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Origin of the Adventure Subglacial Trench linked to Cenozoic extension in the East Antarctic Craton

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ABSTRACT

The Antarctic plate occupies a unique geodynamic setting being mostly surrounded by divergent or transform margins. Major intracontinental basins and highlands characterize its bedrock, buried under the 34 Ma East Antarctic Ice Sheet (EAIS). Their formation atop of the cratonic lithosphere in the interior of East Antarctica remains a major open question. Post-Mesozoic intraplate extensional tectonic activity has been proposed for their development and is supported by this work. Here we focus on the Adventure Subglacial Trench (AST) whose origin is poorly constrained and controversial, as currently available geophysical models suggest either extensional or compressional tectonic origin. The AST is an over 250-km-long, 60-km-wide subglacial trough, elongated in the NNW–SSE direction adjacent to the westernmost flank of the Wilkes Subglacial Basin, and is parallel to regional scale alignments of magnetic and gravimetric anomalies. Geophysical campaigns allowed better definition of the AST physiography showing its typical half-graben geometry. The rounded morphology of the western flank of the AST was simulated through tectonic numerical modelling. We consider the subglacial landscape to primarily reflect a preserved relict of the tectonic processes affecting the interior of East Antarctica in the Cenozoic, due to the negligible erosion/deposition capability of the EAIS. The bedrock morphology was replicated through the activity of the listric Adventure Fault, characterized by a basal detachment at the base of the crust (34 km) and a vertical displacement of 2.5 km. This length suggests its regional/crustal importance. The predicted displacement is interpreted either as a newly formed fault or as the partial reactivation of a weaker zone along a major Precambrian crustal-scale tectonic boundary. The extensional regime in the AST is part of a more extensive 800-km long intraplate corridor characterized by nearly along-strike extension in Cenozoic times with a left-lateral transpressional component. This corridor may represent the effect of far-field stresses induced by plate motions.

1. Introduction

East Antarctica is a Precambrian Craton (EAC) that played a central role in early supercontinents such as Rodinia and Gondwana in Precambrian and Paleozoic times (Torsvik, 2003; Boger, 2011; Dalziel, 2013; Harley et al., 2013; Aitken et al., 2014; Aitken et al., 2015). A large interval of the late Mesozoic and Cenozoic geological history of EAC is dominated by the break-up of Gondwana, its separation from the Australian plate, and its movement towards the present polar location through a poly-phased evolution that included continental rifting, block translations, widespread magmatism and uplift of the Transantarctic Mountains (Stern and ten Brink, 1989; Salvini et al., 1997; Tonarini et al., 1997; Ferraccioli et al., 2001; Fitzgerald, 2002; Rossetti et al., 2003; Jordan et al., 2013; Aitken et al., 2014). Ferraccioli et al. (2011) proposed intraplate Permian–Cretaceous age rifting and transtension associated with the East Antarctic Rift System.

Presently, the Antarctic plate (Fig. 1a) occupies a unique geodynamic setting being almost completely surrounded by divergent or conservative margins, with the exception of the limited subduction zones of the South Sandwich and South Shetland Islands (Hayes, 1991; Lawver and Gahagan, 2003; Cianfarra and Salvini, 2013). According to plate tectonics this setting prevents development of regionally scaled tectonic events in its interiors (Cande and Stock, 2004; Müller et al., 2000; An et al., 2015). Despite the generally accepted expectation of tectonic quiescence, a series of depressions and highlands characterize EAC bedrock (Fretwell et al., 2013).

The geodynamic setting of East Antarctica does not necessarily imply the production of internal compressional stresses that depend from the relative velocity between the rifts and the craton with respect to the plate accretion velocity. The presence of several depressions within the EAC suggests that an overall extension might be the dominant stress condition of the craton induced by plate tectonics since the Gondwana fragmentation (Ferraccioli et al., 2011). For two of these depressions, namely the Aurora and Concordia trenches, post-Mesozoic extensional tectonic activity has been proposed (Tabacco et al., 2006; Cianfarra et al., 2009). The 34 Ma East Antarctic Ice Sheet (EAIS; De Conto and

