# Origin of massive ground ice in the Eureka Sound Lowlands, Nunavut

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Cameron Roy[1], Wayne H. Pollard[1] and Denis Lacelle[2]
[1]Department of Geography, McGill University, Montreal, QC, Canada; cameron.roy@mail.mcgill.ca
[2]Department of Geography, University of Ottawa, Ottawa, ON, Canada

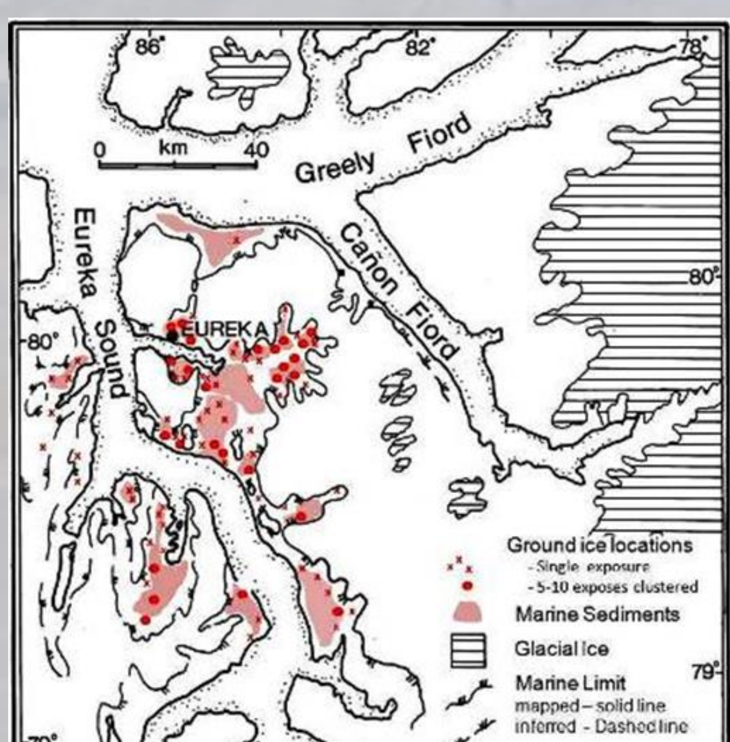
## Introduction

Understanding the nature and origin of ground ice is an important component of reconstructing past climates and the evolution of permafrost landscapes. This study is concerned with resolving uncertainties concerning the origin of massive ground ice in the Eureka Sound Lowlands of Ellesmere and Axel Heiberg islands. Pollard (2000a&b) and Pollard and Bell (1998) have proposed an origin linked to Holocene sea level change and permafrost aggradation with melt water from local ice caps providing the primary groundwater source. The primary objectives of this research are twofold: i) **to characterize the environmental chemistry of massive ground ice bodies for this area** and ii), by looking at the environmental chemistry for massive ground ice from a range of locations and elevations examine **the potential role of other mechanisms of ground ice formation**. This research is timely in view of recent trends in thermokarst and landscape change in this area (Pollard et al 2015).

## Study Area

The Eureka Sound Lowlands are a flat to gently rolling area on central Ellesmere and Axel Heiberg Islands in the Canadian High Arctic.
The **Eureka Sound Lowlands** (ESL) cover an area of ~750 km² on the E coast of Axel Heiberg Island and the W coast of Ellesmere Island, Nunavut.

- High Arctic polar desert
- Depth of permafrost: 500 m (Taylor 1991)
- Mean annual air temperature: -19.7°C
- Mean annual precipitation: <68mm *(Eureka Weather Station, Environment Canada)*




**Left:** map of ESL, with ground ice locations in red (from Pollard et al. 2015)
**Top right:** aerial view of a retrogressive thaw slump, ESL
**Bottom right:** drilling into a massive ice body, summer 2017, ESL

## Permafrost and Ground ice

Deep continuous permafrost underlies the entire area. Ground ice is widespread; pore ice and thin lenses of segregated ice are found in abundance and often grade into massive ice. Ice wedges are ubiquitous over much of the ESL and occur in all surficial materials, although they vary in density, depending on soil type. **Widespread massive ice is associated with marine sediments that lie below the Holocene marine limit**. This stratigraphic setting is a key variable in the analysis of ground ice origin.

## Methods

- Permafrost cores sampled into massive ice bodies using a SIPRE corer in summer 2017
- Cores cut into 2 cm sub-samples for high-resolution profiles
- Analyzed for ice content (gravimetric and volumetric), stable isotopes (δD, $\delta^{18}O$), major cations ($Na^+$, $Mg^{2+}$, $K^+$, $Ca^{2+}$) and anions ($NO_3^-$, $SO_4^{2-}$, $Cl^-$), dissolved organic carbon (DOC)

## δD-$\delta^{18}O$ interpretation

Co-isotope plots (δD-$\delta^{18}O$) are often used to help determine the origin of ground ice, based on the theory that buried glacier ice will have a freezing slope close to the meteoric line (~ 8), while segregated ice will have a slope <6. However, in an open system where there the input of isotopically-depleted water is much greater than the freezing rate, "meteoric" freezing slopes can be produced in segregated ice.

