Earth and Planetary Science Letters 433 (2016) 99–108

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Erosion by tectonic carving in the Concordia Subglacial Fault Zone, East Antarctica

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ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form 23 October 2015
Accepted 26 October 2015
Available online 6 November 2015
Editor: A. Yin

Keywords:
tectonic carving
regional fault zone structure
Concordia Fault
East Antarctica

ABSTRACT

In this work we present the analysis of the footwall morphology of the Concordia subglacial extensional fault in the East Antarctic Craton. The Concordia Fault is a regional fault zone that extends for almost 200 km. The displacement, up to 1800 m, and the listric geometry were recognized by numerical modeling of the resulting hangingwall bedrock morphology and is responsible for the marked asymmetry that characterizes the corresponding scarp in the Concordia Subglacial Trench.

The portion of the footwall in the proximity of the master fault exhibits an excavated morphology, about 500 m deep and up to 5 km wide, showing strong correlation with the master fault displacement. We excluded a predominant glacial and fluvial origin of this morphology considering: (i) the sharp topography of the Concordia Fault, suggesting that the fault activity started after the onset of the ice sheet; (ii) the ice-sheet/bedrock contact is characterized by a general negligible erosion/deposition rates still allowing clast removal; (iii) the lack of significant deposits in the Concordia Trench. We hence explored the possibility that this morphology may result from the combined action of fault-induced fracturing and passive clast removal and scattering by flow and plastic deformation within the ice sheet. We introduced the term tectonic carving for this process.

Our modeling shows that tectonic carving relates to the relative fracture intensity in the Concordia fracture zone, that corresponds to the envelope of master and secondary fault damage zones. Fracture intensity depends on the frequency and the displacement of secondary faulting and can be approximated by a normal distribution. Using a Monte Carlo modeling approach we selected the set of parameters that best fits the data set with the carving theoretical curve. The final results of the Monte Carlo analysis show a root mean square of about 50 meters, comparable with the data resolution. This analysis demonstrates a method to unravel the presence of fracture zones in similar, weak erosional environments.

1. Introduction

The East Antarctic Craton (EAC) represents a unique geological environment in our planet. The presence of the ice sheet protects the underlying bedrock from the erosional agents shaping the surface morphology of the Earth. This relates to the characteristic negligible erosional/depositional characteristics at the contact between ice and rock at the base of the about 4 km thick ice sheet. There, physical conditions mostly prevent, along the interface, the presence of water and ice flows, that would be responsible for glacial erosional processes in other glacial environments. As a consequence the bedrock morphology is shielded by the East Antarctic Ice Sheet (EAIS) thus representing a reference surface for the study of successive tectonic events. It is worthwhile to notice that despite the minimal physical and chemical erosion, the ice sheet maintains a significant transport capability by its slow yet constant plastic flow, as testified by the accumulation of meteorites along its blue ice zones (e.g. Folco et al., 2006; Cuffey and Paterson, 2010). The development of the EAIS is attributed to about 34 Ma and, after a reasonably short early period of wet based conditions (De Conto and Pollard, 2003), prevailing negligible erosion/deposition conditions developed and are still present today (Wilson et al., 2012; Atkins, 2013). The general smooth morphology of the bedrock in the central–eastern part of the EAC (namely the Vostok–Dome C region, Fig. 1; Fretwell et al., 2013) dates from that time and is indicative of peneplanated landscapes. This peneplanation may be the effect of pre-existing and long lasting continental conditions including scattered glacial erosion during the wet conditions (e.g. Eastern North America late–post-glacial landscape; Miall, 2008). This regionally widespread landscape is interrupted by regional sized, elongated depressions that are of

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http://dx.doi.org/10.1016/j.epsl.2015.10.045