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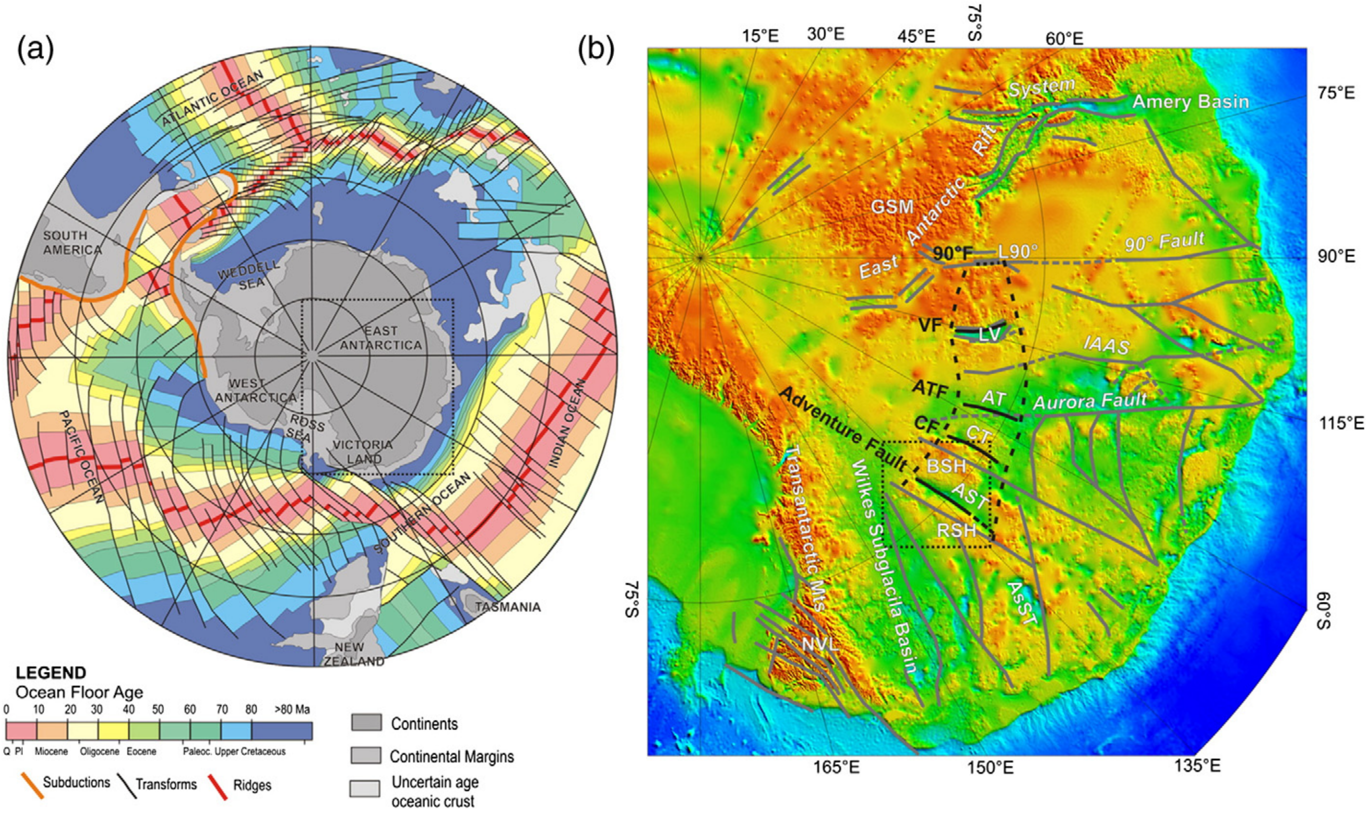

Fig. 1. (a) The Antarctic plate with its surrounding divergent margins and ocean floor age. Rectangle shows the location of (b). (b): Subglacial topography map of the East Antarctic Craton from Bedmap-2 dataset (Fretwell et al., 2013) with the main bedrock physiographic features and proposed faults. Dashed black lines represent the margins of the proposed structural corridor characterized by nearly along-strike extension derived by left-lateral transpression. Black lines are the Cenozoic extensional faults within the corridor. Grey lines are faults from Salvini et al., 1997; Ferraccioli et al., 2011; Aitken et al., 2014. The black square shows the location of Fig. 2. Legend: GSM: Gamburtsev Subglacial Mts; LV: Lake Vostok; NVL: Northern Victoria Land; AT: Aurora Trench; CT: Concordia Trench; BSH: Belgica Subglacial Highlands; AST: Adventure Subglacial Trench; AsST: Astrolabe Subglacial Trench; RSH: Resolution Subglacial Highlands; L90°: Lake 90°; 90°F: Lake 90° Fault; VF: Vostok Fault; ATF: Aurora Trench Fault; CF: Concordia Fault; *IAAA*: Indo-Australo-Antarctic Suture.

