ADVANCING EARTH AND SPACE SCIENCES

Geophysical Research Letters

COMMENTARY
10.1029/2025GL120048

Key Points:
- Basal units near the base of ice sheets are underexplored features
- Young et al. (2025, https://doi.org/10.1029/2025GL115729) characterize a basal unit in East Antarctica using airborne radio-echo sounding (radar)
- They infer unprecedented characteristics of ice, ice-flow history, and geological composition

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Citation:
Eisen, O. (2025). Inferring Antarctic ice dynamics and boundary conditions from the ice sheet's basal unit. *Geophysical Research Letters*, *52*, e2025GL120048. https://doi.org/10.1029/2025GL120048

Received 16 OCT 2025
Accepted 22 OCT 2025

Inferring Antarctic Ice Dynamics and Boundary Conditions From the Ice Sheet's Basal Unit

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Abstract In their study, Young et al. (2025, https://doi.org/10.1029/2025GL115729) employ airborne radio-echo sounding data to map the basal unit over the East Antarctic Ice Sheet over a large area between Dome A and South Pole. The authors use the results to infer conclusions about ice-dynamic behavior of the ice sheet, geology, temporal development of subglacial geomorphology and physical properties of ice and the subsurface in this region. A comparative study has not been performed before. The results are of relevance for a number of disciplines and objectives, among them the quest for finding an ice-core site to yield a record older than 1 million years, constraining the basal boundary conditions for ice-flow modeling as well as determining subglacial geology to improve geothermal heat flow estimates.

Plain Language Summary In their study, researchers used radar data collected from aircraft to create the first detailed map of the deepest hidden layer beneath a vast area of the East Antarctic Ice Sheet, stretching between Dome A and the South Pole. Their groundbreaking work reveals new insights into how the ice sheet moves and evolves, the shape and composition of the landscape buried beneath the ice, and the physical properties of both, the ice and the ground below. The results are valuable for a range of scientific goals, including the search for ice cores that could contain climate records older than 1 million years, improving the accuracy of ice flow models, and refining our understanding of the geothermal heat that influences the ice sheet's behavior. By connecting these discoveries, the study advances our knowledge of Earth's past and helps inform predictions about its future.

1. Commentary

The basal unit of the Antarctic Ice Sheet plays a crucial role in understanding ice dynamics, subglacial processes, and the interaction between the ice sheet and the underlying solid Earth. Although it has long been recognized as a particular zone with relevance for ice-sheet dynamics and paleo-climate reconstruction based on ice cores, it has not been systematically exploited. Young et al. (2025) trace and investigate the basal unit between Dome A and South Pole to learn about its significance for ice-sheet deformation and thermal interactions with the underlying solid Earth.

The basal unit refers to distinct englacial structures located near the ice–bedrock interface, first discussed by Robin et al. (1977). Initially, these features were challenging to detect due to their missing or subtle radar reflection signatures, and consequently the layer was termed "echo free zone (EFZ)" by Drewry and Meldrum (1978). However, advancements in radio-echo sounding technology, in particularly vertical resolution and focusing techniques, have enabled the identification of these units by capturing strong backscatter and near-basal reflections, sometimes several hundred meters thick, in regions typically devoid of echoes. Even in the absence of clear echos, comparison of the EFZ with high-resolution imaging techniques along ice cores were able to link the disappearance of coherence and thus continuous reflections in the ice sheet to small-scale disturbances in ice cores (Drews et al., 2009).

The basal unit is integral to the region where most of the ice-sheet deformation occurs, as indicated in a relative recent summary by Goldberg et al. (2020), which introduced the term "basal unit" as "visibly distinct englacial structures near the ice–bed interface." Overall, basal units encompass or indicated various properties that could influence ice sheet behavior, which is still under discussion in the glaciological community (Figure 1).

At the ice–bed interface, the ice can move through internal strain, thus deform, or by sliding over the bedrock. The type of deformation depends on the temperature conditions: warmer basal temperatures facilitate sliding, while