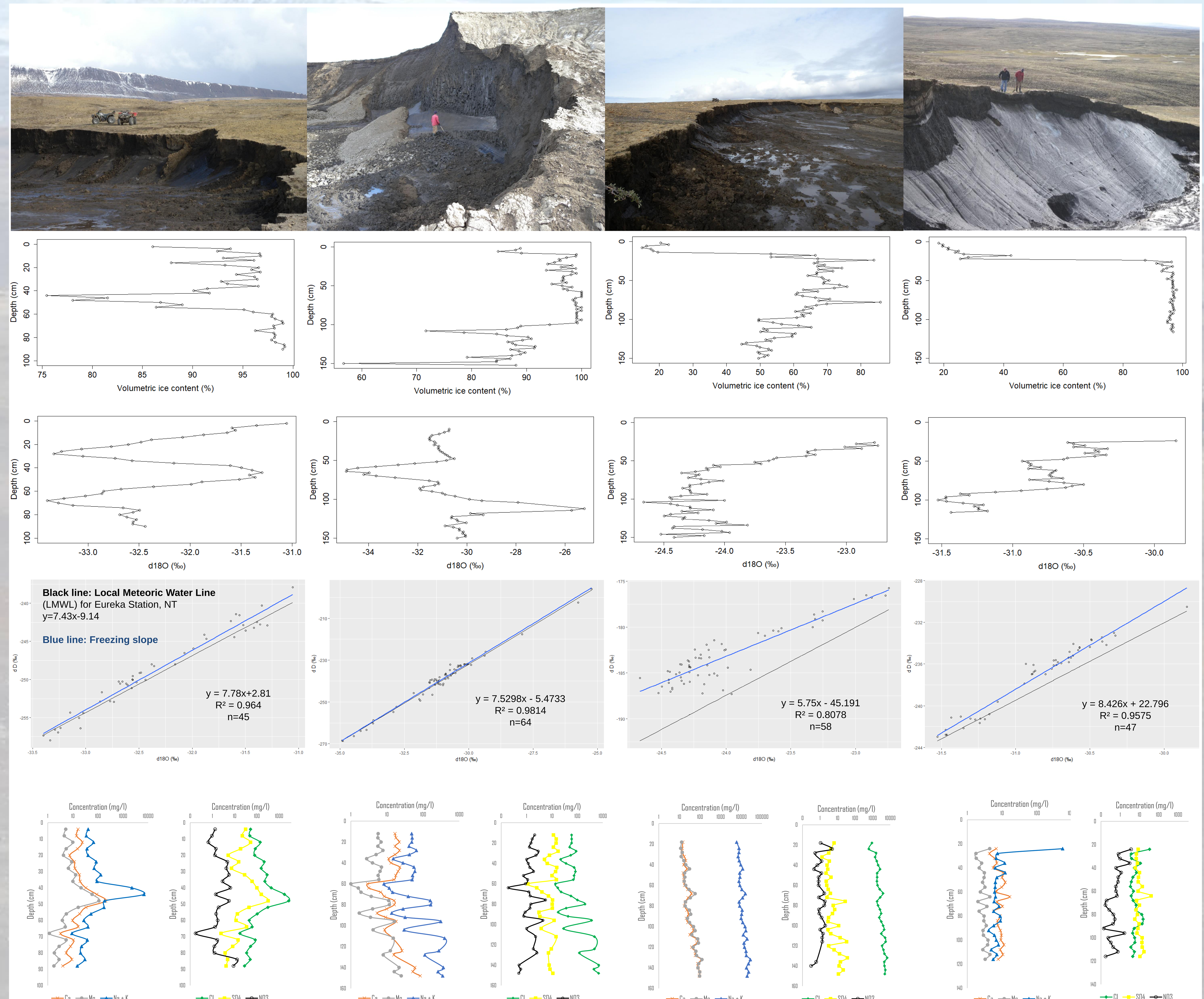
Souchez and Jouzel (1984) give the following equation for a freezing slope (S) at t=0 for the case of a reservoir mixed with a isotopically-depleted input:

$$S = \frac{\alpha[(\alpha-1)(1+\delta i)-(A/S)(\delta A-\delta i)]}{\beta[\beta-1)(1+\Delta i)-(A/S)(\Delta A-\Delta i)]}$$