Pollard, 2003) prevents the direct analysis of the subglacial geology and landscape, leaving most of the geologic information derived from geophysical investigations (Ferraccioli et al., 2011; Fretwell et al., 2013; Jordan et al., 2013; Aitken et al., 2014; An et al., 2015). The discovery of Antarctic subglacial lakes (e.g. Kapista et al., 1996; Tabacco et al., 2002; Siegert et al., 2005; Wright and Siegert, 2012) contributed renewing the interest in the EAC subglacial geology that has been investigated by a number of international geophysical campaigns. The new Bedmap2 compilation sheds new light on the subglacial topography of the EAC (Fretwell et al., 2013, Fig. 1, 2) and further detailed the major depressions and mountain ranges that characterize the interior of East Antarctica. These are hard to explain given that East Antarctica is assumed to be a stable Precambrian craton since at least Edicaran–early Cambrian times.

The observed tectonic setting of East Antarctica links to the broader tectonic issue of basins and ranges formation within intracratonic regions as observed in other cratonic regions. Despite the growing body of geophysical data available for Antarctica, several unanswered questions still exists on the tectonic origin of some subglacial features. Among them, the nature of the tectonic events responsible for the development of the Adventure Subglacial Trench (AST, Figs. 2 and 3) is enigmatic and controversial, and contrasting models on its tectonic origin have been proposed (Ferraccioli et al., 2001; Studinger et al., 2004). Ferraccioli et al. (2001) suggested an extensional tectonic origin for the AST linked to Meso-Cenozoic intraplate extension with a setting similar to the modern Baikal rift system. On the other hand, Studinger et al. (2004), based on extensive aerogeophysical investigations, suggested a compressional scenario for the Precambrian origin of the AST basin.

The aim of this paper is to provide new clues on the geological setting of the AST based on the tectonic modelling of airborne Radio Echo-Sounding (RES) profiles and to understand whether the tectonics result from regional uplift, local events or else we are in the presence of a major structural corridor within the EAC that was affected by Cenozoic reactivation. This was possible since the subglacial landscape primarily reflects a preserved relict of the morphology produced by the tectonic processes affecting the interior of East Antarctica in the Cenozoic (Jamieson et al., 2010; Wilson et al., 2012; Rose et al., 2015). In our modelling efforts we therefore neglected glacial overdeepening effects and flexural responses induced by selective fluvial and glacial erosion within the AST, which may have modified the pre-existing landscape.

2. Geological setting and tectonic numerical modelling of the Adventure Subglacial Trench

Geophysical data collected in the last decades shed new light into the understanding of the crustal architecture of the EAC (Ferraccioli et al., 2001; Studinger et al., 2004; Ferraccioli et al., 2009; Ferraccioli et al., 2011; Jordan et al., 2013; Aitken et al., 2014; An et al., 2015). Gravimetric and aeromagnetic modeling were interpreted to propose a tectonic origin for Lake Vostok (Studinger et al., 2003). Numerical modelling of the buried bedrock physiography contributed to define the extensional tectonic style responsible for the formation of subglacial depressions in the Vostok-Dome C area (Tabacco et al., 2006, Cianfarra et al., 2009; Cianfarra and Salvini, 2013), characterized by a large number of subglacial lakes (Siegert et al., 2005; Tabacco et al., 2006; Wright and Siegert, 2012). Understanding of the tectonic origin of the AST (Figs. 1b and 2) with the possible presence of hydrological connection among lakes (Rémy and Legrésy, 2004; Wingham et al., 2006; Wright et al., 2008; Carter et al., 2009; Ferraccioli et al., 2007; Jordan et al., 2010; Pattyn, 2010), is of utmost importance for comprehending the