

# IODP Proposal Cover Sheet

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Greenland Ice Sheet

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Title	Assessing the history of the south Greenland Ice Sheet and its interaction with ocean circulation, climate, and sea level		
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## Abstract

Sediment drifts on the Eirik Ridge and in the Davis Strait preserve detailed archives of Earth history that are sensitive to the evolution of Greenland Ice Sheet (GIS), surrounding surface ocean conditions, and the Deep Western Boundary Current (DWBC); a major component of Atlantic Meridional Overturning Circulation (AMOC). As a result of sustained seismic and coring efforts and proxy development, our understanding of the sedimentary patterns, physical processes, and paleoenvironmental signals encoded within these sediments has advanced sufficiently that we propose a drilling experiment to investigate the evolution of the south Greenland Ice Sheet (sGIS) and its interaction with ocean circulation and climate from the Pliocene-Quaternary to assess sGIS stability in light of future climate and environmental change. Seven sites across the two sediment drift complexes will provide a spatially-integrated perspective. One site positioned on the lee-side of the Eirik Ridge (EIRIK-01B, a redrill of Ocean Drilling Program (ODP) Site 646) preserves a continuous sequence with relatively expanded sedimentation during interglaciations since the earliest Pliocene (~ 4.5 Ma). One site on the ridge (EIRIK-02A) will capture a high-resolution latest Pliocene and complete Pleistocene record with relatively expanded sedimentation during glaciations. Two sites (EIRIK-03A, EIRIK-04A) will target a series of mudwaves in a time-offset advance piston coring (APC) drilling strategy to recover a shallowly buried Pliocene-aged sediment (~4.5 – 2.6 Ma) at extremely high resolution (>200 m/Myrs). Two drift sites in Davis Strait (DAVIS-04A, DAVIS-09A) are positioned to reconstruct southwest GIS evolution, ocean circulation, and Baffin Bay/northern Labrador Sea surface ocean conditions, potentially since the latest Miocene. Finally, DAVIS-03A will recover and evaluate the age and origin of debris flows linked to southwest Greenland shelf-edge glaciation. All sites will provide information on ocean conditions, faunal responses and evolution, geomagnetic change, and/or the dynamics of neighboring ice sheets and ice caps (e.g., Greenland, Iceland, Laurentide, Innuitian). Provenance, erosion, and paleoenvironmental proxies for ice sheet-extent and paleoceanographic reconstructions of ocean temperature and circulation will be placed in a robust suborbital-scale chronostratigraphic model using a paired geomagnetic relative paleointensity (RPI) and oxygen isotope approach integrated with model-based predictions of fluvial and subglacial transport and iceberg production in order to address the following hypotheses: 1) The Greenland ice sheet is not stable and is tightly coupled to the climate-ocean system, and, 2) the Pliocene represents a time of profound change, not just for the GIS, but also for the surrounding ocean.

## Scientific Objectives

- 1) Document evidence for ice advance and retreat on Greenland during the Pliocene. Using newly developed and traditional proxies, evidence for the south Greenland Ice Sheet (sGIS) will be reconstructed before, during, and after the mid Piacenzian warm period (3.264–3.025 Ma) the most recent example of a climate state in long-term equilibrium with near-future atmospheric CO<sub>2</sub> concentrations.
- 2) Assess the stability of the sGIS through the Plio-Pleistocene. Newly developed and traditional proxies will be applied to investigate the varying response of the sGIS over both long and short timescales to different climatic events and oceanic states since the Pliocene.
- 3) Reconstruct past regional climate states that may have influenced or were influenced by sGIS behavior. Using a variety of paleoceanographic and paleoclimatic proxies we intend to reconstruct the ocean conditions around Greenland that likely played a significant role in sGIS variability.
- 4) Investigate the evolution of the DWBC and connections between the GIS and Northern Hemisphere glaciation. Using textural, accumulation rate, and nutrient proxies we will study the DWBC in detail from the early Pliocene. Davis Strait sites will provide new insights on the ocean circulation system into Baffin Bay and its evolution, potentially since the Miocene.
- 5) Geomagnetic network analysis. Exploit a common regional geomagnetic signal and the high quality of paleomagnetic records in the North Atlantic to develop much higher resolution regional synchronization and more robust chronologies.

