

# Tectonically inherited shelf bathymetry mediates ice-ocean interaction in Lützow-Holm Bay, East Antarctica

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# Structurally preconditioned continental-shelf troughs define potential warm-water pathways in Lützow-Holm Bay, East Antarctica

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## Abstract

We present new shipboard bathymetry from Lützow-Holm Bay, East Antarctica, acquired during three summers with reduced fast-ice cover to resolve glacier-front bathymetry and assess its relationship to inherited crustal structure and potential warm-water access. Echo-soundings in front of glacier systems reveal a network of deep troughs and shallow sills across the inner continental shelf. The Shirase Glacier system is connected to the deeper continental shelf through an entrance approximately 740 m deep, whereas shallower sills of approximately 480–580 m occur at the entrances to the Skallen, Telen, and Honnør glacier-front troughs. These depth contrasts define bathymetric thresholds that may modulate warm-water access under varying oceanographic conditions. The NW–SE-trending segment of the main trough is spatially aligned with a major airborne magnetic boundary and a corresponding structural lineament, suggesting that inherited basement structure may have influenced the localization of glacial erosion. Together, these observations suggest that inherited basement structure may have helped shape a segmented trough-and-sill morphology that now provides potential pathways and bathymetric thresholds for warm-water access, offering a geological framework for interpreting modern and Holocene ice–ocean interactions in Lützow-Holm Bay.

## Introduction

Antarctica became isolated following continental breakup approximately 200 Ma, accompanied by seafloor spreading and plume-related magmatism<sup>1–3</sup>. Its subsequent evolution has been shaped by ice-sheet growth and retreat, ocean-circulation changes, sedimentation, isostatic adjustment, and glacial erosion<sup>4–6</sup>. The continental shelf therefore preserves records of both long-term tectonic inheritance and recent ice-sheet modification. Yet, because of persistent sea ice and limited access, the bathymetry, the basic boundary condition for resolving shelf geometry, remains poorly constrained in many Antarctic coastal sectors. Although the amount of data has recently increased owing to the continuous development of oceanographic surveys and community compilations such as the International Bathymetric Chart of the Southern Ocean (IBCSO)<sup>7</sup>, direct observations remain sparse in many glacier-front areas. Previous studies elsewhere in Antarctica have shown that pre-existing valleys, faults, and structural fabrics in geological basement can guide ice flow and localize subsequent

glacial erosion<sup>8–10</sup>. This limits our ability to resolve the connectivity of deep troughs and shallow sills that can influence warm-water access to ice fronts, and to evaluate how glacial erosion has modified shelf geometry that may have been preconditioned by inherited crustal structure.

Seafloor topography is a key boundary condition for ocean circulation and therefore for simulations of ice–ocean interaction. As ocean models move toward higher horizontal resolution, accurate representation of continental-shelf troughs and sills becomes increasingly important<sup>11,12</sup>. Deep submarine troughs can provide pathways for relatively warm deep water across the continental shelf, whereas shallower sills can impose bathymetric thresholds on its access to glacier fronts. Modified Circumpolar Deep Water (mCDW) can enter the continental shelf through submarine troughs, reach ice-shelf cavities, and drive basal melting that can contribute to ice-shelf thinning and glacier retreat<sup>13–15</sup>. One of the major hotspots of basal melting in East Antarctica is the Shirase Glacier tongue (SGT) in Lützow-Holm Bay (LHB, Fig. 1a), which extends approximately 150 km in a north–south direction along the 37°E–40°E coast. This glacier system is characterized by fast ice flow (>2 km/yr), deep submarine troughs (>1,000 m), mCDW inflow, and high basal melt rates (7–16 m/yr)<sup>16–19</sup>. Numerical experiments using different bathymetric models have demonstrated that uncertainty in regional bathymetry remains a key limitation for quantifying ice–ocean interactions in LHB, particularly because small differences in trough depth and sill geometry can alter the modeled pathways and access of mCDW to glacier fronts<sup>11,19</sup>.

LHB is also important for linking present-day processes with longer-term East Antarctic Ice Sheet behaviour. The maximum ice-sheet extent and subsequent retreat history around Enderby Land since the Last Glacial Maximum remain incompletely constrained<sup>20</sup>, whereas geomorphological and exposure-age records from the Sôya Coast indicate abrupt Holocene ice-sheet thinning<sup>21</sup>. Recent marine geological evidence from the submarine troughs in LHB further shows that enhanced CDW inflow was associated with ice-shelf collapse and simultaneous inland thinning at approximately 9 ka<sup>22</sup>. Hierarchical climate and ocean modelling in that study suggested a meltwater-driven feedback in which freshwater discharge from retreating Antarctic sectors enhanced stratification, strengthened CDW incursions onto adjacent shelves, and promoted further ice-shelf instability. Recent in situ borehole observations at Langhovde Glacier, another outlet glacier in LHB, further demonstrate that surface meltwater can reach the glacier base, elevate subglacial water pressure, and accelerate grounded ice, while the subglacial hydrological system is hydraulically connected to the sub-shelf cavity<sup>23</sup>. Thus, LHB provides an exceptional setting for testing how continental-shelf bathymetry may influence the interaction between ocean forcing and glacier/ice-shelf dynamics, and how this bathymetry relates to inherited crustal structure.

