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Additional contributions to the knowledge of the Taquaral Member, Irati Formation (Lower Permian, Paraná Basin): Taphonomy and paleoenvironmental implications

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Abstract: The silty shale facies of the Taquaral Member (Irati Formation), which is one of the Permian units in the Brazilian Paraná Basin, is discussed here based on the taphonomy relevant to the paleoenvironmental interpretation. The fossils are crustaceans (*Clarkecaris* and other indeterminate forms), isolated teeth, scales and bones of Actinopterygii, "Palaeonisciformes", which are the most common vertebrate remains, and also frequent scales of Coelacanthiformes. The scales, teeth and disarticulated bones are found together in accumulations, which may be interpreted as coprolites. Many of the fossil crustaceans display characteristics of ecdysis.

Key-words:

• Permian;
• Crustaceans;
• Vertebrates;
• Actinopterygii;
• Coelacanthimorpha;
• ecdysis

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Résumé : ***Nouvelle contribution à la connaissance du Membre Taquaral, Formation Irati (Permien inférieur, Bassin du Paraná) : Taphonomie et implications paléoenvironnementales.-*** Le faciès des argilites de la Formation Irati (Membre Taquaral), une des couches du Permien inférieur dans le Bassin du Paraná au Brésil, est discuté dans cette étude à partir de la taphonomie des fossiles, révélant des informations paléoenvironnementales. Ces fossiles incluent des crustacés (*Clarkecaris* et d'autres formes indéterminées), des dents, des écailles et des os d'Actinoptérygiens, "Paléonisciformes", qui sont les restes les plus courants de vertébrés, ainsi que des écailles de Coelacanthiformes. Les écailles, les dents et les os retrouvés dans ces formations sont interprétés comme des coprolithes. De nombreux fossiles de crustacés semblent également représenter des exuvies ou mues.

Mots-clefs :

• Permien ;
• Crustacés ;
• Vertébrés ;
• Actinopterygii ;
• Coelacanthimorpha ;
• exuvies

1. Introduction

The Irati Formation of the Brazilian Paraná Basin is the best known fossiliferous unit of the Lower Permian, because of its dark shales with remains of Mesosauridae reptiles, associated with crustaceans. It is divided into two members; the Taquaral Mb, above it, the Assistência Mb (BARBOSA & GOMES, 1958; CHAHUD, 2007, 2011; MILANI *et al.*, 2007; HOLZ *et al.*, 2010). The Taquaral Member has a thickness ranging from 5m, in marginal areas, to 30m, in the most central Paraná Basin (HACHIRO, 1996).

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Figure 1: Outcrop of the Irati Formation (adapted from HACHIRO, 1996, and CALÇA & FAIRCHILD, 2012).

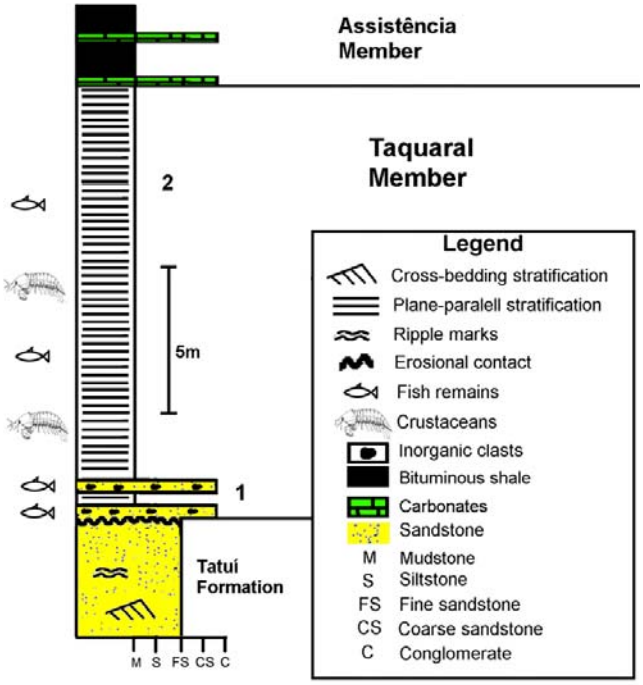

Figure 2: Sketched columnar section of the Taquaral Member, Irati Formation as occurring at the State of São Paulo. 1) Sandy facies; 2) Silty shale facies.

