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A newly discovered subglacial lake in East Antarctica likely hosts a valuable sedimentary record of ice and climate change

Shuai Yan[1,2]*, Donald D. Blankenship[1], Jamin S. Greenbaum[1,3], Duncan A. Young[1], Lin Li[4], Anja Rutishauser[1,5], Jingxue Guo[4], Jason L. Roberts[6], Tas D. van Ommen[6], Martin J. Siegert[7] and Bo Sun[4]

[1]University of Texas Institute for Geophysics, University of Texas at Austin, Austin, Texas 78758-4445, USA
[2]Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, Austin, Texas 78712-1692, USA
[3]Scripps Institution of Oceanography, University of California San Diego, La Jolla, California 92093, USA
[4]Polar Research Institute of China, Shanghai 20000, China
[5]Department of Glaciology and Climate, Geological Survey of Denmark and Greenland, Copenhagen 1350, Denmark
[6]Australian Antarctic Division, Department of Agriculture, Water and the Environment, Kingston, Tasmania 7050, Australia
[7]Grantham Institute and Department of Earth Science and Engineering, Imperial College London, London SW7 2AZ, UK

ABSTRACT

The Princess Elizabeth Land sector of the East Antarctic Ice Sheet is a significant reservoir of grounded ice and is adjacent to regions that experienced great change during Quaternary glacial cycles and Pliocene warm episodes. The existence of an extensive subglacial water system in Princess Elizabeth Land (to date only inferred from satellite imagery) bears the potential to significantly impact the thermal and kinematic conditions of the overlying ice sheet. We confirm the existence of a major subglacial lake, herein referred to as Lake Snow Eagle (LSE), for the first time using recently acquired aerogeophysical data. We systematically investigated LSE's geological characteristics and bathymetry from two-dimensional geophysical inversion models. The inversion results suggest that LSE is located along a compressional geologic boundary, which provides reference for future characterization of the geologic and tectonic context of this region. We estimate LSE to be ~42 km in length and 370 km^2 in area, making it one of the largest subglacial lakes in Antarctica. Additionally, the airborne ice-penetrating radar observations and geophysical inversions reveal a layer of unconsolidated water-saturated sediment around and at the bottom of LSE, which—given the ultralow rates of sedimentation expected in such environments—may archive valuable records of paleoenvironmental changes and the early history of East Antarctic Ice Sheet evolution in Princess Elizabeth Land.

INTRODUCTION

Antarctic subglacial lakes, as a major component of the subglacial hydrology system, interact closely with the overlying Antarctic Ice Sheet (Wingham et al., 2006; Livingstone et al., 2022). Such subglacial water bodies could provide unique biogeochemical environments and valuable sedimentary records of ancient climate change (Wright and Siegert, 2012). So far, >600 subglacial lakes have been identified across the Antarctic continent by different survey methods (Livingstone et al., 2022), such as seismic sounding, repeat altimetry, and ice-penetrating radar (IPR) sounding. Jamieson et al. (2016) described the possible existence of an extensive subglacial canyon and lake system in East Antarctica's Princess Elizabeth Land based on satellite-based remote sensing, assuming the features on the ice surface suggest the form of the large-scale subglacial landscape underneath the East Antarctic Ice Sheet (EAIS). This canyon network was estimated to extend from the north side of Dome A to the Leopold and Astrid Coast adjacent to West Ice Shelf (Fig. 1A). Dowdeswell and Siegert (1999) postulated that very large subglacial lakes occur because entire subglacial valleys become filled with water as a consequence of low hydrological potential gradients. Jamieson et al. (2016) proposed that such a subglacial lake existed within the upstream part of the subglacial canyon system in Princess Elizabeth Land and estimated it to be one of the largest subglacial lakes lying beneath the Antarctic Ice Sheet. We used a suite of aerogeophysical techniques to investigate the site of the proposed subglacial lake to demonstrate its existence, examine its topographic, geological, and glaciological settings, and quantify its volume and basal sedimentary thickness.

