Geomorphology 209 (2014) 133–139

Contents lists available at ScienceDirect

Geomorphology

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

Impact crater morphology: The origin of the Mertz and Ninnis Glaciers, Antarctica

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ARTICLE INFO

Article history:
Received 6 June 2013
Received in revised form 25 November 2013
Accepted 29 November 2013
Available online 17 December 2013

Keywords:
Glaciers
Ice sheets
Wilkes Land Anomaly
Topographic steering
Impact crater

ABSTRACT

East Antarctica, like West Antarctica, poses several questions about its geologic, geomorphic, and glaciologic history. Among these are questions regarding the origins of the Wilkes Subglacial Basin, the Gamburtsev Mountains, the Wilkes Land Anomaly, subglacial lakes, subglacial topography, and the enigmatic Mertz and Ninnis Glaciers. Located immediately inland of George V Coast at the northern extremity of the Wilkes Subglacial Basin, the Mertz and Ninnis Glaciers display characteristics that have posed questions of their sizes, their accompanying subglacial topography, their existence in tandem within the continental ice sheet and their extensions as glacier tongues offshore in the Southern Ocean. The present study examines in particular the underlying craterform morphology as the potential explanation for these several features based upon surveys of the subglacial topography, which include ground-based geophysical survey, airborne radiosound survey, airborne geophysical survey, and satellite remote sensing of the geomorphology beneath the continental ice sheet. On the basis of these investigations, we propose that the Mertz and Ninnis Glaciers are the result of parallel channelizing subglacial valleys and that the entire Mertz and Ninnis Glacier complex is a function of meteorite crater morphology beneath the East Antarctic continental ice sheet.

1. Introduction

Previous investigations of the Mertz and Ninnis Glaciers have revealed them to be enigmatic, glaciological features underlain by complex geomorphology (Weihaupt, 1961, 1975; Wendler, 1996; Frezzotti et al., 1998; Rignot et al., 2011; Weihaupt et al., 2012). First observed as glacier tongues by the U. S. Exploring Expedition of 1840 and the French Exploring Expedition of 1840, the Mertz and Ninnis Glaciers inland of the glacier tongues were later surveyed and described by the Australian Antarctic Expedition of 1911–1914 (Mawson, 1915). Debouching on George V Coast between 144°00′ E. and 149°00′ E. longitudes, their glacier tongues experienced episodes of resurgence and decline during the twentieth century. Since that time, both glacier tongues have largely disappeared, focusing attention on the glaciers per se.

Mid- and late-twentieth century explorations of the region include the French Adélie Land Traverse of 1958–1959 (ALT) (Rouillon, 1960), which penetrated East Antarctica from George V Coast some 300 km in the vicinity of Du'mont d'Urville Station. One year later, the U.S. Victoria Land Traverse of 1959–1960 (VLT) (Weihaupt et al., 2012) crossed the region of the Wilkes Subglacial Basin from the Skelton Glacier (a in Fig. 1) to the endpoint of the ALT (ALT station B-61; VLT station 531) (b in Fig. 1), and then proceeded to the Transantarctic Mountains (c in Fig. 1). Survey by the VLT in the vicinity of the Mertz and Ninnis Glaciers revealed an unusually chaotic ice surface (Fig. 2) and complex subglacial topography. In contrast, the continental ice sheet surface across East Antarctica from the Skelton Glacier to station 531, and from station 531 to the vicinity of the Transantarctic Mountains was unspectacular, except for dramatic sastrugi. Between longitudes 140°00′ E. and 145°00′ E., the ice surface assumed a dynamically disturbed appearance, consisting of basins, troughs, waves, very heavy crevassing, and large ice blocks in the continental ice sheet. The presence of the chaotic ice terrain was regarded at the time to be caused by one or more ice streams in the continental ice sheet and complex subglacial topography inland and upslope some 350 km from the termini of the Mertz and Ninnis Glaciers.

