Journal of Volcanology and Geothermal Research 323 (2016) 80–96

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Subaqueous cryptodome eruption, hydrothermal activity and related seafloor morphologies on the andesitic North Su volcano

Janis Thal [a,*], Maurice Tivey [b], Dana R. Yoerger [b], Wolfgang Bach [a]

[a] MARUM, University of Bremen, 28359 Bremen, Germany
[b] Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA

ARTICLE INFO

Article history:
Received 30 May 2015
Received in revised form 9 December 2015
Accepted 28 April 2016
Available online 10 May 2016

Keywords:
Cryptodome
ROV
Hydrothermal
Cementation
Andesite
Explosivity

ABSTRACT

North Su is a double-peaked active andesite submarine volcano located in the eastern Manus Basin of the Bismarck Sea that reaches a depth of 1154 m. It hosts a vigorous and varied hydrothermal system with black and white smoker vents along with several areas of diffuse venting and deposits of native sulfur. Geologic mapping based on ROV observations from 2006 and 2011 combined with morphologic features identified from repeated bathymetric surveys in 2002 and 2011 documents the emplacement of a volcanic cryptodome between 2006 and 2011. We use our observations and rock analyses to interpret an eruption scenario where highly viscous, crystal-rich andesitic magma erupted slowly into the water-saturated, gravel-dominated slope of North Su. An intense fragmentation process produced abundant blocky clasts of a heterogeneous magma (olivine crystals within a rhyolitic groundmass) that only rarely breached through the clastic cover onto the seafloor. Phreatic and phreatomagmatic explosions beneath the seafloor cause mixing of juvenile and pre-existing lithic clasts and produce a volcaniclastic deposit. This volcaniclastic deposit consists of blocky, non-altered clasts next, variably (1–100%) altered clasts, hydrothermal precipitates and crystal fragments. The usually applied parameters to identify juvenile subaqueous lava fragments, i.e. fluidal shape or chilled margin, were not applicable to distinguish between pre-existing non-altered clasts and juvenile clasts. This deposit is updomed during further injection of magma and mechanical disruption. Gas-propelled turbulent clast-recycling causes clasts to develop variably rounded shapes. An abundance of blocky clasts and the lack of clasts typical for the contact of liquid lava with water is interpreted to be the result of a cooled, high-viscosity, crystal-rich magma that failed as a brittle solid upon stress. The high viscosity allows the lava to form blocky and short lobes. The pervasive volcaniclastic cover on North Su is partly cemented by hydrothermal precipitates. These hydrothermally-cemented breccias, crusts and single pillars show that hydrothermal circulation through a thick layer of volcaniclastic deposits can temporarily increase slope stability through precipitation and cementation.

1. Introduction

More than 32,000 seamounts worldwide rise >750 m above the regional seafloor that have been identified by satellite altimetry and ship-based bathymetry. Most of which are believed to be of volcanic origin (Wessel, 2001; Hillier and Watts, 2007). Despite the enormous number of seamounts, only a few have been studied in detail and little is known about their formation. Over the past decade, technological advances in seafloor imaging and in situ observations, in concert with a number of dedicated research cruises, have increased our knowledge of, and perspective on, submarine volcanism and the architecture of submarine volcanoes (e.g. Wright et al., 2003; Embley et al., 2006; Carey and Sigurdsson, 2007; Chadwick et al., 2008; Allen and McPhie, 2009; Leat et al., 2010; Schipper et al., 2010; Clague et al., 2011; Deardorff et al., 2011; Resing et al., 2011). Seafloor exploration, particularly, by remotely operated vehicles (ROV) and repeated bathymetric surveys has allowed detailed documentation of the temporal changes in seafloor morphology and associated volcanic activity (e.g. Wright et al., 2003; Embley et al., 2006; Carey and Sigurdsson, 2007; Chadwick et al., 2008; Clague et al., 2011; Watts et al., 2012).

