Byrd drainage system: Evidence of a Mesozoic West Antarctic Plateau

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Summary Recent geomorphic and thermochronologic studies in the Byrd drainage system present a paradoxical suite of data that are difficult to interpret under the current paradigm that the Transantarctic Mountains (TAM) are a rift flank uplift that developed in the Eocene. Specifically, recent studies indicate

1) the Byrd outlet originated as an antecedent stream that flowed across the region prior to development of the TAM (Huerta & Reusch, 2005; Huerta, 2006; in revision),
2) the Byrd drainage system once flowed from West Antarctica to East Antarctica, opposite to the current drainage direction (Huerta & Reusch, 2005; Huerta, 2006), and
3) rapid cooling of the crust at ~120 Ma in the region of the Byrd glacier, (Huerta & Winberry, in review, Nature Geoscience).

These data, however, are readily understood in the context of recent geodynamic studies that indicate that the West Antarctic region would have been a high-elevation plateau prior to the onset of extension at ~105 Ma, and that the Transantarctic Mountains may be the abandoned highland margin of the collapsed plateau (Huerta and Harry, 2007; Bialas, in press). This proposed tectonic evolution is consistent with the interpretation of Cretaceous erosion and crustal cooling during the growth of the high-elevation plateau and the development a major drainage system flowing from the West Antarctic highland to East Antarctica. These drainage systems were preserved as flow direction changed during plateau collapse in response to Mesozoic/Cenozoic extension of the West Antarctic Rift System (WARS). Although no one piece of evidence is conclusive in and of itself, taken *in toto*, the evidence is best explained by the presence and subsequent collapse of a Mesozoic West Antarctic Plateau.

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Introduction

The WARS underwent a protracted Mesozoic/Cenozoic stage of diffuse extension across the broad ~ 800 km wide region. In the Victoria Land region, this stage of diffuse extension was followed by focused extension in the adjacent Victoria Land Basin (Cooper & Davey, 1985; Blankenship et al., 1993). Geodynamic models developed to explore the processes and conditions that control the evolution of the WARS system reveal that the extension style is highly sensitive to the pre-rift thermal state of the crust and upper mantle (Huerta & Harry, 2007). Results of finite element models indicate that the transition from a prolonged period of broadly distributed extension to a later period of focused rifting occurs only under a limited set of initial and boundary conditions, and is particularly sensitive to the pre-rift thermal state of the crust and upper mantle. Models that predict diffuse extension in West Antarctica require relatively warm upper mantle temperatures (>680° C) and sufficient crustal heat production to account for ~50% of the upper mantle temperature with significant thermal contribution from the crust. As a subset, the models that predict diffuse extension followed by localization of rifting near the boundary between East and West Antarctica require upper mantle temperatures of 730 ± 50 °C with the same significant thermal contribution from the crust. This initially warm upper mantle results in a buoyant crust and high topography across West Antarctica prior to extension, and predicts the presence of a Mesozoic West Antarctic Plateau.

An independent geodynamic study focusing on the co-evolution of the TAM and WARS recognizes similar pre-rift thermal constraints and plateau topography of the WARS region (Bialas et al., in press). This study focuses on the topographic evolution of the region and recognizes the preservation of marginal highlands during the modeled extension and collapse of the plateau.

The postulated Mesozoic West Antarctic Plateau provides a new paradigm for the interpretation of new, puzzling, thermochronologic and geomorphic data reviewed here.

Quantitative Geomorphology

Recent production of digital elevation models (DEMs) of the Antarctic Continent provide a new data set for quantitative analysis of the landscape, and evidence of interaction between tectonic, fluvial, and glacial processes on the Transantarctic Mountains. A recent study divided the TAM into 19 distinct mountain blocks to investigate lateral variations in the landscape (Huerta, in revision). There is a wide diversity in distribution of slope aspect between the 19 blocks, indicating significant variations in landscape morphologies. Three distinct end-member aspect signals are apparent; bimodal distribution, unimodal distribution, and uniform distribution.