METHOD

The University of Texas Institute for Geophysics (Austin, Texas, USA), the Polar Research Institute of China, and the Australian Antarctic Division have performed several collaborative airborne geophysical surveys in East Antarctica through the ICECAP2 (International Collaborative Exploration of Central East Antarctica through Airborne geophysical Profiling) program (Cui et al., 2020). Through this collaboration, >10,000 km of survey profiles were collected over the proposed lake region between 2016 and 2019 CE (Fig. S1 in the Supplemental Material[1]). The airborne survey platforms used in these expeditions are built on ski-equipped BT-67 aircraft and house instruments such as IPR, gravimeter, magnetometer, laser altimeter, and optical camera (Cui et al., 2018). These surveys provide valuable information on the

*E-mail: shuaiy@utexas.edu

[1]Supplemental Material. Bed echo power, specularity content, gravity and magnetic anomalies data, and supplementary notes and figures. Please visit https://doi.org/10.1130/GEOL.S.19611720 to access the supplemental material, and contact editing@geosociety.org with any questions. Australian Antarctic Division–University of Texas Institute for Geophysics 4346/ICP10 field campaign data are available at the Australian Antarctic Data Centre (https://doi.org/10.26179/5bcfffdabcf92). Ice thickness and bed elevation data from CHINARE surveys can be found at https://doi.org/10.5281/zenodo.4023343.

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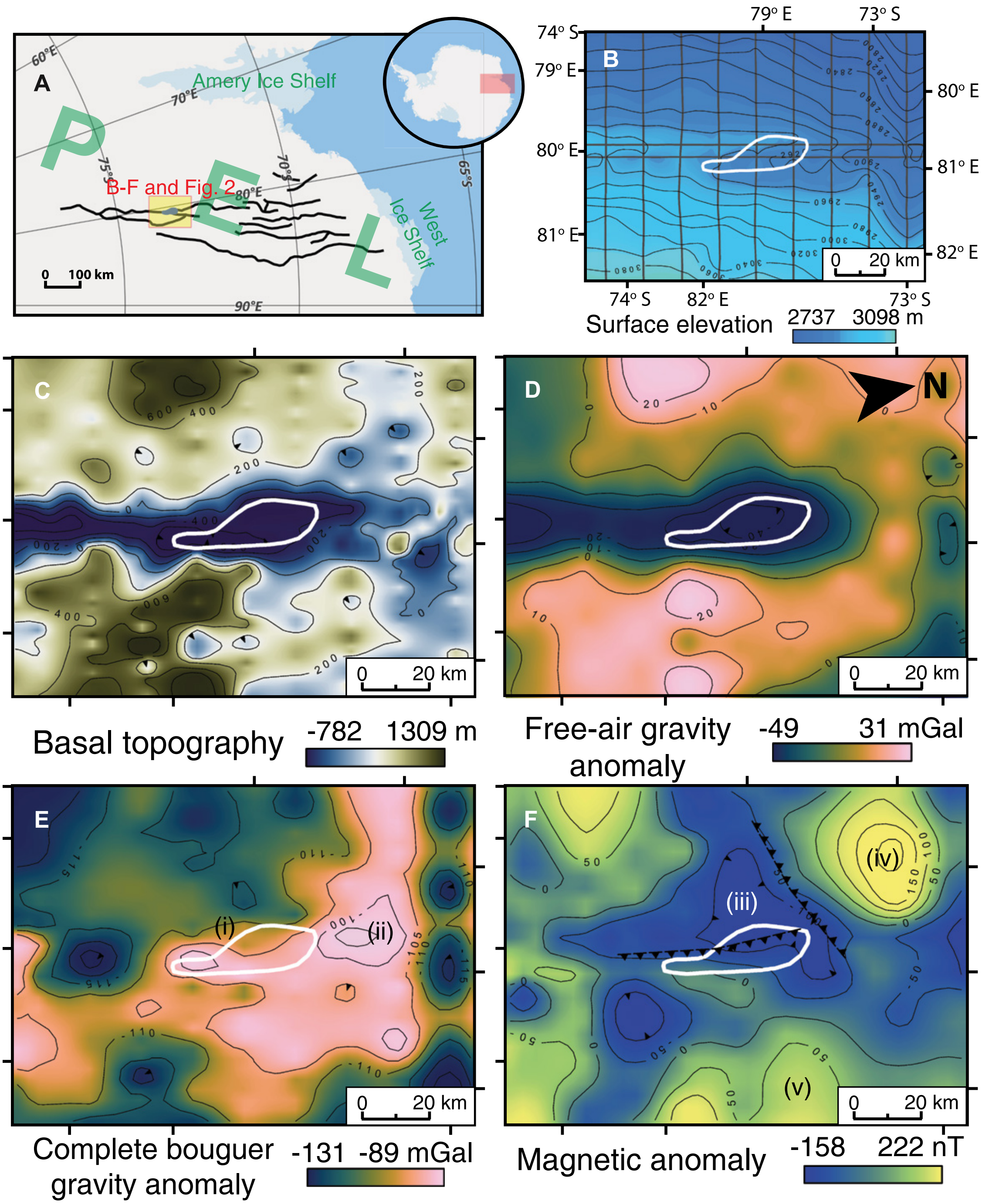

