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Shore platform downwearing in eastern Canada: The mega-tidal Bay of Fundy

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A B S T R A C T

Laboratory and field work was conducted to determine rates of surface downwearing on shore platforms at two sites in the Bay of Fundy, Canada; these data are needed to assess and model the effect of downwearing mechanisms on platform evolution. Sandstone and basalt samples (900) were exposed to semidiurnal tidal cycles over 3 years, using de-ionized water or artificial sea water. They were immersed for 1, 6, or 11 h over each 12 h tidal cycle, representing the lowest high (LHT), mid-, and highest low (HLT) tidal levels, respectively. A further 600 samples were immersed in de-ionized water or artificial sea water for 90 min every 1, 2, or 3 weeks, representing increasingly higher elevations above the LHT level, or exposed for 90 min every 1, 2, or 3 weeks, representing increasingly lower elevations below the HLT level; these experiments ran for 12 months. In the field, surface downwearing was measured at 108 transverse micro-erosion meter (TMEM) stations over 2 to 6 year periods. In the laboratory, mean downwearing rates between the LHT and HLT levels were 0.61–1.80 mm yr^{-1} in sandstones and 0.01–0.18 mm yr^{-1} in basalts; rates were highest at the LHT level. Rates decreased with elevation above the LHT level and were uniformly low below the HLT level. Salt weathering was dominant above the LHT level. Salt weathering and wetting and drying were important in sandstones between the LHT and HLT levels, but salts inhibited rock breakdown in basalts. In the field, the mean downwearing rate was 1.254 mm yr^{-1} in sandstones, which was similar to the experimental data, and 0.722 mm yr^{-1} in basalts, which was much higher than in the experiments with artificial sea water but similar to the experiments with de-ionized water. There was no relationship in the field between downwearing rate and rock hardness or TMEM station elevation.

1. Introduction

Shore platforms are usually produced by marine and subaerial erosion of sea cliffs, and lowering of the residual surface created at the cliff foot by backwearing (erosion in the horizontal plane) and downwearing (erosion in the vertical plane). The efficacy and relative importance of the erosional agents that operate on platform surfaces, including waves, ice, frost, chemical and salt weathering, and bioerosion, vary according to such factors as the climate, wave regime, tidal range, and the physical and chemical characteristics of the rocks (Trenhaile, 1987; Sunamura, 1992). Much of the recent work on shore platforms has been concerned with surface downwearing which, in the absence of abrasive material and bioerosional organisms, has been attributed generally to weathering and removal of the fine-grained debris by waves (Kirk, 1977; Robinson, 1977; Gill and Lang, 1983; Mottershead, 1989; Stephenson and Kirk, 1998; Andrade et al., 2002; Trenhaile et al., 2006; Foote et al., 2006; Swantesson et al., 2006). The responsible weathering processes are assumed to include wetting and drying, involving the expansion and contraction of the rocks as they absorb and desorb water with the rise and fall of the tides, and the expansion of salt crystals within rock voids as the water evaporates. Chemical weathering may also contribute to surface lowering and it has been accorded an important role in some classical models of shore platform development (Bartrum, 1916; Bartrum and Turner, 1928).

Downwearing measurements have usually been made with a micro-erosion meter or its variant, a transverse micro-erosion meter (collectively referred to as a TMEM in this paper) (Stephenson and Finlayson, 2009). Although TMEMs cannot measure erosion through the removal of large rock fragments (quarrying), they have provided important information on more continuous lowering of rock surfaces by weathering (and debris removal), bioerosion, and abrasion, and possibly by wave-generated bottom shear stresses. The processes responsible for surface lowering are generally inferred from the spatial and temporal characteristics of the erosional data, however, and it is difficult to identify or assess the contributions of individual mechanisms. Furthermore, we do not have enough TMEM data, from a variety of environments, to determine the effect of rock type, climate, tidal range, and other factors on downwearing or weathering efficacy.

The present paper discusses TMEM downwearing data that have been collected for up to 6 years at two sites in the mega-tidal Bay of Fundy, and describes an attempt to use laboratory experiments, running for up to 3 years, to supplement and help to interpret the field data. This work was undertaken to determine rates of surface

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downwearing on shore platforms in a mega-tidal environment, in order to provide a firmer basis on which to assess and model the role of weathering and other downwearing mechanisms in the long-term evolution of platform surfaces, in the past, and with rising sea level, in the future (Trenhaile, 2005, 2008; Trenhaile and Porter, 2007). The effect of quarrying and lowering of platform surfaces by backwearing processes by waves and possibly by ice, was not considered in this study.

2. Study areas

There were two main study areas in the Bay of Fundy in northern Nova Scotia, a basalt platform at Scots Bay and a sandstone platform in the Minas Basin at Burntcoat Head (Figs. 1 and 2). The foreshore at Scots Bay consists of the greater North Mountain Basalts, which were formed during a time of increased volcanic activity in the Early Jurassic Period (Crosby, 1962). The basalts tend to be highly vesicular, and basaltic surface features are reinforced by resistant amydules, primarily from the zeolite family (Colwell, 1980). The soft, red, clastic sandstones at Burntcoat Head belong to the Triassic Wolfville Formation, which was deposited either as alluvial fans or aeolian dunes, or on the bed of braided streams (Klein, 1962).