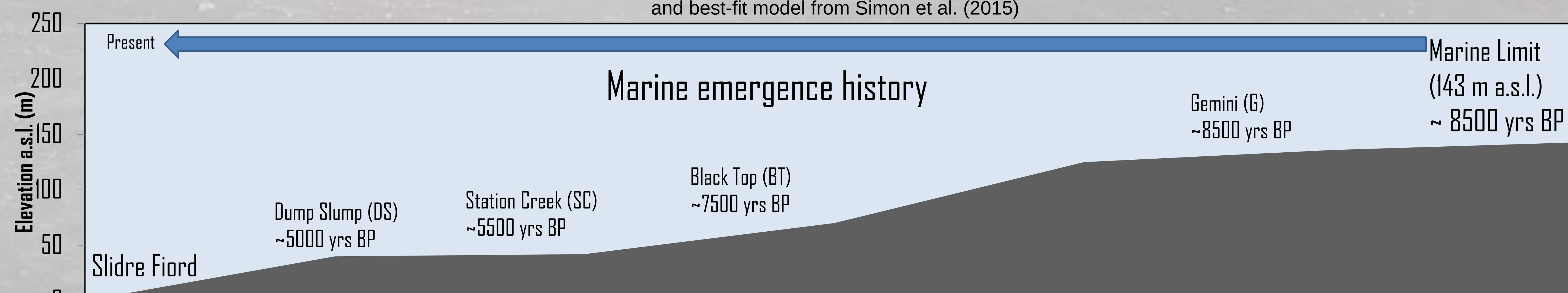
where (*values relevant to this study in italics*):

β = fractionation factor of $^{18}O$ i-w = *1.003 (O'Neil 1968)*
α = fractionation factor of D i-w = *1.0175 (O'Neil 1968)*
δA = input D (‰) ≈ *-260‰ (glacial meltwater from Agassiz Ice Cap; Lecavalier et al. 2017)*
δi = reservoir D (‰) ≈ *-98‰ (modern fiord water, see table above)*
ΔA = input $^{18}O$ (‰) ≈ *-36‰ (glacial meltwater)*
Δi = reservoir $^{18}O$ (‰) ≈ *-13‰ (modern fiord water)*

| Dump Slump (DS) | Station Creek (SC) | Black Top (BT) | Gemini |
|---|---|---|---|
| 40 m a.s.l. | 42 m a.s.l. | 70 m a.s.l. | 125 m a.s.l. |
| 79°58'50"N 85°47'8.75"W | 79°59'53"N 85°53'53"W | 79°59'8.17"N 85°42'3.28"W | 79°58'N, 84°10'W |




Approximate marine emergences for sampling sites across elevational gradient, Fosheim Peninsula, Eureka Sound Lowlands, based off data from Pollard and Bell (1998) and best-fit model from Simon et al. (2015)




## Local water chemistry

| | Slidre Fiord | Black Top Creek | Snowbank | Reticulated ice veins above massive ice body | Collapsed pingo |
|---|---|---|---|---|---|
| δD (‰) | -98.36 | -189.36 | -220.23 | -118.68 | -165.43 |
| δ18O (‰) | -13.21 | -24.83 | -28.77 | -16.02 | -21.84 |
| d excess (‰) | 7.35 | 9.24 | 9.93 | 11.63 | 9.28 |
| DOC (mg/L) | 1.15 | 1.02 | / | 1.79 | 1.02 |
| TN (mg/L) | 0.2 | 0.24 | / | 1.42 | 1.6 |
| Ca (mg/l) | 117 | 24.47 | 0.99 | / | / |
| Fe (mg/l) | / | / | 0.08 | / | / |
| K (mg/l) | 80 | 1.48 | 0.69 | / | / |
| Mg (mg/l) | 199 | 10.21 | 0.28 | / | / |
| Na (mg/l) | 1621 | 10.85 | 3.12 | / | / |
| Sr (mg/l) | 1.32 | 0.08 | 0.00 | / | / |
| SO4 (mg/l) | 596 | 73.00 | 0.55 | / | / |
| NO3 (mg/l) | / | 0.08 | 0.12 | / | / |
| Cl (mg/l) | 4415 | 13.51 | 1.70 | / | / |

## Discussion and Conclusions

Pollard (2000a) concluded that tabular massive ground ice in the ESL is primarily of segregated (intrasedimental) origin, as opposed to buried ice. The massive ice's stratigraphic position (within fine-grained marine sediments and likely underlain by coarse-grained sediments with higher hydraulic conductivities), elevation (below Holocene marine limit) and petrography support a segregated origin and effectively preclude the preservation of buried Pleistocene glacial ice. A landscape model similar to Rampton (1991) was proposed whereby massive ice formed as permafrost aggraded into raised marine sediments, with water continuously supplied from beneath.

Our geochemical analysis, while on-going, seems to support a segregated origin. It implies an open-system freezing scenario, with an input of isotopically-depleted water (glacial meltwater), mixing with a reservoir of isotopically-heavier water, possibly remnant seawater. The rate of freezing and the supply of glacial meltwater from upslope around the time of marine emergence are key factors in explaining chemical and physical variability in massive ground ice in the ESL. For instance, the massive ice sampled from Black Top slump (elev. 70 m a.s.l.) is isotopically heavier, has greater concentrations of dissolved ions and lower volumetric ice content. This could be a reflection of a more rapidly-advancing freezing front, which limits the segregation process and the migration of water to the freezing front.

We will continue this geochemical work to increase its scope, in the hope of obtaining a more complete database of ground ice chemistry across the ESL. We are also working on constraining ground ice age using $^{14}C$-DOC.

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