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Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island of Kauai, Hawaii

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ABSTRACT

Plastic debris is accumulating on the beaches of Kauai at an alarming rate, averaging 484 pieces/day in one locality. Particles sampled were analyzed to determine the effects of mechanical and chemical processes on the breakdown of polymers in a subtropical setting. Scanning electron microscopy (SEM) indicates that plastic surfaces contain fractures, horizontal notches, flakes, pits, grooves, and vermiculate textures. The mechanically produced textures provide ideal loci for chemical weathering to occur which further weakens the polymer surface leading to embrittlement. Fourier transform infrared spectroscopy (FTIR) results show that some particles have highly oxidized surfaces as indicated by intense peaks in the lower wavenumber region of the spectra. Our textural analyses suggest that polyethylene has the potential to degrade more readily than polypropylene. Further evaluation of plastic degradation in the natural environment may lead to a shift away from the production and use of plastic materials with longer residence times.

1. Introduction

Plastic debris in Earth's oceans pose one of the most prominent ecological problems we face (Derraik, 2002; Sheavly and Register, 2007). A 25-fold increase in the production of plastic resin products between 1960 and 2000, and a recovery rate of less than 5%, has resulted in an unparalleled rate of plastic materials entering the environment (McDermid and McMullen, 2004; Moore, 2008). Because plastics are relatively inexpensive to produce and provide limited economic incentive for reuse, they are the fastest growing materials of the waste stream, with 60–80% of marine litter represented by plastic debris (Derraik, 2002; Moore, 2008). Land based sources account for up to 80% of marine debris which is transported to oceans via sewage/drainage systems, natural waterways, wind, or human neglect (Derraik, 2002; Gregory and Andrady, 2003). The remaining plastics are derived from ocean/waterway sources such as cruise ships, recreational boaters and commercial fishing vessels which dump debris directly into the water (Derraik, 2002; Sheavly and Register, 2007).

More buoyant plastic debris floats and can be dispersed over great distances by wind and ocean currents (Hansen, 1990; Corbin and Singh, 1993; Kubota, 1994). While at sea plastics begin to break down by either photo–, thermal, or biological degradation (Gregory and Andrady, 2003; Shah et al., 2008). Large, low density plastic fragments floating on the surface of the ocean become brittle and break into smaller pieces while exposed to UVB radiation, oxygen and seawater (Andrady, 2005; Santos et al., 2009). Plastic debris on land degrades more readily than plastic at sea because of higher solar radiation exposure and subsequent increased bulk temperature (Pegram and Andrady, 1989). Whereas larger plastic pieces are often removed through active beach clean-ups, composition and degradation rates most often dictate retention times of smaller plastic particles on beaches (Corcoran et al., 2009).

Building on previous work by Corcoran et al. (2009), we collected samples from 5 beaches on the island of Kauai to further determine the relationship between particle composition and surface textures in natural plastics degradation. This study evaluates the effects of mechanical and chemical processes on the degradation of plastic debris and considers the daily rate of replenishment of plastics on the beaches of Kauai.

2. Research area and methods

The Hawaiian Islands are located within the North Pacific Central Gyre, an area with an estimated three million tonnes of plastic debris (Moore et al., 2001). The increased accumulation of oceanic debris within the gyre is a result of the large-scale clockwise rotation of ocean currents and high atmospheric pressure (Moore et al., 2001; Moore, 2008). Circulation around the high pressure centre is a result of the Coreolis effect and the frictional surface currents caused by westerly winds on the north side of the gyre and easterly trade winds to the south. The complex system of winds and

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currents results in a buildup of water and debris in the centre of the gyre (Aguado and Burt, 2004).

Plastic fragments were sampled from 5 beaches on the island of Kauai by setting a 40 m transect line on each beach parallel to the shoreline (Fig. 1). Plastics visible to the naked eye were sampled from 50 cm-wide swaths at 10 m intervals stretching from the water to the vegetation lines. Each plastic particle and <5 g of surrounding sediment was collected from the beach surface using a stainless steel tablespoon. Caution was used to avoid scratching the surfaces of plastic particles during sampling. In order to determine a rate of plastics accumulation on a typical Kauaiian beach, samples were collected from Maha'ulepu beach (Fig. 1). The plastics were sampled from a 1 m × 5 m area at a depth of <3 cm over a period of 11 days from March 9–20, 2008.

In order to remove loose debris, $CaCO_3$, NaCl and other residues, the samples were washed in a Branson ultrasonic cleaner with deionized water for 4 min then dried in a Thelco Precision laboratory oven at 35 °C for 45 min. A Bruker IFS55 FTIR equipped with a microscopic stage attachment was used to perform fourier transform infrared spectroscopy (FTIR). A micro attenuated total reflection (micro-ATR) attachment was used to determine plastic composition and level of surface oxidation. Digital photographs were taken using a Hitachi S-4500 field emission scanning electron microscope (FESEM) with a 10 kV electron accelerating voltage and a 30° sample tilt to analyze surface textures. All plastic samples were treated with a light coating of conductive gold prior to analysis to prevent sample charging.

