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Topographic Controls on Channelized Meltwater in the Subglacial Environment

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Key Points:

- Bed topography was the primary control on the morphology and organization of a large paleo-subglacial meltwater corridor in Antarctica
- The morphology of the corridor supports downstream gains and losses in meltwater supply and/or changes in drainage style
- Grounding-line retreat events were significantly larger when channels were active and smaller when channelized drainage had ceased

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract

Realistic characterization of subglacial hydrology necessitates knowledge of the range in form, scale, and spatiotemporal evolution of drainage networks. A relict subglacial meltwater corridor on the deglaciated Antarctic continental shelf encompasses 80 convergent and divergent channels, many of which are hundreds of meters wide and several of which lack a definable headwater source. Without significant surface-melt contributions to the bed like similarly described landforms in the Northern Hemisphere, channelized drainage capacity varies non-systematically by three orders of magnitude downstream. This signifies apparent additions and losses of basal water to the bed-channelized system that relates to bed topography. Larger magnitude grounding-line retreat events occurred while the channel system was active than once channelized drainage had ceased. Overall, this corridor demonstrates that meltwater drainage styles co-exist in time and space in response to bed topography, with prolonged impacts on grounding-line behavior.

Plain Language Summary

Water drainage beneath glacial ice can impact flow of the overlying ice, sediment transport underneath the ice toward the glacier's terminus, and the stability of glacial ice as it transitions from resting on the geologic terrain to floating in the ocean. Despite being an important component of glacial systems, the full range of possible modes of water delivery and how these interact and vary across time and space is not well resolved. We describe a relict subglacial meltwater network preserved on the Antarctic seafloor, representing a persistent pathway for water drainage when the East Antarctic Ice Sheet was much larger. The landforms within the drainage network implicate substantial changes in how subglacial water drainage was influenced by the shape of the underlying terrain and demonstrate the prolonged impacts that meltwater corridors have on the retreat of glacial ice.

1. Introduction

Subglacial hydrology is a critically important, yet elusive, element of glacial systems. The evolution of meltwater transmission is obscured in the ice-covered, subglacial environment, precluding a holistic understanding of glacial response to water routing through time and space. Fundamentally, the presence of basal water encourages deformable beds and basal sliding (R. B. Alley et al., 1986; Engelhardt & Kamb, 1997; Tulaczyk et al., 2000), contributing to accelerated ice-flow velocities associated with ice streams (Bell et al., 2007; Hulbe & Fahnestock, 2004; Kyrke-Smith et al., 2014). The loss of basal water, conversely, can lead to the shutdown of ice streaming (Catania et al., 2006; Raymond, 2000). Yet, basal water pressure and its effect on ice flow depends on how water is transmitted and organized. Basal water supply modulates the processes of transmission, and may be sourced from supraglacial and englacial inputs (Das et al., 2008; Lampkin et al., 2013), basal melt (Pattyn, 2010; Seroussi et al., 2017), release of stored water from subglacial lakes (Fricker & Scambos, 2009; Palmer et al., 2013; Simkins et al., 2017), and groundwater contributions (Christoffersen et al., 2014; Shoemaker, 1986).

Pathways of subglacial water drainage are traditionally described as distributed or channelized (Kamb, 1987; Röthlisberger, 1972), both of which can be typified by a spectrum of forms and spatial scales (Greenwood et al., 2016 and references therein). Importantly, drainage style has been related to efficiency of water transmission, qualitatively characterized as "slow" or "fast" (Raymond et al., 1995). Slow distributed drainage leads to increased basal water pressure and accelerated ice flow, while fast, channelized drainage encourages decelerated ice flow due to capture of porewater (or water within basal cavities) and subsequent reduction of water pressure in the neighboring region (Hoffman et al., 2016; Sole et al., 2013; Tedstone et al., 2015). However, this simple association is challenged (e.g., Gulley, Grabiec, et al., 2012; Gulley, Walthard, et al., 2012) by nonlinear and spatially heterogeneous ice-flow responses (e.g., Cowton et al., 2013; Minchew et al., 2016; Siegfried et al., 2016). Furthermore, drainage style influences sediment properties (Iverson, 2010; Schoof, 2010), grounding-line sedimentation (Simkins et al., 2017), and basal melt of ice shelves (K. E. Alley et al., 2016; Le Brocq et al., 2013; Marsh et al., 2016) and ice cliffs (Motyka et al., 2013)—all of which can directly or indirectly influence glacier behavior.