The Taquaral Member exhibits diversified lithologies, mainly in its lower beds, that are distinguished by predominantly sandy facies. This facies is characterized by lenticular conglomeratic sandstones with granules and pebbles, intercalated with coarse to fine-grained sandstones and muddy sandstones. In spite of its small thickness, it is rich in fish remains, *i.e.*, scales, teeth and bone fragments (CHAHUD *et al.*, 2010; CHAHUD & PETRI, 2008a, 2008b, 2009, 2010a, 2010b, 2014, 2015a, 2015b, 2015c, 2016).

The other facies, a thickly laminated silty-shale, is a more homogeneous and dark grey in colour (when unweathered). According to HACHIRO (1996) the matrix is clayey but contains 20-40 % quartz (may reach 55 %), micaceous plates and pyrite are disseminated in local layers. At the northern border of the basin, this facies diplays an abrupt contact with sandy facies. The upper contact with the Assistência Member is gradual and marked by dark shales and carbonates, typical of this member.

All the studied material occurs in outcrops in the State of São Paulo, southeastern Brazil region. Most of the fossiliferous outcrops of the Taquaral Mb in this state are located around the city of Rio Claro (Figs. 1-2). The silty-shale facies was described by CHAHUD *et al.* (2012) and CHAHUD and PETRI (2013a, 2013b) and now, taking advantage of the increased amount of data, its fossils were taphonomically investigated, providing information for paleoenvironmental interpretation.

2. Paleontological contents

Fossils in the silty-shale facies consist mainly of crustaceans and disarticulated vertebrate remains. Among the crustaceans, the most frequent is the genus *Clarkecaris* that is restricted to this facies. *Clarkecaris* is classified as a Syncarida and thus was considered a freshwater inhabitant by comparison to recent syncarids (MUSSA *et al.*, 1980) but it could also be a transition taxon between older marine taxa and freshwater genera (SCHRAM J.M. & SCHRAM F.R., 1974; CHAHUD & PETRI, 2013a, 2013b). Besides *Clarkecaris*, a new form of crustacean, known only from its uropods and not yet classified (CHAHUD & PETRI, 2013b), seems to be restricted to the Taquaral Member.

The vertebrates are very abundant, but little diversified, and are represented by fish bones only. The Actinopterygii, "Palaeonisciformes", is the most abundant group and is represented by teeth, scales and disarticulated bones. The Coelacanthiformes occur in great quantity, but only scales were reported (CHAHUD & PETRI, 2012, 2013a, 2013b).