### Non-standard measurements technology needed to achieve the proposed scientific objectives

## Proposed Sites (Total proposed sites: 22; pri: 7; alt: 15; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
DAVIS-09A (Primary)	64.72726 -56.74568	777	642	0	642	DAVIS-09A is located to the west of the crest of the Davis Strait Drift Complex (DSDC) and targets a reflector interpreted to be the base of the drift, suggested to date from the Mid-Miocene or Early Pliocene (Nielsen et al., 2011). Drilling DAVIS-09A will allow the age of drift establishment and hence flow of Arctic-Atlantic water exchange through the Davis Strait to be determined. The sediment record at DAVIS-09A will allow unique investigations of the paleoceanographic and ice-sheet history of an ocean circulation gateway not previously studied and paleomagnetic observations from a unique high latitude, western hemispheric perspective.
DAVIS-04A (Primary)	64.38463 -56.38342	746	385	0	385	DAVIS-04A captures the upper unit of the Davis Strait Drift Complex and targets a reflector interpreted as a Pliocene shift in drift morphology (Nielsen et al., 2011). Drilling will allow the age of this transition in Arctic-Atlantic water exchange to be determined. Continuous reflectors can be traced from DAVIS-04A beneath all 5 GDFs present at primary Site DAVIS-03A, thus providing a continuous sequence to interpret the GDF record. Additionally, DAVIS-04A will allow investigations of the paleoceanographic and ice-sheet history of an ocean circulation gateway not previously studied and paleomagnetic observations from a unique high latitude, western hemispheric perspective.
DAVIS-03A (Primary)	64.45325 -55.5511	1005	381	0	381	Drilling at DAVIS-03A targets the age and origin of debris flows imaged in the Davis Strait Drift Complex; interpreted as glaciogenic (GDFs) and thought to reflect Greenland shelf edge glaciations (Nielsen and Kuijpers 2013). We propose to drill to the surface of the second deepest and largest GDF (GDF#2) to assess its age and origin, while sampling overlying GDF#4 and GDF#3 and any smaller debris flows not imaged by seismic reflections. Our intent is to date the overlying drift sediment above the GDFs to determine the age of these potential indicators of shelf edge glaciations.
EIRIK-01B (Primary)	58.2130 -48.3960	3460	350	0	350	EIRIK-01B is a re-drill of ODP Site 646 to develop a continuous record of the south Greenland ice-sheet and regional paleoceanography that can be constrained by a high-resolution paleomagnetic chronology back to 4.5 Ma. Only two holes were drilled during Leg 105 at Site 646; Hole 646A (103.5 mbsf; ~1.3 Ma, APC 89% recovery) and Hole 646B (766 mbsf; ~8.6Ma, APC 74%, XCB 48% recovery). Five APC holes to a target depth of 350 m will ensure recovery of the erosional unconformity (EU) reflector (Müller-Michaelis et al., 2013) and allow construction of a continuous high-resolution record at this 'Goldilocks' site.
EIRIK-02A (Primary)	58.55189 -46.3047	2556	321	0	321	EIRIK-02A, a shallower water complement to EIRIK-01B, provides a continuous record at 2x the sedimentation rate of nearby Site U1307 and is one of three primary sites that make up a high-resolution Eirik Ridge mudwave Plio-Pleistocene transect. Site EIRIK-02A will be triple APC'd to 321 m and targets the uppermost 0-2.5 Ma portion of the transect to construct a continuous ~100m/Myr record of the south Greenland ice-sheet and regional paleoceanography during the Quaternary that can be constrained by high-resolution paleomagnetic chronology.
EIRIK-03A (Primary)	58.50194 -46.4083	2590	346	0	346	EIRIK-03A is the middle of three primary sites that make up a high-resolution Eirik Ridge mudwave Plio-Pleistocene transect. Site EIRIK-03A targets the 2.5-3.8 Ma portion of this transect at >200m/Myr and will be triple (HL)APC'd to a target depth of 346 m to allow overlap with EIRIK-02A and Site U1307 above and EIRIK-04A below. EIRIK-03A is characterized by a condensed late-Pleistocene section above an expanded shallowly buried late Pliocene section. This site will facilitate studying the history of the south Greenland ice-sheet and regional paleoceanography during the Pliocene warm period.
EIRIK-04A (Primary)	58.47751 -46.4592	2647	318	0	318	EIRIK-04A is the oldest of three primary sites that make up a high-resolution Eirik Ridge mudwave Plio-Pleistocene transect. Site EIRIK-04A targets the 3.8-4.5 Ma portion of this transect at > 200 m/Myr and will be triple APC'd to 300 m to allow overlap with EIRIK-03A above and alternate site EIRIK-06A below. EIRIK-04A is characterized by a condensed late-Pleistocene section, above an apparent hiatus with expanded and shallowly buried early-mid Pliocene section below. This site will facilitate studying the Pliocene history of the south Greenland ice-sheet (sGIS) and regional paleoceanography likely prior to GIS development.