3. Results

A total of 6082 pieces of plastic were collected from Maha'ulepu beach at an average rate of 484 pieces/day. The first day of sampling yielded 1243 plastic particles, and during the following 10 days, approximately 400–600 fragments were deposited on the beach daily. FTIR analysis of 56 plastic samples showed that 45 particles are composed of polyethylene (PE) and 11 particles are polypropylene (PP) (Table 1 Supplementary material). Spectra from polyethylene samples display peaks around 2916, 2849, 1471, and 718 cm^{-1}, which are characteristic of this material (Fig. 2a). Polypropylene samples also produced characteristic peaks between 2723 and 2952 cm^{-1} as well as several peaks in the lower wavenumbers between 631 and 1458 cm^{-1} (Fig. 2b). Peaks around 1711 cm^{-1} on several polyethylene and polypropylene samples are increased absorption peaks, which are indicative of oxidized material. Oxidation was classified as low, medium or high based on peak height at 1711 cm^{-1} relative to the characteristic peak height at 1471 cm^{-1}.

The plastic particles examined using SEM were predominantly eroded fragments (<1 cm^2) of larger objects, however, several plastic resin pellets (nurdles) were also recognized. The fragments are of various shapes, sizes and colour, with edges ranging from very angular to well rounded (c.f. Powers, 1953) (Table 1 Supplementary material). The majority of the larger fragments (>7 mm) are sub-angular, angular and very angular. Different surface textures were identified on the polyethylene samples, including flakes,

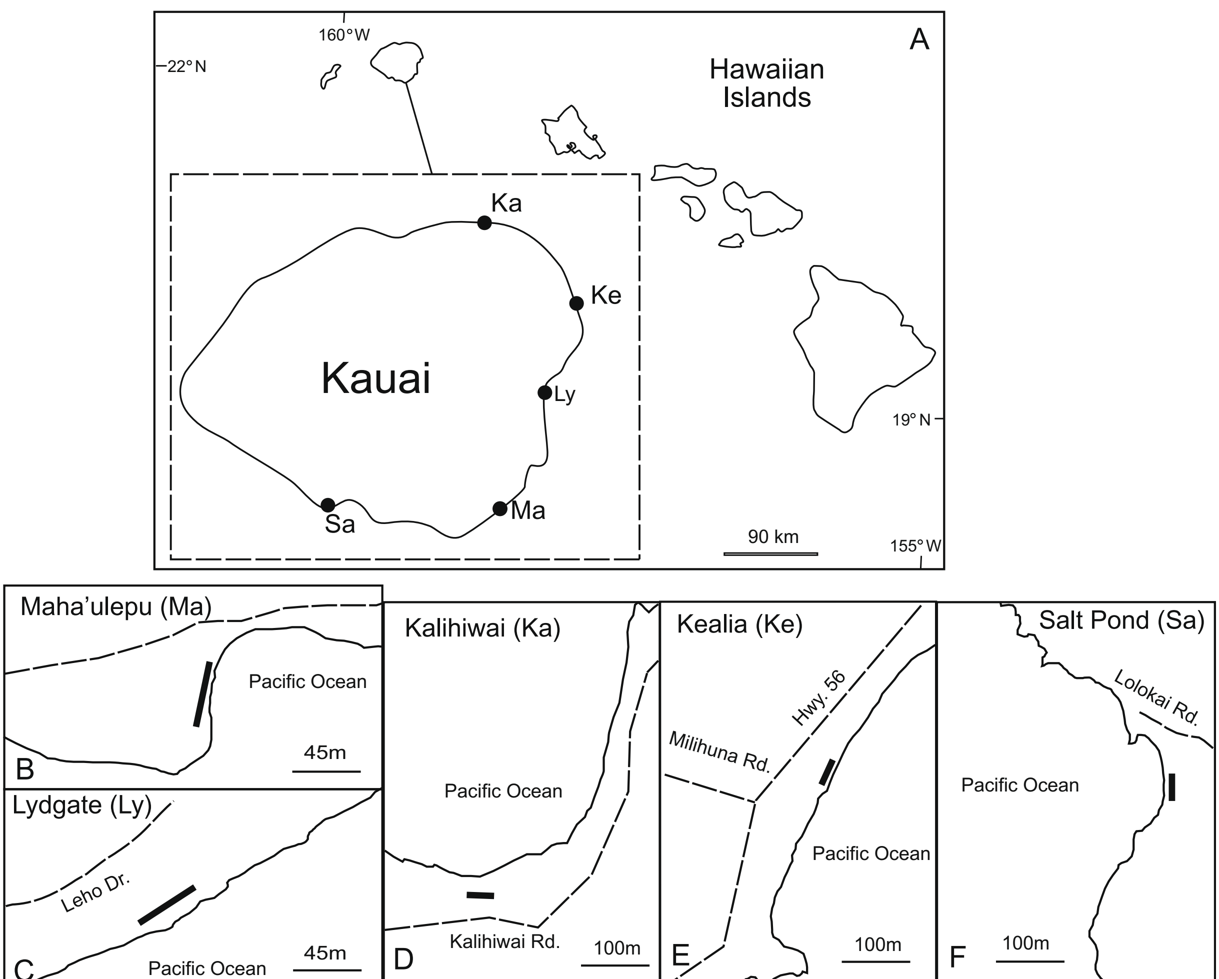

Fig. 1. (A) Sample locations on the island of Kauai, Hawaii. Closed circles indicate beaches where plastic debris was visible to the naked eye. (B–F) Sampling transects along each beach. Solid line is the shoreline, dashed lines represent roads, and short, thick lines represent transects.