IODP³

INTERNATIONAL OCEAN DRILLING PROGRAMME

## PROPOSAL 1123-PRE

# Antarctic cryosphere–carbon cycle feedbacks and ecosystem change: Impacts of sub-decadal to millennial climate variability on the Ross Sea Marine Protected Area

# IODP$^3$ Proposal Cover Sheet

## Proposal Title:

Antarctic cryosphere–carbon cycle feedbacks and ecosystem change: Impacts of sub-decadal to millennial climate variability on the Ross Sea Marine Protected Area

## Broad Geographic Area of the Proposal

Northern Victoria Land and Western Ross Sea, Antarctica

## Project Abstract

The coastal fjords of North Victoria Land (NVL), western Ross Sea, preserve the southernmost ultra-high-resolution Holocene sedimentary archives in Antarctica, including 125 m of laminated diatom-rich sediments deposited since ~11 ka within Edisto Inlet fjord (Battaglia et al., 2024). Existing piston cores recovered the upper ~15 m of the sequence (<3.7 ka), revealing sea-ice variability linked to solar forcing (Tesi et al., 2026), while most of the archive remains unexplored.

Edisto Inlet occupies a strategic position between East Antarctic outlet glaciers and the Ross Sea and lies within the Ross Sea Region, the world's largest marine protected area (RSRMPA). As a semi-enclosed fjord, it provides a natural system to investigate interactions among glacier meltwater, sea ice, High Salinity Shelf Water, Circumpolar Deep Water, and Antarctic Bottom Water formation. The surrounding area hosts recently discovered methane seeps and mud volcanoes, linking climate, cryosphere dynamics, and subseafloor fluid systems.

Exceptional sedimentation rates and continuous preservation make the Edisto Inlet succession an ideal laboratory for investigating Antarctic environmental change since the Last Glacial Maximum (LGM). Constraining Antarctic Ice Sheet evolution along the Victoria Land margin and its links with ocean circulation, carbon cycling, and ecosystem change is essential for reducing uncertainties in future sea-level projections.

We propose a phased drilling strategy using a lightweight intermediate-depth coring system deployable from stable fast ice. The Essential scenario targets Site EDIF-01A (125 mbsf) to recover the Holocene succession and reconstruct variability in sea ice, meltwater discharge, fjord circulation, marine productivity and ecosystems. The Intermediate scenario adds Site EDIF-02A (60 mbsf), targeting glacimarine deposits to constrain grounding-line retreat and Marine Ice Sheet Instability during deglaciation.

The Full scenario includes Site MBAY-01A (~43 mbsf) in Moubray Bay and Site ADAR-01A (~38 mbsf) on the Cape Adare outer shelf, recovering post-LGM deglacial deposits and a bottom-current sediment drift, respectively. Together, these sites provide a framework to reconstruct cryosphere–ocean interactions from the Last Glacial Maximum to the present.

The project has three objectives: (1) reconstruct Holocene-to-modern environmental and coastal ecosystem variability using sedimentological, geochemical, and ancient DNA records; (2) determine the history of methane seepage, gas hydrate destabilisation, and subglacial fluid discharge to evaluate cryosphere–carbon cycle feedbacks; (3) quantify the roles of ocean thermal forcing and glacio-isostatic rebound in controlling grounding-line migration and East Antarctic outlet-glacier dynamics. These records will provide a baseline for assessing environmental change and supporting management of the Ross Sea Region MPA under a changing climate.

## Scientific Objectives

**Objective 1 – Ecosystem response to meltwater discharge, sea-ice variability, and coastal processes.**
Recover a high-resolution Holocene sedimentary archive from Edisto Inlet fjord (Battaglia et al., 2024; Tesi et al., 2026) to reconstruct meltwater discharge, fjord circulation, sea-ice conditions, and marine productivity. Biogeochemical proxies will be integrated with sedimentary environmental DNA (Armbrecht, 2020) to reconstruct Holocene histories of Ross Sea Region MPA species: Antarctic krill, Adélie and Emperor penguins, Antarctic toothfish, and phytoplankton, providing baselines for CCAMLR Conservation Measure 91-05.

**Objective 2 – Carbon-cycle feedbacks associated with subseafloor fluid migration and greenhouse gas release since the LGM.**
Constrain the post-LGM history of methane seepage, gas hydrate destabilisation, and subglacial brine and freshwater discharge in North Victoria Land (Busetti et al., 2024; Seabrook et al., 2025). Integrate geochemical, microbial, and geophysical data with numerical modelling to reconstruct fluid migration pathways and assess cry osphere–carbon cycle feedbacks.

**Objective 3 – Ice-sheet dynamics and ocean control on EAIS outlet glacier behaviour.**
Test the "warm-to cold cavity switch" versus glacioisostatic rebound hypothesis for explaining grounding-line migration for outlet glaciers in the Ross Sea sector (Lowry et al., 2024). Drill-core records spanning the deglacial

transition will provide the first geological assessment of ocean thermal forcing on EAIS outlet glaciers in North Victoria Land, informing ice-sheet models and future sea-level projections. The ultra-high sedimentation rates preserved in fjordic deposits enable a unique opportunity within a relatively simple, semi-enclosed glacial system to understand whether the dynamics of AIS outlet glaciers are sensitive to decadal- to millennial-scale climate variability.

## Science Communication Plain Language Summary

Antarctica is undergoing rapid environmental change, with warming oceans, retreating glaciers, and declining sea ice affecting global sea level and ocean circulation. To determine whether these changes are unprecedented and improve future predictions, we need climate records extending far beyond the instrumental period.

This project focuses on Edisto Inlet, a fjord in North Victoria Land (Ross Sea), where up to 125 m of finely laminated marine sediments have accumulated since the end of the last ice age (~11 ka). These sediments preserve an exceptional record of past changes in sea ice, ocean conditions, glacier meltwater, and marine ecosystems.

We will recover this archive using a lightweight drilling system deployed directly on stable fast sea ice. This proven approach enables near-complete recovery of sediment sequences exceeding 100 m below the seafloor, providing access to one of Antarctica's highest-resolution Holocene marine climate archives. Edisto Inlet also hosts one of Antarctica's most distinctive coastal ecosystems, making it an ideal site to investigate links between climate, oceanography, and ecosystem change.

The full drilling strategy includes additional shorter cores (up to 40 m) from nearby sites. Together, these records will provide a regional framework to compare fjord and continental-shelf evolution and reconstruct cryosphere–ocean interactions along the North Victoria Land coast.

The project addresses three main questions.

1) How have Antarctic glaciers, oceans, sea ice, and ecosystems responded to climate change since the last ice age? We will combine sedimentological, geochemical, and environmental ancient DNA analyses to reconstruct past changes in key Ross Sea organisms, including krill, penguins, whales, Antarctic toothfish, and phytoplankton, providing long-term ecological baselines for management of the Ross Sea Marine Protected Area.

2) Did glacier retreat and changing ocean conditions trigger methane release from beneath the seafloor? Geochemical, isotopic, microbial, and sedimentological analyses will reconstruct the timing, intensity, and controls of methane seepage and other subseafloor fluid discharge, improving understanding of Antarctic cryosphere–carbon cycle feedbacks.

3) What controls the advance and retreat of East Antarctic outlet glaciers? Geological records and numerical modelling will test the influence of ocean thermal forcing and glacio-isostatic rebound on grounding-line migration, improving predictions of future ice-sheet change and sea-level rise.

Overall, this project will provide an unprecedented long-term perspective on Antarctic environmental change, improving climate projections and supporting evidence-based management of the Ross Sea ecosystem.