IODP Proposal Cover Sheet

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Antarctic Cryosphere Origins

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Title	Tracing Antarctic Cryosphere Origins to Climate And Tectonics (TACOCAT)
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Area	Ross Sea

Proponent Information

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Abstract

Antarctica's ice sheets profoundly influence the global climate system and carbon cycle by impacting ocean and atmospheric circulation, biogeochemical cycles, and sea level. Large ice sheets developed in Antarctica as the Earth transitioned from the warm, high-CO2 Greenhouse world of the Paleocene-Eocene, into the moderate-CO2 world of the Oligocene-Miocene. However, constraints regarding the timing and magnitude of Antarctica's earliest ice sheets come mostly from indirect inferences based on distant marine geochemical records that are a mix of ice volume and temperature signals - rather than a direct, ice-proximal perspective from the Antarctic continental shelf. There are very few direct records of Eocene-Cretaceous climates at high latitudes in Antarctica, and new records will provide important constraints of the magnitude of polar amplification during greenhouse climates.

Several mechanisms exist to explain Antarctic glacial onset, including declining atmospheric CO2 and the tectonic opening of the Southern Ocean. It is also generally assumed that initial ice sheet expansion near the Eocene/Oligocene boundary was limited to terrestrial East Antarctica ice sheets, because ice could not easily expand across a marine-inundated West Antarctica in the moderate-CO2 worlds and warmer Oligocene climates. However, late Cretaceous-Cenozoic rifting, alongside Neogene erosion, has led to widespread subsidence in West Antarctica. A more elevated West Antarctica in the Oligocene could hold more terrestrial ice than today, even though the climate was warmer-than-present. Consequently, the ice sheet evolution of the Ross Sea is hypothesized to be strongly-coupled to the tectonic and subsidence history of West Antarctica, rather than climate forcings (e.g. temperature, CO2) alone. Therefore,obtaining direct records of rift timing and climate/glacial history is required to understand these competing influences. A further implication of understanding the tectonic history of West Antarctica, is that active rifting in the Ross Sea is thought to be a keystone in resolving models of Cenozoic global plate motion circuits.

The Ross Sea is perfectly situated to obtain new perspectives on the tectonic influences on Antarctica's climatic and ice sheet evolution. It is located within West Antarctic Rift System, which allows for direct assessment of rift timing, but also has formed large sedimentary basins that capture climatic records at high latitudes in Antarctica since Late Cretaceous times. We target 2-3 continental shelf drill sites in the Ross Sea, which form a longitudinal-transect designed to capture this integrated history of tectonic, climate and glacial influences from both East and West Antarctica.

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Scientific Objectives

Objective 1: Obtain direct evidence of the earliest ice sheets in East and West Antarctica expanding into the Ross Sea.
Objective 2: Obtain geological reconstructions of "pre-icehouse" climates at high latitudes in Antarctica during the Late Cretaceous to Eocene.
Objective 3: Constrain the timing of late rift phases in the Ross Sea to resolve mechanisms of crustal extension in the Ross Sea, in order to test hypotheses of global plate tectonic models, and understand tectonic controls on ice sheet evolution.

We will achieve these objectives by:
A) Drilling a total of two-three sites, as part of an East to West transect on the Ross Sea continental shelf, that will provide records of early ice sheet histories sourced from both East and West Antarctica.
B) Drill into syn-rift strata (Cretaceous-Late Eocene), and post-rift strata (Eocene-Early Miocene) at each site to obtain climate archives. We aim to core above and below unconformities formed near the Eocene/Oligocene boundary, when the first large-continental scale Antarctic ice sheets are proposed to have formed.
C) Date syn-rift strata in separate continental shelf basins, to provide minimum constraints of the time of active Ross Sea rift propagation.

This proposal directly address Challenges 1 and 2 of the IODP Science Plan, and Strategic Objectives 2, 3, 4 an 5 in the 2050 Framework, as well as the Ground Truthing Future Climate Change Flagship Initiative.

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

N/A. We envision drilling via established geotechnical vessel capability - or via ice shelf platform similar to ANDRILL

Have you contacted the appropriate IODP Science Operator about this proposal to discuss drilling platform capabilities, the feasibility of your proposed drilling plan and strategies, and the required overall timetable for transiting, drilling, coring, logging, and other downhole measurements?

yes

Science Communications Plain Language Summary

Using simple terms, describe in 500 words or less your proposed research and its broader impacts in a way that can be understood by a general audience.

