Fossil hailstone imprints in Mesoproterozoic (1.7 Gyr) quartzite of the Tombador Formation (Chapada Diamantina Group), Brazil

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Abstract

Fossil pockmarks, 2.5-4 cm in diameter, 3-8 mm deep, with raised, asymmetrical borders are preserved in Mesoproterozoic quartzite representing fluvial and eolic lithofacies of the Tombador Formation (Chapada Diamantina Group) deposited 1.7 billion years ago in what is now northeastern Brazil. Indentations created by projecting 2-4 cm diameter ice pellets into moist beach sand were of the same type - with raised, asymmetrical borders and equivalent diameters and depths – strongly supporting the hypothesis that the fossil features represent impressions of paleohailstone impacts. These well-defined and well-preserved paleohailstone impressions represent the oldest known features of their type in the world, and the first records from South America.

Keywords: hailstone impressions, raindrop impressions, hail.

Impressões fósseis de granizo em quartzito do Mesoproterozoico (1.7 Ga) da Formação Tombador (Grupo Chapada Diamantina), Brasil

Resumo

Lajes de quartzito do Mesoproterozoico representando litofácies fluviais e eólicas da Formação Tombador (Grupo Chapada Diamantina) e depositadas há 1,7 bilhões de anos no nordeste do Brasil, apresentam impressões 2,5-4 cm de diâmetro e 3-8 mm de profundidade, com bordas assimétricas elevadas. As impressões criadas pelo lançamento de pedaços de gelo de 2-4 cm de diâmetro na areia úmida de uma praia eram do mesmo tipo – bordas elevadas e assimétricas e diâmetros e profundidades equivalentes – apoiando a hipótese de que as feições fósseis representam impressões preservadas de impactos de granizo. Esses bem-definidas e bem-preservadas impressões fosseis representam as feições mais antigas conhecidas desse tipo no mundo, e os primeiros registros da América do Sul.

Palavras-chave: impressões de granizo, impressões de chuva, fósseis.

1. Introduction

Geological studies and the fossil record have slowly revealed the history of our earth, the forces that have molded its landscapes, and the plants and animals that have populated its (ever-changing) continents and ecosystems. The identification of fossils preserved in stone, such as shells, bones, petrified wood, and footprints is often straightforward in terms of their identification – while other traces are more cryptic, presenting only mute clues that must be interpreted to decipher their origins.

The sidewalk in the center of the town of Lençóis, Bahia State, Brazil (41.391462 W x 12.560535 S) is paved with quartzite flagstones cut from a quarry (approx. 12.305 S x 41.409 W) of quartzite (Figure 1) with an attributed age of approximately 1.7 billion years (Mesoproterozoic), representing fluvial and eolic lithofacies of the Tombador Formation (Chapada Diamantina Group), with an estimated thickness of 220 m (Brasil, 1990), Some of those flagstones have unique pock-marks, approximately 2.5-4 cm in diameter (Figure 2A, B, C).

The hypothesis presented and examined here is that these impressions were formed by hailstones.