## Proposed Sites (Continued; total proposed sites: 22; pri: 7; alt: 15; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
DAVIS-01A (Alternate)	64.467571 -55.3704	945	759	0	759	Drilling at DAVIS-01A targets the age and origin of debris flows imaged in the Davis Strait Drift Complex. These debris flows are interpreted as glacial (GDFs) and thought to reflect Greenland shelf edge glaciations (Nielsen and Kuijpers 2013). In this alternate site, we propose to drill through all five GDFs to the base of the oldest, hypothesized to be ~4.5 Ma, to assess their age and origin to inform on the timing and initiation of shelf edge glaciations in SW Greenland."
DAVIS-02B (Alternate)	64.43132 -55.81954	1016	320	0	320	Drilling at DAVIS-02B targets the age and origin of debris flows imaged in the Davis Strait Drift Complex. These debris flows are interpreted as glacial (GDFs) and thought to reflect Greenland shelf edge glaciations (Nielsen and Kuijpers 2013). In this alternate site, we propose to drill to the surface of the second deepest and largest GDF (GDF#2) to assess its age and origin, while sampling GDF#4 and any smaller debris flows not imaged by seismic reflections. Our intent is to date the overlying drift sediment above the GDFs to determine the age of these potential indicators of shelf edge glaciations.
DAVIS-05A (Alternate)	64.58329 -56.34533	795	525	0	525	DAVIS-05A, an alternate site with the same objectives as Primary Site DAVIS-04A, captures the upper unit of the Davis Strait Drift Complex and targets a reflector interpreted as a Pliocene shift in drift morphology (Nielsen et al., 2011). Continuous reflectors can be traced from DAVIS-05A beneath all 5 GDFs imaged, providing constraints on their ages. Additionally, DAVIS-05A will allow investigations of the paleoceanographic and ice-sheet history of an ocean circulation gateway not previously studied and paleomagnetic observations from a unique high latitude, western hemispheric perspective.
DAVIS-06A (Alternate)	64.67335 -56.33904	812	558	0	558	DAVIS-06A, an alternate site with the same objectives as Primary Site DAVIS-04A, captures the upper unit of the Davis Strait Drift Complex and targets a reflector interpreted as a Pliocene shift in drift morphology (Nielsen et al., 2011). Continuous reflectors can be traced from DAVIS-06A beneath all 5 GDFs imaged, providing constraints on their ages. Additionally, DAVIS-06A will allow investigations of the paleoceanographic and ice-sheet history of an ocean circulation gateway not previously studied and paleomagnetic observations from a unique high latitude, western hemispheric perspective.
DAVIS-07A (Alternate)	64.56088 -56.59721	783	558	0	558	DAVIS-07A is located to the west of the crest of the Davis Strait Drift Complex (DSDC) and targets a reflector interpreted to be the base of the drift, suggested to date from the Mid-Miocene or Early-Pliocene (Nielsen et al., 2011). DAVIS-07A is an alternate for Site DAVIS-09A with similar objectives, including establishment of the age of drift development and hence flow of Arctic-Atlantic water exchange through Davis Strait. DAVIS-07A will yield a paleoceanographic and ice-sheet history record of an ocean circulation gateway not previously studied, while making paleomagnetic observations from a unique high latitude, western hemispheric perspective.
DAVIS-08A (Alternate)	64.67842 -56.7207	782	641	0	641	DAVIS-08A is located to the west of the crest of the Davis Strait Drift Complex (DSDC) and targets a reflector interpreted to be the base of the drift, suggested to date from the Mid-Miocene or Early-Pliocene (Nielsen et al., 2011). DAVIS-08A is an alternate for Site DAVIS-09A with similar objectives, including establishment of the age of drift development and hence flow of Arctic-Atlantic water exchange through Davis Strait. DAVIS-08A will yield a paleoceanographic and ice-sheet history record of an ocean circulation gateway not previously studied, while making paleomagnetic observations from a unique high latitude, western hemispheric perspective.
EIRIK-05A (Alternate)	58.48485 -46.4438	2627	300	0	300	EIRIK-05A is an alternate site on the high-resolution Eirik Ridge mudwave Plio-Pleistocene transect. It is positioned to ensure overlap between EIRIK-03A and EIRIK-04A should shipboard analysis suggest that there is a chronological gap between the two sites. EIRIK-05A would be triple APC'd to a target depth of 300 m. Combined these sites will generate a high-resolution composite APC record back into the early-Pliocene. Site EIRIK-05A is characterized by a condensed late-Pleistocene section above an apparent hiatus with an expanded, shallowly buried mid-Pliocene section with sedimentation rates likely greater than 200m/Myrs, below.

