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Could there be 2-million-year-old ice at North Patch near Dome C, Antarctica?

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New modeling combined with radar observations show that North Patch, near Dome C, presents an exciting potential ice-core drilling location where ice up to 2 Myr old may exist with a detectable paleoclimatic signal.

Drilling for old ice in Antarctica

Ice cores offer scientists an invaluable record of the climate of the past. Whether we are studying the composition of the ancient atmosphere in air bubbles or analyzing water isotope ratios ($\delta^{18}O$ and δD) to infer past temperatures, obtaining the oldest ice possible remains a challenge for ice-core research. Currently, the oldest continuous ice core comes from the European Project for Ice Coring in Antarctica (EPICA) at Dome C (EDC), which has given us a climate record from the past 800 kyr (Bazin et al. 2013). The International Partnerships in Ice Core Sciences (IPICS) community set the Oldest Ice challenge of extracting a continuous ice core which covers over 1 Myr (Fischer et al. 2013). An ice-core record of this length would allow us to directly measure past atmospheric greenhouse gas concentrations. It would also help us to understand the change in the periodicity of climate cycles, which occurred between 1.2–0.7 Myr BP, known as the Mid-Pleistocene Transition (Clark et al. 2006). Fischer et al. (2013) determined that a potential Oldest Ice site should have a low accumulation rate and a relatively thin ice sheet to avoid basal melting, and minimal horizontal ice flow, as basal sliding can cause distortion or even folding of the deepest, oldest ice (Dahl-Jensen et al. 2013).

The European Beyond EPICA consortium selected a site and began drilling in 2021 at a location known as Little Dome C (LDC) on the East Antarctic Plateau, where they hope to find ice up to 1.5 Myr old. The Australian Antarctic Division has also selected a site on LDC for their Million Year Ice Core (MYIC) project. In this article, we look at North Patch (Parrenin et al. 2017), an area approximately 10 km north of EDC. Our preliminary age modeling presents North Patch as an exciting prospect for a new Oldest Ice drill site with ice potentially up to 2 Myr old.

1D numerical age-depth model

Our model determines the age of ice, past accumulation rates and melt rate at a given location. It is a 1D model which means it only considers the vertical flow of ice and takes into account three parameters. The first parameter is the model's best-fit ice-sheet thickness. From the difference between the best-fit ice thickness and the observed ice thickness, we can infer either a basal melt rate or a layer of stagnant ice (ice with no vertical flow). The second model parameter is the average past snow accumulation rate whose temporal variations can be inferred using the EDC ice-core record (Bazin et al. 2013). The accumulation rate corresponds to an annual snowfall which forms a layer on the surface of the ice sheet. Subsequent snowfall covers and compresses the snow below, slowly turning it into ice. As each layer is compressed further, it becomes thinner and moves deeper, as time goes by. The final parameter in the model accounts for this thinning process.

We provide the model with known age-depth constraints from observations made with radar surveys. We can use radar systems to send a signal deep into the ice sheet, and from the reflections we can detect the internal structure of the ice sheet. The radar images show internal reflection horizons.

