INTERNATIONAL OCEAN DRILLING PROGRAMME

PROPOSAL 998-FULL-2

Tracing Antarctic Cryosphere Origins to Climate And Tectonics (TACOCAT)

IODP Proposal Cover Sheet

998 - Full - 2

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Title	Tracing Antarctic Cryosphere Origins to Climate And Tectonics (TACOCAT)
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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. For our preferred plan (Intermediate), we target 2 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.

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 sites, as part of an Central to Eastern Ross Sea transect on the 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 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. We present a ADVANCED plan, that could utilize the JOIDES Resolution or D/V MengXiang. We acknowledge both of these scenarios are dependent on funding considerations that are outside of IODP3
control – and it is only an optimistic best case scenario (and unlikely). However, we believe retaining this as the advanced plan is relevant, as Antarctic drilling is a likely a priority for the US and Chinese drilling programmes – and that IODP 998 could provide a catalyst to develop a joint drilling project of this scale.

We emphasize that we expect a low weighting to be placed on our ADVANCED plan **– and that the scientific merit of our proposal should be judged on the INTERMEDIATE and ESSENTIAL plans**

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 - we contacted prior to submitting 998 - Full. In this revision, we use the same calculations and guidance from the iSEP review of 40-50m/day drill rates, and have checked these again with the operator.

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 thank the iSEP for the supportive review, which noted:
"This proposal was well-received during the last SEP meeting in June 2024, addressing previous feedback and aligning with IODP 2050 Science Framework goals, although severe concerns were raised about the operations. This iSEP evaluation in IODP3 acknowledges again that the scientific objectives, related hypotheses, and methods in this proposal are excellent and align well with the goals of the 2050 Science Framework."

Consequently, we have focussed our revision on developing operational plan that does not compromise on achieving the scientific objectives, and limits total core recovery to a maximum of 1600-1700m. We have also corrected the minor data issues that were noted.

There were no science objectives that needed to be altered, but we are aware changing our operations could impact the objectives we can achieve. Below we outline our revised plan, and the impact each option will have for our objectives. We detail operational timelines for each plan.

We assign time for downhole logging, but note this will be vessel dependent. We will limit the total length (water column + sediment) to 2000 m for running the downhole logs. We also recognise most drilling capability does not allow for nuclear log (for porosity and density). In scenario we are unable to conduct downhole logging, we note it does not compromise our objectives.

Revised operation plan.

To make operations feasible, we have now clearly emphasized that the INTERMEDIATE plan is the most likely scenario to be implemented, and is built around a two month operational window in the Ross Sea using a geotechnical vessel. For this plan, we have reduced the number of sites to two (ERSCS-06A and CENCS-01A), with shallower penetration at each to date RSU7 (as the deepest reflector we need to date) as the primary objective – and only thinner intervals of strata beneath this reflector (although it timing during the cruise allows we may opportunistically drill deeper).

We do still note a ADVANCED Plan as having three sites, including the CHCS sites – but this is only achievable in the scenario that a specialist Scientific Drilling Vessel can be made available. This includes the possibility that the JOIDES Resolution is put back into service, or (more likely) if the Chinese vessel DV Meng Xiang is available. We acknowledge both of these scenarios are dependent on funding considerations that are outside of IODP3 control – and it is only an optimistic best case scenario (and unlikely). However, we believe retaining this as the advanced plan is relevant, as Antarctic drilling is a likely a priority for the US and Chinese drilling programmes – and that IODP 998 could provide a catalyst to develop a joint drilling project of this scale.

We emphasize that we do not expect a high weighting to be place on our ADVANCED plan – and that the scientific merit of our proposal should be judged on the INTERMEDIATE and ESSENTIAL plans.

We provide a more comprehensive response to the review as a separate pdf.

Proposed Sites (Total proposed sites: 13; pri: 2; 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 (Alternate/ Primary in FULL)	-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	645	950	0	950	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	646	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	600	950	0	950	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	704	950	0	950	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	950	0	950	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 (Alternate)	-77.9402 -160.4316	666	950	0	950	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	548	950	0	950	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	950	0	950	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 (Primary)	-77.668106299 -160.740589980	620	750	0	750	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.