Visual inspection of topographic maps, geologic maps, and DEMs reveals that the end-member aspect signals correspond with three distinct landscapes (Fig. 1). The bimodal signal records the dominance of straight, parallel walls of small fjords, indication of a landscape modified by glacial erosion. The unimodal signal is dominated by seaward facing escarpments formed by normal fault scarps that have not been significantly modified by glacial erosion. The uniform rose diagrams correspond to landscapes lacking fjords and escarpments, and retain fluvial drainage patterns. These results indicate that, on an orogen scale, the slope aspect can be used to recognize the relative impact of fluvial, glacial, and tectonic processes on the shaping of the Transantarctic Mountain landscape.

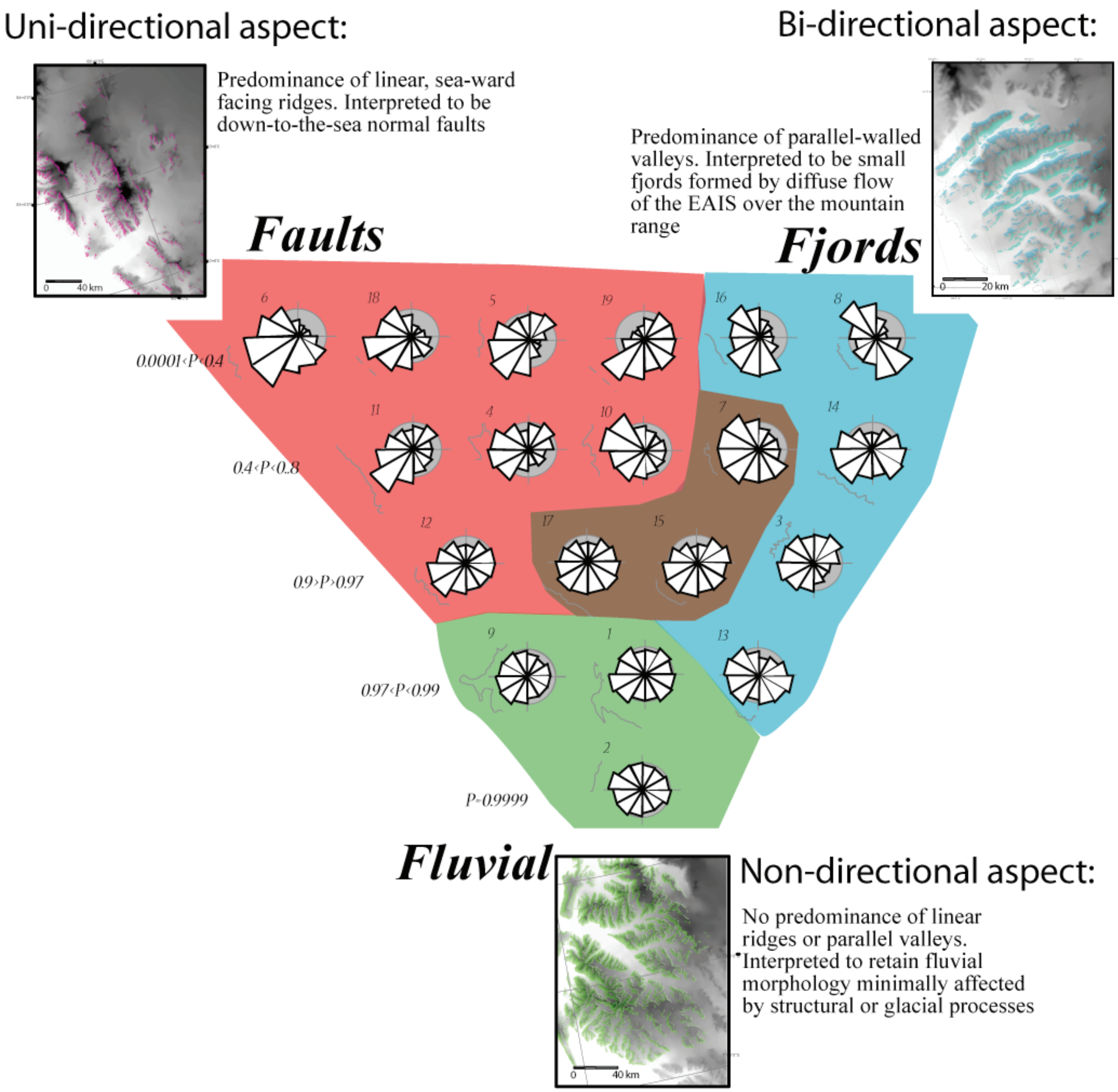

Figure 1. Ternary diagram displaying the classification of the 19 mountain blocks of the TAM with respect to three end-member distributions of aspect and the associated landscape morphologies. (*P* is the probability that the distribution is sampled from a uniform distribution)

