Plastic rocks: Interactions between plastic pollution and geology

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Abstract: The presence and impacts of pollution by plastics and other solid waste have been detected in all spheres of our planet: atmosphere, hydrosphere, biosphere, and lithosphere. More recently, new types of samples, composed mainly – though not exclusively – of plastic, have been found in nature and are described in the global scientific literature as integrating, interacting, resembling or incorporating rocks. Thus, the objective of the present study was to present and discuss these different types of relationships between marine litter and geological materials, reflecting on their significance for geology and on our role and responsibility as a society in the face of this persistent problem.

According to the United Nations Environment Programme (UNEP), pollution has been listed as one of the three main environmental threats of the century, sharing the ranking with climate change and biodiversity loss. Among the various forms of pollution that affect our planet is marine litter, which is mostly generated on the continent and then reaches the ocean, mainly due to failures in the various stages of urban solid waste management. Given its importance, this problem is highlighted in Sustainable Development Goal 14: Life Below Water.

The magnitude of pollution in marine, coastal, and oceanic environments by solid waste, particularly plastics, goes beyond its mere presence on beaches or its impact on the organisms that inhabit these places. Interaction with the biota, whether through ingestion, entanglement, entrapment, etc., has been widely reported in the scientific literature. However, the occurrence of plastics – especially microplastics – has also been evidenced in the atmosphere, hydrosphere, and lithosphere of continental, marine, and transitional environments.

The lithosphere, Earth's upper layer composed of rocks, minerals, sediments, and other geological materials, has received increasing attention since the middle of the second decade of the 21st century regarding possible impacts and evidence of pollution by marine litter

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and new rock forms containing plastic and other materials in their composition. In this article, we will present and discuss key aspects of the relationship between plastic pollution and the geological compartment, but first, it is important to review some concepts from the study of Geology.

GEOLOGY: SEDIMENTS, ROCKS, AND PLASTICS?

Geology (from the Greek: geo, Earth + logy, study) is the study of planet Earth and it has the difficult task of recounting the history of our planet through the description and dating of rocks and the investigation and understanding of the dynamics of Earth. The main target material of this branch of science are rocks (natural aggregates of one or more minerals), subdivided into three types: i) igneous or magmatic rocks, formed by the cooling and crystallization of magma (e.g. basalts and granites); ii) sedimentary rocks, formed through a set of physical and chemical processes (diagenesis) that compact and cement sedimentary grains, transforming them into rock (lithification) (e.g. sandstone, siltstone); they can also be formed through the burial and alteration of organic matter (e.g. peat, coal) or the chemical precipitation of carbonates and other salts (e.g. limestone, evaporite); and, finally, iii) metamorphic rocks, formed through the transformation, in a solid state, of a pre-existing rock (protolith) – which can be either igneous or sedimentary or even another metamorphic rock – that, due to the increase in pressure and temperature, has its structure reorganized and, often, its mineralogical composition altered, forming a new rock (e.g. quartzite, gneiss, schist, marble).

Some authors argue that we can draw parallels between some anthropogenic particles (e.g. microplastics) and their natural analogues (e.g. sand, silt, and clay) and that their behavior, dispersion, and deposition in the natural environment would follow the same "rules" as natural particles. Thus, considering that virtually no modern depositional environment, such as beaches, deserts, lakes, or ocean basins, is free from plastic contamination, recent sedimentological studies should include this anthropogenic component when analyzing and describing the sediments of these environments. In this sense, we can ask ourselves: if the sedimentary rocks we find were formed from the diagenesis and lithification of sediments from ancient depositional environments, and they are composed of the materials present there at that time (mineral grains, shells and carapaces of organisms, organic matter), would it be possible that plastic and other anthropogenic materials could be part of the sedimentary rocks that are being formed at this very moment? Yes, it is reasonable to infer that they are. But what does science have to say about this? What evidence has already been found?

UNDERSTANDING THE "PLASTIC VS. GEOLOGY" RELATIONSHIPS

For about a decade, scientific articles have been published reporting on the relationship between plastics and geological material. For better understanding, we will classify below, and in Figure 1, these types of relationships as:

- Integration (in the sedimentary matrix): where litter particles represent yet another component of the sediment and are, therefore, susceptible to the same processes as their natural counterparts (Gabbott et al., 2020).