Surveys of the submarine topography of LHB began with the 9th Japanese Antarctic Research Expedition (JARE9) in 1968. Point echo-soundings acquired through sea-ice drill holes during JARE9–22 were compiled into the first bathymetric map of LHB (1981)<sup>24–27</sup> and later used in

hydrographic observations and ocean modelling<sup>11,19</sup>. Although these on-ice soundings revealed the first-order bathymetric structure, including a deep trough in front of the SGT, their positions were determined from triangulation, aerial photographs, sea-ice markers, and over-ice distance measurements, leading to positional uncertainties of approximately 1 km. Persistent land-fast sea ice has also severely limited opportunities for direct shipboard acoustic observations near glacier fronts, leaving the inner bay without well-positioned shipboard bathymetric observations.

In the austral autumn of 2016, extensive fast-ice breakup<sup>28</sup> enabled ship access to the inner bay and the first comprehensive shipboard observations in front of the SGT (Fig. 1). Here we present well-positioned shipboard acoustic depth measurements derived from sub-bottom profiler records in LHB, integrate them with legacy on-ice soundings to map trough distribution and connectivity, and compare the resulting shelf morphology with airborne magnetic anomalies. We use these data to assess the relationship between glacier-front bathymetry, inherited crustal structure, and potential pathways for warm-water access, and to consider implications for modern and Holocene ice-ocean interactions in LHB. All echo-sound-derived depth picks and compiled grids are publicly available from the data repository.

## **Results and Discussion**

### **Seawater sound velocity structure**

Velocity-depth profiles for the study area were derived from CTD/XCTD profiles collected during JARE58 ( $n = 50$ ) and JARE59 ( $n = 13$ ) (Fig. 2)<sup>19</sup>. The sound velocity at the top was approximately 1440 m/s, and there was a spatial inhomogeneity of approximately 5 m/s at depths shallower than 30 m. This variability likely reflects the influence of sea ice melting and the associated fluctuations in surface water temperature. The speed of sound continued to increase monotonically to a depth of 250–300 m. From this depth to 600 m, the monotonic increase had an even steeper gradient. Notably, this layer has the largest heterogeneity in the sound velocity structure, with a maximum difference of approximately 10 m/s at the same depth, which likely reflects spatial variability associated with mCDW inflow and meltwater-rich outflow. Sound velocity continued to increase below this layer, reaching approximately 1470 m/s at 1200 m depth.

Because contemporaneous hydrographic profiles were not available along every sounding line, including those acquired during JARE57, a Gaussian-averaged profile derived from the 63 JARE58–59 datasets was adopted as a representative one-dimensional velocity model for consistent depth correction across the inner continental shelf. Offshore profiles near the continental slope were used only for soundings deeper than 1000 m. The observed spatial variability in sound velocity corresponds to differences in corrected depth of less than 2 m and generally less than 1 m. These uncertainties are substantially smaller than the tens- to hundreds-of-metres bathymetric contrasts among the major troughs and sills considered in this study.

## **Unveiled bathymetry off glacier tongues**

The bathymetric features off glacier tongues in the LHB were substantially updated based on 901,520 points of well-positioned echo-sounding data corrected with the representative sound velocity model described above (Fig. 3). These measurements were derived from seafloor picks along shipborne sub-bottom-profiler tracks rather than from swath multibeam bathymetry.

A broad trough, approximately 10–30 km wide and 600–1200 m deep, extends from the inner continental shelf in front of the SGT toward the outer shelf, with a pronounced change in orientation along its course. Near the western coast of LHB, the trough shoals markedly to depths of less than 400 m, forming a shallow sill within the otherwise deep pathway. The continental shelf break in the surveyed area is approximately 600 m deep, shallower than the depths used in previous oceanographic and modelling studies<sup>11,19</sup>. The glacier-front bathymetry off the Skallen, Telen, and Honnør systems is also characterized by deep but partly isolated troughs. These troughs are approximately 10–20 km wide and 500–1100 m deep, but include intervening shallow sills less than 600 m deep. A ~1000-m-deep trough occurs in front of the Skallen and Telen glaciers, yet its connection to the main central trough leading to the Shirase Glacier is interrupted by a sill sampled at approximately 580 m depth. Similarly, available profiles indicate a shallower sill of approximately 480 m at the entrance to the Honnør Glacier trough. The troughs also vary in orientation along their length. The southern part of the main central trough trends approximately NNW–SSE, the central part trends nearly N–S, and the northern part turns to a NW–SE orientation. This spatial change in trough orientation is notable because the NW–SE segment is spatially aligned with a major magnetic boundary discussed below. Sub-bottom profiles show few laterally continuous sedimentary reflectors at most locations, indicating limited acoustic penetration and/or little acoustically resolvable sedimentary cover. This may reflect coarse-grained or poorly sorted glacigenic substrates, locally exposed basement, or thin and discontinuous sedimentary cover.