Observations and theoretical developments suggest complex spatiotemporal coupling between the different components of subglacial drainage systems. In Greenland and other temperate settings, subglacial drainage behavior evolves over short timescales. During the summer, distributed drainage is replaced by channelized drainage that develops and expands where increasing volumes of surface meltwater access the bed (Andrews et al., 2014; Bartholomew et al., 2010; Chandler et al., 2013; Cowton et al., 2013). Even parts of the bed with only weak hydraulic connectivity, conceptualized as leaky cavities, undergo basal pressure variations on seasonal timescales in response to evolving water supply (Hoffman et al., 2016; Rada & Schoof, 2018). In the absence of surface-driven, seasonal controls on subglacial hydrology, a major spatial transition from relatively distributed to concentrated drainage beneath Thwaites Glacier, Antarctica coincides with changes in basal shear stress, water flux, and ice-surface slope (Schroeder et al., 2013).

Transitions in subglacial water drainage form are not rare in the landform record of paleo-glacial systems (e.g., Burke et al., 2012; Greenwood et al., 2017; Hättestrand & Clark, 2006; Kehew et al., 2012; Lewington et al., 2020; Margold et al., 2013; Turner et al., 2014), often coinciding with changes in observed bed properties and perceived water supply. Broad pathways with integrated meltwater landform assemblages ("meltwater corridors") are increasingly explained in the context of spatiotemporally variable water supply (Burke et al., 2012; Peterson et al., 2018; Utting et al., 2009) and exchange between channelized water and the surrounding distributed drainage (Lewington et al., 2020). Temporal evolution in the landform record is not trivial to constrain but, while some meltwater systems are interpreted as products of single, high-energy drainage events (e.g., Burke et al., 2008, 2012; Hooke & Jennings, 2006; Jørgensen & Sandersen, 2006), other similarly large systems call for incremental landform development requiring spatially and temporally persistent drainage pathways (e.g., De Geer, 1940; Hebrand & Åmark, 1989; Livingstone & Clark, 2016; Livingstone et al., 2020; Mäkinen, 2003; Storrar et al., 2014).

Greater perspective on the evolution of different drainage styles is needed for realistic understanding of water influence on ice behavior. Deglaciated terrains are particularly useful in mapping subglacial drainage pathways that leave an imprint on the bed in the form of infilled Röthlisberger (R) channels (i.e., eskers) incised upward into basal ice and bed-incised Nye (N) channels (Greenwood et al., 2016; Kehew et al., 2012; and references therein). Many examples of meltwater landforms are found in regions formerly covered by glacial systems that experienced significant ice-surface melting, whereas there have been fewer definitive landforms observed in Antarctica (Greenwood et al., 2012; Munoz & Wellner, 2018; Simkins et al., 2017). We describe a relict subglacial meltwater corridor, marking spatially expansive channelized drainage on the Antarctic Ross Sea continental shelf in Pennell Trough (Figure S1 in Supporting Information S1; partially reported by Wellner et al., 2006). We examine causes of abrupt changes in channelized meltwater drainage, and elucidate the influence of active meltwater transmission on grounding-line retreat.

2. Methods

Geophysical data in the western Ross Sea support asynchronous retreat of the East Antarctic Ice Sheet (EAIS) since the Last Glacial Maximum (LGM; Anderson et al., 2014; Prothro et al., 2020), yet many seafloor landforms were unrecognized prior to the use of multibeam echo sounders capable of resolving meter to sub-meter elevations (Lee et al., 2017; Greenwood et al., 2018; Simkins et al., 2017). Bathymetry data from Pennell Trough (Figure S1 in Supporting Information S1; Figures 1a and 1b) were collected onboard the RVIB *Nathaniel B. Palmer* (NBP) 15-02 cruise using a Kongsberg EM122 operating in dual swath mode at 12 kHz frequency (Text S1 in Supporting Information S1; DOI: 10.7284/901477). The bathymetry data