Figure 1. Data products from airborne geophysics surveys over the Lake Snow Eagle region, East Antarctica. (A) Map of Princess Elizabeth Land (PEL). Solid dark lines indicate location of PEL canyon channels estimated from RADARSAT ice surface morphology data (Jezek et al., 2013). Location of data-product maps B–F is marked as a yellow rectangle. (B–F) Data products from aerogeophysical survey. White line marks the outline of Lake Snow Eagle derived in this study. The thin dark lines are contours with intervals of 20 m, 200 m, 10 mGal, 5 mGal and 50 nT, respectively. In the surface-elevation map B, gray solid lines mark survey flight paths. In the magnetic anomaly map F, dark dashed lines with sawteeth mark approximate locations of the two thrust faults constrained from two-dimensional geophysics inversions of magnetic anomaly.

thickness, internal structure, and basal condition of the ice sheet, confirm the presence of the proposed subglacial lake, and enable the inference of its bathymetry and crustal framework. Data products such as ice-surface elevation, basal topography, and gravity and magnetic anomalies over the study area are shown in Figure 1. More detailed descriptions of the survey methods can be found in the Supplemental Material.

RESULTS

Geophysical Evidence of Lake Snow Eagle

Geophysical evidence, discussed here, demonstrates the existence of the lake herein referred to as Lake Snow Eagle (LSE). Over the lake area, we observed subglacial hydraulic flatness, elevated basal reflectivity, and high basal specularity from airborne IPR sounding (Fig. 2; Figs. S2–S6). The IPR-measured subglacial hydraulic slope is <0.2° over the lake, which is the subglacial hydraulic slope uncertainty for our data set (Fig. 2A). The relative basal reflectivity over the lake is ~15 dB higher than for the surrounding area, which is a consequence of the difference in reflectivity between wet and dry bed (Peters et al., 2005; Christianson et al., 2016) (Fig. 2B). The basal specularity derived from our IPR survey shows a significant anomaly of >0.2 over the lake (Fig. 2C). These observations, in combination, meet the criteria for identifying subglacial lakes via IPR sounding (Carter et al., 2007; Young et al., 2016). Adjacent spots with high relative basal reflectivity, low basal specularity, and subglacial hydraulic non-flatness are also observed, which we interpret as unconsolidated water-saturated sediment at the ice-sheet bed surrounding the lake (Peters et al., 2005; Carter et al., 2007).

The IPR-measured ice-surface elevation in the LSE area shows an overall tilt toward the Amery Ice Shelf (toward the northwestern direction), with a local 20 m depression over the