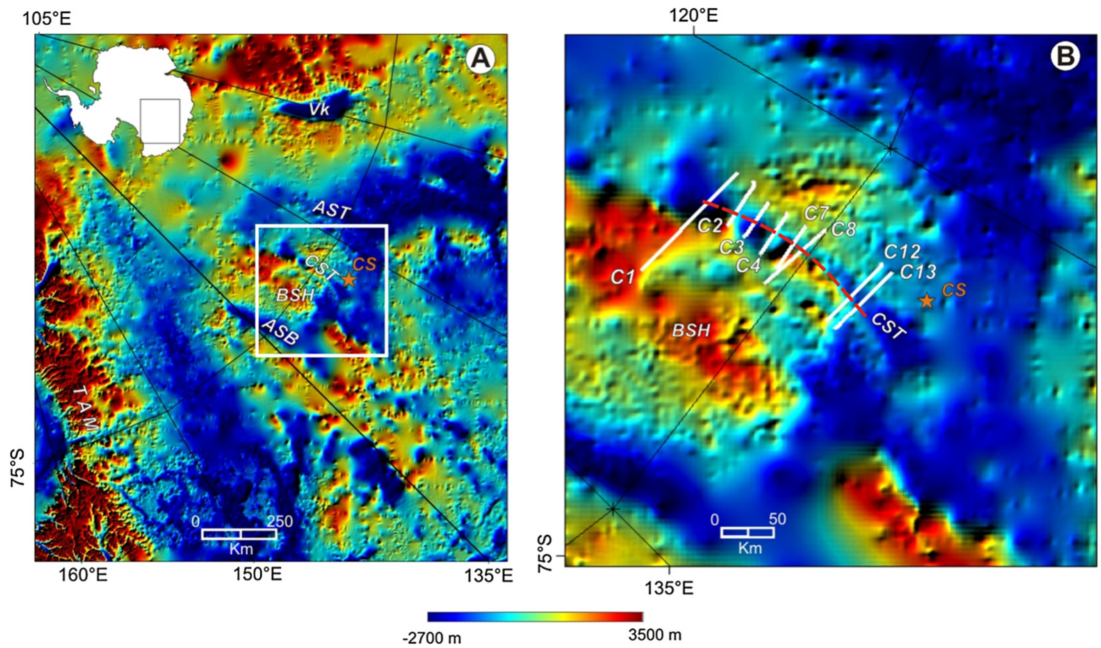

Fig. 1. The Concordia Trench in the frame of the Vostok–Dome C region. A) The inset shows its location within the East Antarctic Craton (*EAC*). B) Location of the Radio-Echo Sounding (RES) profiles (in white color) across the Concordia Fault (red dashed line) with their reference number. Location is the white rectangle in A. Legend: *TAM*, Transantarctic Mts.; *Vk*, Vostok; *CS*, Concordia Station; *CST*, Concordia Subglacial Trench; *AST*, Aurora Subglacial Trench; *ASB*, Adventure Subglacial Basin; *BSH*, Belgica Subglacial Highlands. Bed elevation from BEDMAP2 dataset (Fretwell et al., 2013). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

scientific interest due to the presence of extended water reservoirs (subglacial lakes) that represent a unique bio-environment and are a product of localized ice melting possibly related to pressure and/or geothermal gradient variations. The static origins of these waters indicate anyhow their negligible erosional and transport capability, with local exceptions (Wingham et al., 2006; Jordan et al., 2010). Some of these depressions (e.g. Vostok, Aurora, and Concordia trenches) are characterized by a strong transverse asymmetry hardly referable to glacial excavation. As evidenced by Tabacco et al. (2006), Cianfarra et al. (2009), Cianfarra and Salvini (2013, 2014a) these depressions represent the result of the activity of crustal size listric normal faults with lengths of over 100 km and with displacements up to about 2 km. These results were achieved by comparing the less steep valley side with a listric fault hangingwall morphology. On the other hand, the footwalls present a characteristic blunt morphology suggesting that bedrock material has been removed in the area approaching the fault plane projection. This work is focused on the analysis of the blunt morphology of the Concordia Fault footwall. This feature involves a zone up to few kilometers wide with a thickness of removed material up to 900 m nearby the main fault. Since the specific described subglacial environment prevents from the activity of erosional agents, we successfully explored the possibility that this geometry of the footwall results from the interaction between the fault zone and the transport capability of the ice sheet flow (Atkins et al., 2002; Atkins, 2013). This removes the clasts produced by fracturing associated to the activity of the main fault and its secondary faulting within the wider fracture zone (Turcotte and Schubert, 2014).

2. Geodynamic setting of the Concordia Trench

The growing body of geophysical data collected in the last decades by the international scientific community over Antarctica highlighted the morphology of its topography below the ice sheet, namely the bedrock (Fretwell et al., 2013) revealing the crustal architecture of the EAC (Studinger et al., 2004; Filina et al., 2008; Leonov and Popov, 2009; Ferraccioli et al., 2011; Jordan et al., 2013; Aitken et al., 2014; An et al., 2015). One prominent physiographic features is the Concordia Subglacial Trench, hereafter CST (Tabacco et al., 2006; Cianfarra et al., 2009). The CST was detailed during the Italian geophysical campaigns from 1995 to 2004 when a total of 12,400 km of radio echo-sounding (RES) profiles were acquired over East Antarctica, from the Transantarctic Mts. to the Vostok region (Tabacco et al., 1998, 2002, 2006). In the Dome C area, 6600 km of these RES data were collected near the CST, in support of the EPICA drilling project as a means to constrain the geological setting of the buried bedrock morphology and of the lake district found in the area (Tikku et al., 2005; Tabacco et al., 2006; Cianfarra et al., 2009).

The CST is an over 200 km long, 20 km wide subglacial trough roughly parallel to the 124.5°E meridian. It cuts through the Belgica Subglacial Highlands from 76.3°S to 74.5°S (Fig. 1B). The across-strike RES profiles of this regionally sized valley revealed an articulated morphology of the steeper, eastern slope that contrasts with the gentler western slope characterized by a convex shape (Fig. 2). At the southern termination the trench reaches the maximum relative depth of about 1300 m. In the northern part of the trench there is a depression with an areal extent of about 1500 km^2 that hosts a basin lake (sensu Tabacco et al., 2006), the Concordia Subglacial Lake (Tikku et al., 2005).

Tabacco et al. (2006) and Cianfarra et al. (2009) confirmed the tectonic origin of the CST and interpreted its asymmetric across-strike morphology as the result of the activity of a west dipping, crustal normal fault, the Concordia Fault. The Concordia Fault is a N–S trending, regionally sized fault characterized by a length exceeding 180 km whose northern tip is located approximately at 74.2°S and 124.5°E.

To the South the fault either continues to a latitude higher than 76.3°S, as inferred from the computed along strike fault displacements, or abruptly terminates in correspondence to a transverse fault(s). The modeled topography (Cianfarra et al., 2009) replicates the present-day smoothly rounded morphology of the western side of the CST (Fig. 2). The Concordia Fault is part of a subparallel normal fault array that spans the area from the Lake Vostok, to the W, to the Adventure Subglacial Basin, to the E (Cianfarra and Salvini, 2013). Their surface expression on the EAIS as persistent