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Plastistone: Novel Forms and Ecological Impact

Monali Raut
PhD Scholar, Dept. of Soil Science & Agricultural Chemistry,
University of Agricultural Science, GKVK, Bengaluru-560065
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Abstract

Sedimentary rocks dominate Earth's surface, yet human activity influences these formations, giving rise to plastic-rock complexes like plastiglomerate and plasticrust. Understanding the formation and fate of these novel plastic rock types is limited. Plastistone, a proposed term, describes these composite formations, combining plastic waste and clasts from existing rocks. Often found globally, plastistones alter microbial communities and contribute to micro- and nanoplastics in the environment. Formation occurs via campfire burning, wave action, or chemical bonding. Plastistone highlights the role of human activity as an exogenic geological force, reshaping our planet's geological record.

Key words: Plastic debris, plastistone, marine pollution, sedimentary rock, microplastic

INTRODUCTION

Plastic debris has emerged as a critical environmental challenge, contaminating ecosystems across the globe. The volume of plastic released into the environment ranges from approximately 22 to 48 million metric tons annually, although this estimate varies across different studies. Plastic has already been documented in diverse environments, including coastal areas (Cozzolino *et al.*, 2020), remote islands (Jones *et al*., 2021); mountains (Allen et al., 2019; Honorato-Zimmer et al., 2021), polar regions (Smith et al., 2016; Eriksen *et al*., 2020), the sea surface (Zhang *et al.*, 2020; Naidu *et al*., 2021), and the deep ocean (Peng *et al.*, 2018; Agostini *et al*., 2021).

Technological advancements, coupled with increasing human production and consumption, are amplifying humanity's impact on all of Earth's systems (Haff, 2013) and potentially causing irreversible changes to geological processes. In this context, plastic contamination has become a global issue of such magnitude that it necessitates the emergence of new geomaterials unprecedented in Earth's history (Stubbins et al., 2021).

Natural sedimentary rocks, which form from the lithification of various types of sediment, precipitation from solution, or the consolidation of plant or animal remains are ubiquitous across the Earth's surface. These rocks cover over 75% of the Earth's land surface and have been widely utilized by humans for purposes such as agricultural improvement (e.g., limestone for soil

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amendment) (Braga *et al.*, 2024), construction (e.g., sandstone for building and pavement material) (Bernardi *et al.*, 2014), and energy production (e.g., shale gas extraction) (Chandra and Vishal, 2021). However, The significant deposition of plastic, especially in urban areas, agricultural soils, and waste sites, forms plastic-rock complexes. These stable, stone-like materials, incorporating plastic residues into host rocks, are likely to persist in the environment and may serve as geological records for future generations (Zalasiewicz *et al*., 2014).

PLASTISTONE:

Definition:

The definition of "plastistone" by Santos *et al.* (2022) describes plastic debris with a smooth, silky surface typical of melted plastic. It consists of homogeneous plastic material and is classified into in situ and clastic types, exhibiting porosity from low to high. It showcases vesicles, flow structures, a plastic matrix, and polygonal fracturing patterns. Occasionally, the surface features encrustations of lithic and biogenic fragments (≤5%)."

Santos *et al.* (2022) reported melted plastics, not plastic-rock complexes. They initially considered "clastic plastistone" synonymous with "pyroplastic," a term used to describe homogeneous plastic forms resulting from melted plastic materials (Turner *et al*., 2019).

Wang & Hou (2023) revised the original definition of "plastistone" for use in sedimentary geology, excluding homogeneous plastic forms like pyroplastic that lack lithification with clasts. This exclusion is because plastic polymers were not lithified with clasts from pre-existing rock, a key element in natural sedimentary rock formation. Under the revised definition, "plastistone" encompasses novel plastic forms lithified with natural rocks, including "plastiglomerate," "plasticrust," "plastitar," "plastisandstone," and "anthropoquinas," but not purely molten plastic forms like "pyroplastic."

Formation of plastiostone:

Plastistones are formed when plastic and clasts from pre-existing rocks are bonded together. These rocks have been discovered globally, in both coastal and inland areas. The most common polymers in plastistones are polyethylene (PE), polyethylene terephthalate (PET), and polypropylene (PP), originating from domestic waste or maritime activities. Plastistones can result from burning plastic waste, wave action, evaporation, or chemical bonding. For instance, Plastiglomerate and pyroplastic have been linked to (un)intentional and partial plastic combustion in beach campfires, debris incineration fires, and ship fires. (Corcoran *et al.*, 2014; Turner *et al.*, 2019). But Pyroplastics are evidently different from plastiglomerate in terms of bulk density (Turner *et al*., 2019).