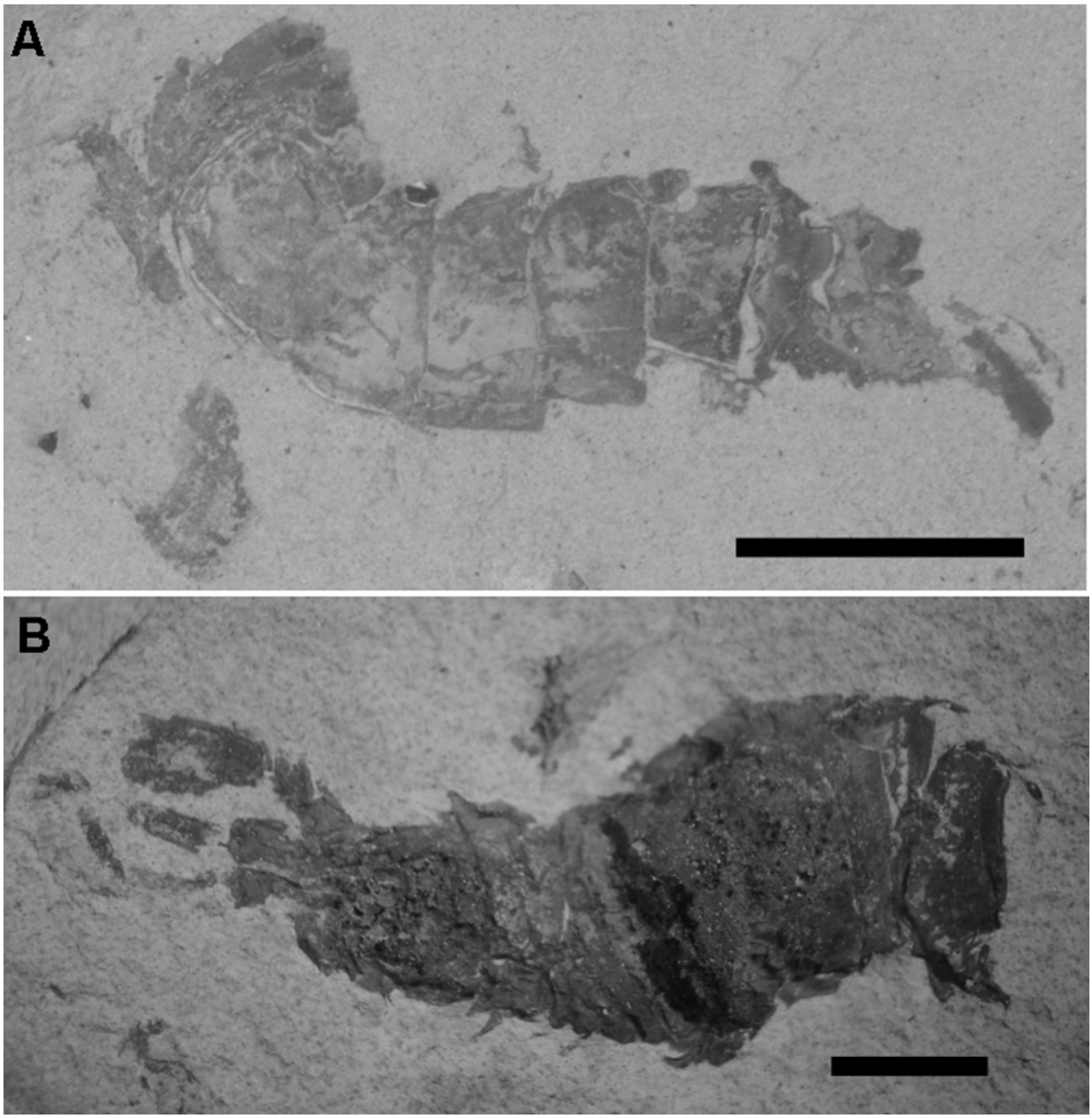

Figure 3: Ecdysis of *Clarkecaris*. Bar-scale 2.5mm.

Other, very rare fossils include: small bivalves, pollens, spores, algae and indeterminate acritarchs (LAGES, 2004; CHAHUD & PETRI, 2013a).

3. Taphonomy and paleoenvironmental implications

Most of the fossils from the silty shale facies, both of invertebrates and vertebrates, are fragments of a few millimeters to several centimeters, essentially preserved in two dimensions. All the fossils show signs of flattening and compression.

The crustacean's carapaces display different kinds of chitin somite preservation (Figs. 3 - 4). Loose articulated segments of the bodies are rather common and few specimens of *Clarkecaris* are complete or semi-complete (Fig. 3).