## Proposed Sites (Continued; total proposed sites: 22; pri: 7; alt: 15; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
EIRIK-06A (Alternate)	58.46042 -46.4944	2778	300	0	300	EIRIK-06A is an alternate site on the high-resolution Eirik Ridge mudwave Plio-Pleistocene transect. It is positioned to recover the early-Pliocene portion of the record and will extend the composite section below primary Site EIRIK-04A. EIRIK-06A would be triple APC'd to a target depth of 300 m. Combined, these sites will generate a composite high-resolution APC record back into the early-Pliocene. EIRIK-06A is characterized by a condensed late-Pleistocene section above an apparent hiatus with an expanded shallowly buried early-Pliocene section with sedimentation rates likely greater than 400m/Myrs, below.
EIRIK-07A (Alternate)	58.44542 -46.5254	2830	300	0	300	EIRIK-07A is an alternate site on the high-resolution Eirik Ridge mudwave Plio-Pleistocene transect. It is positioned to recover the early-Pliocene portion of the record and will extend the composite section below primary Site EIRIK-04A, overlapping and extending the record of alternative site EIRIK-06A. EIRIK-07A will be triple APC'd to a target depth of 300 m. EIRIK-07A is characterized by a condensed late-Pleistocene section above an apparent hiatus with an expanded shallowly buried early-Pliocene section with sedimentation rates likely greater than 400m/Myrs, below.
EIRIK-08A (Alternate)	58.43412 -46.5484	2852	487	0	487	EIRIK-08A is an alternate site on the high-resolution Eirik Ridge mudwave Plio-Pleistocene transect. It is positioned to target Reflector 2 at approximately 5.6 Ma, extending the record below alternate Site EIRIK-07A. EIRIK-08A would be triple APC'd to refusal followed by RCB to the 487 m target depth. Site EIRIK-08A is characterized by a condensed late-Pleistocene section above an apparent hiatus with an expanded shallowly buried Early Pliocene and Late-Miocene section with sedimentation rates that could exceed 500m/Myrs, below.
EIRIK-10A (Alternate)	58.1766 -48.0645	3399	655	0	655	EIRIK-10A will permit recovery of sediment between reflectors EU (~4.5 Ma) and R2 (~5.6 Ma) that pinches out at the location Site EIRIK-01B (Site 646) ~17.5km to the west. The primary objective of this site is the recovery of the material below the R1 (~2.5 Ma) reflector at ~200 mbsf to R2 reflector at ~655 mbsf using RCB drilling, with two holes an option depending on recovery. Drilling will allow recovery of early Pliocene to late Miocene sediments to facilitate a better understand of drift deposition and the system prior to an extensive Greenland lcesheet.
EIRIK-11A (Alternate)	58.2402 -48.6512	3485	1055	0	1055	Drilling EIRIK-11A 55.6 km to the west of EIRIK-01B provides the shallowest access to the basement along Line AWI-00090004. By drilling the entire sedimentary column, target depth 1055 m, we target drift initiation hypothesized to be during the early Miocene. Uppermost sediments will be similar to those recovered at primary sites EIRIK-1B and EIRIK-10A and it will extend observations beyond that recovered at ODP Site 646 which penetrated 767 mbsf (~ 8.6 Ma).
EIRIK-12A (Alternate)	58.2845 -47.4289	3129	730	0	730	EIRIK-12A is a high-resolution alternate site with the similar objectives as EIRIK-01B; a continuous record of the south Greenland ice-sheet and regional paleoceanography that can be constrained by a high resolution paleomagnetic chronology. EIRIK-12A targets the R2 reflector (~5.6 Ma) at ~730 mbsf yielding a record with sedimentation rates in excess of 100m/Myrs for the Mio-Quaternary. Located in a similar water depth it will add a spatial component to, and complement the interpretation of, EIRIK-01B and IODP Site U1305.
EIRIK-13A (Alternate)	58.2383 -47.1779	3112	417	0	417	Site EIRIK-13A is a high-resolution alternate site with the similar objectives as EIRIK-01B and EIRIK-12A; a continuous record of the south Greenland ice-sheet and regional paleoceanography that can be constrained by a high resolution paleomagnetic chronology. EIRIK-13A targets the R1 reflector (~2.5 Ma) at ~417 mbsf yielding a record with sedimentation rates in excess of 160m/Myrs for the Pleistocene. Located in a similar water depth it will add a spatial component to, and complement the interpretation of, EIRIK-01B and IODP Site U1305.
EIRIK-14A (Alternate)	57.8029 -47.3911	3218	235	0	235	Site EIRIK-14A is an alternate site with the similar objectives as EIRIK-01B and EIRIK-12A; a continuous record of the south Greenland ice-sheet and regional paleoceanography that can be constrained by a high resolution paleomagnetic chronology. EIRIK-14A targets the EU reflector (~4.5 Ma) at ~235 mbsf yielding a record with sedimentation rates around 50m/Myrs for the Plio-Pleistocene. Located in a similar water depth it will add a spatial component to, and complement the interpretation of, EIRIK-01B and IODP Site U1305 and alternate sites EIRIK-12A and EIRIK-13A.