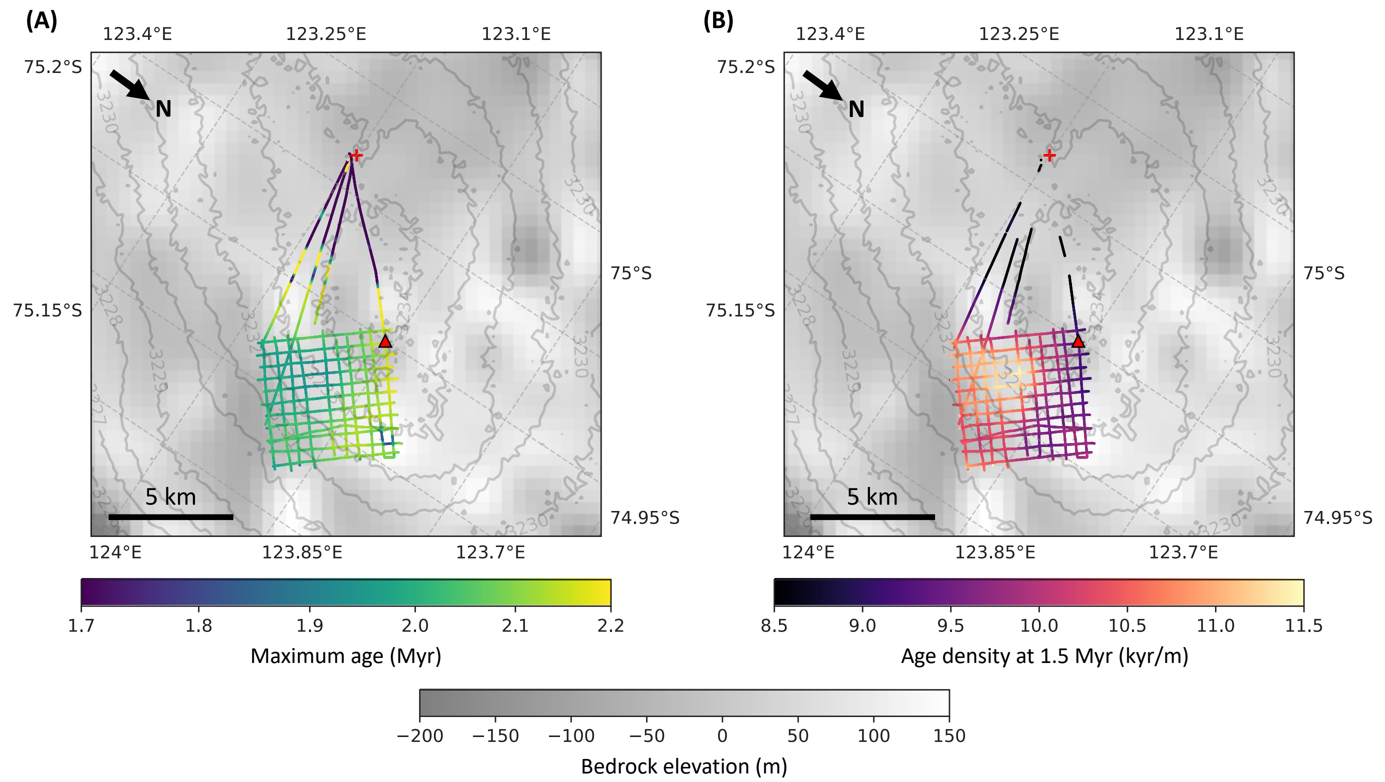

Figure 1: The model was run using 20 horizons traced in DELORES radar data at North Patch. The red cross marks EDC and the red triangle marks a promising North Patch site shown in Figure 2. **(A)** Modeled maximum age of ice at North Patch. **(B)** Modeled age density of 1.5 million-year-old-ice at North Patch.