Research on post-mortem degradation of living taxa of crustaceans similar in shape and size to Late Paleozoic Syncarida, were carried out by HARDING (1973), PLOTNICK (1986), and HOF and BRIGGS (1997). They observed *post-mortem* changes under anaerobic and aerobic conditions. Under anaerobic condition, the cephalothoraxes were completely disarticulated and degraded four days after death, while it took twenty five weeks for the rest of body. Under oxidizing surface action of bioturbation and higher temperatures, the specimens lost their appendages in one week, but buried a few centimeters deep in the sedi-

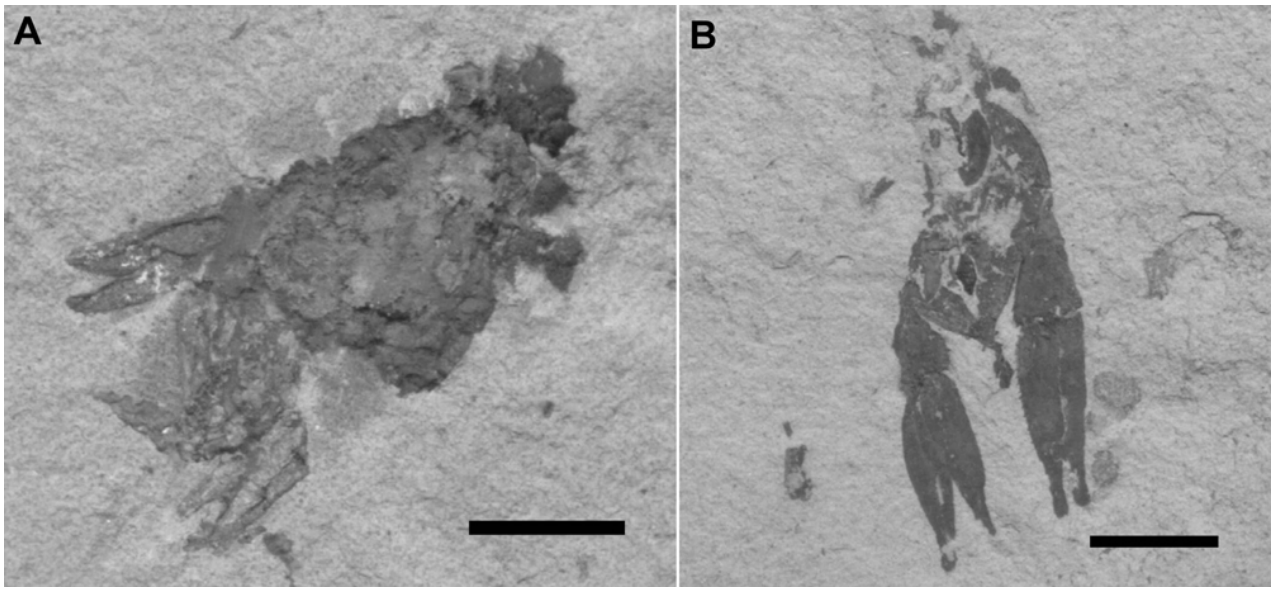

Figure 4: Ecdysis of uropods of indeterminate crustaceans. Bar-scale 5mm.

ment, it took six weeks. These studies are useful for understanding the Late Paleozoic Syncarida fossilization as pointed out by PERRIER *et al.* (2006) who studied the Upper Carboniferous Syncarida from the Montceau Lagerstätte.

Some *Clarkecaris* that are well preserved attest to little influence of bioturbation, otherwise, the depth of the burial was sufficient to prevent deterioration.

Among the best preserved *Clarkecaris* specimens are those that are enrolled, imbricated or stretched. Enrolled or slightly enrolled trilobites are interpreted as a protective response against predators or paleoenvironmental disturbance (SILVA & FONSECA, 2005). However, there are neither indications of predators and nor biostratonomic evidence for diisturbance during the deposition of the silty shale.

The frontal part of the cephalon of *Clarkecaris* is rarely preserved, and MEZZALIRA (1952) suggested that the thorax may have consisted of material that was prone to weathering. The presence of complete specimens of *Clarkecaris* in the Taquaral shale of the Brazilian states of Paraná and center east of São Paulo (BRITO & QUADROS, 1978; PINTO, 1985) might be explained by sediment flux, with dense water clouds carrying fine detritus that smothered specimens. However, if so, that would result in mass mortality, which was not observed.