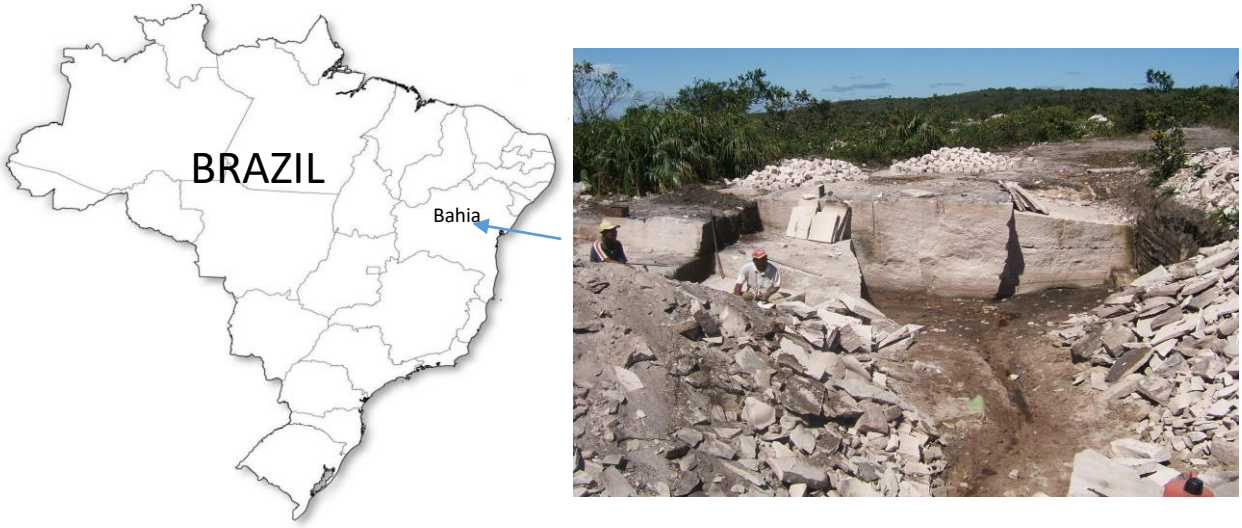

Figure 1. Artisanal quarry of white quartzite (Mesoproterozoic, approximately 1.7 billion years). Bahia State, Brazil (approx. 12.305 S x 41.409 W). Source: Author.

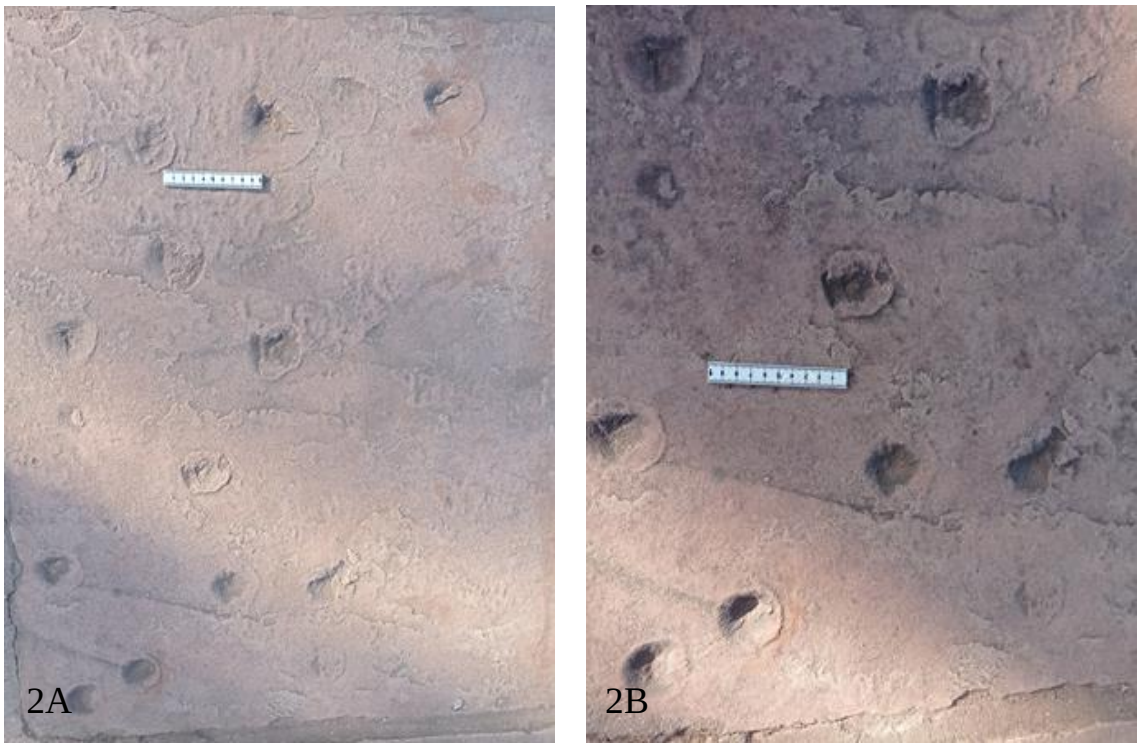

Figure 2A. A quartzite flagstone in the sidewalk in the town of Lençóis, Bahia State, Brazil. (12.560535 S x 41.391462 W) showing paleohailstone impact depressions. Source: Author.

Figure 2B. Closeup of the bottom top left-hand corner of Fig.1A. The impacts appear to have occured at a steep angle from right to left (the original orientation of the slab could not be determined). Source: Author.

Figure 2C. Another quartzite flagstone in the sidewalk in the town of Lençóis, Bahia State, Brazil (12.561100 S x 41.392739 W) showing paleohailstone impact depressions. Source: Author.

2. Materials and Methods

To examine whether the impressions in the quartzite flagstones could have been formed by hailstones, small, round, ice pellets, approximately 2.5-4 cm in diameter, were thrown by hand, or fired using a slingshot, into both fine sand along a seashore as well as moist coarse sand in a riverbed.