The observed first-order bathymetric pattern is broadly consistent with that documented by Moriwaki and Yoshida<sup>24</sup>. Depth differences between the shipboard and legacy on-ice soundings vary spatially and exceed 100 m in some areas (Fig. 4a). Such differences cannot be explained by sound-velocity uncertainty, which contributes less than 2 m to the corrected depth based on the observed profile-to-profile variability. Instead, the largest discrepancies occur near steep slopes, indicating that positional uncertainty in the on-ice soundings is the dominant source of local mismatch. Because the positioning associated with on-ice observations at that time was performed by combining triangulation and aerial surveys, positional errors likely arose from the combined uncertainties associated with triangulation, aerial photo interpretation, sea-ice drift, and over-ice distance measurements. Nevertheless, the histogram of depth differences shows an approximately normal distribution centered near zero (Fig. 4b), indicating that the legacy on-ice soundings captured the first-order bathymetric

pattern of LHB. These data therefore remain valuable for regional-scale bathymetric compilation, provided that their positional uncertainty is explicitly considered, particularly near steep slopes and narrow troughs. For the following discussion, shipboard echo sounding (this study) and on-ice echo sounding<sup>24</sup> were compiled into a 500 m grid, with individual observations represented within a 2-km search (Fig. 5).

### **Consequences for ocean and ice sheet dynamics**

The submarine troughs in front of the Shirase, Honnør, Skallen, and Telen glacier systems likely reflect selective erosion by past ice streams, as suggested by previous on-ice sounding and geomorphological interpretations<sup>24</sup>. The main N–S trough along the Shirase Glacier system is consistent with a former ice-stream pathway, whereas the NW–SE-oriented troughs off the Honnør, Skallen, and Telen systems suggest another former drainage pathway toward the bay. This geographical configuration would have provided potential pathways for mCDW to enter glacier-front troughs. Where such pathways were sufficiently deep and connected, warm-water access could have enhanced basal melting and contributed to grounding-line retreat or ice-shelf instability<sup>21,22</sup>.

The available bathymetry also reveals pronounced differences in sill depth among the glacier systems. The Shirase Glacier system is connected to the deeper continental-shelf trough through an entrance of approximately 740 m, whereas the Telen and Skallen systems are connected through a sill of approximately 580 m, and the Honnør system through a shallower sill of approximately 480 m (Fig. 5a). These depth contrasts suggest that trough connectivity provides an important bathymetric constraint on potential mCDW access. In LHB, the upper boundary of mCDW commonly occurs at approximately 400–500 m<sup>19</sup>, but its depth varies seasonally and in response to changes in oceanographic and atmospheric forcing<sup>11,19</sup>. The 480–580 m sills should therefore not be regarded as permanent barriers; rather, they define bathymetric thresholds whose effectiveness in limiting warm deep water access is likely to vary through time. Relative to the deeper Shirase pathway, the shallower entrances to the Skallen, Telen, and Honnør systems may reduce warm-water access under some oceanographic conditions, but the magnitude and frequency of this effect cannot be determined from bathymetry alone and require dedicated oceanographic observations and modelling.

The same shallow sills may also have acted as local pinning points during past grounding-line retreat, although their origin and former glaciological role cannot be resolved from bathymetry alone. Moreover, the bathymetric separation of the trough systems does not necessarily imply dynamical independence among the associated glaciers. Overall, the new bathymetry defines the geometric framework within which time-varying mCDW access and glacier response can be evaluated. In the following section, we examine whether this contrasting continental-shelf geometry may in part reflect inherited crustal structure as well as glacial erosion.

## **Origin of the trough and shallow shelf: Insight from tectonic evolution of Gondwana**

The LHB continental shelf contains both deep troughs and shallow sills whose origin can be evaluated by comparison with coastal geology and airborne potential-field data. LHB lies within the Lützow-Holm Complex (LHC), a Late Neoproterozoic to Cambrian orogenic belt near the former junction of Africa, India, Madagascar, and Antarctica<sup>29,30</sup>. U–Pb geochronology further indicates that the LHC comprises multiple crustal domains with distinct protolith ages, and a complex Pan-African metamorphic history<sup>31–33</sup>. The LHC preserves a dominant NW–SE-trending structural grain developed during Pan-African deformation, and this fabric is locally cut by younger NE–SW-trending right-lateral strike-slip faults that subdivide the complex into several crustal blocks<sup>34,35</sup>. Airborne magnetic data indicate that some of these structural boundaries continue offshore beneath LHB<sup>35</sup>. Although this tectonic framework is well established on land, its relationship to the present continental-shelf morphology remains poorly constrained.

The shallow seafloor highs in front of the Honnør, Skallen, and Telen glaciers do not coincide with distinctive magnetic anomalies in the available airborne dataset. This observation argues against a simple interpretation as strongly magnetized igneous bodies, but it does not uniquely determine their origin. The highs may represent erosion-resistant basement relief, weakly magnetized lithologies, glacialigenic or morainal accumulations, or a combination of bedrock and sedimentary relief. The limited penetration and spatial resolution of the available sub-bottom and aeromagnetic data preclude discrimination among these possibilities.