A hypothesis for the few complete or almost complete, well preserved specimens, could be a low population density of *Clarkecaris* thriving in this basin.

An alternative hypothesis, not previously discussed but favoured in this paper, would be that most of the crustacean remains were the result of ecdysis. During ecdysis, the front part of the skeleton is completely lost (PHLIPPEN *et al.*, 2000) which could explain the headless specimens. This could also explain why enrolled uropods are the only remains of the indeterminate crustacean reported herein (Fig. 4).

The ecdysis might be preserved by intense precipitation of the finest detritus and very rapid burial, "obruption deposits", resulting in a complete fossilization.

The low density (approximately 1/m²) of crustacean specimens could be the reason why they are not frequent and are restricted to certain levels.

It is important to emphasize that no ichnofossils (neither burrows nor tracks) were observed associated with these crustaceans. The silty shale displays widespread pyrite crystals over large areas, without interruption. The low oxygen level would represent favorable conditions for the crustaceans during ecdysis in the absence of predators.

The vertebrates, founded in the silty shales of Taquaral Member, are rare and dispersed,. Most of them are represented by isolated scales of Coelacanthiformes and Actinopterygii (Fig. 5.A-B), and bone pieces, see the "Palaeonisciformes" maxilla (Fig. 5.C).

Accumulation of either crustacean fragments or bone elements and scales of Coelacanthiformes and "Palaeonisciformes" are rare (Fig. 6). Many of these are probably parts of worn out ecdyses (Fig. 6.A). Others may be loose fragments of the same specimen, not yet completely disarticulated (Fig. 6A). Most of the vertebrate fragments accumulation do not belong to the same specimen (different kinds and sizes of the elements, jointed together) and possibly represent weathered coprolites of large animals (Fig. 6.B-C).

