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Assessing topographic controls on flow direction in washover deposits using measurements of Magnetic Fabric

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ABSTRACT

A set of anomalous sand deposits enclosed between paleosol layers were identified in Okains Bay on eastern Banks Peninsula, New Zealand. These were investigated to determine flow patterns during their deposition and the influence of topography on these patterns. This was achieved using a combination of sedimentary analyses, Magnetic Fabric (MF) and Ground Penetrating Radar (GPR). Two washover facies were identified, based on stratigraphic context, particle size analyses and flow direction during deposition from MF results. These deposits, which decrease in thickness with distance inland, comprise two layers of fine-medium sand and are situated 1.3 km from the coast on an estuary margin. Results show the sand sheets were deposited as overwash from the estuary, with the extent and deposition patterns controlled by local topography and the presence of relict dune ridges. MF is demonstrated as a versatile and important technique for determining flow patterns and depositional mechanisms. Flow patterns identified here from MF highlight the importance of river channels as conduits for short-lived high energy marine inundation events. Additionally, these results support the importance of topography in controlling deposition patterns, which has important implications for the reconstruction of events where the paleotopography is unknown.

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1. Introduction

Geological observation of sediment deposits has long been used in a variety of contexts to understand geomorphic processes and assess the impact of catastrophic events on the landscape. In the coastal environment, catastrophic events that may leave an anomalous sedimentary signature in the record include storms, tsunamis and river floods. Identifying and characterising such deposits has been the subject of a considerable amount of research in recent decades, particularly distinguishing storm and tsunami deposits (e.g. Goff et al., 2004; Cochran et al., 2005; Kortekaas and Dawson, 2007; Goto et al., 2011). The reconstruction of events from their deposits relies on numerous techniques to assist in the interpretation of depositional mechanisms, and a study of the flow direction is one of these.

The configuration and topography of the coastline has a significant impact on the depositional process and thus the form of preserved features (Dawson, 1994; Sugawara et al., 2008). In the case of coastal events such as storms and tsunamis, inundation distances and patterns are affected by topography, surface roughness and elevation (Kon'no, 1961; Sugawara et al., 2008; MacInnes et al., 2009). In particular, rivers may form a path of preferential flow due to the low elevation of the channels and low friction of the water surface (Gomez et al., 2011). Consequently, it is important to note that inundation may occur from directions other than perpendicular to the coast and this can significantly affect deposition patterns.

The geological signature of high energy washover events depends on the type and availability of source material for transport, flow dynamics, topography and preservation potential (Shiki et al., 2008). These deposits are often initially identified by stratigraphic context, occurring frequently as anomalously coarse-grained deposits in a background of lower energy material (Minoura and Nakaya, 1991; Clague and Bobrowsky, 1994; Benson et al., 1997; Clague et al., 1999; Hutchinson et al., 2000; Chagué-Goff et al., 2002; Switzer et al., 2005; Nichol et al., 2007). In the case of a sandy coast, washover deposits typically comprise a landward-fining and widespread sheet of well-sorted marine-derived sand, deposited beyond the limit of usual marine influence and commonly preserved in low energy environments such as coastal lagoons or low-lying areas (Dawson and Shi, 2000; Sedgwick and Davis, 2003; Switzer et al., 2005; Dawson and Stewart, 2007; Moore et al., 2007).

One of the most significant challenges in the study of washover deposits is the identification of cause and distinguishing sedimentary characteristics. Many onshore coastal deposits share commonalities

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that can cause difficulty in determining their depositional mechanism. It can be difficult to distinguish deposits relating to storm surge, river outwash deposits, mouth migrations and sea level changes (Switzer et al., 2005, 2006; Dawson and Stewart, 2007; Shiki et al., 2008; Switzer and Jones, 2008). In particular, overwash due to storm surge can produce a deposit very similar to that of a tsunami; and differentiating between these two mechanisms has been the subject of much work in recent decades (e.g. Nanayama et al., 2000; Tuttle et al., 2004; Switzer et al., 2005; Morton et al., 2007; Medina et al., 2011; Ramírez-Herrera et al., 2012). On the other hand, sea level changes are less likely to be confused with rapid-deposition high energy events, as the sedimentary changes occur more gradually (Switzer and Jones, 2008), and river outwash deposits can usually be distinguished by their flow direction, complex sedimentary structure, and terrigenous material (Tunbridge, 1981; Zwoliński, 1992; Boggs, 2001).

The purpose of this research is to determine the flow patterns in a suite of washover deposits, most likely related to historical tsunami, and assess the role of topography and landscape configuration on the patterns of deposition. Magnetic Fabric (MF) is presented as a tool to investigate these objectives and aid in understanding past events from their deposits.

1.1. Magnetic Fabric technique as a proxy for flow direction in unconsolidated sediments

Magnetic Fabric (MF) is an electromagnetic technique that is widely employed in geophysical research to investigate rock fabrics and infer dynamics of emplacement mechanisms (Hamilton and Rees, 1971; Ellwood, 1980; Tarling and Hrouda, 1993; Borradaile and Henry, 1997; Bradák, 2009). This was previously known as Anisotropy of Magnetic Susceptibility (AMS), but has recently been changed to MF to recognise the precedence of the AMS acronym in radiocarbon dating. MF works on the principle that when a sample is exposed to a magnetic field an induced magnetic moment is generated in susceptible grains, which can be visualised as a magnetic ellipsoid. This ellipsoid varies in shape and alignment according to the composition and fabric of the grains in the sample, which is a function of the orientation of their long axes and crystalline mineral structure (Tarling and Hrouda, 1993). The fabric determined from the magnetically susceptible grains acts as a proxy for that of the entire sample.