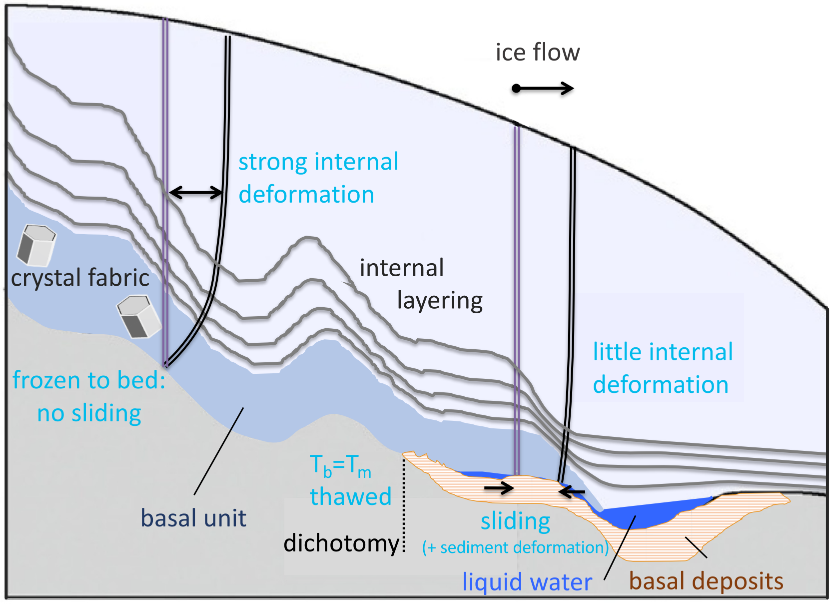

Figure 1. Schematic drawing of internal structure of the ice sheet: in the top and middle parts of the ice sheet regular layering of internal reflection horizons can be observed (Bingham et al., 2025). Where the basal temperature T_b is below the pressure melting point T_m, the ice is frozen to the bedrock, no sliding occurs. Consequently, the motion of ice is accommodated by internal deformation. This is illustrated in the figure by a fictive straight borehole deforming over time. Toward the base, where most of the horizontal shear stresses are present, this gives rise to disruption of internal layers and the appearance of the basal unit, coming along with the formation of anisotropic crystal fabric. When T_b reaches T_m, sliding sets in and the internal deformation is reduced. Thus, a borehole would deform much less over time. In addition to basal sliding, deformation of subglacial material can occur, contributing to the overall displacement of the ice as observed at the ice-sheet surface. When enough energy is available at the base, subglacial melting occurs, which can lead to the formation of subglacial water bodies like lakes or highly saturated sediments, thus allowing for easier deformation of subglacial deposits. Over time, basal melting removes the basal unit advected from further upstream until it eventually disappears and the stratigraphically layered ice comes into contact with the base. The dichotomy observed by Young et al. (2025) occurs most likely in the area where basal conditions change from cold (frozen) to temperate (melting).

colder conditions promote internal deformation. For instance, as part of the pre-site survey for the European Beyond EPICA–Oldest Ice project, a high-resolution ground-based radar was employed to focus in particular on the continuity of the age–depth record above and into the basal unit (Lilien et al., 2021). They inferred that the basal unit does not consist of ice which participates in the current deformation of active ice flow, but could in fact be composed of rather stagnant ice—stagnant with respect to the magnitude of contemporarily observed ice deformation above. Thus, the upper limit of the basal unit would correspond to a “false bed.” This would imply that conventional ice-flow models, which use the full ice thickness from radar measurements as boundary conditions, would overestimate the effective ice thickness relevant for ice-dynamic internal deformation.

The alignment of ice crystals within the basal unit affects the ice's rheological properties. In regions where the ice is frozen to the bed, the crystal orientation fabric can provide information about past flow dynamics and strain history. Though best interpretations of crystal evolution is available from ice-core observations (e.g., Saruya et al., 2025), indirect observations from the surface with radar or seismics also provide insights. For instance, strongly varying ice-crystal fabric on small scales could lead to discontinuity of internal reflections and thus yield a radar response comparable to that of the basal unit, thus helping to map the distribution of particular fabric properties.

Debris and sediments entrained at the ice—bedrock interface can modify the mechanical properties of the basal unit. Studies have observed such debris in basal ice sequences, influencing the ice's behavior and interactions with the bed. Franke et al. (2024) employed synthetic radar responses generated through electromagnetic forward modeling to interpret the material properties of these basal units. By comparing them with observational radar data in the coastal region of Dronning Maud Land (East Antarctica) they revealed such basal reflections and linked them to the entrainment of basal material, providing insights into the internal structure and dynamics of the ice sheet.

The interaction between the ice sheet and the underlying solid Earth is governed by geothermal heat flow (GHF) (Reading et al., 2022). GHF influences the thermal state of the basal unit, affecting whether the bed is frozen or thawed. In regions where the GHF is high, the basal temperatures may be close to or above the pressure melting point, promoting basal sliding and influencing ice dynamics. Conversely, low GHF regions may result in a frozen bed, leading to different deformation behavior. Recent research has focused on evaluating available and potentially refining GHF estimates to better understand its spatial variability and implications for ice sheet behavior (e.g., Lösing et al., 2025). For instance, studies have highlighted the need for improved GHF maps to accurately model basal conditions and ice flow dynamics.

This is where the study of Young et al. (2025) is offering key insights into the nature and role of the basal unit in East Antarctica. Using advanced airborne radar sounding from the southern flank of Dome A and the South Pole Basin, they identify an extensive radioglaciologically defined basal unit beneath Dome A that is abruptly truncated at a marked bedrock dichotomy within the South Pole Basin. They interpret this unit as transporting material—potentially eroded and entrained from the Gamburtsev Subglacial Mountains—into the South Pole Basin, where basal melting and deposition contribute to the formation of a smooth, hilly subglacial landform complex they term the Elbow Complex. Their study highlights a strong coupling between basal ice structure, underlying bedrock geology, and localized GHF. Their findings underscore that basal units can play an active role in redistributing debris and sediments across large regions, influencing local melt–freeze dynamics and ice–bed interactions. Importantly, the work shows that even in the slow-moving interior of East Antarctica, basal processes exert a significant control on ice-sheet evolution over long time scales. For numerical ice sheet modeling, these results stress the necessity of incorporating heterogeneities in basal units and their interactions with subglacial sediments and geothermal anomalies—factors that are otherwise easily oversimplified or neglected.

Incorporating basal units into numerical ice sheet models presents significant challenges to date. Such models often struggle to accurately represent the complex interactions at the ice–bed interface due to the heterogeneous nature of basal units and the variability and unknown character in their properties. Additionally, the spatial resolution of current models may not be sufficient to resolve the fine-scale structures of basal units, leading to uncertainties in predictions of ice-sheet dynamics and contributions to sea-level rise. The study by Young et al. (2025) shows that enhancing the representation of basal units in numerical models is crucial for further improving the accuracy of future projections—both, a challenge and a chance.

Conflict of Interest

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

Data Availability Statement

Not applicable.

Acknowledgments
The author thanks Steven Franke, Reinhard Drews, Frédéric Parrenin, Catherine Ritz, and Dorthe Dah-Jensen for discussions about the state and fate of the basal unit.

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