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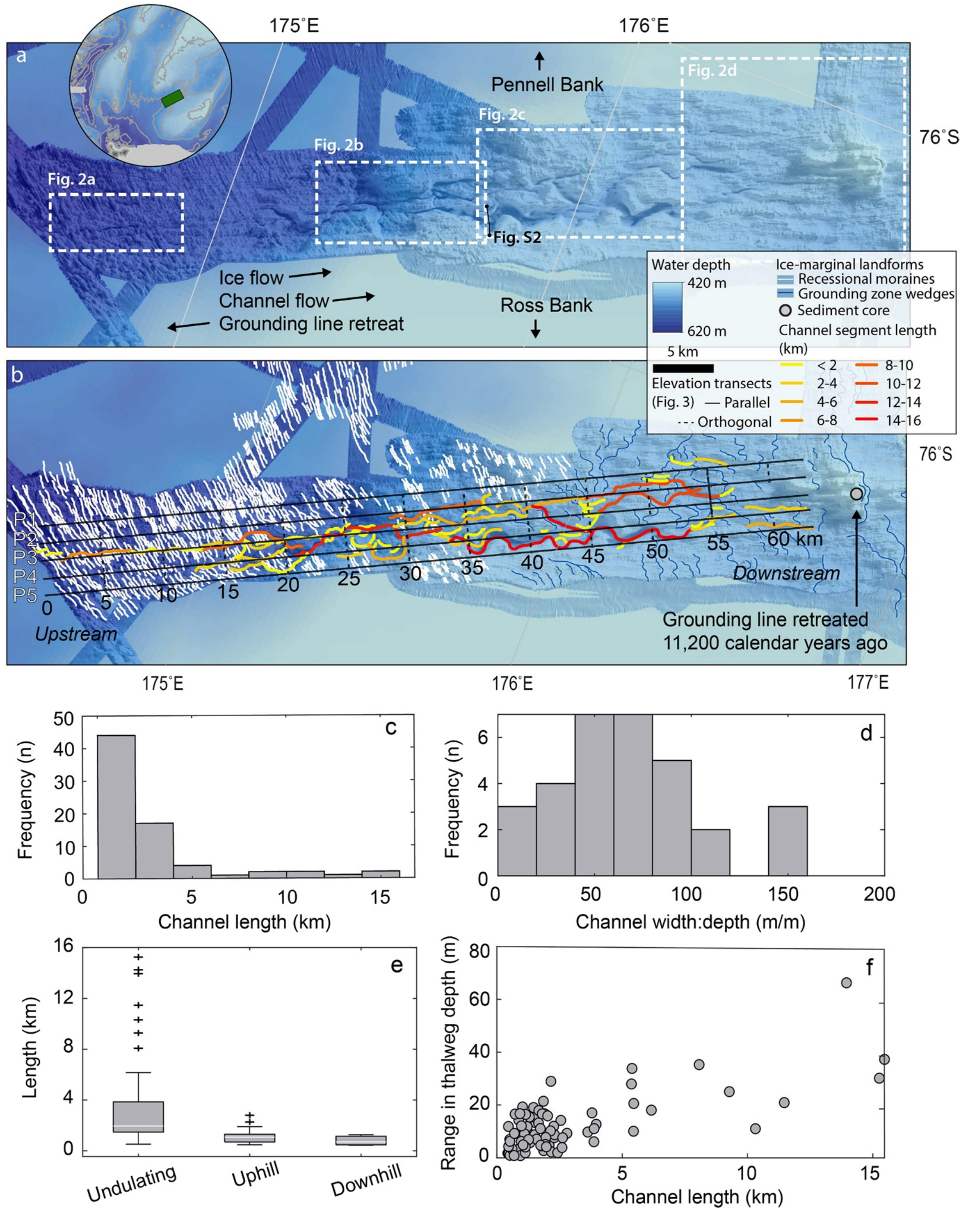

Figure 1. Overview of the meltwater corridor. (a) Bathymetry of Pennell Trough and inset of the region with 150-meter depth contours. (b) Mapped landforms, the location of core NBP1502A JPC01 that constrains the retreat time, corridor-orthogonal and corridor-parallel transects. (c) Individual channel lengths across the corridor. (d) Channel width-depth ratios ($n = 60$) captured in the orthogonal transects, excluding one outlier with a ratio of 1,200. (e) Thalwegs are undulating if they occur across bed elevations that migrate up and down, uphill if on an exclusively uphill bed, and downhill if exclusively on a downhill bed. (f) Correspondence of channel length with maximum change in thalweg depth measured as a difference in highest and lowest elevations taken at a 500-m interval along individual thalwegs. Cross-sectional area of the channels was determined assuming bankfull flow to the lowest elevation bank and using appropriate channel geometries for each. Bed slope for corridor-parallel transects was assessed by using a 1-km moving window.

used in this study are gridded at 20-m (Text S1 in Supporting Information S1). Ice-marginal and meltwater landforms were visually interpreted and mapped from the bathymetry data (Text S1 in Supporting Information S1). Both the bathymetry data and mapped landforms are archived as Data Set S1 and by the United States Antarctic Program Data Center (DOI: 10.15784/601474). The region presented here is geographically located on the stoss side of a topographic high, or saddle, connecting two banks (Figure S1 in Supporting Information S1) and seafloor geology is characterized as Miocene sediments of varying degrees of lithification overlain by till with no known bedrock exposures at the seafloor (Halberstadt et al., 2016; Shipp et al., 1999). The LGM grounding-line position is ~100-km downstream (seaward) from the study region (Figure S1 in Supporting Information S1); therefore, all ice-marginal landforms formed beneath thick marine-based ice and mark post-LGM deglaciation (Figures 1a and 1b; Prothro et al., 2020).