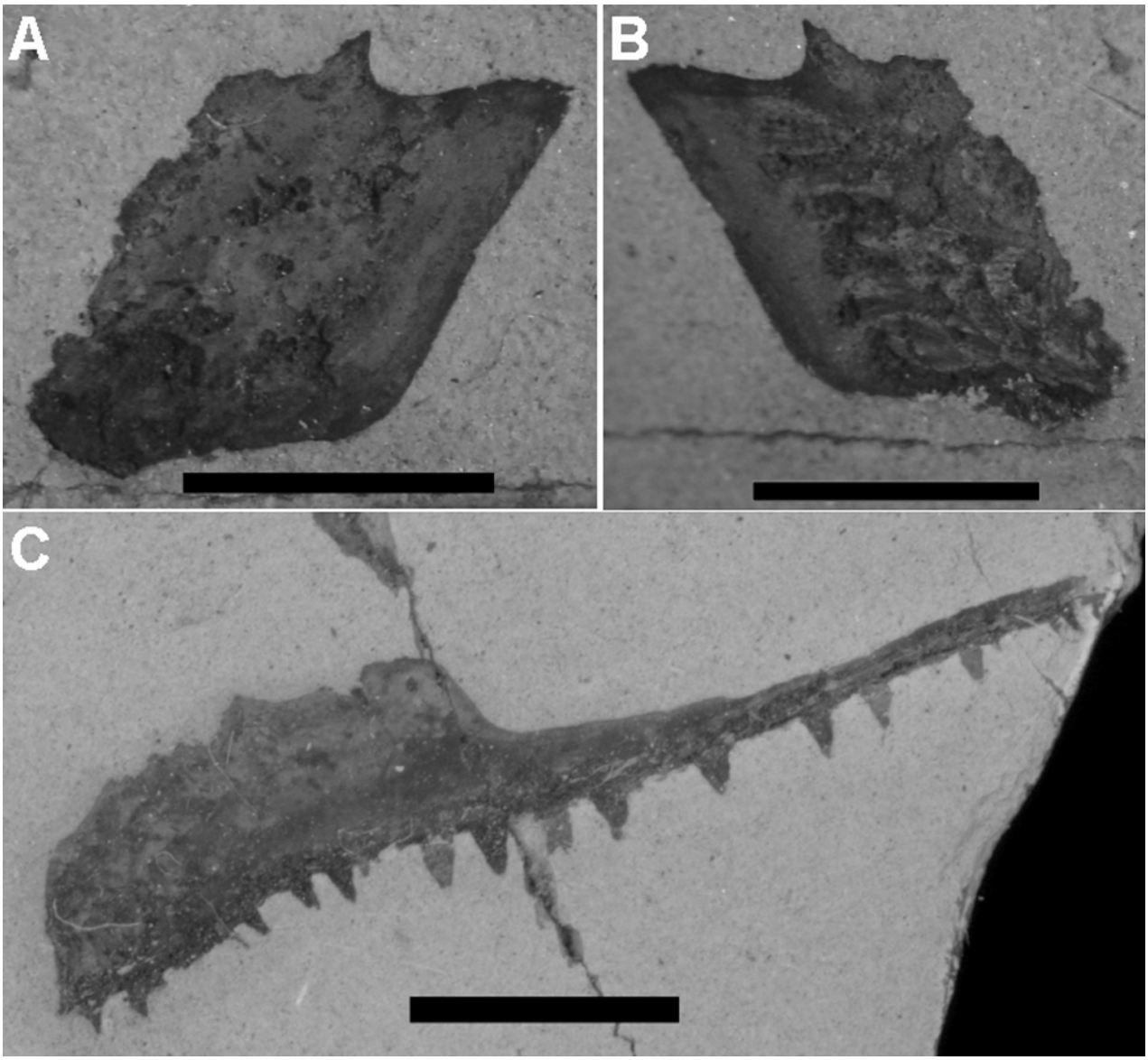

Figure 5: Fragmented parts of Osteichthyes. A) Palaeonisciformes scale part (GP/2E-6222a); B) counterpart (GP/2E-6222b); Bar-scale: 2 mm. C) Palaeonisciformes maxilla (GP/2E-6231). Bar-scale: 4 mm.

Paleoenvironmental interpretation of these fossils wasnot conclusive for determining whether the environment was marine, freshwater or brackish. Some fossils reported from the same levels in the literature, were not observed, such as the gastropods of the genera *Loxonema* and *Bellerophon*, initially mentioned by CLARKE (1920), but not confirmed by BEURLEN (1931). Other fossils are restricted to particular parts of the basin, such as small bivalves in thin calcareous layers (KAZUBEK & SIMOES, 2003a, 2003b; ROHN *et al.*, 2003; LAGES, 2004).

Besides the fossils referred to here, other researchers reported spores, pollens, acritarchs and the alga *Bothryococcus* (CAZZULO-KLEPZIG *et al.*, 1989; SOUZA *et al.*, 1992; HOLZ & DIAS, 1998; LAGES, 2004; CARDOSO, 2010). These fossils can be found in waters of different salinities, and thus do indicate a unique specific paleoenvironment.

4. Conclusions

Clarkecaris are preserved in different ways: rarely as complete articulated and semi-articulated specimens, and more often fragmented. The presence of complete specimens of *Clarkecaris* from head to tail and some of larger fragments, should be the result of extremely rapid depositional episodes, caused by major disturbances, like storms, burying the specimens.

Likewise, the presence of coprolites in low energy deposits without significant bioturbation, very rapid burial in deeply located and undisturbed deposits.