- Appearance: where plastic forms present external characteristics that are similar to natural rocks, as exemplified in Table 1.

Anthropogenic plastic form	Analogous natural rock	Reference
Plastiglomerate	Conglomerate	Corcoran et al., 2014
Pyroplastic	Lithic pebbles	Turner et al., 2019
Plastistones	Rock slabs	Santos et al., 2022

Table 1. Examples of plastic forms of anthropogenic origin and their analogous natural rocks.

- Adhesion: where the plastic is adhered to the surface of rocks, such as in the case of plasticrusts (Gestoso et al., 2020).

- Incorporation: where litter items are naturally cemented to natural particles, forming part of the composition of the new rock formed, as in the case of anthropoquinas (Fernandino et al., 2020).

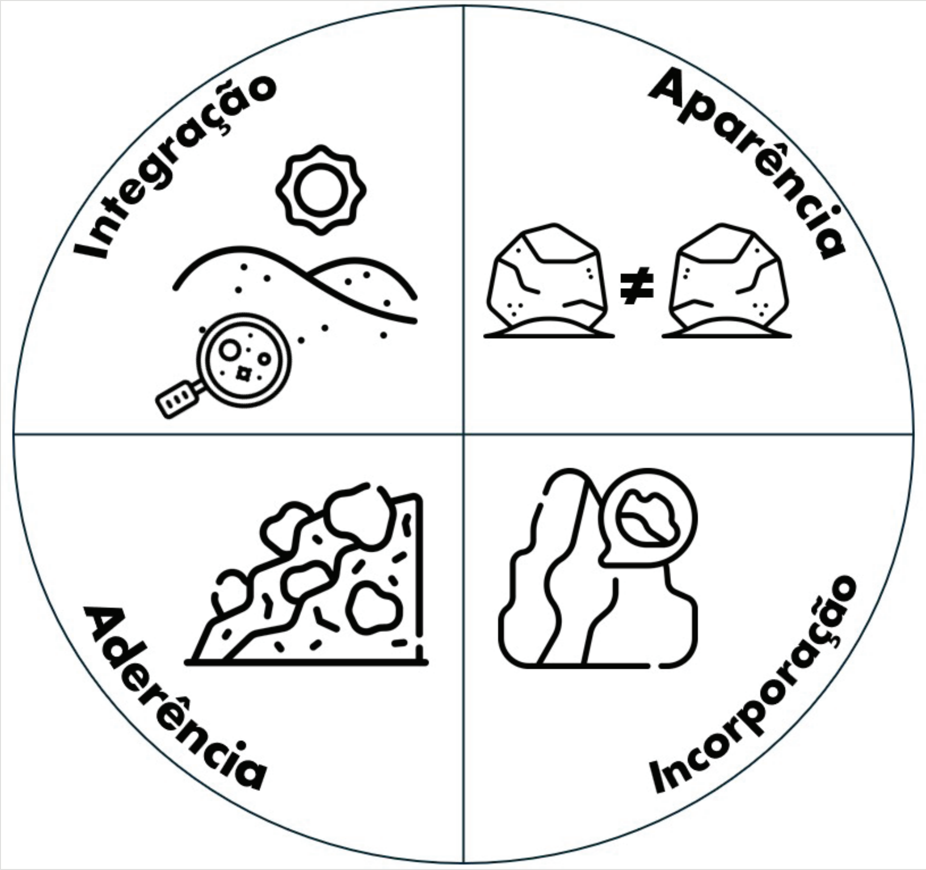

Figure 1. Diagram illustrating the four types of interactions between marine litter and geological materials