3. Results and Discussion

The indentations created in the sand at the seashore by the impacting ice pellets (Fig. 3) were nearly identical to the impressions seen in the quartzite flagstones, having raised, asymmetrical borders, and equivalent diameters and depths, although natural hailstones tend to be slightly irregular, and so would not be expected to leave round, symmetrical imprints. The impressions created by hurling the ice pellets, at the same velocity, into the coarse sand of a riverbed were shallow and did not have noticeably raised borders (not shown).

Figure 3. Marks of ice-pellets projected into fine sea sand at a steep angle, from right to left. Note that the two lower impact marks, in softer, wetter sand (slightly closer to the surf line), are less well-defined. Source: Author.

The age of the fossil impressions means that they cannot have originated from any biological source, such as the similar-looking putative tetrapod tracks reported from the Devonian Era in Poland (Niedzwiedzki et al, 2010).

The sand matrix of the current find, and the apparent lack of any organic components in the deep, white, and uniform beds seen in the quarry, make it unlikely that gas bubbles bursting on the surface could have been responsible for forming the small hollows – as the impressions discussed here are asymmetrical, and have raised borders – distinct from depressions left by bursting bubbles in clayey substrates (Lyell, 1851).

These large impressions (2-3.5 cm diameter) cannot, likewise, be confused with raindrop patterns, which are reasonably common throughout the fossil record in fine-grained rocks derived from volcanic dust, mud, and fine sand (Lyell, 1851; Boggs, 2006), although questions may arise concerning their interpretation (Metz, 1981). Interestingly, there are dozens of quartzite flagstones from the same quarry along the same walkway described here that bear considerably smaller, raindrop patterns (approximately 3-5 mm in diameter and ~1 mm deep), which are quite distinct from hailstone impressions (Figure 4) and do not show significantly raised borders (Remin et al, 2014; Metz, R., 1981).

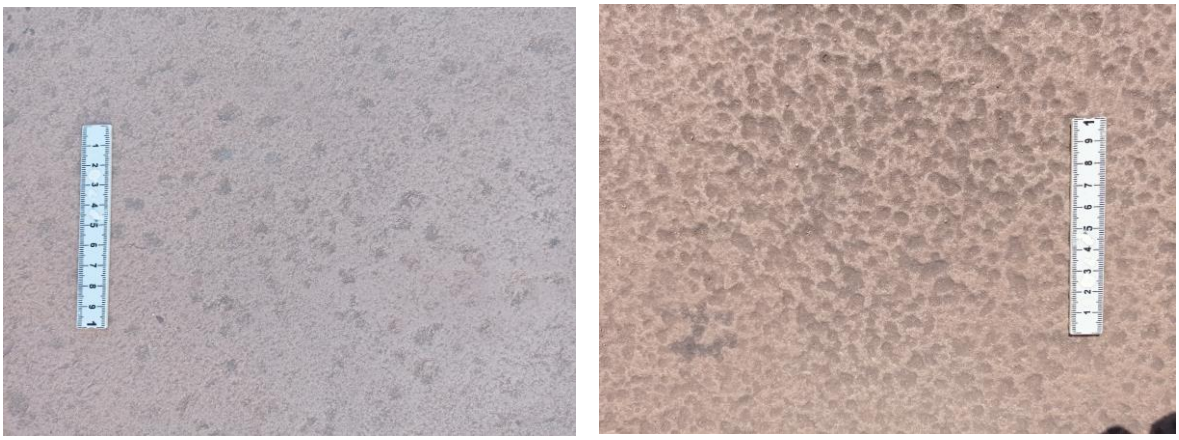

Figure 4. Fossil raindrop impressions in quartzite flagstones along the sidewalk in the town of Lençóis, Bahia State, Brazil. Source: Author

It is interesting to note that the hailstone indentations in a large quartzite flagstone (Figure 2A) (approximately 70 x 80 cm) occupy only about two-thirds of that slab – which is curious, because hailstorms would not be expected to have sharp "boundaries". However, the experiences of projecting ice pellets against sand along the seashore indicated that only a very narrow range of substrate humidity would leave imprints. Sand that was too dry was too hard to allow easy deformation, while very moist and soft sand tended to flow back into any depression and fill it (Remin et al, 2014). The strips of hard, medium-density (of the correct texture for retaining pock-marks), and very soft sand were found to be separated by distances of only a few decimeters on the sloping beach. The beach where the impressions were made sloped downwards (from the footprint to the ice pellet in Figure 3), with drier, firmer sand above and water-saturated and softer sand below. Note the similarity to the impressions in Figure 2A.