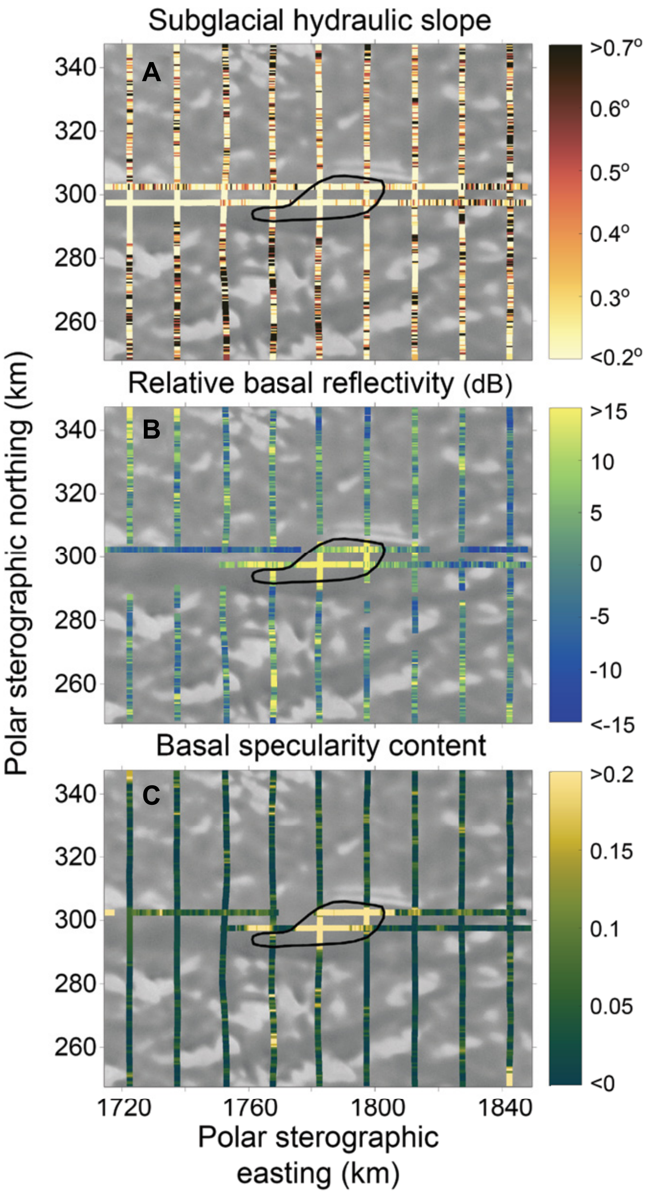

Figure 2. Maps of subglacial hydraulic slope (A), relative basal reflectivity (B), and basal specularity content (C) over Lake Snow Eagle region in East Antarctica. Dark line marks the outline of Lake Snow Eagle derived in this study. Coordinates are in EPSG 3031–WGS 84 / Antarctic Polar Stereographic. Background image shows RADARSAT ice-surface morphology (Jezek et al., 2013).

lake (Fig. 1B). This measurement agrees well with previous observations from satellite-based remote sensing, from which LSE was proposed (Jamieson et al., 2016). The IPR-measured bed topography shows that LSE is located in a deep elongated subglacial trench, which is aligned in the north-south direction with a width of ~15 km and incised ~800 m into the surrounding bedrock (Fig. 1C). The free-air gravity data show a short-wavelength negative anomaly over the subglacial trench with the lowest value observed over LSE (Fig. 1D), reflecting the density contrast between ice sheet, subglacial water, unconsolidated sediment, and bedrock.

Subglacial Crustal Framework of LSE

Over the study area, the complete Bouguer gravity anomaly shows a steep change of ~15 mGal near the western shore of LSE (i in Fig. 1E) and a distinctively high anomaly aligned in the east-west direction on the north shore of LSE (ii in Fig. 1E). The measured magnetic anomaly is predominantly composed of three short-wavelength anomalies: one negative anomaly along the west shore of LSE (iii in Fig. 1F), and two positive anomalies on the northwest (iv in Fig. 1F) and east of LSE (v in Fig. 1F). These gravity and magnetics anomaly patterns are not correlated to basal topography, indicating changes in properties such as density and magnetic susceptibility within the bedrock; thus, a change in subglacial crustal framework is most likely (Nettleton, 1971; Grauch and Hudson, 2011).

Knowledge of the geologic framework of the trench housing LSE provides crucial insight toward the tectonic context of the lake. Such information also provides important constraints for obtaining the lake bathymetry, given that the slope or shape of the lake bed may be defined by certain discontinuities within the bedrock. Assuming that the observed gravity and magnetic anomalies over the LSE area are primarily caused by the subglacial lake and its crustal framework, we performed a series of two-dimensional (2-D) geophysical inversions, aiming to build a coherent crustal framework model for the LSE area (see the Supplemental Material text; Figs. S7 and S8). The inversion results suggest that LSE is located along a compressional geologic boundary, given that models with compressional geological features (such as thrust faults and folds) provide (1) a more coherent crustal framework, and (2) magnetic responses that match the measured anomaly better than the alternative models. The inversion results also suggest the existence of two thrust faults, one along the northern shore of LSE and another along the western shore (marked as dashed lines with sawteeth in Fig. 1F). The northern and western margins of LSE appear to be defined by these two thrust faults, which have orientations that correlate well with the Indo-Australo-Antarctic suture zone (Arora et al., 2020) and the Lambert Rift (Ferraccioli et al., 2011), respectively. These insights into the tectonics of Princess Elizabeth Land could provide reference for future characterization of the geological context of the region and its relevance to, and connections with, elsewhere in East Antarctica.