We measured channel length by mapping all incidences of continuous incision from upstream to downstream along thalwegs. The minimum channel incision depth is 90 cm; less incision is likely not resolved in the bathymetry data. Near the channels in Pennell Trough, sediment cores reveal minimal post-glacial deposition of a thin drape of diatomaceous sediments ranging from 0 to 50 cm in thickness (Prothro et al., 2018) and acoustic surveys collected on cruise NBP15-02 show that channel infilling is insignificant with few exceptions in the largest channel that appear to be partially filled with subglacial sediments (Text S1 and Figure S2 in Supporting Information S1). Therefore, the incised channels have overall been well-preserved. Cross-sectional area of the channels, used here as a metric for channelized meltwater capacity, was determined assuming bankfull flow to the lowest elevation bank and using appropriate channel geometries for each, whether triangular, trapezoidal, or half-circular. Bed slope for corridor-parallel transects was assessed by using a 1-km moving window.

3. Results

3.1. Morphology of the Meltwater Corridor

Glacial landforms associated with post-LGM glacial activity are observed in Pennell Trough (Figure S1 in Supporting Information S1), including 80 sediment-based channels on the stoss side of a topographic saddle (Figures 1a and 1b). Individual channels vary from 0.45–15.2 km in length, 4–36 m in incision depth, and 0.2–2 km in width (Figures 1a–1c), and the vast majority of the channels display triangular cross-sectional geometries. Width-depth ratios of the channels vary by two orders-of-magnitude along the corridor (Figure 1d), and are predominantly greater than such ratios of subaerial braided and meandering channels floored by gravel and sand (Finnegan et al., 2005; Rhoads, 2020). Cross-cutting relationships—superposition and bisection of ice-marginal landforms—and predominantly undulating (74%; Figure 1e) thalwegs lead us to interpret the channels as subglacial meltwater landforms. We reconstruct water transmission uphill from southwest to northeast due to increased sediment accumulation at the apparent terminus of the system, channel activity concurrent with grounding-line retreat to the southwest, and the independently known ice-flow direction (Figures 1a and 1b; Halberstadt et al., 2016). We collectively refer to this drainage system as a meltwater corridor similar in scale to those described in deglaciated landscapes of the Northern Hemisphere (e.g., Burke et al., 2012; Lewington et al., 2020; Peterson et al., 2018; Utting et al., 2009), albeit here seemingly purely erosional meltwater landforms. The lack of discernible glaciofluvial deposition may be due to the fine-grained (clay to silt) nature of the bed (Halberstadt et al., 2018) that would favor suspension as the primary sediment transport mode within the channels.

The upstream-most expression of the corridor (0–12 km) is dominated by quasi-straight channels (Figure 2a) that form a fragmented, but solitary, channelized pathway. Overprinting recessional moraines obscure the true connectivity of channels. An abrupt transition to sub-parallel channels occurs at 12-km downstream, followed by a gradual transition to convergence and divergence of anastomosing channels of variable length, many of which are "blind," meaning they initiate without a definable headwater source (Figure 2b). From 34 to 51 km along-corridor, greater focusing of drainage is evidenced by a relatively deep and sinuous main channel (up to 36 m deep) and adjacent channels (up to 10 m deep; Figure 2c). Within the sinuous channel, temporal fluctuations of water discharge are revealed by smaller, embedded channels. Between 50- and 55-km downstream, channelized drainage once more dispersed into shallow (<5 m deep), discontinuous sub-parallel channels (Figure 2d). The downstream-most channels appear to terminate in a laterally restricted zone of heightened sediment accumulation within closely spaced grounding-zone wedges (Figure 2d), implying that the corridor was capable of delivering relatively high sediment volumes to the grounding line.

Rather than drainage convergence and downstream accumulation of water (i.e., dendritic or sub-dendritic), we observe a channelized system with an anastomosing planform organization with parallel and blind channels, all of which morphologically vary in a non-systematic manner downstream (Figure 1). The number of

