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Large kelp-rafted rocks as potential dropstones in the Southern Ocean

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ABSTRACT

Cyclonic winds in April 2017 forced oceanic kelp rafts onshore in southeastern New Zealand, providing a ‘snapshot’ of ongoing kelp-rock transport. About 10% of observed southern bull kelp (*Durvillaea antarctica*) holdfasts contain substantial remnants of their original rocky substrates. The largest rock weighs ~7 kg, and was derived from the Mesozoic sedimentary Murihiku Terrane of southern New Zealand, > 100 km from the beach where it was deposited. Several other rafted rocks were derived from the same general source area, including a conglomerate clast with 10 cm igneous cobbles. Genetic sequencing of the kelp specimens confirmed their southern New Zealand derivation, which is distinct from sub-Antarctic or northern New Zealand clades. The floating rocks had been colonised by goose barnacles (*Lepas australis*), the largest of which were approximately 5 mm long, implying that the rocks had been floating for approximately 16 days before being blown ashore. The rocks may have travelled up to 200 km in that time in a northeasterly directed ocean current that flows at 10–15 km/day. If these rock-bearing kelp rafts had not been blown ashore in the cyclonic weather event, they would likely have continued to travel northeast in the Subtropical Front zone where they would likely have been deposited as dropstones. Abundant dropstones noted on the nearby Chatham Rise and Campbell Plateau, have previously been assumed to have been ice-rafted. A component of these dropstones could have been derived by kelp rafting, especially on the Chatham Rise, where the Subtropical Front is deflected east. A thick weathering rind, and remnant organic veneer, if present, along with clast provenance, may be the best distinguishing features of kelp-rafted dropstones compared to ice-rafted dropstones.

1. Introduction

Dropstones, which are anomalously large isolated clasts in finer grained sediments, are sparse but widespread features of the modern ocean floor and the marine sedimentary record (Bennett et al., 1996; Snoeckx et al., 1999; Carter et al., 2002). At high latitudes or at times of global cool climate, dropstones are generally attributed to ice-rafting of till in polar glaciers calved into the ocean (Snoeckx et al., 1999; Hoffman and Schrag, 2002; Carter et al., 2002; Allen and Etienne, 2008; Stickley et al., 2009). However, at middle latitudes the origin of dropstones is less clear-cut, as some biological rafting from nearby landmasses can also occur (Bennett et al., 1994; Bennett et al., 1996; Vogt and Parrish, 2012). In particular, the mid-high latitudes of both hemispheres can receive both ice-rafted dropstones and dropstones from biological rafting (Bennett et al., 1996; Vogt and Parrish, 2012). Hence, the paleoclimatic implications of the presence of these latter dropstones in the sedimentary record may be confused by uncertainties in their origins (Bennett et al., 1996; Vogt and Parrish, 2012).

Most dropstones in the marine environment are small (coarse sand, pebbles, or small cobbles), so details of their lithological origins and modes of transport are difficult to determine. Rare large dropstones are almost always attributed to ice-rafting as this is the most plausible explanation for long-distance marine transport (Cullen, 1962; Hoffman and Schrag, 2002; Allen and Etienne, 2008; Stickley et al., 2009). However, in this paper, we provide new evidence for kelp-rafting of large rocks offshore of New Zealand (Fig. 1), in a region in which icebergs with attendant till inclusions have been drifting since at least the Pleistocene (Carter et al., 2002). The numerous occurrences of dropstones on the sea floor in this area have all been previously attrubuted to ice-rafting (Cullen, 1962; Kudrass, 1984; Kudrass and von Rad, 1984; Carter et al., 2002). These conclusions have been influenced by (i) the presence of linear troughs and circular pits ascribed to grounding icebergs (Stewart et al., 2016); (ii) lithologies consistent with Antarctic rocks; and (iii) historical records of icebergs on Chatham Rise (Fig. 1; Brodie and Dawson, 1971).

This study was made possible because a period of strong easterly winds associated with Cyclone Cook in April 2017 drove drifting kelp from the offshore region to exposed beaches of southeastern New

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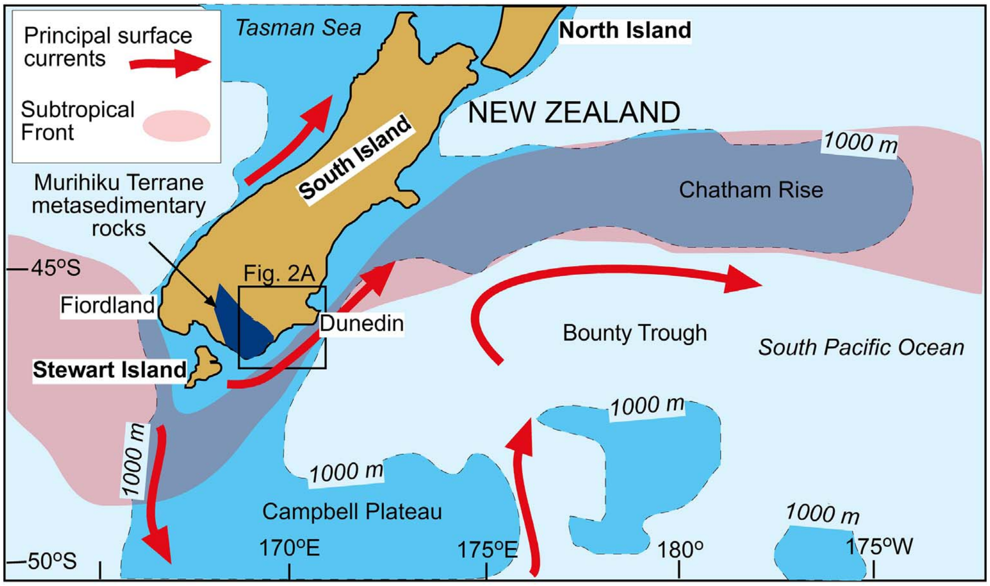

Fig. 1. Location map showing the seafloor topography and approximate range of the Subtropical Front zone around the South Island of New Zealand. Principal surface currents are indicated (simplified from Carter et al., 2002).