In contrast, the NW–SE trending segment of the main trough system is spatially aligned with a major magnetic boundary (Fig. 5a)<sup>35</sup>. Importantly, this magnetic boundary is parallel to the dominant NW–SE structural grain of the LHC, rather than to the younger NE–SW strike-slip faults. The correspondence therefore more directly supports a relationship with inherited basement fabric or a crustal boundary than with the younger fault set. This spatial correspondence suggests that pre-existing basement heterogeneity, potentially including zones of relative mechanical weakness, may have influenced where glacial erosion was preferentially focused.

Previous work proposed fault control on major troughs in LHB<sup>24</sup>, but the present comparison suggests a more nuanced relationship. The NW–SE segment is more closely aligned with the regional basement grain and magnetic boundary, whereas the role of the younger NE–SW strike-slip faults in localizing the mapped troughs is less clear. We therefore interpret the bathymetry more generally as structurally preconditioned rather than uniformly fault-controlled.

These relationships suggest that inherited basement structure may have provided part of the initial template on which subsequent glacial erosion acted. The resulting segmented trough-and-sill morphology now defines potential pathways and bathymetric thresholds for warm water access, although the effectiveness of these pathways depends on the time-varying oceanographic structure discussed above. In this sense, tectonic inheritance may indirectly influence present-day ice–ocean

interaction by shaping the geometry on which glacial erosion subsequently operated (Fig. 5b).

Further testing of this interpretation will require higher-resolution mapping of both seafloor and sub-seafloor structures. Multibeam bathymetry would better resolve trough and sill geometry, whereas seismic or higher-resolution sub-bottom data could distinguish bedrock-controlled relief from sedimentary or morainal features. Combined with repeated oceanographic observations and high-resolution ocean modelling, these datasets would allow the influence of inherited bathymetry on mCDW pathways and basal melting to be tested more quantitatively.

## **Implications**

Using rare ship access during three summers with reduced fast-ice cover, we conducted shipboard acoustic depth surveys in LHB, East Antarctica. The resulting bathymetric map provides the first well-positioned constraint on the geometry and connectivity of glacier-front troughs and shallow sills in this sector. The map reveals a complex configuration of deep troughs and shallow sills that defines potential pathways and bathymetric thresholds for mCDW access to glacier fronts, and therefore provides a geometric framework for evaluating spatial differences in ocean forcing among the glacier systems. The spatial correspondence between the NW–SE-trending trough segment of the main trough and a major airborne magnetic boundary further suggests that inherited basement structure may have influenced the localization of glacial erosion. Comparative analysis of bathymetric and geophysical structure may provide a useful approach for evaluating structural preconditioning on other Antarctic continental shelves. In the context of recent evidence for Holocene ice-shelf collapse and inland thinning in LHB<sup>22</sup>, our results identify the bathymetric and structural framework through which inherited shelf roughness may have conditioned both modern and past warm-water access to glacier fronts. More broadly, our results place bedrock structure, glacial trough development, and potential warm-water pathways within a common geomorphic framework, offering a transferable framework for evaluating how inherited continental-shelf morphology may influence ice–ocean interaction around Antarctica.

## **Methods**

### **Shipboard echo sounding and data analysis**

Shipboard bathymetric surveys were conducted in LHB from the Japanese icebreaker Shirase (AGB-5003) during three austral summer seasons: February 2016, December 2016–February 2017, and December 2017–February 2018. These campaigns were carried out during JARE57–59 as part of the shipboard marine geophysical monitoring programme (AMG0903) and the Research of Ocean–Ice Boundary Interaction and Change around Antarctica (ROBOTICA) project at the National Institute of Polar Research. The bathymetric observations were conducted in collaboration with the Japan Coast Guard. Survey lines were designed to complement oceanographic observations targeting warm-water

inflow toward the SGT cavity and meltwater-rich outflow from the cavity.

Acoustic depth measurements were acquired using a high-resolution chirp sub-bottom profiler (SyQwest Bathy-2010, SyQwest, Inc., USA). The system provides single-beam acoustic profiles along the ship track rather than swath multibeam bathymetry. Initial seafloor depths were obtained using the Bathy-2010 bottom-tracking system based on the amplitude of the returned acoustic signal, with receiver gain and transmission power adjusted during acquisition. The automatically picked seafloor returns were subsequently inspected and manually edited using SonarWiz software (Chesapeake Technology, Inc., Canada) to remove noise-related outliers and erroneous depth picks. The resulting dataset therefore represents discrete seafloor-depth measurements along the ship tracks, and the bathymetric grids presented in this study involve interpolation between these observations.