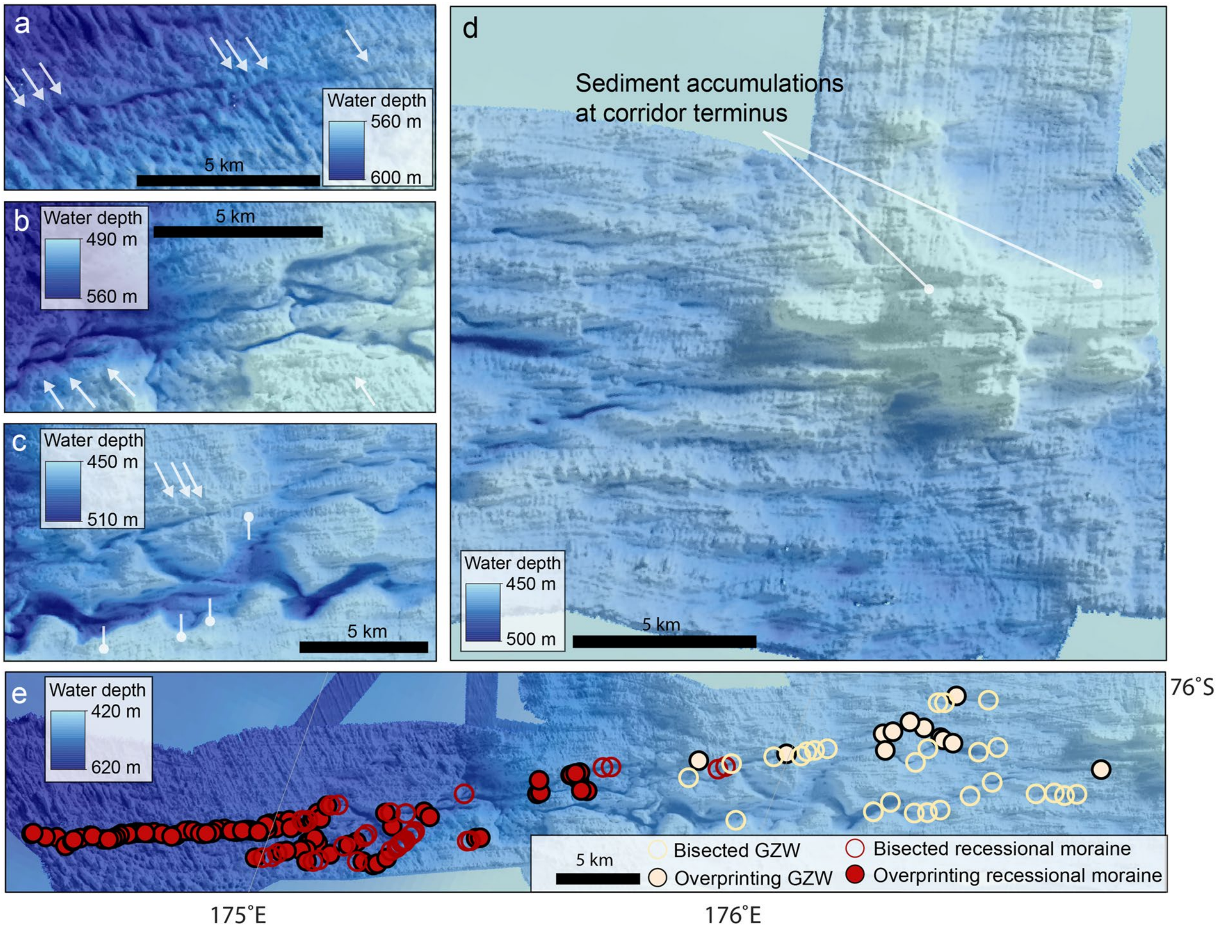

Figure 2. Corridor morphology and relationship with ice-marginal landforms. (a) Upstream channels are dominantly overprinted by ice-marginal landforms. (b) Poorly organized, anastomosing channels and blind channels. (c) A relatively deep and sinuous channel with embedded channels and adjacent convergent channels. In panels (a–c), select ice-marginal landforms are highlighted by white arrows and the dot-lines mark smaller, nested channels. (d) Shallow, discontinuous channels terminate as locally thick sediment accumulations within two generations of grounding-zone wedges. (e) The spatial distribution of the subset of ice-marginal landforms that overprint channels (n = 101) and abruptly terminate at channel banks (n = 58).

channels and their incision depth increases downstream in the corridor, punctuated by a dramatic increase in incision depth between 30- and 35-km downstream (Figure 3a). But, incision depths subsequently shallow from 50-km downstream to the terminus. While there is a general relationship between channel width and incision depth, the tendency of width and depth to scale positively has no correspondence downstream (Figure 3b). Drainage capacity, estimated by cumulative cross-sectional area of channels, varies non-systematically by three orders of magnitude (Figure 3c), pointing to substantial gains and losses in bed-channelized water that occur within short (≤5 km) distances. While notable gains in drainage capacity begin at 25-km downstream, a maximum capacity is observed at 45-km downstream. Within 15-km downstream from maximum capacity, drainage capacity drops to just 3% of its maximum so that the cross-sectional area at the upstream- and downstream-most transects (5- and 60-km, respectively) is the same (~2,300 m^2).