Figure 2 displays the distribution of the landscape types along the length of the mountain range. Regions that retain the fluvial signal are limited to the northern portion of the mountain range. The fluvial classification of these regions is consistent with previous work in these areas that recognizes the fluvial nature of the landscapes (Baroni, et al, 2005; Sugden et al, 1999). Regions dominated by fjords are scattered along the mountain range, and do not correlate with latitude or altitude. Three continuous swaths of the mountain range retain fault-dominated landscapes that also do not correlate with latitude or altitude.

Inspection of the bedrock topography along the length of the mountain range reveals the 1:1 correlation between the three swaths of fault dominated landscapes and the presence of three very deep troughs. These three troughs cut across the mountain range entirely at or below sea level, and connect the Ross Sea with deep basins on the other side of the mountain range (the Wilkes Subglacial Basin or the Weddell Sea). Numerical models have shown that glacial outlets play a critical role in the drainage and elevation of the East Antarctic Ice Sheet (Kerr and Huybrechts, 1999), and currently the efficient drainage through these very deep troughs prevents local thickening of the ice sheet. The preservation of the structural landscape in the vicinity of these very deep troughs suggests that these troughs have *always* provided efficient drainage. The efficient drainage of the ice sheet has limited the local thickening of the ice sheet and minimized the overtopping and glacial erosion of the mountain front, thus preserving the structural landscape in these three regions.

