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Construction of volcanic records from marine sediment cores: A review and case study (Montserrat, West Indies)

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ABSTRACT

Detailed knowledge of the past history of an active volcano is crucial for the prediction of the timing, frequency and style of future eruptions, and for the identification of potentially at-risk areas. Subaerial volcanic stratigraphies are often incomplete, due to a lack of exposure, or burial and erosion from subsequent eruptions. However, many volcanic eruptions produce widely-dispersed explosive products that are frequently deposited as tephra layers in the sea. Cores of marine sediment therefore have the potential to provide more complete volcanic stratigraphies, at least for explosive eruptions. Nevertheless, problems such as bioturbation and dispersal by currents affect the preservation and subsequent detection of marine tephra deposits. Consequently, cryptotephras, in which tephra grains are not sufficiently concentrated to form layers that are visible to the naked eye, may be the only record of many explosive eruptions. Additionally, thin, reworked deposits of volcanic clasts transported by floods and landslides, or during pyroclastic density currents may be incorrectly interpreted as tephra fallout layers, leading to the construction of inaccurate records of volcanism. This work uses samples from the volcanic island of Montserrat as a case study to test different techniques for generating volcanic eruption records from marine sediment cores, with a particular relevance to cores sampled in relatively proximal settings (i.e. tens of kilometres from the volcanic source) where volcaniclastic material may form a pervasive component of the sedimentary sequence. Visible volcaniclastic deposits identified by sedimentological logging were used to test the effectiveness of potential alternative volcaniclastic-deposit detection techniques, including point counting of grain types (component analysis), glass or mineral chemistry, colour spectrophotometry, grain size measurements, XRF core scanning, magnetic susceptibility and X-radiography. This study demonstrates that a set of time-efficient, non-destructive and high-spatial-resolution analyses (e.g. XRF core-scanning and magnetic susceptibility) can be used effectively to detect potential cryptotephra horizons in marine sediment cores. Once these horizons have been sampled, microscope image analysis of volcaniclastic grains can be used successfully to discriminate between tephra fallout deposits and other volcaniclastic deposits, by using specific criteria related to clast morphology and sorting. Standard practice should be employed when analysing marine sediment cores to accurately identify both visible tephra and cryptotephra deposits, and to distinguish fallout deposits from other volcaniclastic deposits.

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1. Introduction

The products of an individual subaerial volcanic eruption are often rapidly buried beneath later eruption products, eroded or covered by vegetation soon after their deposition, making it difficult to reconstruct comprehensive volcanic histories from terrestrial exposures alone. As a consequence, dispersed explosive-eruption products (tephra) sampled within marine- and lake-sediment cores are widely used to reconstruct explosive eruption records of volcanoes (e.g. Paterne et al., 1988; Ortega-Guerrero and Newton, 1998; Wulf et al., 2004, 2012; de Fontaine et al., 2007; Bertrand et al., 2008; Gudmundsdóttir et al., 2012). In making such reconstructions, it is important that explosive eruption deposits are correctly identified, and can be discriminated from volcaniclastic sediments deposited via other mechanisms (e.g. Ruddiman and Glover, 1972; Schneider et al., 2001; Trofimovs et al., 2006; Manville et al., 2009; Hunt et al., 2011). If this can be achieved, and if these tephra deposits are preserved within an environment of continuous sediment accumulation, then subaqueous sediment cores can be used to produce explosive eruption records that are more complete, and which have better age-constraints, than those typically derived from subaerial deposits. Marine and lacustrine sediments can thus provide a medium by which to assess the periodicity of eruptions and potential hazards posed by volcanoes, across a range of temporal and spatial scales (McGuire et al., 1997; Pyle et al., 2006; Kutterolf et al., 2008, 2013; Carel et al., 2011; Watt et al., 2013; Van Daele et al., 2014).

The interpretation of sediments containing volcaniclastic material is not without pitfalls (Boygle, 1999; Schneider et al., 2001; Juvigné et al., 2008; Gudmundsdóttir et al., 2011; Schindlbeck et al., 2013). In order to avoid erroneous or inconsistent identification of explosive volcanic eruption deposits, it is important that well-defined techniques are adopted for the analysis of volcaniclastic deposits within sediment cores. Inadequate detection techniques may overlook thin or dispersed tephra layers, that are invisible to the naked eye (cryptotephras), or misinterpret volcaniclastic sediments deposited via other mechanisms (Manville et al., 2009) as tephra fallout layers.

1.1. Rationale and aims

There have been considerable advances in the methods used to detect, date and characterise volcaniclastic deposits in the last few decades (Froggatt, 1992; Turney et al., 2004; Blockley et al., 2005; Gehrels et al., 2008; Manville et al., 2009; Lowe, 2011). However, subjective elements in the criteria used to identify a tephra layer deposited from an explosive volcanic eruption still remain.

Tephra deposits have been generally used for two broad applications, which differ in their spatial scales, and specifically in the typical distance of tephra sampling from the volcanic source. The first application involves the correlation of widespread (distal) deposits from very large (Plinian) and relatively infrequent explosive eruptions (e.g. Machida and Arai, 1983; Pyle et al., 2006). Volcanic ash may be transported vast distances. For example, glass shards from the El Chichón (Mexico) eruption in 1982 were identified in Greenland ice, ~10,000 km from the source (Zielinski et al., 1997). Such widespread deposits thus provide useful isochronous markers over thousands of square kilometres and are widely used in palaeo-climate studies (e.g. Allen et al., 1999; Lowe et al., 2008). Correlation of these distal deposits is aided by their deposition far from active volcanic sources, where volcaniclastic grains are a rare grain-type and where deposition via airfall may be the only plausible origin of volcaniclastic material (e.g. Matthews et al., 2012). It is thus possible to separate these grains from their host sediment (Blockley et al., 2005; Bourne et al., 2010) and to correlate them across widely-spaced sites using their glass or mineral chemistry (e.g. Kotaki et al., 2011; Matsu'ura et al., 2011; Smith et al., 2011; Albert et al., 2012). As well as providing chronological markers, such correlations provide constraints on the magnitude and frequency of large explosive eruptions.