Channel preservation within the corridor requires them to have been persistent or preferred (i.e., reoccupied) pathways of water flow to prevent complete channel closure (e.g., Flowers, 2015), while nested channels within the deep and sinuous channel (~35–45-km downstream) and truncation of some pathways (Figure 2) clearly indicate time-varying discharge. Overall, this supports the longevity of drainage pathways without discernible infill by deformation till or glaciofluvial sediments despite indications of waning meltwater supply. Bisection of grounding-zone wedges in the downstream section of the corridor (Figure 1b) indicates active drainage during a phase of grounding-line retreat that lasted hundreds to several thousand

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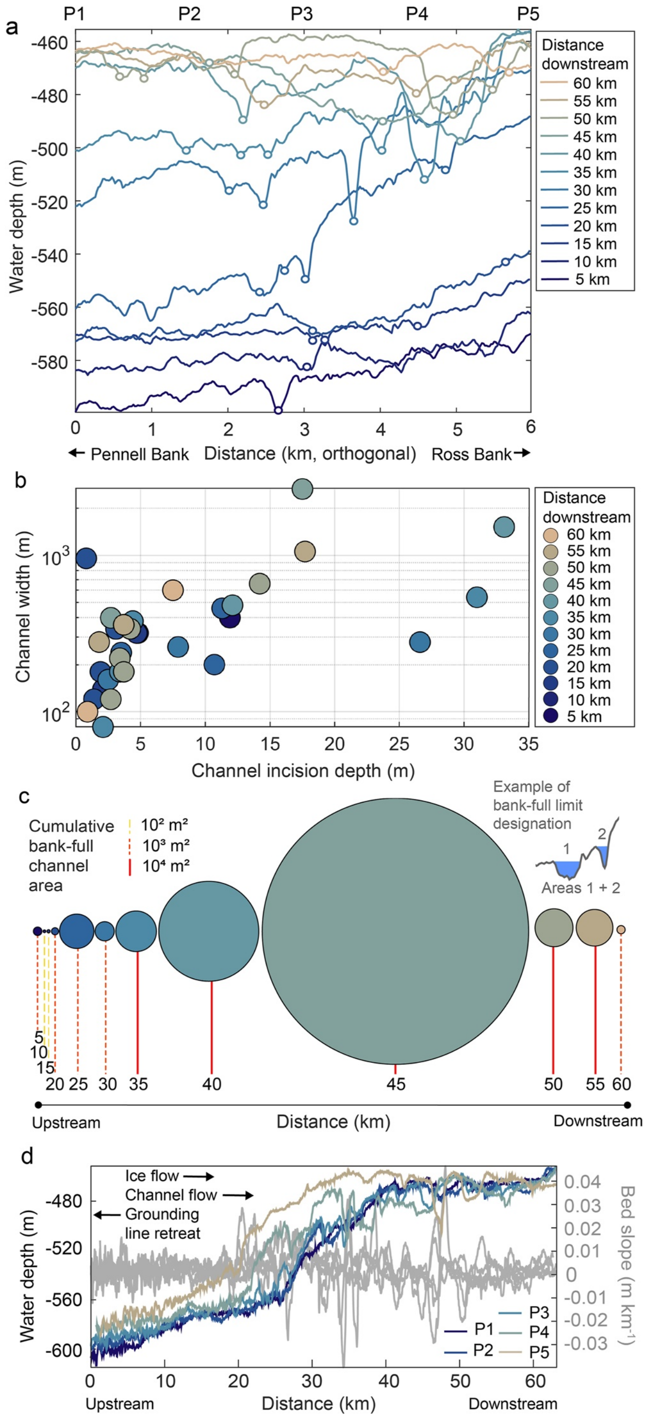

Figure 3. Corridor drainage in relation to bed topography. (a) Across-corridor transects, plotted according to their downstream position (locations in Figure 1b), with thalwegs indicated by circular points. (b) Channel width scales positively with channel depth, but neither evolve consistently with its downstream position. (c) Cumulative bankfull channel area in each across-corridor transect, expressed as relative scaling of circles and vertical line color. (d) Abrupt changes in bed topography and slope along the length of the corridor (locations in Figure 1b) correspond to major downstream transitions in corridor morphology and capacity.

years based on ice-marginal landforms of similar size elsewhere in the Ross Sea and a range of plausible sediment fluxes (Simkins et al., 2017).

3.2. Grounding-Line Retreat Across the Corridor

As the grounding line retreated toward the southwest on a regionally retrograde bed slope (Figure 1), the length of the active corridor progressively shortened and numerous ice-marginal landforms indicate periodic grounding-line standstills across the corridor. Whether an ice-marginal landform is bisected by a channel or overprints it indicates if channels were active or not, respectively, at those grounding-line positions (Livingstone & Clark, 2016; Simkins et al., 2017; Figures 1 and 2). We find that both the morphology of ice-marginal landforms and their relationship with an (in)active channel system changed systematically as retreat progressed. Discontinuous, visually "smeared" grounding-zone wedges, often bisected by meltwater channels, occur in the lower (downstream) corridor, from 38 to 63 km. Sublinear recessional moraines, most commonly overprinting inactive channels, dominate the upstream sections, from 0 to 38 km (Figure 2e). On this basis, we interpret that the corridor largely ceased to deliver channelized water as grounding-line retreat progressed upstream off the topographic saddle.