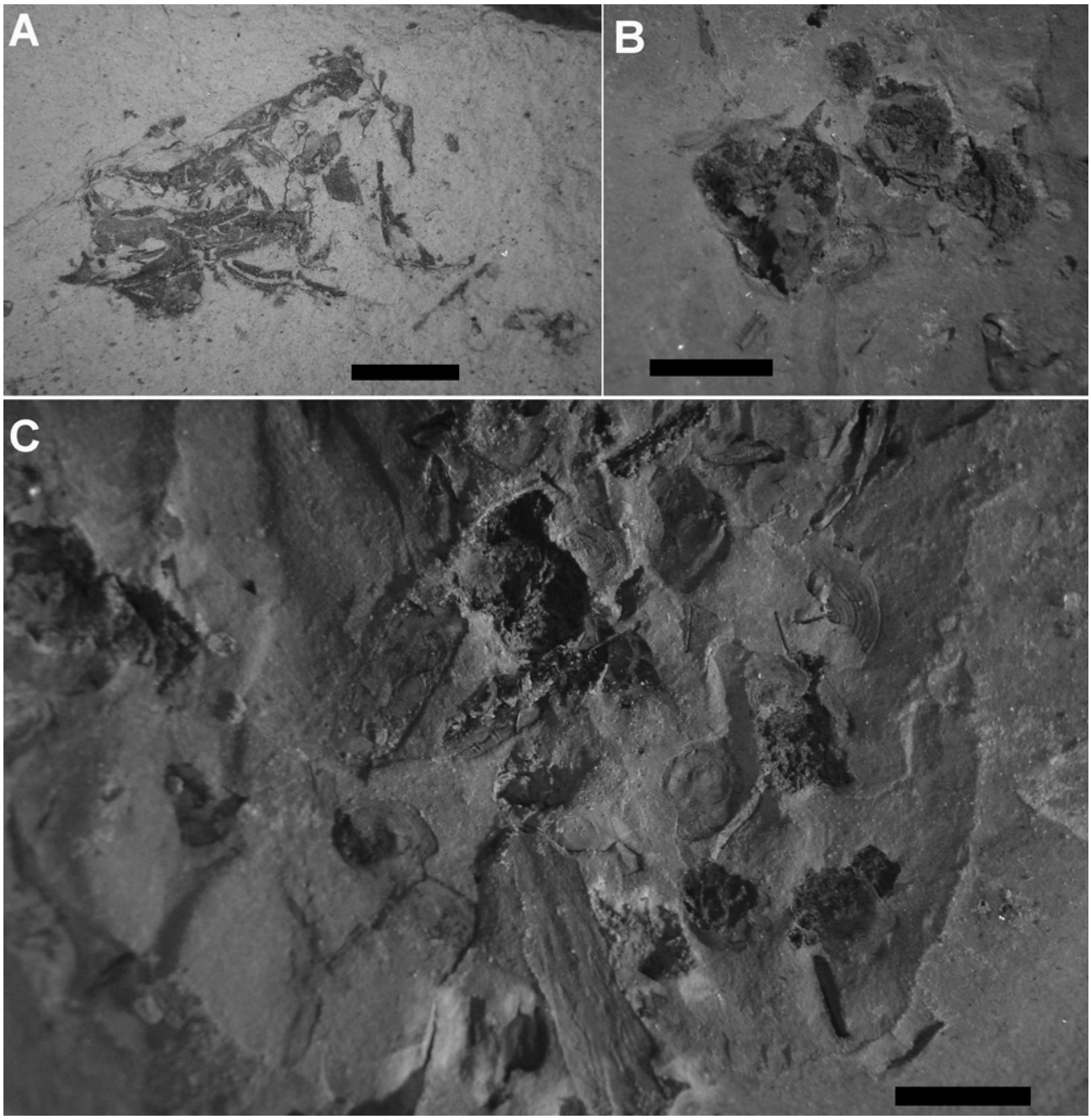

Figure 6: Punctual fossils accumulations. A) Crustaceans fragments; B-C) Scales and bone parts. Bar-scale: 2mm.

No complete fish skeletons were found in the Taquaral Member, only bone pieces, well preserved loose scale and some punctual accumulations. Some scales and bone pieces accumulations look like coprolites, other accumulations might be due to short flooding episodes possibly responsible for their burial.

The Clarkecariidae is endemic in the silty-shale facies and unknown in other formations and basins. The presence of this family is indicative of the long isolation of the Taquaral Member paleoenvironment. Other fossils from the silty-shale facies are not ideal as paleoenvironmental indicators.

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