Lake Bathymetry and Subglacial Sedimentary Record

To estimate the bathymetry of LSE, we conducted 2-D geophysical inversions of the measured gravity data, with IPR-derived ice-sheet thickness and basal topography and the aforementioned inversion-derived crustal framework as constraints (Fig. 3; see the Supplemental Material text; Figs. S9–S11). We find LSE to be ~42 km in length and 370 km^2 in area. The total water volume of LSE is estimated to be ~21 km^3, and the maximum water depth is >200 m. These findings confirm LSE to be one of the largest Antarctic subglacial lakes (cf. Wright and Siegert, 2012), by far the farthest large subglacial lake (area >100 km^2) from an ice divide, and the closest large subglacial lake to the grounding line.

Our airborne IPR observations and geophysical inversion results together suggest the presence of a layer of unconsolidated water-saturated sediment around and at the bottom of LSE (Fig. 3; see the Supplemental Material text; Figs. S9 and S10). The total volume of sediment is estimated to be ~20 km^3, and the maximum sediment thickness is >300 m. More than 75% of the water and sediments lie in the larger and deeper northern basin. The average sediment layer thickness in the northern basin is ~100 m. Such a layer of sediment requires glacial, periglacial, and possibly preglacial deposition mechanisms, as it exceeds the estimated depositing capacity of mechanisms under