Sound velocity correction was based on conductivity, temperature, and depth (CTD) and expendable CTD probe (XCTD; Tsurumi-Seiki Co., Ltd.) observations. Sound velocity was calculated using Del Grosso's equation<sup>36</sup> as reformulated by Wong and Zhu<sup>37</sup>. A total of 63 hydrographic profiles, comprising 50 datasets from JARE58 and 13 from JARE59, were used to characterize the spatial variability of the water column within LHB. Because contemporaneous CTD/XCTD profiles were not available along every sounding line, including those acquired during JARE57, a Gaussian-averaged profile constructed from these 63 datasets was adopted as a representative one-dimensional sound-velocity model for consistent depth correction across the inner continental shelf. The offshore sound-velocity profiles near the continental slope were applied only to soundings deeper than 1000 m.

The observed spatial variability in sound velocity corresponds to differences in corrected depth of less than 2 m and generally less than 1 m. These differences were estimated by comparing depths obtained when the same two-way acoustic travel time was interpreted using alternative observed sound-velocity profiles. At the approximate sill depths discussed in this study (480–740 m), the maximum differences were approximately 1 m. These uncertainties are substantially smaller than the tens- to hundreds-of-metres bathymetric contrasts among the major troughs and sills considered in this study.

Bathymetric grids were generated using Generic Mapping Tools (GMT, version 5.4.5, <https://www.generic-mapping-tools.org/download/>)<sup>38</sup>. For the shipboard bathymetry shown in Fig. 3b, the corrected depth picks were first spatially reduced using blockmedian with a 1-km block spacing. The resulting values were interpolated using the adjustable-tension continuous-curvature spline algorithm (surface) onto a grid with 200-m spacing and a tension factor of 0.65. Interpolation was restricted using grdmask to within 1.1 km of the block-median input locations, thereby limiting extrapolation into areas without nearby shipboard observations.

For the regional bathymetric compilation shown in Fig. 5a, shipboard and legacy on-ice sounding datasets<sup>24</sup> were initially gridded separately. Each dataset was generated from 1-km block-median values using surface with a tension factor of 0.65 at 500-m grid spacing, with interpolation restricted

to within 2 km of the input locations. To prioritize the better-positioned shipboard observations, legacy bathymetry within 1 km of the area constrained by the shipboard dataset was excluded before merging. The 500-m shipboard grid and the remaining legacy bathymetry were then combined, spatially reduced at 500-m spacing, and re-interpolated onto a final 500-m grid using the same tension factor of 0.65 and a 2-km spatial mask.

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## **Author contributions**

M.F. conceived the study, analyzed the data, and wrote the manuscript. M.F. and Y.N. conducted the field observations. All authors discussed the results and commented on the manuscript.

## **Competing interests**

The authors declare no competing interests.

## **Data availability**

The bathymetric depth picks and compiled bathymetric grids generated in this study are publicly available from the National Institute of Polar Research Arctic and Antarctic Data archive System (ADS) at <https://ads.nipr.ac.jp/dataset/A20250127-001>. The CTD/XCTD-derived seawater sound

velocity profiles used for depth correction are available at <https://ads.nipr.ac.jp/dataset/A20250127-002>.

### Supplementary information

Supplementary information includes representative sub-bottom profiler records used to assess seafloor reflection characteristics.

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# Figure legends

**Figure 1. Study area in Lützow-Holm Bay, East Antarctica.** **a** Location of Lützow-Holm Bay in East Antarctica. **b** Regional bathymetry, shipboard survey tracks, and XCTD locations. Green, red, and blue lines show the icebreaker *Shirase* survey lines during JARE57, JARE58, and JARE59, respectively; yellow circles indicate XCTD stations. Bathymetry is based on GEBCO<sup>39</sup>, BedMachine Antarctica<sup>40</sup>, and previously compiled regional bathymetric datasets<sup>11,19</sup>. Contour interval = 100 m. **c–e** Survey area superimposed on MODIS/Aqua satellite imagery showing sea-ice conditions on 3 March 2016, 24 February 2017, and 14 March 2018, respectively. Maps were generated using GMT, version 5.4.5<sup>38</sup>.