From 1960 until 1980, few investigations were conducted in the region; but between 1980 and 2012 renewed investigations (Steed and Drewry, 1982; Jezek, 2002; Reigber et al., 2002; Barthelmes, 2003; Armadillo et al., 2004; Bozzo and Ferraccioli, 2007; Ferraccioli et al., 2009; Weihaupt et al., 2010; Jordan et al., 2013) have enabled us to further evaluate the geomorphology of the region. This evaluation confirms the presence of parallel channelizing lowlands in the vicinity of the Mertz and Ninnis Glaciers.

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0169-555X/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2013.11.031

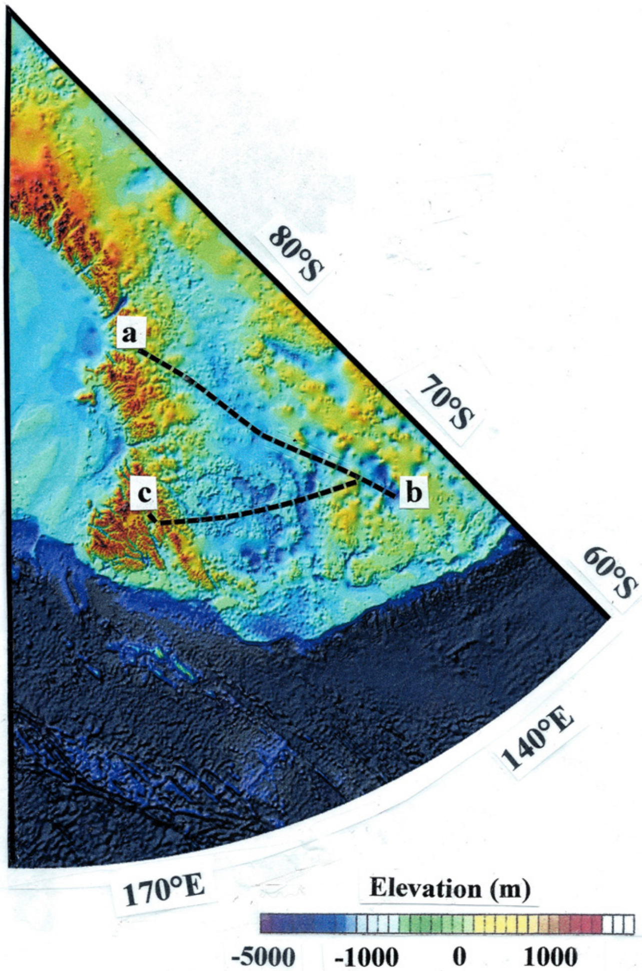

Fig. 1. Map of the U. S. Victoria Land Traverse route from the Skelton Glacier (a) to the end-point of the French Adélie Land Traverse (b), and to the Transantarctic Mountains (c).

Among the questions raised by these features, noting that the ice supply does not differ substantially from the ice supplies available to other such glaciers, are: (i) why two unusually large glaciers exist in the continental ice sheet; (ii) why they exist in tandem, parallel with one another, and in the same location, unlike other known glaciers and glacier tongues in Antarctica; (iii) whether the subglacial geomorphology is capable of creating these conditions; and (iv) what accounts for the subglacial geomorphology? While the Mertz and Ninnis Glaciers conform generally to the radial flow of East Antarctica, they depart locally — the departures having the potential to shed light on several questions. The importance of these questions lies not only in explaining the characteristics of the glaciers but in their potential for explaining the ice drainage from a significant portion of the East Antarctic ice sheet, exercising control of the delivery of ice to the Southern Ocean, affecting the configuration of the East Antarctic ice sheet, and in furthering our understanding of the relationships between continental ice sheets, continental ice sheet glaciers, and subglacial geomorphology elsewhere.

