed successively new benches of scientific researches. Taking in consideration that the limestone mine activities in the area continuously reveals new data, it is developed rescue actions to avoid the loss of the paleontological heritage, such as frequent specific fieldtrips every two months and new paleontological researches. Thus the protection of this site is made through of an agreement that join action of CIBRASA company and Universidade Federal do Pará. However these rescue actions must be better argued, and to involve institutions, national agencies and the CIBRASA, safeguarding the economic interests of the company which withholds the rights of mineral exploration.

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