Of the ice-marginal landforms (n = 101) that overprint channels within the corridor, 90% of those landforms are recessional moraines. The overwhelming majority of grounding-zone wedges were deposited when channels were actively draining water to the grounding line, whereas the recessional moraines were largely formed after the corridor had shut down (Figure 2e). We additionally find that the spacing between series of grounding-zone wedges and recessional moraines changes upstream from a median of 700 m (standard deviation of 1.4 km) to 300 m (standard deviation of 400 m), respectively, indicating lower-frequency, but higher-magnitude and more variable retreat events when the channels were active.

4. Discussion

Collectively, channel organization, morphology, and drainage capacity variations suggest that this meltwater landform assemblage is a product of non-uniform water supply (spatially and/or temporally), contrary to theoretical models of channel development via porewater siphoning from a uniform supply of meltwater (Röthlisberger, 1972; Shreve, 1972). We first consider that our morphological record may be a composite, cumulative product of a long-lived channelized drainage system whose segments have evolved over time. Nested and truncated channels attest to time-varying bed-incision and channel pathways, and are found in particular in the mid-corridor (Figure 2c). Apparent orders of magnitude increases in drainage capacity could, we envisage, correspond to a grounding-line position, allowing channel enlargement in the middle sections after the downstream-most sections (low drainage capacity) had deglaciated. However, there is no ice-marginal landform evidence for such a prolonged standstill. We consider also that lateral migration of dominant pathways may have produced "duplicate" channel segments. Even if this were the case, much of the drainage capacity increase is due to enlargement of the primary, single channel. While temporal expansion of corridor drainage capacity likely occurred, we demonstrate here that this was not spatially consistent or predictable.

Large R- and N-type subglacial conduits, similar in scale to those within the corridor in Pennell Trough, are commonly thought to be fed by spatially focused and short-lived enhanced supply via seasonal surface melt and/or flood outburst (Andrews et al., 2014; Chandler et al., 2013; Greenwood et al., 2016; Gulley, Grabiec, et al., 2012; Hooke & Jennings, 2006; Jørgensen & Sandersen, 2006; Storrar et al., 2014). While an appealing mechanism to account for localized, order-of-magnitude increases in drainage capacity and nested channels, surface supply of meltwater today is negligible in Antarctica outside of ice-shelf settings and near low-albedo nunataks and blue-ice exposures (Bell et al., 2018; Kingslake et al., 2017), and is believed to have been insignificant during the LGM. Furthermore, conditions during the post-LGM deglaciation through Pennell Trough were not favorable for surface meltwater production; therefore, we do not consider surface melting a likely contributor to basal meltwater supply within the corridor.

Spatiotemporal changes in the basal environment—in meltwater supply and/or modes of drainage (e.g., upward incision of channels into the ice base or interactions with a porewater system)—are required to produce the observed landform imprint. Basal sources of water to the corridor may stem from reoccurring drainage from subglacial lake sources, enhanced melt due to strain heating, porewater siphoning, or perhaps a combination of all three. Floods from subglacial lakes may result in greater channel incision in the upper reaches of the drainage system due to these parts being glaciated longer and experiencing more flood events. Contrastingly, floods may yield less focused flow upstream (i.e., little to no channelization), becoming more focused (i.e., channelized) farther downstream (Flowers et al., 2004). Yet, we are not able to identify a subglacial lake source of water to the corridor, nor would floods explain the abrupt, non-systematic changes in drainage capacity *and* the sustained drop in drainage capacity in the final ∼10-km of the corridor (Figures 3c and 3d).

Instead, we find that increases in channelized drainage capacity correspond to steepening of the topography and increased variability in bed slope (Figure 3d). The topography along the corridor gently climbs with little local variability up to 20- to 25-km downstream, but thereafter climbs steeply with large positive and negative changes in bed slope to 50-km downstream in the corridor (Figure 3d). The downstream increases in the number and incision depth of channels, and substantial capacity increase from 30 to 45-km correspond to a positive jump in relief of tens of meters and heightened bed roughness (Figures 3c and 3d). The maximum drainage capacity at 45-km downstream occurs just prior to the topography beginning to plateau. Despite gains in water transmitted through bed-incised channels, ultimately, all gains are lost toward the terminus of the corridor. The drop in drainage capacity beginning at 50-km downstream corresponds to reduced variability in bed slope and flattening of bed topography (Figures 3c and 3d). Despite the loss of incised drainage capacity, we observe the number of channels to increase and the corridor to widen (Figure 3a), indicating the continued persistence of channelized flow.