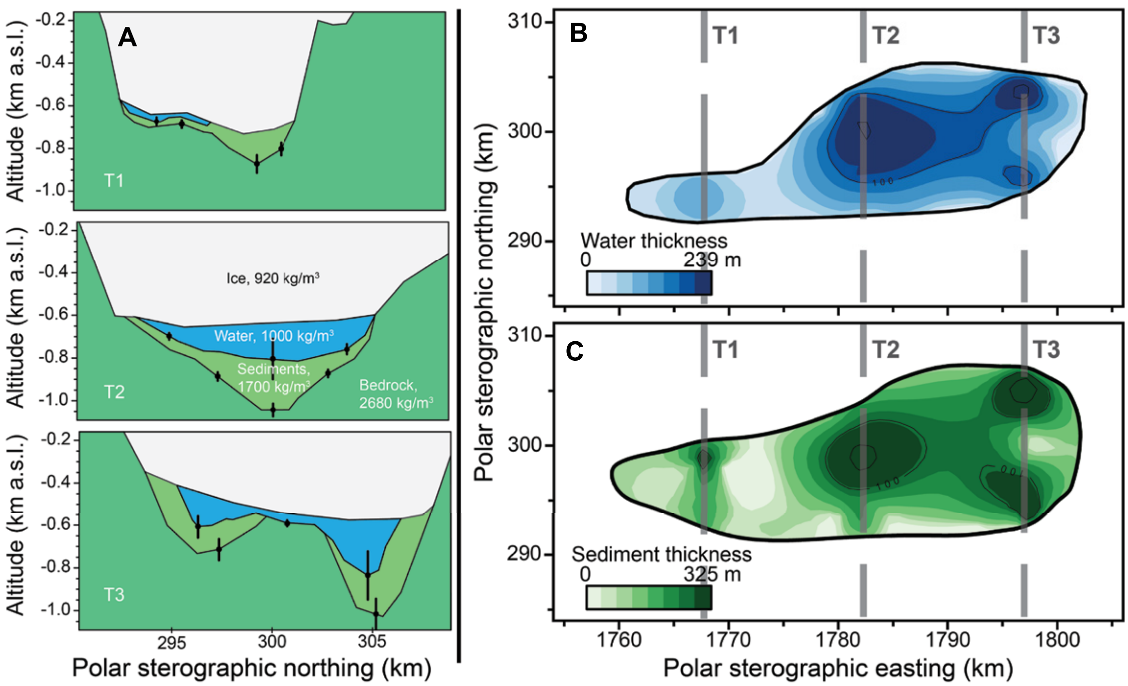

Figure 3. Modeled bathymetry of subglacial Lake Snow Eagle in East Antarctica. Coordinates are in EPSG 3031–WGS 84 / Antarctic Polar Stereographic. (A) Cross sections resulting from two-dimensional geophysics inversions of the measured free-air gravity anomaly, aiming to estimate thickness of lake water and the sediment layer. Profile locations are marked as gray dashed lines in B and C. Density of each block is shown in subplot T2. Dark vertical marks represent uncertainties of the modeled subsurface depth, which are estimated by comparing a series of inversion models that generate misfit no larger than the repeatability statistics of the measured data. a.s.l.—above sea level. (B) Interpolated map of water distribution from inversion profiles. This interpolation represents a conservative estimate of the volume of water. Thin dark lines are contours of water thickness with an interval of 100 m. (C) Interpolated map of sediment distribution from the inversion profiles. This interpolation represents a conservative estimate of the volume of sediment. Thin dark lines are contours of sediment thickness with an interval of 100 m.

glacial conditions alone (Filina et al., 2008; Bentley et al., 2011; Smith et al., 2018). The bottom portion of the sedimentary column is potentially dominated by fluvial sediment that predates Antarctic glaciation, given that the subglacial canyon network was likely initiated by a tectonic event and then deepened by subaerial fluvial drainage before glaciation (Jamieson et al., 2016). The initiation and growth of the EAIS around the Gamburtsev Mountains would then have provided a substantial amount of sediment discharge into the channels (DeConto and Pollard, 2003; Sun et al., 2009; Herman et al., 2021), constituting the middle to upper part of the sediment sequence. Following periglacial and glacial erosion would then have carved the sediment layer to its current shape, after which it was capped by sediment deposited by the ice sheet and any subglacial hydrology network.

The rate of sedimentation would dictate how far back in time this sedimentary sequence goes. Smith et al. (2018) examined a range of potential sedimentary processes for subglacial Lake Ellsworth in West Antarctica and concluded that the upper 6 m of sediment at the bed of the lake represents a period of at least 150–200 k.y. and possibly >1 m.y. If the same assumptions hold for LSE, we can expect the 200 m thickness of sediments to go much further back in time, potentially allowing an unprecedented and uninterrupted record of ice and climate change. Smith et al. (2018) pointed to a change in sedimentation style between subglacial and proglacial systems. Thus, as in subglacial Lake Ellsworth, one essential characteristic to identify in any such record is a change in sediment type, which would correspond to a major alteration in sedimentary processes and, potentially, the timing of glaciation in Princess Elizabeth Land (relating directly to question 34 of the Antarctic scientific horizon scan by Kennicutt et al. [2015, p. 9]: "How will the sedimentary record beneath the ice sheet inform our knowledge of the presence or absence of continental ice?").

IMPLICATIONS AND CONCLUSION

Our study presents geophysical evidence supporting the existence of LSE, systematically investigates its geological context and bathymetry, and confirms it to be one of the largest subglacial lakes in Antarctica. Unconsolidated sediment at the bottom of LSE, situated between the stable ice of Dome A and the more dynamic ice margin of the Amery Ice Shelf and the Leopold and Astrid Coast, could archive valuable records of the geological framework of interior Princess Elizabeth Land and preglacial paleoenvironmental changes as well as the evolution of the EAIS and its subglacial hydrology. In particular, given that the Princess Elizabeth Land sector may have experienced significant change in the Quaternary and Pliocene (Mackintosh et al., 2011; Siegert et al., 2022), this sediment record provides a unique opportunity for the simultaneous study of the geological and paleoenvironmental change of interior East Antarctica as well as the evolution of the EAIS from its initiation to present. We note that despite being one of the major challenges identified in the 2014 Antarctic scientific horizon scan (Kennicutt et al., 2015), very little progress has been made in identifying and recovering sedimentary records from beneath the ice (Kennicutt et al., 2019). Such a record would allow major insights into Antarctic climate history and its relevance globally (Florindo et al., 2022).

While this study is able to produce an estimated bathymetry of LSE from 2-D geophysical inversions, we recommend conducting active-source seismic surveys over the lake region and collecting additional aerogeophysical data to support more sophisticated three-dimensional (3-D) geophysical inversions for the bathymetry of LSE and the thickness and potential structure of the underlying sediment. Additionally, we recommend numerical modeling of the limnological processes within LSE to provide a better understanding of the relationship between the overlying ice and the underlying sediment. The geophysical measurements presented here demonstrate that LSE is an excellent target for direct measurement and sampling of subglacial systems, especially considering its location proximal to an existing logistics station (Siegert, 2002).

