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KEYNOTE: Beyond ice coring —wide aperture exploration of the deep ice sheets

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Exploring deep polar ice sheets is critical for reconstructing past climate history and for discovering basal physical conditions operative during present and future global change. Importantly, subglacial geology and heat flow together help govern ice-sheet stability, including both flow conditions and preservation potential of oldest ice. Variations in rock composition, age, heat production, tectonic setting (e.g., basins vs. shields vs. volcanic terrains), faults, and other fluid pathways have a large integrated effect on basal ice temperature and sliding potential. The composition and structure of subglacial geology may be deduced from ice-penetrating radar and potential-field geophysics, but validation of actual basal properties is best addressed by direct-access drilling.

Emerging drill and probe technologies extend deep ice-coring capability by rapidly capturing glacial stratigraphy, observing and sampling the basal cryosphere boundary, measuring physical properties, and establishing 4D observatories in an ice sheet suitable for long-term instrumentation. Rapid, deep ice-sheet access by drilling and melt probes complements radar imaging and deep ice coring to determine paleoclimate history and to observe present-day basal conditions. Rapid drilling penetration rates allow for multiple boreholes over a short time to validate remote sensing data and to ground-truth materials and conditions by direct sampling and measurement. Creating arrays of boreholes and probe penetrations thus has the potential to significantly expand the aperture of our view into the ice sheets.

The U.S. Rapid Access Ice Drill (RAID) is a new technology designed to address inter-disciplinary problems in paleoclimate history, ice-sheet dynamics, and continental tectonics in Antarctica (Goodge & Severinghaus, 2016). Primary aims of RAID are: 1) defining glacial stratigraphy; 2) validating ice age with borehole logging and short ice cores; 3) measuring in situ temperature and heat flow; 4) observing basal conditions; 5) subglacial rock coring for landscape histories and sampling the lithosphere; and 6) creating 'navigable' legacy boreholes for englacial age correlation and long-term study of ice dynamics, seismology and geodetics. With these goals, RAID is a key technology useful to search for ≥1.5 My ice.

In field trials on an Antarctic piedmont glacier at Minna Bluff in 2019-20, RAID achieved 'top-to-bottom' drilling in three boreholes (Goodge et al., 2021). Key successes included routine use of a packer to seal the borehole in firn; fast borehole drilling in thick ice using reverse fluid circulation (penetration rates up to 1.2 m/min); intersection of the glacial bed at 677 m; retrieval of a 3.2 m core of ice, basal till and subglacial bedrock; and optically logging boreholes on wireline. Field testing demonstrates the effectiveness of the system to drill rapidly in thick ice (equiv. to 3,000 m in <48 hours) and penetrate the glacial bed to retrieve bedrock cores.

Primary author: GOODGE, John

Presenter: GOODGE, John