In contrast to mid ocean ridges, volcanic activity in arc settings is clearly highly diverse in space, time and composition and featuring variable eruption styles from explosive to effusive dome emplacement (e.g. Embley et al., 2006; Carey and Sigurdsson, 2007; Allen et al., 2010; Resing et al., 2011). As an example, volcanoes along the Tonga–Kermadec-arc have been important in understanding the eruption products of arc-related submarine volcanism and the architecture of such volcanoes (de Ronde et al., 2006; Chadwick et al., 2008; Clague et al., 2011; Watts et al., 2012). In particular, Brothers volcano in the Kermadec arc has been studied in detail and provides an especially important example of the surface expressions formed by volcanic eruptions, along with processes associated with extensive hydrothermal activity and slope collapse (de Ronde et al., 2011).

* Corresponding author.
E-mail address: ja_th@uni-bremen.de (J. Thal).

http://dx.doi.org/10.1016/j.jvolgeores.2016.04.041

This paper presents a broad systematic analysis of seafloor structures of the active andesite North Su submarine volcano, the central edifice of the SuSu Knolls, based on two geologic mapping campaigns and sets the stage for future in-depth volcanology studies. The SuSu knolls formed in a back-arc-volcanic system in the eastern Manus Basin of the Bismarck Sea. The associated hydrothermal setting is the submarine equivalent of terrestrial high-sulfidation Cu–Au mineralization deposits (Binns et al., 1997; Moss and Scott, 2001; Yeats et al., 2008). The North Su volcano hosts an active multi-component hydrothermal system which is a potential analog for the highly prospective volcanic hosted massive sulfide deposits (Hedenquist and Lowenstern, 1994; de Ronde et al., 2003, 2011; Hannington et al., 2005). The host rock composition combined with the entrainment of volatile species from the magmatic system facilitates the enrichment of economically important metals such as copper, gold and zinc (e.g. Sangster, 1980; Herzig, 1999; Iizasa, 1999; Hannington et al., 2005, 2011; Mosier et al., 2009). The bathymetry and geological observations of North Su volcano collected from three cruises in 2002, 2006 and 2011, combined with a Geographical Information Systems (GIS) database of AUV-based micro-bathymetry as well as video recordings, rock analyses and temperature measurements are used to understand the recent volcanic and hydrothermal activity of North Su volcano.

2. Regional geology

The Manus Basin is a rapidly opening back-arc basin in the south-eastern Bismarck Sea that is associated with the northward subduction of the Solomon Sea plate at the New Britain Trench (Taylor, 1979; Taylor et al., 1994; Martinez and Taylor, 1996, 2003) (Fig. 1). A band of active seismicity called the Bismarck Sea Seismic Lineation (BSSL) effectively divides the basin into the North and South Bismarck Plates (Tregoning et al., 1998). The BSSL is defined by left-lateral transform faults and small spreading segments including the Manus Spreading Center (Fig. 1). Rapid clockwise rotation (~8° Ma^{-1}) of the South Bismarck Plate (Tregoning et al., 1999) results in an asymmetric spreading of the North and South Bismarck Plate, which causes an eastward propagation of the BSSL.

In the central Manus Basin, MORB-like lava at the Manus Spreading Center (MSC, Fig. 1) indicates true seafloor spreading (Martinez and Taylor, 1996; Sinton et al., 2003). In contrast, remnant mid-Cenozoic island arc crust (Coleman and Packham, 1976; Falvey and Pritchard, 1982; Kroenke and Rodda, 1984) is rifted in the eastern part of the basin creating a series of sigmoidal neovolcanic ridges (the South East Ridges; SER) and solitary volcanoes with lava compositions ranging from basalt to rhyodacite (Binns and Scott, 1993; Sinton et al., 2003). The ~70 km long SER volcanic zone is situated at the easternmost tip of the BSSL and, due to the asymmetric spreading, exhibit the highest spreading rates in the Manus Basin (up to 137.5 mm a^{-1}; (Tregoning et al., 1998, 1999; Tregoning, 2002)).

Two left-lateral transform faults (the Djaul and Weitin transforms, Figs. 1 and 2) border the SER (Martinez and Taylor, 1996) and create an intra-transform configuration that produces a stepwise en-echelon alignment of volcanic ridges and seamounts. Several hydrothermal vent areas, including PACManus, Desmos and SuSu Knolls have been discovered at the SER (Binns and Scott, 1993; Auzende et al., 1996, 2000; Gamo et al., 1997; Hashimoto et al., 1999; Tivey et al., 2006; Bach et al., 2011; Thal et al., 2014). The accumulation of polymetallic sulfides in these areas has been considered a modern analog of ancient Volcanic Massive Sulfide (VMS) deposits mined on land (e.g. Binns and Scott, 1993; Petersen et al., 2003; Yeats et al., 2014).

