Journal of Volcanology and Geothermal Research 250 (2013) 106–128

Contents lists available at SciVerse ScienceDirect

Journal of Volcanology and Geothermal Research

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

Volcanic activity and its link to glaciation cycles: Single-grain age and geochemistry of Early to Middle Miocene volcanic glass from ANDRILL AND-2A core, Antarctica

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ARTICLE INFO

Article history:
Received 25 September 2012
Accepted 14 November 2012
Available online 27 November 2012

Keywords:
Alkaline volcanism
Trace elements
Glass
^{40}Ar–^{39}Ar dating
ANDRILL
Paleoenvironment

ABSTRACT

In the frame of the ANtarctic DRILLing Program, volcanic glass fragments were collected from the AND-2A core between ~354 and 765 m below sea floor (mbsf) as accumulations (5–70 vol.%) within sediments. Here, we present the physical characteristics, age and geochemistry of the glass, which enable us to reconstruct Early to Middle Miocene volcanic activity in southern McMurdo Sound and, for the first time, document the response of volcanism to climate change in Antarctica.

Glass-rich sediments include muddy-to-fine sandstone and stratified diamictite. Glass varies in color, size, vesicularity, crystal content, angularity, and degree of alteration. The mostly fresh glass exhibits delicate cuspate forms indicating deposition as primary ash fall. ^{40}Ar–^{39}Ar age determinations on individual glass grains are in good agreement with the depositional age model of the sediments (ca. 15.6 to 18.6 Ma), supporting for most of them a primary origin, however, some samples do contain older fragments that indicate glass recycling during times of enhanced glacial erosion.

Most glasses are mafic (MgO = 3 to 9 wt.%) and vary from hypersthene to nepheline normative with a restricted range in SiO_2 (45.2 ± 0.8 wt.%, 1σ) and trace element concentrations typical of the rift-related alkaline rocks in the Erebus Volcanic Province. The glass extends known composition of early phase Mount Morning activity (ca. 11–19 Ma), the only known Early to Middle Miocene source, to a more mafic end, revealing a previously unknown explosive, strongly alkaline, basaltic phase and the most primitive forms of both strongly alkaline (basanite to phonolite) and moderately alkaline (alkali basalt to trachyte) magma associations.

The glass-rich sediments occur in glacimarine sequences that record 56 cycles of glacial advance and retreat. Volcanic response to glacial cyclicity is observed both physically and geochemically in AND-2A glass. Higher glass volumes in sediments correlate with ice minimum conditions between 300 and 800 mbsf. Ratios of Ba to Hf, Nb, La and Zr in mafic glasses (≥5 wt.% MgO) show a systematic increase in mean values during intervals of ice retreat and decreasing values with ice expansion, suggesting tapping of magmas with variable incompatible to compatible trace element ratios. This may be related to changes in the stress state of the crust in response to rapid ice volume fluctuations over the volcano, which may influence magma chemistry by varying the duration and depth of magma storage.

1. Introduction

The climate of Antarctica throughout the geologic past has been extremely different from today's icehouse conditions, experiencing a dynamic environment with several fluctuations in climate, glacial advance and retreat, and sea-level change (Harwood et al., 2009; Mckay et al., 2009; Naish et al., 2009; Warny et al., 2009). Understanding how fast, large, and frequent these fluctuations occurred in the past utilizing paleoclimate reconstructions will provide invaluable information in the understanding of the future of global climate change, as a much wider range of possible climatic behaviors existed in the past than in modern environments (Naish et al., 2001, 2009; Shevenell and Kennett, 2007). The investigation of glacimarine sediments and the volcanic materials within them, chiefly tephra layers in sediment cores in key Antarctic basins, are essential in constraining the timing of volcanic, tectonic, and climatic events (Smellie et al., 2008, 2011).

The ANtarctic DRILLing (ANDRILL) project is a multi-national project, developed along the western margin of the West Antarctic rift system bordering the Transantarctic Mountains. The purpose of this project is to collect and examine drill cores from proximal sedimentary basins along the coast of Antarctica in order to build up stratigraphic

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http://dx.doi.org/10.1016/j.jvolgeores.2012.11.008

data that record key events of the glacial and climate history, as well as volcanic and tectonic events in the region (Naish et al., 2007; Harwood et al., 2009). The sediment input into the marine depositional system close to the Antarctic continent is directly affected by changes in the terrestrial environment, making it an excellent location to use the stratigraphic record as a paleoclimate proxy (Mckay et al., 2009; Warny et al., 2009). Two cores have been drilled: the McMurdo Ice Shelf (MIS) project AND-1B core in 2006 and the Southern McMurdo Sound (SMS) project AND-2A core in 2007 (Fig. 1), both of which contain a significant volcanic component (Pompilio et al., 2007; Panter et al., 2008) from the late Cenozoic Erebus Volcanic Province (EVP), which surrounds and is within the Victoria Land Basin (Fig. 1; Kyle, 1990).

The AND-2A core in particular targeted sediments containing an expanded Early to Middle Miocene section, a key interval of time in the development of the modern Antarctic climatic conditions, which experienced exceptionally dynamic and often “cyclic” climatic changes (Passchier et al., 2011). The sediments of the AND-2A core thus offer a unique opportunity to examine and reconstruct glacial conditions as well as their relationship to volcanic activity. Indeed, glacial unloading of lithosphere during a warming climate may be a factor controlling the volume, explosiveness, and timing of volcanic activity. The relationship between rapid de-glaciation and increased volcanism has been suggested in Iceland (Slater et al., 1998; Maclennan et al., 2002; Sigvaldason, 2002; Stinton et al., 2005), Germany and France (Nowell et al., 2006) as well as Canada (Edwards et al., 2002). It is possible then, that the frequent glacial loading and unloading caused by the dynamic environment in Antarctica during the Miocene could affect the input of volcanic material into the AND-2A core.