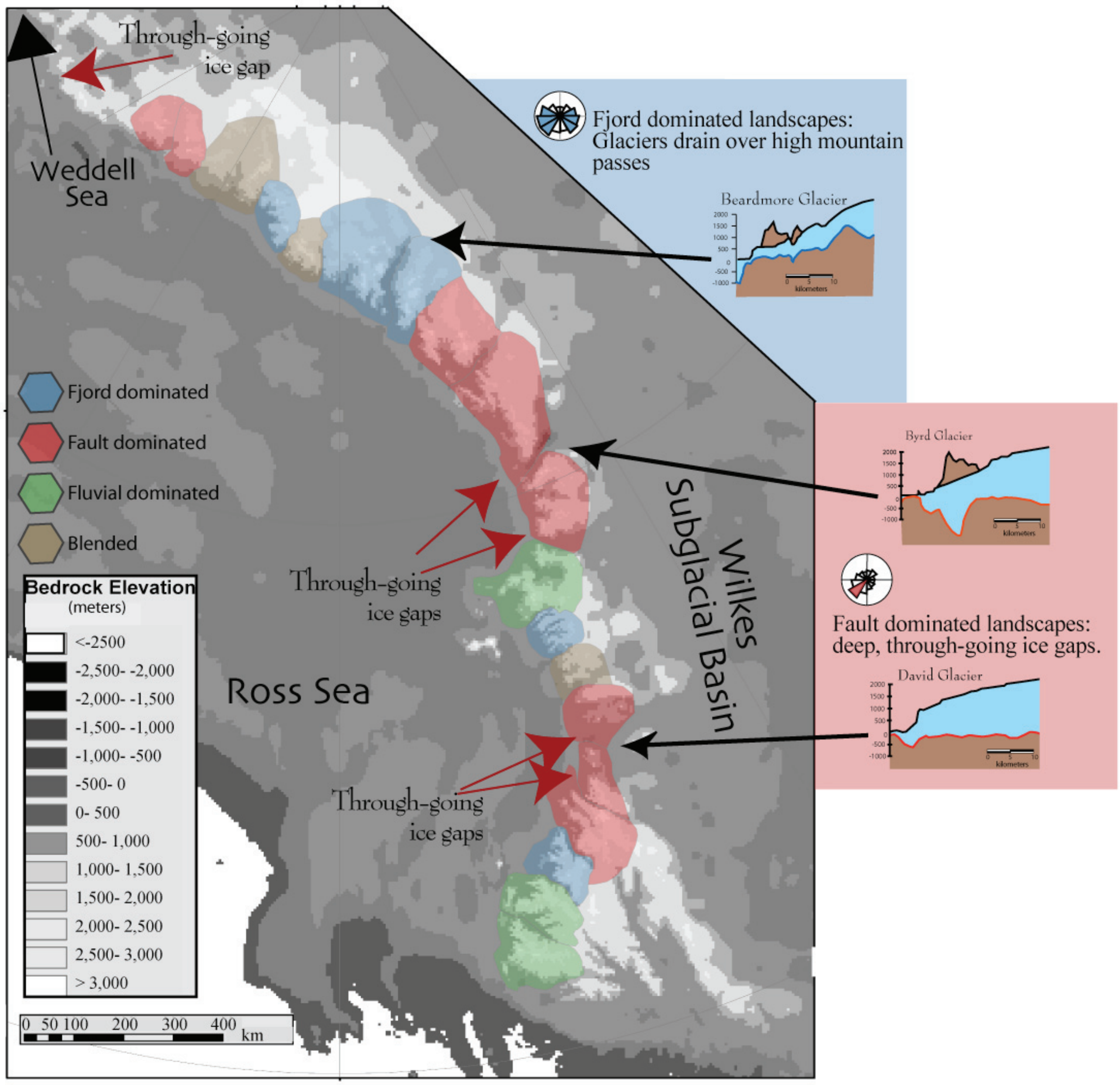

Figure 2. Distribution of landscape types displayed on DEM of bedrock elevation. Note the one-to-one correlation between fault-dominated landscapes and troughs incised below sea level (ice gaps).

These results indicate that these outlets existed prior to the onset of glaciation. If, indeed, these troughs were not formed by ice draining from the high-elevation EAIS, then one must envision a setting where a stream would carve across the entire TAM. The most reasonable scenario would be that these troughs are the result of antecedent streams that flowed across the region prior to the development of the current mountain range.

Drainage reversal

Inspection of the Byrd region reveals three major tributaries of the Byrd glacier that form acute angles pointing *upstream* of the current flow direction, evidence of drainage reversal (Fig. 3; Huerta, 2006). Additionally, there is evidence of drainage capture and reversal in the Beardmore drainage system where the upstream portion of a major tributary flows towards East Antarctica, and then carves a sweeping u-turn to merge with Beardmore and drain to West Antarctica. These geometries indicate that earlier in the evolution of the drainage systems the base level was lower in East Antarctica than West Antarctica.

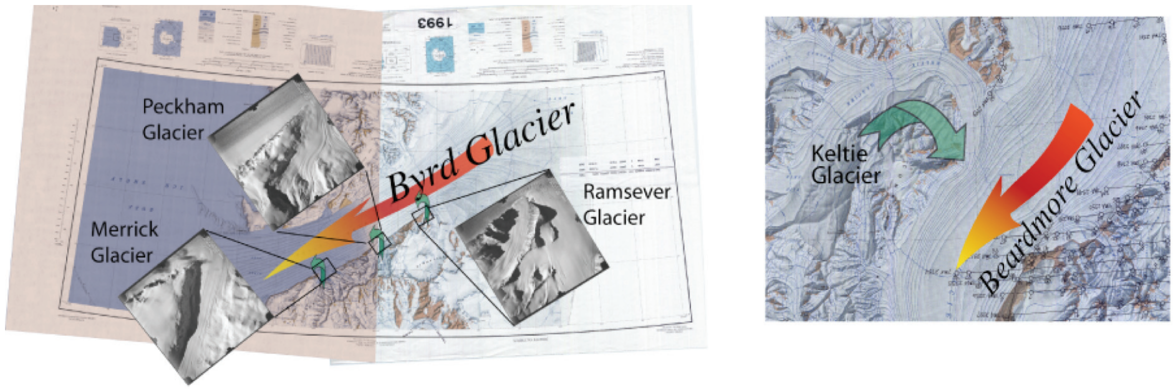

Figure 3. Evidence of drainage reversal in Byrd and Beardmore drainage systems.