Models indicate that retreat of the marine-based Antarctic Ice Sheet is likely to be triggered if we exceed the 1.5-2ºC global warming target of the Paris Agreement, while the threshold for future significant inland melting of the Antarctic Ice Sheet remains uncertain. Future AIS retreat in the near future is of concern, because geological archives indicate ice sheet loss has previously led to a series of cascading tipping points that affect the entire Earth climate system. However, because of the complexities of this system, ice-ocean-atmospheric-biosphere feedbacks are poorly represented in ice sheet and climate models used for future projections. Filtering out the influence of long-term feedbacks (tectonics, paleotopography) that are not relevant to future change, but may have influenced ice sheet evolution in past, is critical if such models are to be used as future climate change “analogues”.

Deep sea oxygen isotope records have been fundamental to our understanding of Earth’s ice sheet history in climates that are similar to what is projected for the end of the century and beyond - as they record a signal of temperature and global ice volume, which are commonly assumed to covary through time. However, factors such as tectonic rifting/subsidence of the Antarctic continent and oceanic gateway opening making an assumption of a uniform relationship between global temperature change, global ice volume and atmospheric CO2 highly unlikely. Indeed, recent topographic reconstructions indicate that West Antarctica was more mountainous prior to the Miocene, 23 million years ago (Ma). This is due to extensive rifting, subsidence and erosion that has happened since that time, and the continent was capable of holding larger-than-present ice sheets despite the climate being warmer than today. These topographic considerations have the potential to fundamentally alter our view of Antarctic ice sheet development and its evolution through the Cenozoic, and reconcile the apparent non-linearity between past global temperature change, global ice volume and atmospheric CO2 from global proxy records.

Recent sea level reconstructions and short sediment cores collected in Antarctica have also cast doubt on the long-standing paradigm that ice sheet development in Antarctic occurred at Eocene/Oligocene boundary (34 Ma). It has long been debated if the initiation of major Antarctic glaciation was triggered by the tectonic opening of the Southern Ocean gateways, thermally isolating Antarctica from other landmasses - or was driven by declining atmospheric CO2 concentrations. We aim to drill into Ross Sea sediments between 23 and >65 Ma in age to assess if sea level falls at that time were associated with Antarctic glaciation. We seek to determine: 1) topographic influences on ice sheet evolution in both East and West Antarctic under a range of past climates; 2) the duration and extent of major glaciation (if any) prior to the tectonic opening of the Southern Ocean gateways at 34 Ma, and the relationship of these events to shifts in atmospheric CO2; and 3) the extent of polar temperature amplification and high-latitude carbon cycles feedbacks,in extreme greenhouse climates of the Eocene and Paleocene.

Review Response

Submission Type | Resubmission from previously submitted proposal

We were asked to explain how the sites off the continental shelf (4km water depth) will address the guiding hypothesis. As we are now proposing geotechnical vessel to drill our sites, the alternate deep water (>2km) sites have now all been removed.

We have provided more detail on the proxies used to derive paleobathymetry, which is a key method for achieving our objectives as requested. As the review noted, proponents on the proposal have previously published in this field - and we (proponents De Santis and Colleoni) are currently completing this work for Miocene and younger from Exp 374 results.

We were asked to explain how our results build on previous core top studies, and now note these works, although emphasize that deep drill cores (Cape Roberts, CIROS, DSDP leg 28) in the Central and Western Ross have been the most instrumental in development of the hypotheses we aim to test - so our background is more heavily weighted to those. We agree that these snapshot short cores will provide valuable latitudinal context for more continuous cores collected by this new proposal.

We have refined Objective 3 and moved a guiding hypothesis from objective 1 to more clearly demonstrate how the tectonic history could decouple the ice volume and temperature histories in Antarctica. This hypothesis has recently been presented by Duncan et al., 2023 (Nature Geoscience) for the Oligocene/Miocene boundary from DSDP site 28 in the region - but is likely to be a more significant factor for earlier advances.

We have revised the proponent team, with many senior/retired proponent happy to be replaced by early career scientists with similar skill sets. Our gender split is now more evenly weighted.