In case of anthropoquina, the term "anthropoquina" was chosen due to the frequent presence of mollusk shells cemented together with siliciclastic grains and anthropogenic items.

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Additionally, the samples analyzed were collected among coquina clasts, commonly found along the coast of Rio Grande do Sul, Brazil (Fernandino *et al.*, 2020).

Pyroplastics are clearly formed by melting or burning plastic, setting them apart from manufactured (primary and secondary) marine plastics in terms of origin, appearance, and thickness (Turner *et al.*, 2019). Notably, the limits for cadmium (Cd) and lead (Pb) in electrical plastics, as defined by the Restriction of Hazardous Substances (RoHS) Directive (European Parliament and Council, 2003), are set at 100 μg g^{-1} and 1000 μg g^{-1}, respectively. These limits are exceeded in the pyroplastics. (Turner *et al.*, 2019) which pose significant concern of pyroplastics as the potential source for heavy metals to be mobilised or enter the food-chain.

"Plasticrusts" likely originate from packaging materials, such as single-use plastic bags, though further testing is needed to confirm this.

Widespread presence of plastistone:

Ten years earlier, geologists first identified these hybrid rock specimens along the coast of Hawaii. Since then, similar stones have been discovered in five continents and eleven countries both in coastal and inland regions (Wang and Hou, 2023)

It is estimated that more than 80% of ocean plastic originates from land. However, the potential presence of plastic-rock complexes in inland areas has been largely neglected. (Wang and Hou, 2023).

Although novel plastic variants were first reported in 1983, interest in the topic has only recently started to gain momentum.

Plastiglomerate, 2013
Photographed on board the RSV Norseman in Hallo Bay, Alaska
Source: andyhughes.net

Pyroplastics retrieved from the strandline at Whitsand Bay
source: Turner *et al.*, 2019

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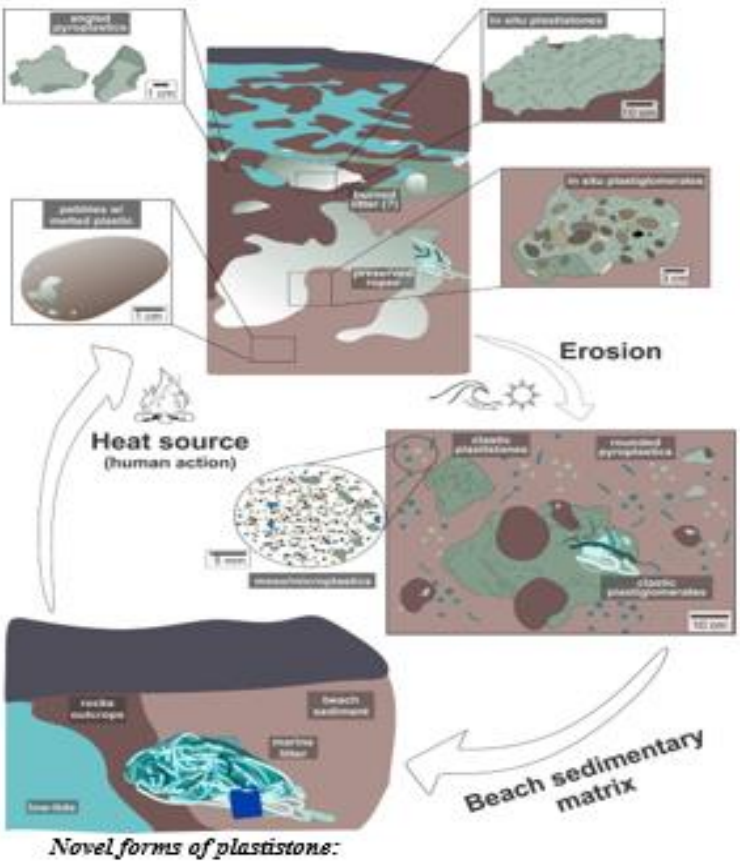
Plasticrusts on the surface of the rocks in Madeira Island encrusted by plastic. Source: Gestoso *et al*., 2019.