Thermochronology

The Byrd Glacier is the largest of the outlet glaciers draining the East Antarctic Ice Sheet through the TAM. Conventional wisdom holds that this valley was incised after Eocene uplift of the mountains by glaciers flowing over the TAM to the Ross Sea. Recent apatite fission track thermochronology of basement rocks sampled at the surface of the Byrd Glacier (elev=500 m) yields a cooling age of 120 Ma (Huerta & Winberry, submitted). The modeled cooling history indicates that the sample cooled to ~50° C by 100 Ma, followed by a protracted period of thermal stability. The rapid Cretaceous cooling suggests the development of significant relief and erosion during the Cretaceous.

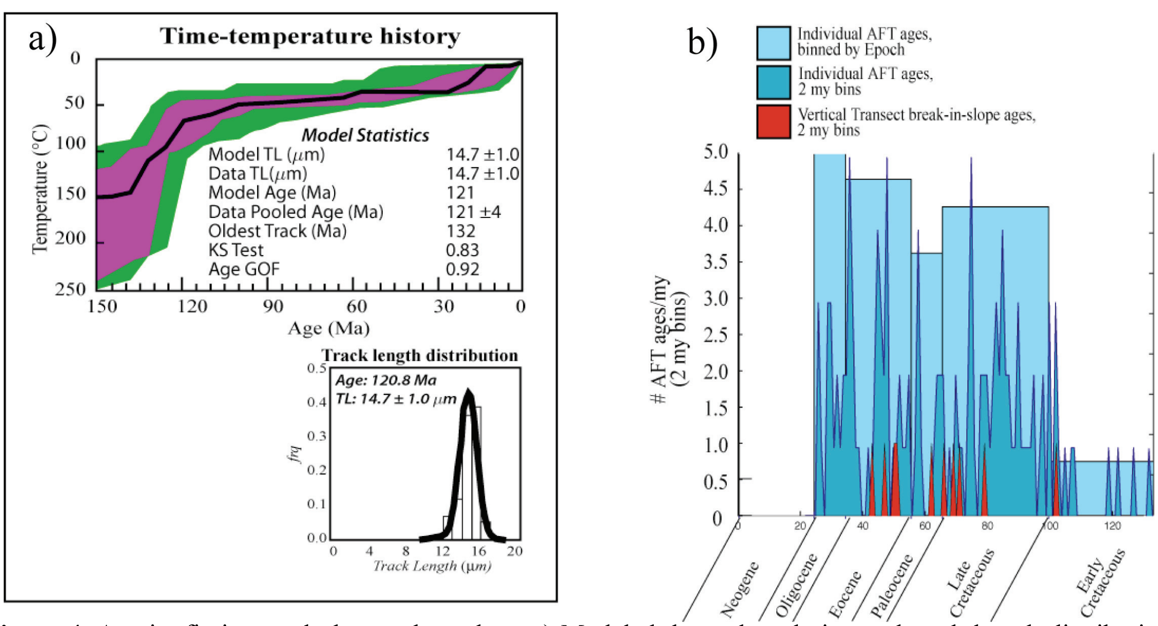

Figure 4. Apatite fission track thermochronology a) Modeled thermal evolution and track length distribution showing Cretaceous rapid cooling of sample collected from the bedrock adjacent to the surface of Byrd Glacier. (Huerta & Winberry, in review, Nature Geoscience). b) Distribution of AFT cooling ages throughout the TAM showing numerous Late Cretaceous ages. Compiled from Fitzgerald & Gleadow, 1988; Gleadow & Fitzgerald, 1987; Fitzgerald, 1992; Stump & Fitzgerald, 1992; Fitzgerald & Stump, 1997; Balestrieri, et al, 1997.