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REFERENCES CITED

Arora, D., Pant, N., Pandey, M., Chattopadhyay, A., Greenbaum, J., Siegert, M., Sun, B., Blankenship, D., Rao, N.V.C., and Bhandari, A., 2020, Insights into geological evolution of Princess Elizabeth Land, East Antarctica—Clues for continental suturing and breakup since Rodinian time: Gondwana Research, v. 84, p. 260–283, https://doi.org/10.1016/j.gr.2020.05.002.

Bentley, M.J., Christoffersen, P., Hodgson, D.A., Smith, A.M., Tulaczyk, S., and Le Brocq, A.M., 2011, Subglacial lake sediments and sedimentary processes: Potential archives of ice sheet evolution, past environmental change, and the presence of life, *in* Siegert, M.J., and Kennicutt, M.C., II, eds., Antarctic Subglacial Aquatic Environments: American Geophysical Union Geophysical Monograph 192, p. 83–110.

Carter, S.P., Blankenship, D.D., Peters, M.E., Young, D.A., Holt, J.W., and Morse, D.L., 2007, Radar-based subglacial lake classification in Antarctica: Geochemistry Geophysics Geosystems, v. 8, Q03016, https://doi.org/10.1029/2006GC001408.

Christianson, K., Jacobel, R.W., Horgan, H.J., Alley, R.B., Anandakrishnan, S., Holland, D.M., and DallaSanta, K.J., 2016, Basal conditions at the grounding zone of Whillans Ice Stream, West Antarctica, from ice-penetrating radar: Journal of Geophysical Research: Earth Surface, v. 121, p. 1954–1983, https://doi.org/10.1002/2015JF003806.

Cui, X.B., Greenbaum, J.S., Beem, L.H., Guo, J.X., Ng, G., Li, L., Blankenship, D., and Sun, B., 2018, The first fixed-wing aircraft for Chinese Antarctic expeditions: Airframe, modifications, scientific instrumentation and applications: Journal of Environmental & Engineering Geophysics, v. 23, p. 1–13, https://doi.org/10.2113/JEEG23.1.1.

Cui, X.B., et al., 2020, Bed topography of Princess Elizabeth Land in East Antarctica: Earth System Science Data, v. 12, p. 2765–2774, https://doi.org/10.5194/essd-12-2765-2020.

DeConto, R.M., and Pollard, D., 2003, Rapid Cenozoic glaciation of Antarctica induced by declining atmospheric CO_2: Nature, v. 421, p. 245–249, https://doi.org/10.1038/nature01290.

Dowdeswell, J.A., and Siegert, M.J., 1999, The dimensions and topographic setting of Antarctic subglacial lakes and implications for large-scale water storage beneath continental ice sheets: Geological Society of America Bulletin, v. 111, p. 254–263, https://doi.org/10.1130/0016-7606(1999)111<0254:TDATSO>2.3.CO;2.

Ferraccioli, F., Finn, C.A., Jordan, T.A., Bell, R.E., Anderson, L.M., and Damaske, D., 2011, East Antarctic rifting triggers uplift of the Gamburtsev Mountains: Nature, v. 479, p. 388–392, https://doi.org/10.1038/nature10566.

Filina, I.Y., Blankenship, D.D., Thoma, M., Lukin, V.V., Masolov, V.N., and Sen, M.K., 2008, New 3D bathymetry and sediment distribution in Lake Vostok: Implication for pre-glacial origin and numerical modeling of the internal processes within the lake: Earth and Planetary Science Letters, v. 276, p. 106–114, https://doi.org/10.1016/j.epsl.2008.09.012.

Florindo, F., Siegert, M., De Santis, L., and Naish, T.R., 2022, Antarctic climate evolution, *in* Florindo, F., et al., eds., Antarctic Climate Evolution (second edition): Amsterdam, Elsevier, p. 1–7, https://doi.org/10.1016/B978-0-12-819109-5.00007-4.

Grauch, V.J.S., and Hudson, M.R., 2011, Aeromagnetic anomalies over faulted strata: The Leading Edge, v. 30, p. 1242–1252, https://doi.org/10.1190/1.3663396.

Herman, F., De Doncker, F., Delaney, I., Prasicek, G., and Koppes, M., 2021, The impact of glaciers on mountain erosion: Nature Reviews Earth & Environment, v. 2, p. 422–435, https://doi.org/10.1038/s43017-021-00165-9.