The 'Large Tide Range' (the mean of the highest tide each year, over a 19 year period) is 13.5 m at Scots Bay and 16 m at Burntcoat Head (the highest range in the world) (Canadian Hydrographic Service, 2009), although the mean spring tidal range in each of these areas is 2–3 m lower than these extremes. Southwesterly, westerly and northwesterly waves predominate in the Bay of Fundy, and about half have significant deep water heights of less than 0.5 m and peak periods of less than 4 s; in the sheltered Minas Basin, more than three-quarters of the waves are lower than 1 m (Eid et al., 1991). Nevertheless, previous work using graduated steel poles and video-recorders to measure waves over complete tidal cycles has shown that the wave pressures generated in rock joints and other discontinuities are high enough to dislodge large rock fragments (wave quarrying) (Trenhaile and Kanyaya, 2007). Ice protects the coast from waves from January to April.

The Bay of Fundy experiences crustal subsidence owing to glacio-isostatic adjustment. Andrews (1989) proposed that relative sea level rose by more than 6 m in the last 2000 years, and is rising today by 2 m per 1000 years. Amos (2004) also noted that tidal range has changed in conjunction with changing relative sea level in this area (Fig. 3).

There are very wide shore platforms along much of the southern shore of the Minas Basin. The platform at Burntcoat Head is backed by a steep and active cliff, about 15 m high. The shore platform is slightly concave upwards with gradients in the study area of about 2.5° in the upper part and from 1° to 1.5° in the lower portion (Fig. 4). The exposed platform surface is more than 500 m in width during low spring tides. There are undulating areas of more resistant sandstone in some places and low ridges, a few centimetres in height, of cemented, rounded pebbles that were deposited by ancient streams. Most of the platform surface has few marine organisms, apart from some grazing gastropods and isolated patches of seaweed, although there are a variety of borers and burrowers in some large pools, and an almost continuous cover of barnacles near the low tidal level. The lower portion of the platform at Scots Bay, several metres below the mid-tidal level, passes into, and presumably continues beneath, a wide, sandy tidal flat. The exposed, upper part of the shore platform is about 120 to 130 m in width, and it extends to an elevation above all but the highest tides to the foot of a largely grass covered rock and rubble bluff, a few metres in height. The upper portion of the platform above the mean high tidal level is discoloured and weathered. The lower segments of the exposed platform surface contain an assortment of rounded boulders ranging from 50 to 300 mm in diameter, and much of the lower platform is covered by seaweed and small barnacles.

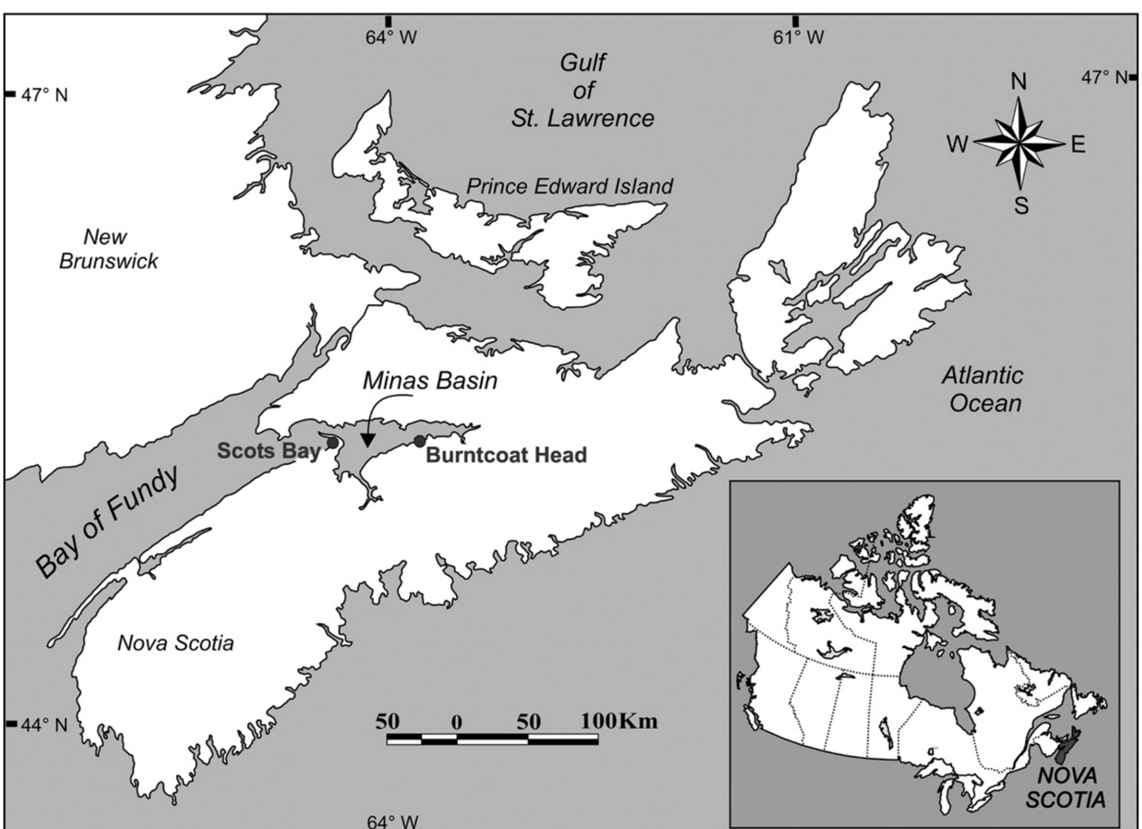

Fig. 1. The study areas at Scots Bay and Burntcoat Head in the Bay of Fundy, eastern Canada.