Regarding the high velocities (2200-2400 m/s) at shallow depths. The Ross Sea has experienced significant overburden from sediments that have subsequently been eroded by overriding ice sheets (which also act to load sediments). Consequently, it is age rather than depth below sealfoor that is most important in the Ross Sea basin. We are targeting Early Miocene to Cretaceous strata - occurring beneath Ross Sea Unconformity 5 (~18 Ma). Perez et al., 2021 (GSA Bulletin) used VSP measurement at Site U1521 to show that Pwave velocities below RSU5 are ~2598–2690 m/s. We address SEP's query by reassessing all our velocity data.

Regarding operations, we now anticipate the use of a geotechnical vessel as an MSP, but similar logistical issue relating to sea ice and icebreaker support that were required for the JOIDES Resolution will be required for a geotechnical vessel (e.g 1-2 days for polynya access, but no need for full escort). The limited sea ice and icebergs in the open waters of the Ross Sea polynya still makes the drilling feasible (as proven by IODP Exp 374) without need for a dedicated icebreaker for the duration of the drilling.

Proposed Sites (Total proposed sites: 13; pri: 3; alt: 10; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
CHCS-01B (Alternate)	-77.24254196 172.36368123	666	1508	0	1508	1) Obtain direct geological evidence of the earliest history of ice sheets in East Antarctica, by sampling strata aboveRSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to mid Miocene (~16 Ma) record of EAIS advance. 2) Reconstruction “pre-icehouse” climates in East Antarctica during the Paleocene to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma). 3) Constrain timing of late rift phases in the Western Ross Sea. This will be achieved by dating RSU6 and coring syn-rift strata.
CHCS-02B (Primary)	-77.29991666 171.95923896	735	1300	0	1300	1) Obtain direct geological evidence of the earliest history of ice sheets in East Antarctica, by sampling strata aboveRSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to mid Miocene (~16 Ma) record of EAIS advance. 2) Reconstruction “pre-icehouse” climates in East Antarctica during the Paleocene to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma). 3) Constrain timing of late rift phases in the Western Ross Sea. This will be achieved by dating RSU6 and coring syn-rift strata
CHCS-03A (Alternate)	-77.0727 171.5629	712	1300	13	1313	1) Obtain direct geological evidence of the earliest history of ice sheets in East Antarctica, by sampling strata aboveRSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to mid Miocene (~16 Ma) record of EAIS advance. 2) Reconstruction “pre-icehouse” climates in East Antarctica during the Paleocene to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma). 3) Constrain timing of late rift phases in the Western Ross Sea. This will be achieved by dating RSU6 and coring syn-rift strata
CENCS-01A (Primary)	-77.4516 -177.8407	616	1200	0	1200	1) Obtain direct geological evidence of the earliest history of ice sheets in East Antarctica, by sampling strata aboveRSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to Early Miocene (20 Ma) record of marine environments, with influence of combined EAIS/WAIS or local ice cap advance in central Ross Sea. 2) Reconstruction “pre-icehouse” climates in Central Ross Sea during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma). 3) Constrain timing of late rift phases in the Central Ross Sea. This will be achieved by dating RSU6 and coring syn-rift strata.
CENCS-02A (Alternate)	-77.6402 -179.2478	648	809	51	860	1) Obtain direct geological evidence of the earliest history of ice sheets in East Antarctica, by sampling strata aboveRSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to Early Miocene (20 Ma) record of marine environments, with influence of combined EAIS/WAIS or local ice cap advance in central Ross Sea. 2) Reconstruction “pre-icehouse” climates in Central Ross Sea during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma). 3) Constrain timing of late rift phases in the Central Ross Sea. This will be achieved by dating RSU6 and coring syn-rift strata.
CENCS-03A (Alternate)	-77.2200 -178.6336	645	1097	0	1097	1) Obtain direct geological evidence of the earliest history of ice sheets in East Antarctica, by sampling strata aboveRSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to late Oligocene (25 Ma) record of marine environments, with influence of combined EAIS/WAIS or local ice cap advance in central Ross Sea. 2) Reconstruction “pre-icehouse” climates in Central Ross Sea during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma). 3) Constrain timing of late rift phases in the Central Ross Sea. This will be achieved by dating RSU6 and coring syn-rift strata.
CENCS-04A (Alternate)	-73.99148766 -177.28643477	700	1200	0	1200	1) Obtain direct geological evidence of the earliest history of ice sheets in East Antarctica, by sampling strata aboveRSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to late Oligocene (25 Ma) record of marine environments, with influence of combined EAIS/WAIS or local ice cap advance in central Ross Sea. 2) Reconstruction “pre-icehouse” climates in Central Ross Sea during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5 Ma). 3) Constrain timing of late rift phases in the Central Ross Sea. This will be achieved by dating RSU6 and coring syn-rift strata.