2. Geological and glaciological setting

East Antarctica experienced substantial Precambrian tectonic and metamorphic changes (Rolandone et al., 2002), late Cretaceous uplift (ten Brink et al., 1997; Karner, 2004), subsequent magmatism in the Jurassic, large-scale sedimentation in late Eocene–Neogene, and volcanic activity in the Neogene. Repeated ice age conditions have marked the glaciological history of East Antarctica, the most recent onset of glaciation having occurred in late Eocene–early Oligocene (Karner, 2004). Continental ice sheet thicknesses approached 1000 m in the study region during the last glacial maximum (Goodwin and Zweck, 2000; Weihaupt et al., in press), whereas ice thicknesses and extents diminished during the Holocene. Near-coastal undersea geomorphological features reveal variations in the extent of the ice in Wilkes Land (Anderson et al., 2002; Escutia et al., 2005; Le Brocq et al., 2008), while glacial episodes alternated with episodes of retreat during interglacial times (Escutia et al., 2005; Weihaupt et al., in press).

The climate of East Antarctica is cold, dry, and windy, exhibiting slightly more moderate temperatures and higher atmospheric moisture in near-coastal areas such as that of the Mertz and Ninnis Glaciers. Over the last 50 years neither East Antarctica nor the French coastal weather station at Du'mont d'Urville has experienced any measureable warming or cooling (Turner et al., 2005), although precipitation increased minimally from 1979 to 1999 (Bromwich et al., 2004), exhibiting a statistically significant increase of 1.3 to 1.7 mm yr^{-1} over the continent as a whole. Because of the constant and intense wind in the vicinity of Du'mont d'Urville, precipitation and accumulation measurements are inconclusive in the vicinity of the Mertz and Ninnis Glaciers (Wendler, 1996).

The Antarctic continental ice sheet is presently 1.42×10^7 km^2 in area, of which 1.44×10^6 km^2 overlie East Antarctica, and 2.70×10^5 km^2 overlie the Wilkes Subglacial Basin (WSB). Ultimately supplying a volume of 810,000 km^3 of ice to George V Coast, the WSB has adequate ice volumes to account for the ice expelled from the Mertz and Ninnis Glaciers, as well as ice expelled elsewhere along George V Coast, although no glaciers of comparable size presently exist in the continental ice sheet east of the Mertz and Ninnis Glaciers. The drainage basins of the Mertz and Ninnis Glaciers (Fig. 3) (Rignot et al., 2007) are adequate to account for the great lengths of the Mertz and Ninnis Glaciers at the time of the Australasian Antarctic Expedition in 1911–1914. Recent RADARSAT imaging confirms Rignot's determinations and provides excellent confirmation of the drainage basins in the surface of the continental ice sheet (Jezek, 2008; Le Brocq et al., 2008).

3. Principal observations

The first observations of the Mertz and Ninnis Glacier termini were made by Lieutenant Charles Wilkes' U. S. Squadron in 1840 and by the French Squadron the same year (Mawson, 1915). Mawson refers to these early observations in his book, *Home of the Blizzard*, viz., 'We were unable to see any trace of the high land (ice) reported by the United States Squadron (1840) as lying to the west and south beyond the compact ice… (or of)…the great (ice) barrier which the French ships followed in 1840…,' that represented the termini of the Mertz and Ninnis Glaciers at that time. These expeditions and surveys suggest the likelihood that the glaciers previously penetrated even farther into the Southern Ocean. In contrast to their great extent in 1840, the lengths of the Mertz and Ninnis Glaciers observed as glacier tongues by Mawson in 1911 were considerably less (Wendler, 1996), debouching on George V Coast at longitudes 145°00′ E. and 148°00′ E. (Fig. 4). By 1959 the ice sheet immediately inland of the Mertz and Ninnis Glaciers in the vicinity of 71°45′ S., 141°30′ E. was described as undulating, sometimes displaying broad basins up to 6.5 km in diameter, and one or more long troughs up to 5.0 km long appearing as 50 to 100-m depressions in the ice surface (Weihaupt, 1958-1960).

Geophysical data have enabled confirmation of the presence of complex subglacial topography beneath the Mertz and Ninnis Glaciers and enhanced the definition of the subglacial craterform morphology (Fig. 5). This subglacial morphology provides a good rationale for the size and location of the Mertz and Ninnis Glacier drainage basins, suggesting the value of a theoretical model, a schematic, of the probable pattern of ice flow in the vicinity of the glaciers. The observations to