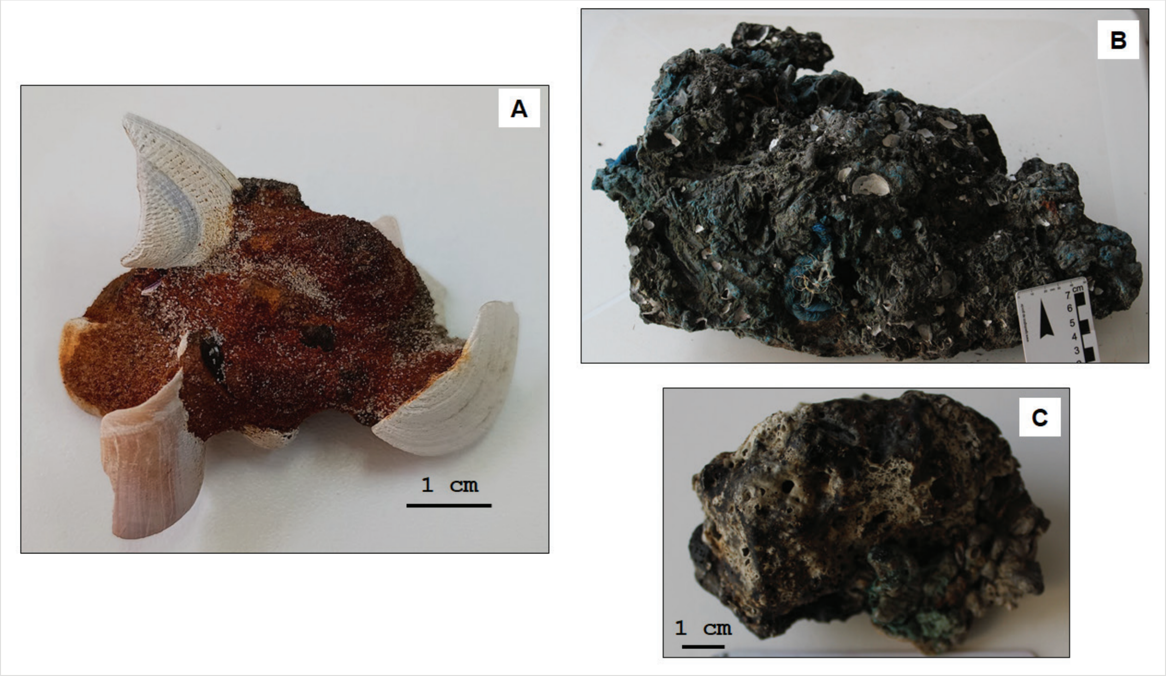

Figure 2: Examples of samples representing interactions between marine litter and geological materials. A) Anthropoquina formed by a metallic litter item with sandy sediment and cemented bioclasts; B) Plastiglomerate formed by molten plastic, fragments of fishing ropes, and bivalve mollusk shells; and C) Plastistone formed essentially by molten plastic. Credits: Gerson Fernandino

Among the four types mentioned above, integration and incorporation are the ones that show that anthropogenic components are in fact part of natural cycles and are participating in geological processes, such as transport, deposition, remobilization, diagenesis, and lithification, as other natural sedimentary particles. Among all these new types of samples mentioned, anthropoquinas stand out as those that can in fact be considered rocks and are important evidence of the integration of waste produced by human society into geological cycles, contributing yet another argument to the Anthropocene debate. Although the Anthropocene has not yet been formalized by the competent international bodies as a new geological Epoch and its request for formalization was denied in 2024, it is undeniable that human activities have influenced the great natural cycles of the planet, across all its spheres (atmosphere, hydrosphere, biosphere, lithosphere), impacting the balance of processes with Earth's Systems.

The human footprint on the planet is profound and its persistence over time is still uncertain. However, our traces, to a greater or lesser extent, will be recorded in the sedimentary rocks of the future and may be the subject of study and investigations by geologists in the distant future.

Reversing the problem of marine plastic pollution is a huge challenge, and there is no single simple solution, given its complexity and multiple facets. Changes must be made on a large scale, on a global scale, involving the articulation of society, driven by public policies that combat the problem from sources, in oil and gas exploration, through industrial processes, and finally reaching consumption and reuse/final disposal of solid waste. But do we have time to wait for these changes on such a large scale? Will marine, coastal, and oceanic ecosystems be able to wait? Will our health be able to wait for these changes? These are some of the questions we need to reflect on as individuals and as a society. In the meantime, we continue to share space with plastic, this persistent – and insistent – pollutant, that has even become part of our rocks.

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