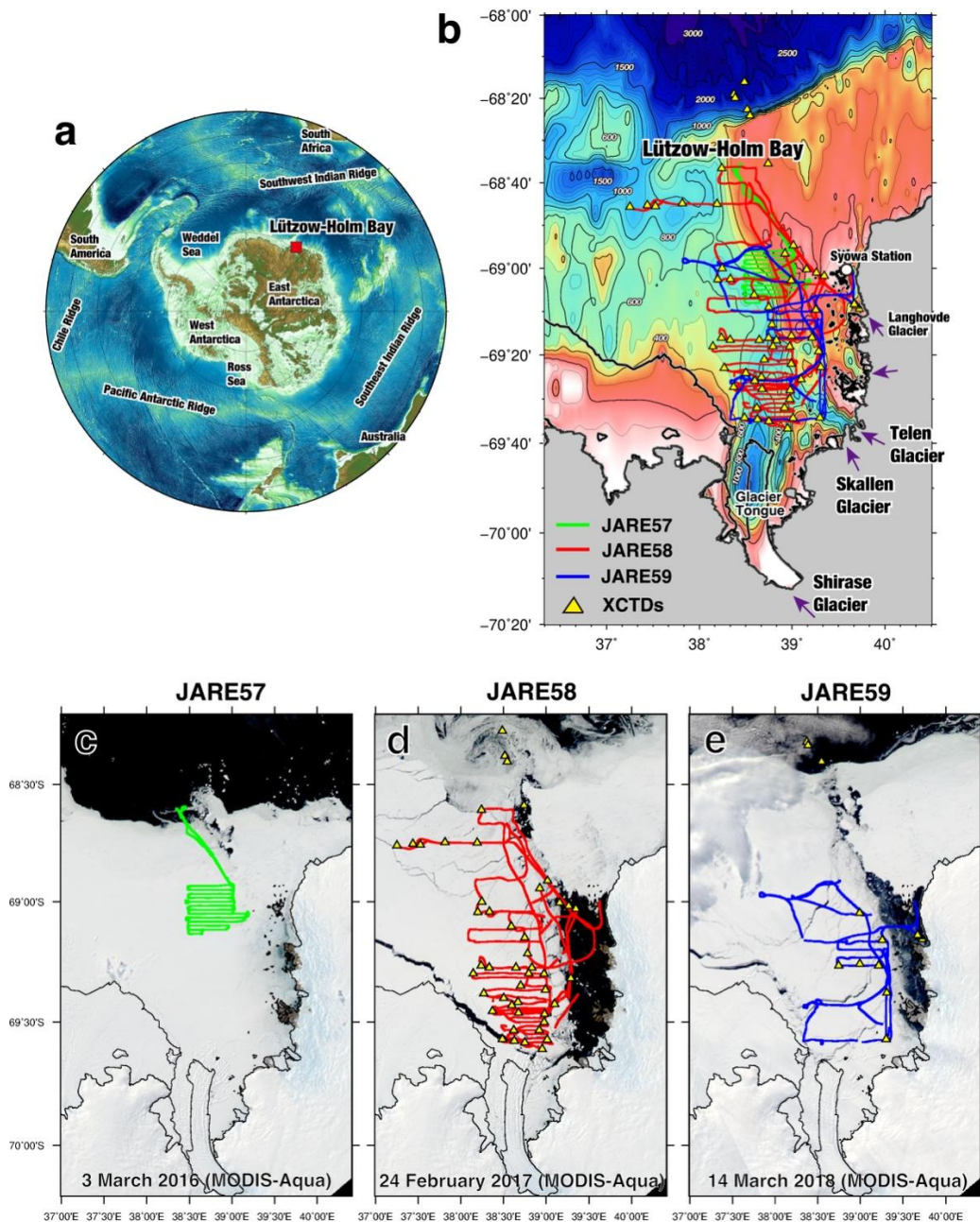




**Figure 2. Water-column structure in Lützow-Holm Bay.** Temperature, salinity, and calculated seawater sound velocity are shown from left to right based on 63 CTD/XCTD profiles. The Gaussian averaged sound velocity profile used for depth correction is shown as a red line. Offshore profiles near the continental slope, used only for soundings deeper than 1000 m, are shown as gray lines.

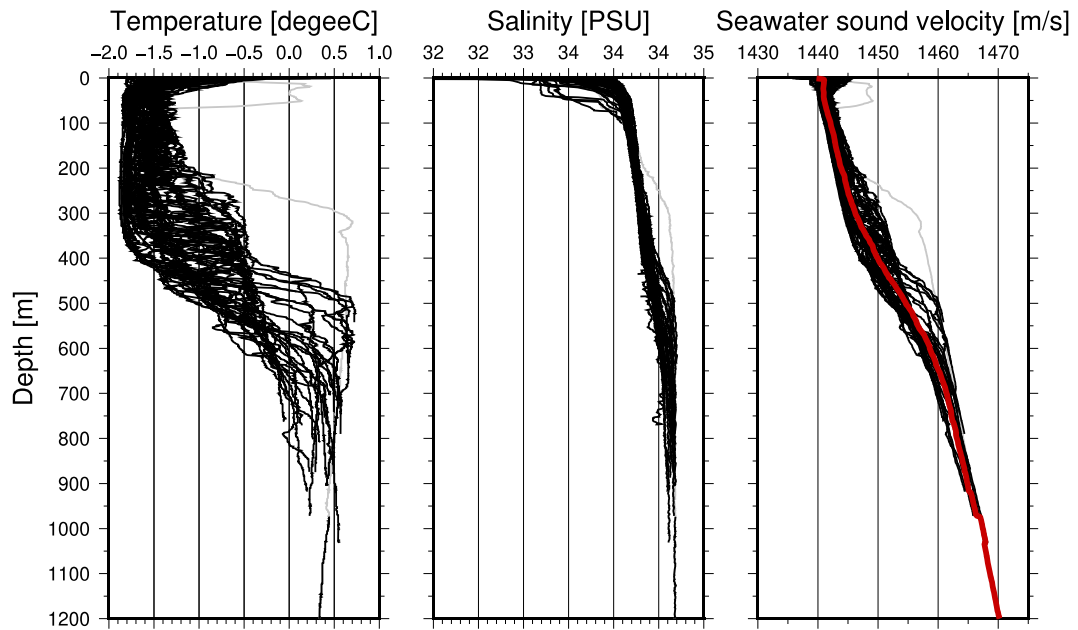


**Figure 3. Shipboard acoustic depth measurements and interpolated bathymetry in Lützow-Holm Bay.** **a** Sound-velocity-corrected seafloor-depth picks derived from single-beam Bathy-2010 sub-bottom-profiler records along the ship tracks. **b** Bathymetric grid generated from the shipboard depth picks at 200-m spacing, with interpolation restricted to within 1.1-km of the input data. Contour interval = 40 m. Maps were generated using GMT, version 5.4.5<sup>38</sup>.