Anthropoquinas found along the coast of Rio Grande do Sul, Brazil. Source: Fernandino *et al.* 2022

Plastitar in Playa Grande beach (Tenerife), source: Domínguez-Hernández *et al.*, 2022



Conceptual depositional system model of plastic debris forms on Parcel das Tartarugas. Source: Santos *et al.*, 2022

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SL No	Forms of plastisone	Description	Composition of the plastic material	References
1.	Plastiglomerate	An anthropogenic multi-composite matrix is composed of melted plastic, beach sediment or sand, basaltic lava debris, bottle tops, and pieces of organic material. Its formation primarily results from the burning of plastic materials, such as during campfires or illegal waste burning.	Polypropylene (PP)	Corcoran *et al.*, 2014
2.	Pyroplastic	An amorphous matrix appears to be formed by the burning or melting of plastic, typically characterized by a single, neutral color (black-charcoal-grey, off-white, or brown), with occasional hues of green, blue, pink, or yellow. It features cracks, fractures, pits, and cavities. The primary sources of this matrix are open campfires and the burning of plastic waste on beaches.	polyethylene (PE) polyethylene terephthalate (PET) polypropylene (PP)	Turner *et al.*, 2019
3.	Plasticrusts	Plastic pieces embedded in intertidal rocks may persist over time, likely caused by coastal waves crashing larger plastic items against rock outcrops. High summer rock surface temperatures contribute to this process.	polyethylene (PE) polyethylene terephthalate (PET) polypropylene(PP)	Gestoso *et al.*, 2019
4.	Anthropoquina.	Sedimentary rock containing anthropogenic objects, including plastic, wood, burnt waste, glass, sand, and organic materials.	polypropylene(PP)	Fernandino *et al.*, 2020
5.	Plastitar	An accumulation of tar and mainly microplastics measuring 1–5 mm in size, with wood pieces, glass, small rocks, and sand grains also present, attaches to the rock surface, binding both materials.	polyethylene (PE) polypropylene(PP)	Domínguez-Hernández *et al.*, 2022

Ecological effects of plastistones:

Plastistones have been found to disrupt the microbial communities in their vicinity and contribute to the formation of substantial quantities of microplastics and nano-plastics. The potential release of these particles into surrounding areas raises concerns regarding the long-term ecological impact. For instance, Plastiglomerate poses a pressing threat to ocean sustainability, the blue economy, and overall human health (Wang & Hou, 2023).

The presence of plastistone on beaches has been shown to threaten wildlife (Gestoso *et al*., 2019), cause human injuries (Dixon and Dixon, 1981), and hinder economic growth by reducing scenic quality (Rangel-Buitrago *et al*., 2018).

Plasticrusts may impact the surrounding fauna, as they often coexist with common benthic invertebrates like patellid limpets, barnacles, and snails. Notably, the littorinid gastropod *Tectarius striatus* was observed around and on top of plasticrusts. This grazer typically feeds on diatoms and algae on intertidal rocks, but it might also graze on plasticrusts (Gestoso *et al.*, 2019). Recent laboratory studies have shown that the related periwinkle species, *Littorina littorea,* cannot distinguish between algae with adherent microplastics and clean algae as a food source (Gutow *et al*., 2019).

The presence of tar in coastal environments poses a significant risk due to its photo-oxidizable hydrocarbons, which can negatively affect the marine ecosystem by altering ecological balances. For instance, polycyclic aromatic hydrocarbons (PAHs) in tar, which are persistent organic pollutants, can bioaccumulate and have moderate to high acute toxicity, acting as endocrine disruptors and carcinogens. When combined with plastic materials, as plastitar; this creates a dual threat to marine life, with unknown environmental impacts, as plastics can be ingested by marine organisms, causing intestinal blockages, internal injuries, oxidative stress, and inflammation, among other serious issues (Domínguez-Hernández *et al.*, 2022).

Way forward: To advance research on plastistones, a multidisciplinary approach is essential. Investigating the formation, distribution, and environmental impact across various settings, such as marine and terrestrial, will deepen our understanding. Collaboration between marine biologists, geologists, and environmental scientists can facilitate comprehensive data collection, allowing for a clearer picture of plastistone dynamics. Implementing field studies, lab analyses, and advanced imaging techniques will provide insights into their composition and lifecycle. Furthermore, integrating socio-economic assessments can highlight the broader implications for pollution and conservation. By exploring plastistones from multiple angles, we can better inform strategies to manage plastic waste and mitigate its environmental footprint.

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