There were notable differences between the results of the detailed experiments performed by Remin et al (2014) and those presented here, likely due to differences in the substrates used and probable differences in the terminal velocities of the ice pellets and their weights. The clayey substrate used by Remin et al, when impacted by ice pellets of different sizes, resulted in craters 2.2 to 4.5 times larger than the diameter of the pellet and approximately twice as deep. The ice pellets impacting the sand substrate formed impressions only slightly larger than the diameter of the pellet itself, and not as deep. Those differences may more reflect the heavier texture of the sea sand (as compared to the clayey substrate) than the final velocity of the pellet, but the crude field conditions of the present experiment do not allow a more accurate appraisal. The ice pellets impacting the sand almost invariably rebounded away from the impressions formed.

It is of significant interest that cerrtain quartzite flagstones appear to hold natural casts, or molds, of paleohailstone impressions (Figure 5). It can be seen that the central portion of each is raised, and the border around it depressed – very similar to some of the molds produced by Remin et al, with the same central "cone" and a depressed ring around it.

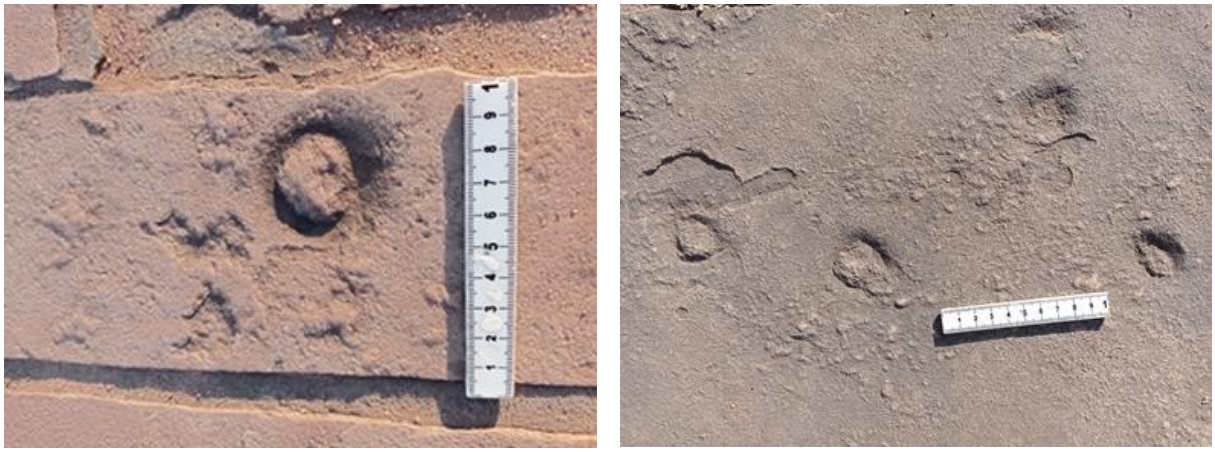

Figure 5. "Molds" of fossil hailstone depressions in quartzite flagstones along the sidewalk in the town of Lençóis, Bahia State, Brazil. Source: Author.

There have been very few fully documented reports of fossil hailstone impressions, with records in Triassic shale (251-201 my) in the USA (Lyell, 1851), in Permian sandy shale (299-252 my) in South Africa (Kent, 1938), and in Jurassic shale (~160 my) in England (Long, 1963). Remin et al (2014) tentatively re-interpreted the supposed raindrop imprints illustrated by Álvaro (2012) as hailstone impressions, considering their large sizes. There have been no reports yet of fossil hailstone impressions from South America, nor from Mesoproterozoic formations, as reported here.

Hailstorms are much less frequent than rainstorms and are limited to mid-latitudes (and can therefore aid in determining the approximate geographical location of the site during the mid-Proterozoic era), and lasting impressions will depend on exacting local conditions of substrate type, humidity, and post-storm preservation, as well as accidental recovery.

4. Conclusions

Pockmarks observed in Mesoproterozoic quartzite flagstones, dating to approximately 1.7 billion years and representing fluvial and eolic lithofacies of the Tombador Formation (Chapada Diamantina Group) in northeastern Brazil, are identified as impressions of hailstone falls preserved in the fossil record. Their origin was simulated by projecting ice pellets into fine, moist sand along the seashore – generating impressions that were essentially identical to those observed in the flagstones and very similar to those generated under controlled conditions. These are the oldest and best-preserved paleohailstone impressions yet reported, and are therefore of significant general interest as well as potentially useful for interpreting paleoclimatic and paleogeographic conditions.

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6. Authors' Contributions

The author was responsible for the conception, experimentation, and elaboration of the text.

7. Conflicts of Interest

No conflicts of interest.

8. Ethics Approval

Not applicable.

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