Discussion

The geomorphic and thermochronologic data reviewed here is difficult to reconcile with the current model of Eocene uplift of the Transantarctic Mountains. In contrast, this data suggests the development of relief during the Cretaceous and the pre-Oligocene (pre-glacial) development of drainage systems that flowed from West Antarctica towards East Antarctica. This evolution is consistent with the presence of a Mesozoic West Antarctic Plateau as suggested by geodynamic models (Bialas, in press; Huerta & Harry, 2007).

Summary

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References

Balestrieri, M. L., G. Bigazzi, and C. Ghezzo (1997), Uplift-denudation of the Transantarctic Mountains between the David and the Mariner glaciers, northern Victoria Land (Antarctica); constraints by apatite fission-track analysis, in C. A. Ricci, ed., International Symposium on Antarctic Earth Sciences, vol.7: Siena, Terra Antarctica Publication, 547-554.

Baroni, C., V. Noti, S. Ciccacci, G. Righini, and M. C. Salvatore (2005), Fluvial origin of the valley system in northern Victoria Land (Antarctica) from quantitative geomorphic analysis: Geological Society of America Bulletin, 117, 212-228.

Bialas, R. W., W. R. Buck, M. Studinger, and P. Fitzgerald (in press), Plateau Collapse Model for the Transantarctic Mountains/West Antarctic Rift System: Insights from Numerical Experiments: Geology.

Blankenship, D. D., R. E. Bell, S. M. Hodge, J. M. Brozena, J. C. Behrendt, and C. A. Finn (1993), Active volcanism beneath the West Antarctic ice sheet and implications for ice-sheet stability: Nature, 361, 526-529.

Cooper, A. K., and F. J. Davey (1985), Episodic rifting of Phanerozoic rocks in the Victoria Land Basin, western Ross Sea, Antarctica: Science, 229, 1085-1087.

Fitzgerald, P., and A. J. W. Gleadow (1988), Fission-track geochronology, tectonics and structure of the Transantarctic Mountains in northern Victoria Land, Antarctica: Chemical Geology: Isotope Geoscience Section, 73, 169-198.

Fitzgerald, P. G., 1992, The Transantarctic Mountains of southern Victoria Land; the application of apatite fission track analysis to a rift shoulder uplift: Tectonics, 11, 634-662.

Fitzgerald, P. G., and E. Stump (1997), Cretaceous and Cenozoic episodic denudation of the Transantarctic Mountains, Antarctica; new constraints from apatite fission track thermochronology in the Scott Glacier region: Journal of Geophysical Research, B, Solid Earth and Planets, 102, 7747-7765.

Huerta, A. D. (2006), Crustal Heat Production and Rifting Evolution: Margins workshop, Gulf of California, Rifting Continental Lithosphere.

Huerta, A. D. (In Revision), Coupled Evolution of the Transantarctic Mountains and the East Antarctic Ice Sheet: Insights from Landscape Analysis: Geomorphology.

Huerta, A. D., and Reusch. D.B. (2005), Quantitative Analysis of Glaciated Landscapes: Eos, Transactions.

Huerta, A. D., and D. L. Harry (2007), The transition from diffuse to focused extension: Modeled Evolution of the West Antarctic Rift System: Earth and Planetary Science Letters, 255, 133-147.

Huerta, A. D., and J. P. Winberry (In Review), Slow erosion by a fast glacier: Nature Geoscience.

Kerr, A., and P. Huybrechts (1999), The response of the East Antarctic ice-sheet to the evolving tectonic configuration of the Transantarctic Mountains: Global and Planetary Change, 23, 213-229.

Stump, E., and P. G. Fitzgerald (1992), Episodic uplift of the Transantarctic Mountains; with Suppl. Data 92-08: Geology, 20, 161-164.

Sugden, D. E., M. A. Summerfield, G. H. Denton, T. I. Wilch, W. C. McIntosh, D. R. Marchant, and R. H. Rutford (1999), Landscape development in the Royal Society Range, southern Victoria Land, Antarctica: stability since the mid-Miocene: Geomorphology, 28, 181-200.

Wilson, T. J. (1995), Cenozoic transtension along the Transantarctic Mountains-West Antarctic Rift boundary, southern Victoria Land, Antarctica: Tectonics, 14, 531-545.