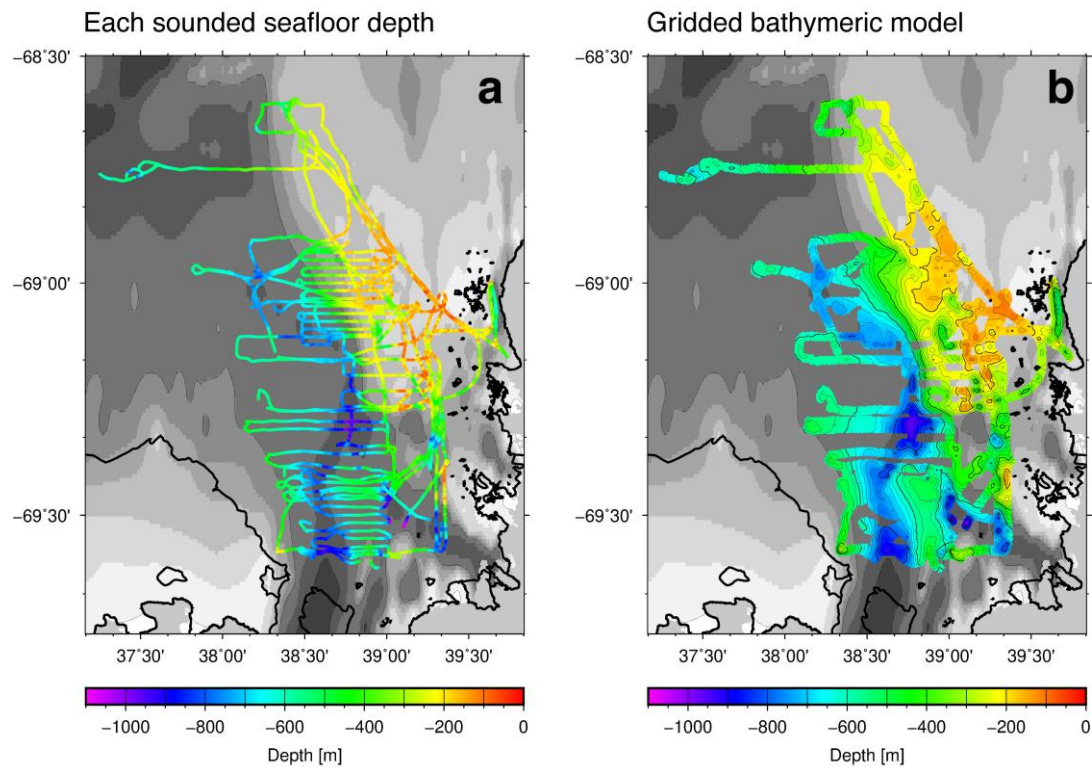


**Figure 4. Comparison between shipboard and legacy on-ice echo sounding depths. a** Spatial distribution of depth differences between the shipboard observations acquired in this study and legacy on-ice echo sounding of Moriwaki and Yoshida<sup>24</sup>. Large and small symbols indicate absolute depth differences greater than and less than 100 m, respectively. **b** Histogram of shipboard-minus-legacy depth differences. Maps were generated using GMT, version 5.4.5<sup>38</sup>.