Proposed Sites (Continued; total proposed sites: 13; pri: 3; alt: 10; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
ERSCS-01A (Alternate)	-77.61010423 -160.84500232	620	1082	0	1082	1) Obtain direct geological evidence of the earliest history of ice sheets in West Antarctica, by sampling strata above RSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to Early Miocene (20 Ma) record of WAIS advance in Marie Byrd Land 2) Reconstruction “pre-icehouse” climates in Eastern Ross Sea/ Marie Byrd Land during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma) and RSU7 (Late Cretaceous to Eocene?) 3) Constrain timing of late rift phases in the Eastern Ross Sea. This will be achieved by dating syn-rift strata below RSU7.
ERSCS-02A (Primary)	-77.9402 -160.4316	660	1052	18	1070	1) Obtain direct geological evidence of the earliest history of ice sheets in West Antarctica, by sampling strata above RSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to Early Miocene (20 Ma) record of WAIS advance in Marie Byrd Land 2) Reconstruction “pre-icehouse” climates in Eastern Ross Sea/ Marie Byrd Land during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma) and RSU7 (Late Cretaceous to Eocene?) 3) Constrain timing of late rift phases in the Eastern Ross Sea. This will be achieved by dating syn-rift strata below RSU7.
ERSCS-03A (Alternate)	-78.3925 -164.7040	541	1039	11	1050	1) Obtain direct geological evidence of the earliest history of ice sheets in West Antarctica, by sampling strata above RSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to Early Miocene (20 Ma) record of WAIS advance in Marie Byrd Land 2) Reconstruction “pre-icehouse” climates in Eastern Ross Sea/ Marie Byrd Land during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma) and RSU7 (Late Cretaceous to Eocene?) 3) Constrain timing of late rift phases in the Eastern Ross Sea. This will be achieved by dating syn-rift strata below RSU7.
ERSCS-04A (Alternate)	-78.3509 -162.5913	706	1335	15	1350	1) Obtain direct geological evidence of the earliest history of ice sheets in West Antarctica, by sampling strata above RSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to Early Miocene (20 Ma) record of WAIS advance in Marie Byrd Land 2) Reconstruction “pre-icehouse” climates in Eastern Ross Sea/ Marie Byrd Land during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma) and RSU7 (Late Cretaceous to Eocene?) 3) Constrain timing of late rift phases in the Eastern Ross Sea. This will be achieved by dating syn-rift strata below RSU7.
ERSCS-05A (Alternate)	-78.2274 -161.5268	615	1200	0	1200	1) Obtain direct geological evidence of the earliest history of ice sheets in West Antarctica, by sampling strata above RSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to Early Miocene (20 Ma) record of WAIS advance in Marie Byrd Land 2) Reconstruction “pre-icehouse” climates in Eastern Ross Sea/ Marie Byrd Land during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma)
ERSCS-06A (Alternate)	-77.668106299 -160.740589980	620	1287	0	1287	1) Obtain direct geological evidence of the earliest history of ice sheets in West Antarctica, by sampling strata above RSU6 (thought to be 34-26.5 Ma). Will obtain a Oligocene (~34 Ma) to Early Miocene (20 Ma) record of WAIS advance in Marie Byrd Land 2) Reconstruction “pre-icehouse” climates in Eastern Ross Sea/ Marie Byrd Land during the Late Cretaceous to Eocene, by sampling material below RSU6 (thought to be ~34-26.5Ma) and RSU7 (Late Cretaceous to Eocene?) 3) Constrain timing of late rift phases in the Eastern Ross Sea. This will be achieved by dating syn-rift strata below RSU7.