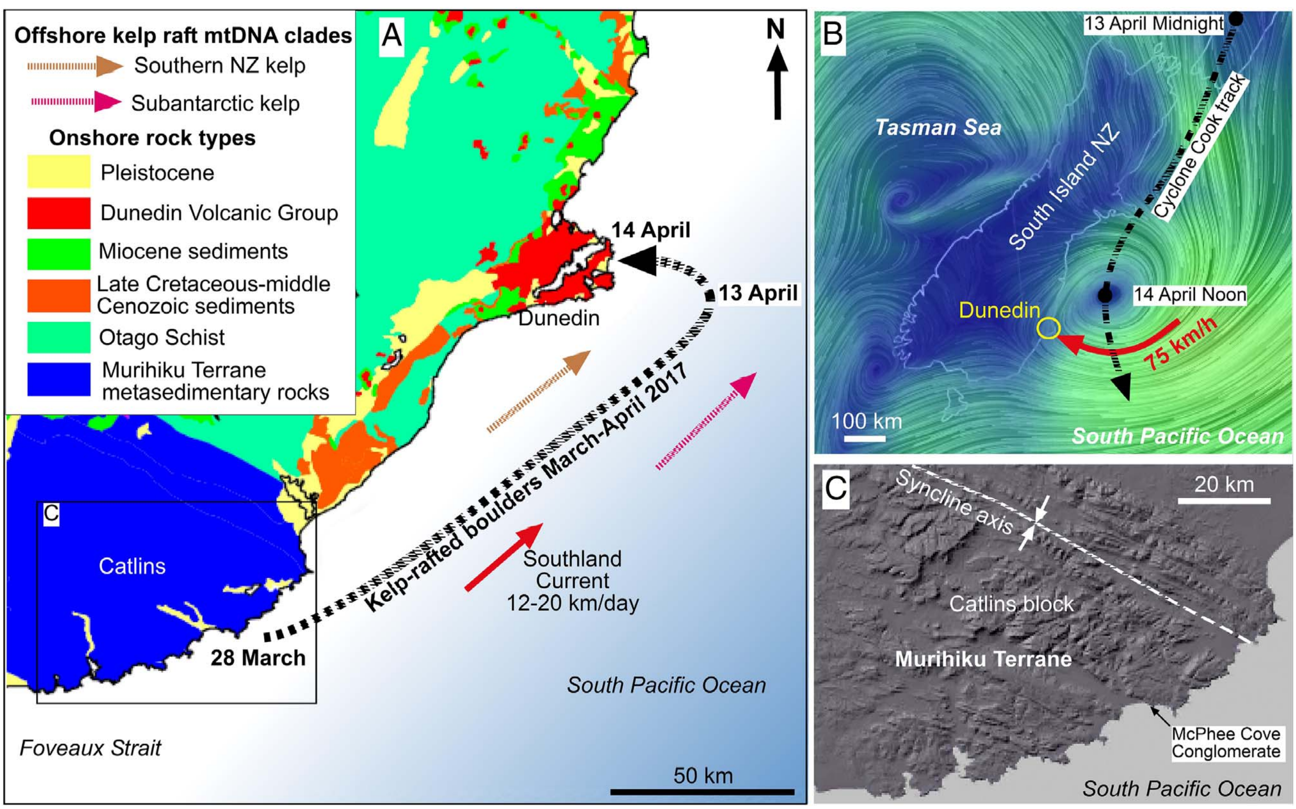

Fig. 2. Regional setting for the kelp-rafted rocks examined in this study. A. Summary geological map of the coastal portions of southeastern South Island (indicated in Fig. 1), after Bishop and Turnbull (1996) and Turnbull and Allibone (2003). Offshore arrows indicate migration of kelp rafts of differing genetic sources (Garden et al., 2014). Inferred trajectory and timing of large kelp-rafted rock transport is shown with dashed black arrow (see text). B. Digital simulation of wind directions and relative velocities in Cyclone Cook at noon on 14 April 2017 (from https://earth.nullschool.net; accessed 24 April 2017). C. Hillshade image of the topography of the Catlins structural block (as in A) showing strike ridges of Mesozoic Murihiku Terrane sandstones, many with associated conglomerates, and the rugged coastline that cuts across the structure.

Zealand (Fig. 2a, b). Longshore kelp-rafting of rocks was known to occur in this area, carrying rocks along individual beaches or further along the coast (Garden et al., 2011; Garden and Smith, 2015). However, this cyclone event has provided a ‘snapshot’ of rafting material that is not normally readily accessible. Samples of this material give new insights into the nature of rock-bearing kelp rafts that are often 30–40 km offshore (Fig. 2a; Garden et al., 2014), and indicate the size and mobility of large rocks that has not previously been well understood (but see Garden and Smith, 2015). By using a combination of geological and biological observations, we reconstruct the travel history of these large rocks, and infer that kelp-rafting has probably contributed substantially to the widespread dropstones of this region.