In this study we provide single-grain ^{40}Ar–^{39}Ar ages and LA-ICP-MS trace element data on mafic glass fragments from the AND-2A core between ~364 and 765 m below seafloor (mbsf) to assess the volcanic response to glacial dynamism in the southern McMurdo Sound area during the Early to Middle Miocene.

2. Geological background

The AND-2A core recovered sediments deposited into the southern Victoria Land Basin, which developed as part of the West Antarctic rift system (Fig. 1). The accommodation space needed to allow for deposition of sediments in the basin was created by fault and flexure-related subsidence associated with rifting (Wilson, 1999; Fielding et al., 2008b). The Victoria Land Basin contains ca.14 km thick sequence of Mesozoic-Cenozoic strata with dominant sediment supply being from the Transantarctic Mountains, followed volumetrically by volcanic detritus from the EVP. The Transantarctic Mountains are comprised of late Precambrian to Cambrian basement metamorphic rocks from the

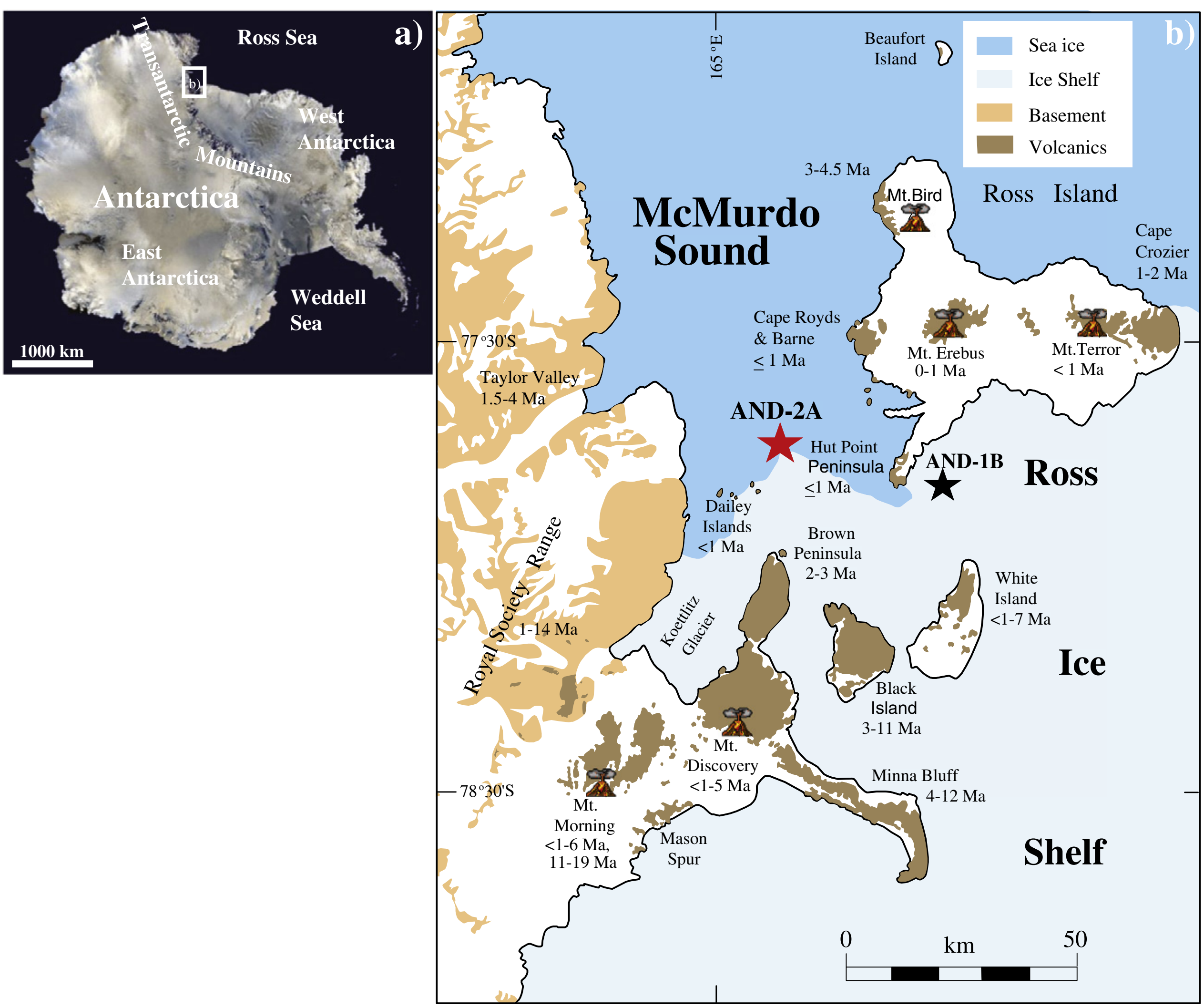

Fig. 1. Landsat satellite mosaic of Antarctica (a) showing the location of study area next to the Transantarctic Mountains in the Ross Sea. b) McMurdo Sound area map showing ANDRILL SMS (AND-2A) and MIS (AND-1B) drill-sites relative to deposits of the Erebus Volcanic Province (brown) and older non-volcanic lithologies (orange). Ages are from Di Vincenzo et al. (2010 and references therein).