INSIGHTS INTO ICE-OCEAN INTERACTIONS ON EARTH AND EUROPA. J. D. Lawrence[1], B. E. Schmidt[1], L. Winslow[2], P. Doran[3], S. Kim[4], C. C. Walker[1], J. J. Buffo[1], M. Skidmore[5], K. M. Soderulund[6], D. D. Blankenship[6], N. Bramall[7], A. Johnson[8], F. Rack[9], W. B. Stone[10], and the SIMPLE Field Team. [1]Georgia Tech (jlawrence@gatech.edu), [2]USGS, [3]LSU, [4]San Jose State, [5]Montana State, [6]UTIG, [7]Leiden Measurement Tech., [8]U. Ill. Chicago, [9]UNL, [10]Stone Aerospace.

Introduction: On the surface Europa and Earth are drastically different worlds, yet below their respective icy crusts the two likely share similar oceanic conditions including temperatures, pressures (relatively), and salinity. Thus the interface between Earth's thick ice shelves and ocean provides an important and little-explored analog for the physicochemical, and potentially microbial, characteristics of icy worlds. Subshelf processes of melt, freeze, and accretion are controlled by gradients in ice thickness, currents, ocean temperature, and salinity, but due to the remote nature and challenges in exploring beneath the ice even on Earth these details are not well characterized.

In particular, the impact these processes may have on the potential for the ice at the interface to host or influence communities is poorly understood. For Europa, any material formed at the interface may be subject to transport upward through convection or diapirism, potentially participating in an ice "conveyor belt" delivering ocean-derived materials to the shallow subsurface that would affect the habitability of Europa's ice and ocean alike. In planetary environments, an ice-ocean interface may not only provide a habitable niche, but also influence habitability throughout ice shells by cycling nutrients. Moreover, ice accretion may entrain evidence of oceanic conditions that could influence remote measurements.

SIMPLE: NASA's ASTEP program funded the Sub-ice Investigation of Marine and PLanetary-analog Ecosystems (SIMPLE) project to address the fundamental processes occurring at ice ocean interfaces, the extent and limitations of life in sub-ice environments, and how these environmental properties and biological communities interact. In addition to constructing a comprehensive picture of processes at the ice–ocean interface, the technologies supported by SIMPLE are advancing NASA's capabilities to detect intra-ice processes and properties by ice penetrating radar and with *in situ* measurements that will support the upcoming Europa Flagship mission and future landers.

Analog Fieldwork in Antarctica: We have recently completed the final field season of a multi-year investigation of the McMurdo Ice Shelf (MIS), a small portion of the larger Ross Ice Shelf easily accessible from USAP's McMurdo Station (Fig. 1). In the 2012, 2014, and 2015 austral summer Antarctic field seasons SIMPLE characterized ice and ocean processes below and within the MIS.

Figure 1. Location of field operations in 2015.

The MIS is "ice starved," cut off from the main tributary glaciers of the Ross Ice Shelf, which creates a unique and dynamic environment despite the shelf being relatively thin. Thus it is an ideal place to study accretion and melt at the base of a shelf.

As supercooled water flows upward along the basal slope of an ice shelf, frazil ice precipitates and rises, accumulating at the interface. In thermally stable parts of the subshelf environment, platelet ice grows at the interface and accumulations of the large, platy crystals contribute to a marine ice layer [1]. The thickest marine deposits on Earth can exceed ~500 m.

While physical conditions differ slightly below sea ice, large platelets can still form beneath columnar sea ice adjacent to the shelf outflow. These platelet accumulations display a looser aggregation than those formed in a subshelf environment due to less stable thermal conditions, transport via currents, and greater atmospheric heat exchange through the relatively thin sea ice (Fig. 2). Platelet deposits beneath sea ice measured from 0 to ~4 m in thickness, and were also observed to form on instruments in the water column at varying rates during our study. Here, we present results from CTD and imaging data gathered beneath the MIS to highlight how ice conditions in a Europan analog environment depend upon ocean conditions.

Results: In 2012, the first of three austral summer Antarctic seasons, the team explored at a single location 5 km back from the front of the ice shelf using the small ROV SCINI (Submersible Capable of under Ice Navigation and Imaging, SJSU, S. Kim) in order to produce preliminary characterizations of the ice-ocean interface and processes. We observed ablation of the ice and a heterogeneous water column, consistent with melting by fast moving impingent currents. Imaging data and the CTD profiles were also supportive of this conclusion.