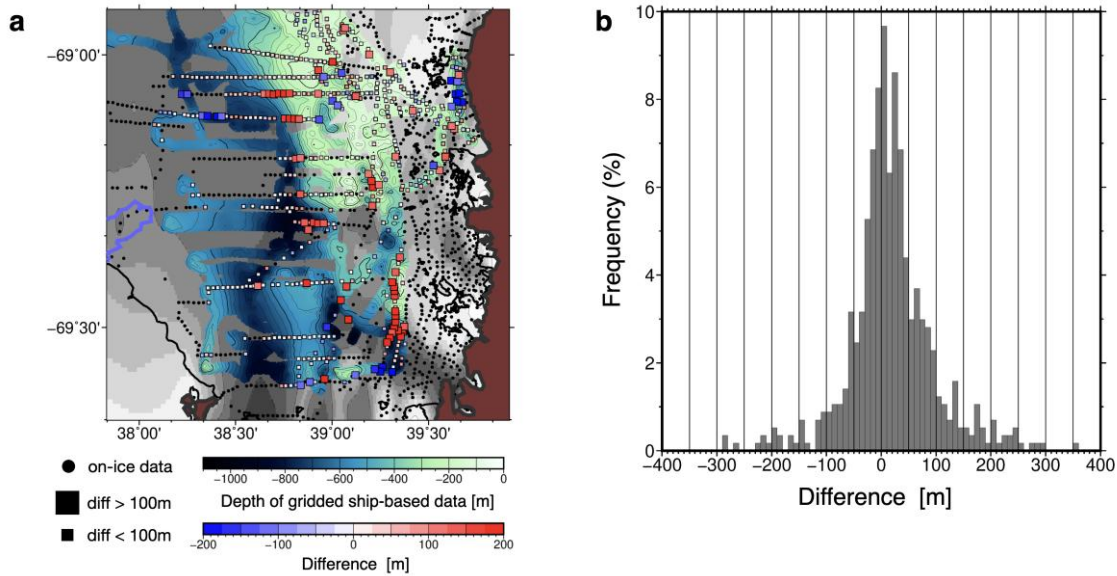
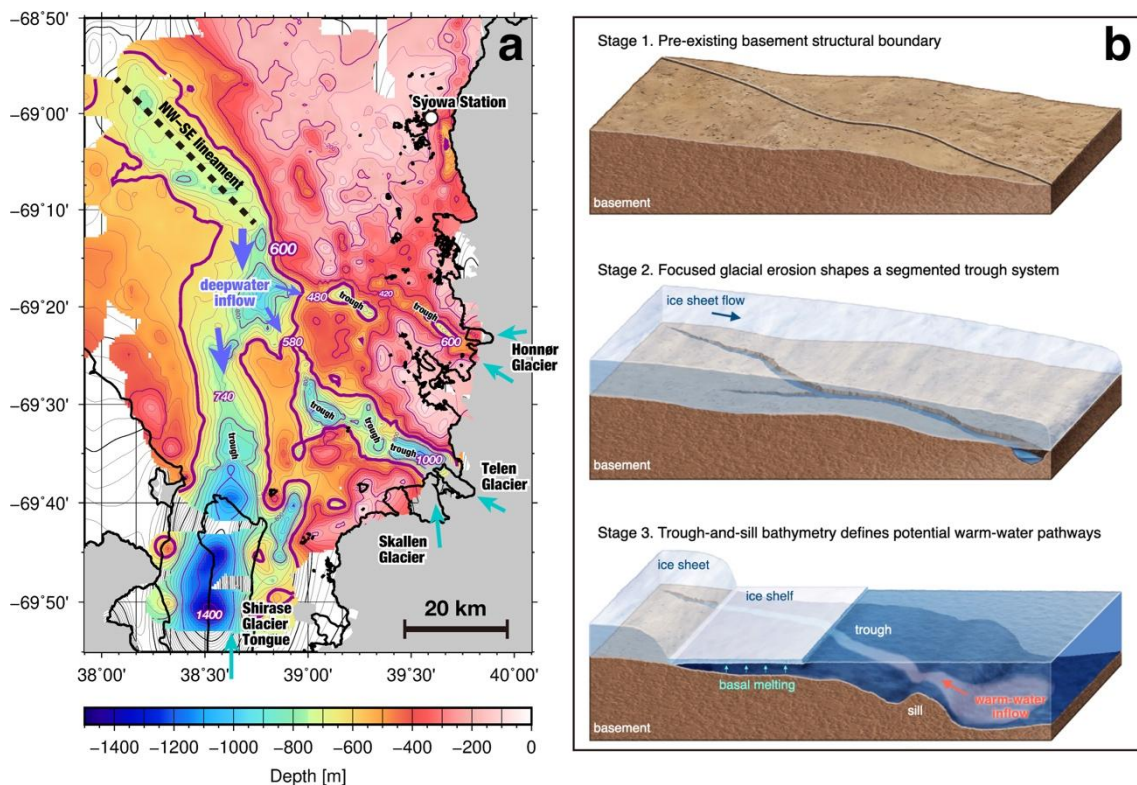


**Figure 5. Continental-shelf bathymetry of Lützow-Holm Bay and conceptual model for structural preconditioning of trough development.** **a** Regional bathymetric compilation and representative troughs and sills in front of the Shirase, Honnør, Skallen, and Telen glacier systems. Shipboard echo-sounding data from this study and legacy on-ice echo-sounding of Moriwaki and Yoshida<sup>24</sup> were merged with priority given to the better-positioned shipboard observations. A NW–SE-trending major airborne magnetic boundary and a corresponding structural lineament are shown for comparison<sup>35</sup>. Maps were generated using GMT, version 5.4.5<sup>38</sup>. **b** Conceptual three-stage model showing (1) inherited basement structure, (2) subsequent localization of glacial erosion and development of a segmented trough system, and (3) preservation of this bathymetric framework as a potential pathway and threshold for modern warm-water access. The resulting trough-and-sill morphology may subsequently define potential pathways and bathymetric thresholds for warm-water access to glacier fronts. The illustration is conceptual and does not imply that all trough segments are controlled by a single fault or structural boundary.



## Supplementary Files

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