The application of MF to unconsolidated deposits is a recent research development that has proven to be very successful in determining flow direction during deposition (Wassmer et al., 2010; Wassmer and Gomez, 2011). MF is able to provide critical information regarding flow energy and dynamics that cannot be directly obtained using traditional sedimentological and paleontological techniques (Wassmer and Gomez, 2011). In particular, MF has been successfully used to provide important information about the flow dynamics of successive waves within a tsunami sequence, including both the uprush and backwash facies (Wassmer and Gomez, 2011). However, this method is restricted to use in deposits composed primarily of sand, as samples with a significant proportion of either coarse or fine material cannot be measured effectively by MF (Wassmer et al., 2010; Wassmer and Gomez, 2011).

Parameters commonly used in analysis of MF include magnetic foliation (F), corrected degree of anisotropy (P_j), alignment parameter (F_s), shape parameter (T) and the shape factor (q). The direction of flow can be determined from the orientation and declination of the maximum axis, and the other parameters can be used to infer hydrodynamic conditions during deposition (Hamilton and Rees, 1970; Ellwood, 1980; Park et al., 2000; Wassmer et al., 2010). Of particular interest are the alignment parameter (F_s), which increases with the increasing energy of bottom currents (Park et al., 2000), and the shape factor (q), both of which are indicators of the quality of the Magnetic Fabric and thus the degree of particle alignment. The shape parameter (T) is related to the shape of the ellipsoid, with oblate ellipsoids ($0 > T < 1$) common in sub-aqueous environments and representing deposition from suspension (Tarling and Hrouda, 1993).

2. Regional setting

The study was undertaken at Okains Bay, an eastern facing bay on Banks Peninsula, New Zealand. The Banks Peninsula complex was formed by two shield volcanoes of late Miocene age (Sewell, 1988) and comprises deep, steep-sided valleys and bays controlled by the geometry of lava flow remnants. The volcanic bedrock is covered by a thick mantle of fine loess material, which is subject to considerable erosion. The peninsula bays are infilled by fine sediments and occasionally marine sands, which are supplied to some of the bays by longshore drift from south of Banks Peninsula (Dingwall, 1966, 1974).

Okains Bay is a pocket beach, situated to the northeast of Banks Peninsula (Fig. 1). It is one of the larger bays of the peninsula, extending 8 km from the beach to the head of the valley and reaching a maximum elevation of 573 m asl. The width of the bay at the beach is 0.9 km, with a maximum length of 2 km from the beach to the outer headlands. The walls of the valley are steep sided basaltic lava remnants, with gentler slopes grading down into the infilled valley floor. This consists of fine sands and relict dune ridges, formed by extensive progradation throughout the late Holocene (Dingwall, 1974; Stephenson and Shulmeister, 1999). A small stream flows down the valley, forming an estuary in its lower reaches. The sandy beach is composed of fine yellow-brown siliclastic sand with a dissipative nearshore environment that is sheltered from the high energy southern swell by the two headlands.

The deposits are located in a low-lying part of the coastal plain adjacent to the estuary and 1.3 km from the coast (Fig. 1). The area of interest extends 60 m southeast from the estuary, formed of a flat terrace-like area, backed by relict dune ridges that lie parallel to the coast and longitudinal to the study area.

3. Materials and methods

3.1. Ground Penetrating Radar (GPR)

GPR was employed to determine the subsurface structure over the study area. A series of transects was surveyed using a PulseEkko GPR system connected to a 500 MHz antenna. Data comprised 11 intersecting transects taken at approximately 5 m intervals across the field site, with 4 oriented perpendicular and 7 oriented parallel to the estuary (Fig. 1). A further 5 transects were surveyed parallel to the estuary, but poor signal quality resulted in unusable data and they were omitted from further analysis (Fig. 1). Data were analysed using ReflexW software, according to the procedure presented by Neal (2004). The signal was enhanced through AGC gain and energy decay, followed by pulse velocity correction and topography adjustment through static migration. The velocity adjustment was calculated by fitting a curve to the geometry of refraction hyperbolae in the radargrams and the values applied ranged from 0.04 to 0.085 m ns^{-1}.

3.2. Sediment analyses and stratigraphy

Five trench sites were selected within the study area, adjacent to the estuary and a man-made drainage ditch (Fig. 1). Stratigraphy was recorded in detail in the field at each sampling site and trenches were sampled for grain size at 2 cm intervals. In the laboratory, organic matter was removed from the sediment samples with hydrogen peroxide and particle size analysis was performed by laser diffraction using a Malvern Multisizer. Statistical parameters (mean grain size, standard deviation, skewness and kurtosis) were calculated using GRADISTAT software according to the geometric method of moments.

CM diagrams were constructed by from the particle size results to infer the transport conditions during deposition. Passega (1957, 1964)

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