In 2014, SIMPLE utilized SCINI and a new AUV/ROV vehicle, *Icefin* (Georgia Tech, B. Schmidt), to characterize 5 sites below the MIS ranging between 10 and 20 km from the shelf front. Here, we encountered very different ice conditions than in 2012. Large amounts of platelet ice formation were observed regardless of ice shelf thickness. The layer of platelets was between 1 and 3 m thick depending on the site, and ranged between relatively uniform in character to regions with large platelet spears and columns. At one site, we noted the possible formation of a compressed layer of platelet ice, physically separated from the bottom of the shelf by a thin water lens above it We observed a homogeneous water column below the ice, consistent with the formation of platelet ice, and a complex community of organisms at the sea floor near Black Island under this permanent ice cover.

During the third and final field season we deployed ARTEMIS, a 4.3 m long-range hybrid autonomous underwater vehicle, through the sea ice over the McMurdo Sound out beneath the MIS on missions up to 5 km in length. ARTEMIS was designed and built under the SIMPLE program. Onboard instrumentation included CTD, pH, PAR, turbidity, chlorophyll-a, current profiler, mapping sonars, water sampler, cameras, and an experimental protein fluorescence spectrometer to detect intra-ice microbiological communities and test life detection techniques.

In the early phase of the season (September through early November), we observed high rates of platelet ice growth beneath SIMPLE camp, situated on 3.25 m thick multiyear sea ice 150 m north of the MIS terminus (77° 53.854'S, 166° 29.483'E). Platelet accumulation beneath the camp reached thicknesses of 5 to 6 m with peak accretion rates of up to 0.5 m week^{-1}. We did not observe any columnar or spire structures as in previous seasons, rather imaging and sonar data showed rough dune-like relief and more subtle topography (Fig. 2).

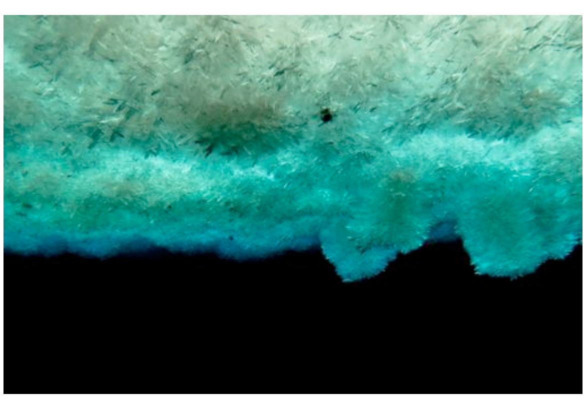

Figure 2. Platelet crystals growing beneath columnar sea ice.

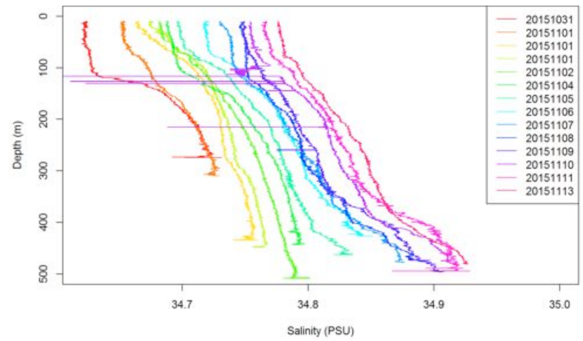

Figure 3. CTD Cast Multi Profile at SIMPLE camp, 2015.

The team also completed daily CTD casts in November to at least 300 m depth beneath camp in order to characterize the water column supporting platelet accumulation. We observed generally homogenous waters to approximately 80 to 120 m depth (Antarctic Surface Water) (Fig. 3), and increasing salinity with additional depth. Disparities between casts may be attributed to tidal fluctuations. Select casts also appeared to show a secondary water mass below 450 m, potentially Antarctic Bottom Water. When possible, we also deployed a current meter to better quantify local tidal influence and measured absolute tidal amplitude using a differential GPS station at camp and reference point on Ross Island.

Conclusions and Future Work: We present results from CTD and imaging systems onboard SCINI, Icefin, and ARTEMIS and compare results across the MIS. In the study area platelet accumulations were ubiquitous beneath the shelf, composed of large crystals tens of cm in diameter. While larger scale platelet morphologies varied spatially over tens of km, sub-shelf ice was found to be more compact and resilient than the loose aggregations observed beneath sea ice.

To confirm sensor data, ARTEMIS also carried an onboard water sampler capable of up to 36 125 ml water samples, taken in quadruplicate at specific sampling locations 0, 1, or 2 m below the ice shelf interface. Cell counts will help quantify biologic activity and provide context for the experimental protein fluorescence spectrometer. These samples, via repeated stations, may also provide time series insights into biology during the onset of the austral summer.

References: [1] Smedsrud L. H. and Jenkins A. (2004) *JGR, 109*, C03025.

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