We argue that topography is the first-order control on the channel number, size, and organization, affecting the way in which meltwater drainage is transmitted along-flow and incises its bed. Topography fundamentally impacts hydraulic gradient and effective pressure via ice thickness, dictating how water drains and organizes in the subglacial environment. We expect the hydraulic gradient to shallow in response to the reverse bed slope, perhaps allowing drainage pathways to migrate more freely. Bed erosion and sediment deposition in response to these factors (Swift et al., 2021) may result in gains and losses specifically in the downward-incised component (i.e., the morphological record) of the channel system (e.g., Greenwood et al., 2017; Livingstone et al., 2016). Additionally, we expect there were positive feedbacks between channel growth, porewater siphoning, basal melt, and fluvial erosion as channel surface area increased at the ice-bed interface.

The increase in channelized drainage capacity (Figure 3c), broadly simultaneous with the increased complexity of the network morphology (Figures 1a and 1b), may result from local but sustained increases in meltwater production. This could have driven channel growth in the mid-corridor section, arising from strain heating due to the steepening of the topography and increased variability in bed slope. Local meltwater production could explain the presence of blind channels that lack a definable headwater source. Furthermore, changes in topography-induced pressure gradients would likely increase porewater pressure, driving oversaturation of sediments and delivery of water to the channels, and vice versa. However, we are not able to constrain magnitudes of strain heating or porewater pressure variability at the kilometer or even sub-kilometer scale needed to investigate controls on channel morphology and organization.

The variability in apparent drainage capacity may, alternatively, be due to vertical migration of the channels upward into the ice base. Landforms in the Northern Hemisphere (Greenwood et al., 2017; Lewington et al., 2020; Livingstone et al., 2016) indicate that a single conduit may transition between incision into the substrate, producing a meltwater channel, and incision into the ice base, producing an esker. It is possible that the apparent gains and losses in conduit capacity here are morphologic (i.e., relating to drainage mode) rather than hydrologic (i.e., related to meltwater supply). Livingstone et al. (2016) discuss such vertical migration of meltwater conduits and, following Ng (1998) and Fowler (2011), suggest that upwards incision into basal ice is favored under low effective pressure (relatively lower overburden and/or high-water pressure), while erosion of the substrate is favored under high effective pressure. The apparent loss of drainage capacity downstream may arise from a predictable switch towards upwards incision under thinner ice towards the grounding line. However, substantially enlarged channels in the mid-corridor also require a commensurate increase in glaciofluvial erosion. Changes in erosion rates are expected to arise due to feedbacks with bed topography, hydraulic gradient, effective pressure, water supply, and non-uniform relationships with sediment load (Beaud et al., 2016, 2018), but are so far little explored in a sediment substrate (Carter et al., 2017).

The bisection of downstream grounding-zone wedges by active channels while upstream moraines overprint inactive channels echoes similar relationships between channels and ice-marginal landforms elsewhere in the western Ross Sea, where the topography is relatively flat compared to Pennell Trough (Simkins et al., 2017). This similarity between sites suggests that, while topography influences channelized drainage in Pennell Trough, channelized drainage has a fundamental influence on ice-marginal landform products and magnitudes of grounding-line retreat events. This is an important empirical finding that suggests grounding-line behavior is sensitive to long-lived subglacial hydrologic systems.

5. Conclusions

The meltwater corridor represents a large, persistent meltwater pathway composed of tens of channels that existed beneath the EAIS when it covered the seafloor in Pennell Trough. The abrupt gains in bed-accommodated channelized drainage capacity require a mid-corridor enhancement in basal meltwater supply and/or change in drainage behavior via variable erosional capacity and channel incision into the ice base, corresponding to a jump in topography and increase in bed-slope variability. Despite the gains in capacity, water is subsequently lost from the bed-incised channels, corresponding to flattening of the topography and bed slope. This loss could potentially result from alteration of sediment rheology or flux via exchanges with the porewater system and/or effective pressure changes near the grounding line, perhaps via tidal processes and the grounding line being near buoyancy limits that would force drainage mode changes.

Incision of subglacial meltwater channels into the substrate is rarely considered by subglacial hydrology theory, and coupling with fluvial erosion mechanisms for their development even less so. The downward fluvial incision, persistence of channelized drainage, and sediment rheological outcomes through spatiotemporal variability in meltwater transmission is an area of research urgently required from both physical and empirical perspectives. This study highlights the importance of sub-kilometer scale changes in topography that would drive changes to modes of subglacial water drainage and the influence of such on grounding-line behavior.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The NBP15-02 multibeam echo sounding bathymetry is available through the Marine Geoscience Data System at https://doi.org/10.7284/901477 (Cruise DOI: 10.7284/901477) and provided as a georeferenced TIFF in Data Set S1 along with shapefiles of the glacial landforms within the corridor. Data Set S1 is archived by the United States Antarctic Program Data Center, an online data repository for Antarctic projects funded by the National Science Foundation hosted by the Lamont-Doherty Earth Observatory of Columbia University, under the DOI: 10.15784/601474 (https://doi.org/10.15784/601474).

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