The SuSu Knolls area comprises three volcanic edifices (South Su, North Su and Suzette, Figs. 3 and 4) situated on the NNW striking Tumai Ridge (Moss and Scott, 2001). In 1993, the PACMANUS II cruise detected a strong water column plume anomaly over the SuSu Knolls area (Binns and Parr, 1993) and several subsequent cruises including the 1996 PACMANUS III, 1997 PACMANUS IV, and 2000 Binatang cruises went on to document the SuSu Knolls hydrothermal district using video sled and dredge surveys (Binns et al., 1997; Yeats et al., 2014). More recently, the area has been visited by several expeditions for commercial economic exploration (e.g. Crowhurst and Lowe, 2011) as well as by international research cruises that focused on the hydrothermal fluid chemistry, mineral deposition, biology and geology (Auzende et al., 2000; Tivey et al., 2006; Bach et al., 2011).

SuSu Knolls lies at the intersection of the Tumai Ridge with Bugave Ridge, a NE-trending extensional rift structure that overshoots the Weitin transform (Fig. 3). Both ridges are comprised of lavas with compositions ranging from basaltic to dacitic (Binns and Scott, 1993; Moss, 2000). The SuSu Knolls hydrothermal area hosts three hydrothermal

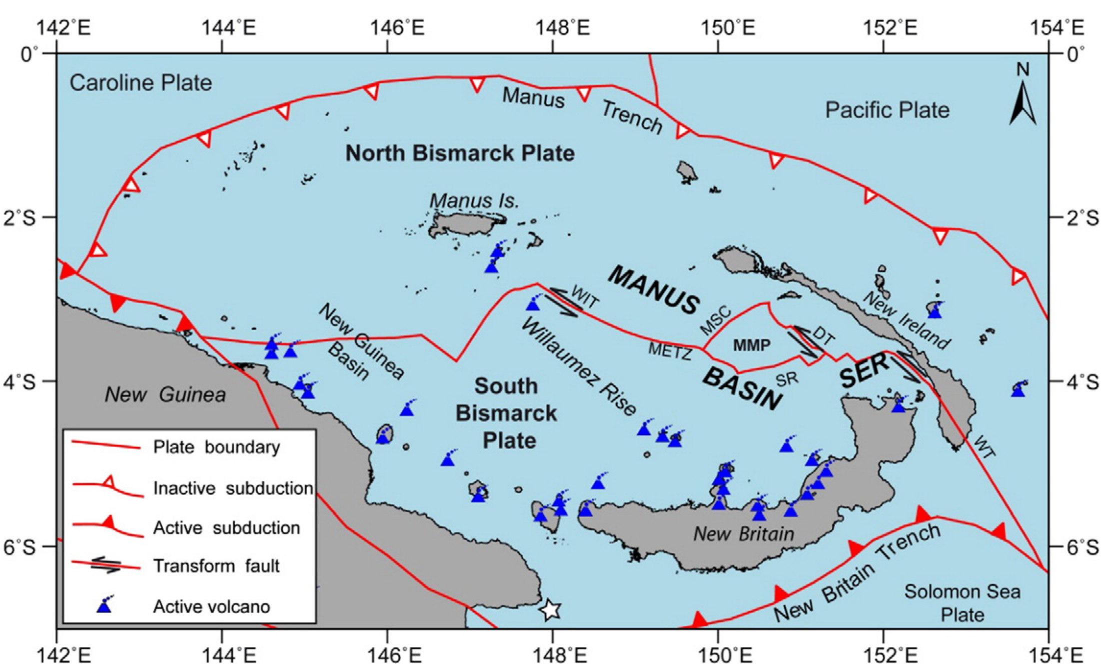

Fig. 1. Tectonic setting of the Bismarck Sea. Plate boundaries from (Bird, 2003). WIT: Willaumez Transform; MSC: Manus Spreading Center; MMP: Manus Microplate; DT: Djaul Transform; WT: Weitin Transform (Thal et al., 2014).