Jamieson, S.S.R., Ross, N., Greenbaum, J.S., Young, D.A., Aitken, A.R.A., Roberts, J.L., Blankenship, D.D., Sun, B., and Siegert, M.J., 2016, An extensive subglacial lake and canyon system in Princess Elizabeth Land, East Antarctica: Geology, v. 44, p. 87–90, https://doi.org/10.1130/G37220.1.

Jezek, K.C., Curlander, J.C., Carsey, F., Wales, C., and Barry, R.G., 2013, RAMP AMM-1 SAR image mosaic of Antarctica, version 2: Boulder, Colorado, NASA National Snow and Ice Data Center Distributed Active Archive Center, https://doi.org/10.5067/8AF4ZRPULS4H (accessed September 2012).

Kennicutt, M.C., II, et al., 2015, A roadmap for Antarctic and Southern Ocean science for the next two decades and beyond: Antarctic Science, v. 27, p. 3–18, https://doi.org/10.1017/S0954102014000674.

Kennicutt, M.C., II, et al., 2019, Sustained Antarctic research: A 21st century imperative: One Earth, v. 1, p. 95–113, https://doi.org/10.1016/j.oneear.2019.08.014.

Livingstone, S.J., et al., 2022, Subglacial lakes and their changing role in a warming climate: Nature Reviews Earth & Environment, v. 3, p. 106–124, https://doi.org/10.1038/s43017-021-00246-9.

Mackintosh, A., et al., 2011, Retreat of the East Antarctic ice sheet during the last glacial termination: Nature Geoscience, v. 4, p. 195–202, https://doi.org/10.1038/ngeo1061.

Nettleton, L.L., 1971, Elementary Gravity and Magnetics for Geologists and Seismologists: Society of Exploration Geophysicists Geophysical Monograph 1, 132 p., https://doi.org/10.1190/1.9781560802433.

Peters, M.E., Blankenship, D.D., and Morse, D.L., 2005, Analysis techniques for coherent airborne radar sounding: Application to West Antarctic ice streams: Journal of Geophysical Research, v. 110, B06303, https://doi.org/10.1029/2004JB003222.

Siegert, M.J., 2002, Which are the most suitable Antarctic subglacial lakes for exploration?: Polar Geography, v. 26, p. 134–146, https://doi.org/10.1080/789610135.

Siegert, M., Hein, A.S., White, D.A., Gore, D.B., De Santis, L., and Hillenbrand, C.-D., 2022, Antarctic Ice Sheet changes since the Last Glacial Maximum, *in* Florindo, F., et al., eds., Antarctic Climate Evolution (second edition): Amsterdam, Elsevier, p. 623–687, https://doi.org/10.1016/B978-0-12-819109-5.00002-5.

Smith, A.M., Woodward, J., Ross, N., Bentley, M.J., Hodgson, D.A., Siegert, M.J., and King, E.C., 2018, Evidence for the long-term sedimentary environment in an Antarctic subglacial lake: Earth and Planetary Science Letters, v. 504, p. 139–151, https://doi.org/10.1016/j.epsl.2018.10.011.

Sun, B., Siegert, M.J., Mudd, S.M., Sugden, D., Fujita, S., Cui, X.B., Jiang, Y.Y., Tang, X.Y., and Li, Y.S., 2009, The Gamburtsev mountains and the origin and early evolution of the Antarctic Ice Sheet: Nature, v. 459, p. 690–693, https://doi.org/10.1038/nature08024.

Wingham, D.J., Siegert, M.J., Shepherd, A., and Muir, A.S., 2006, Rapid discharge connects Antarctic subglacial lakes: Nature, v. 440, p. 1033–1036, https://doi.org/10.1038/nature04660.

Wright, A., and Siegert, M., 2012, A fourth inventory of Antarctic subglacial lakes: Antarctic Science, v. 24, p. 659–664, https://doi.org/10.1017/S095410201200048X.

Young, D.A., Schroeder, D.M., Blankenship, D.D., Kempf, S.D., and Quartini, E., 2016, The distribution of basal water between Antarctic subglacial lakes from radar sounding: Philosophical Transactions of the Royal Society A: Mathematical, Physical, and Engineering Sciences, v. 374, 20140297, https://doi.org/10.1098/rsta.2014.0297.

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