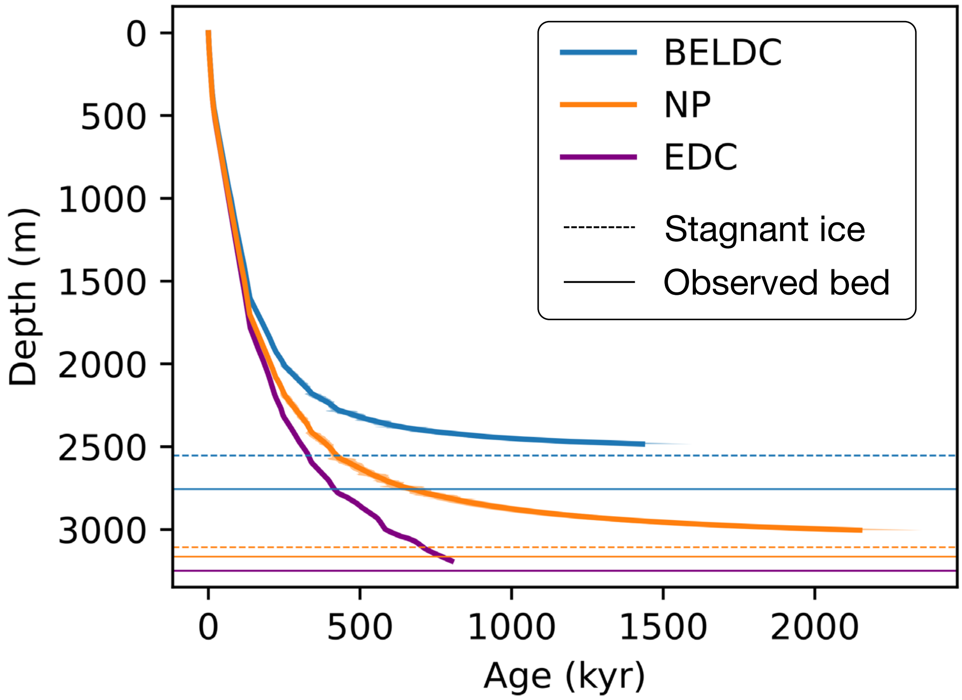

Figure 2: Age-depth profile of EDC (purple) determined experimentally (Bazin et al. 2013), modeled profiles for Beyond Epica LDC (BELDC) – the current ice-core drill site for Beyond EPICA (blue) project (Chung et al. 2023) - and for a promising North Patch site (orange). Dashed lines show the top of the stagnant ice layer, and solid lines show the bedrock depths observed in radar data in colors corresponding to each location.

Since the ice at each horizon was formed from snow which fell at the same time, under the same conditions, the age of the ice along a given horizon is constant. By connecting these radar lines to the EDC age-depth profile, we can determine their ages. Taking into account the three model parameters mentioned above –mechanical ice thickness, average past accumulation rate, and the thinning parameter– the model fits the ages of these isochrones and the surface, and extrapolates down to the bedrock to give us a complete age profile along the radar line.

Modeling at North Patch
At North Patch, the sledge-borne DEep LOoking Radio Echo Sounder (DELORES) was used to collect radar data from 21 lines in a 5x5 km^2 grid (Chung et al. 2023). From these data, 20 isochrones were dated by linking them to EDC with four radar lines (Fig. 1). The isochrones were then used to constrain a 1D numerical model.

The model is able to determine the age of ice at a given depth from the surface. The maximum age of the ice at a given location is either at the bedrock, or if the age density is equal to 20 kyr/m (20,000 annual layers per vertical meter). At this limit, paleoclimate reconstruction becomes impossible as obliquity cycles cannot be distinguished, at least using current experimental techniques (Fischer et al. 2013). Figure 1a shows that the maximum ice age predicted by the 1D model is generally between 2.2 and 1.9 Myr, around 500 kyr older than the expected age at the current Beyond EPICA drill site. The age density for 1.5 Myr-old ice at North Patch is generally between 9 and 11 kyr/m, which is twice as good as what we expect to find at Beyond EPICA (Chung et al. 2023) (Fig. 1b).

Modeling showed that there is very little, if any, basal melting at North Patch. There is also significantly less stagnant ice, which means that the climate record could be analyzed over the entire ice column. This results in thicker annual layers than at LDC, which would give us larger ice samples to analyze.

Potential North Patch drill site comparison
We chose a promising Oldest Ice location at North Patch and compared the age-depth relationship with that of the EDC and Beyond EPICA ice-core sites (Fig. 2).

The EDC ice core gave us a climate record (Fig. 2) which could be analyzed along almost the entire length, as the large ice thickness meant that age density was relatively low (Bazin et al. 2013). However, basal melting meant that the paleoclimatic record older than 800 kyr had been distorted, or completely destroyed (Tison et al. 2015). Modeling suggests that there is no basal melting at the Beyond EPICA drill site on LDC and there could be ice up to 1.5 Myr-old (Fig. 2). However, due to the thinner ice sheet, the oldest ice is likely to have very small annual layer thicknesses (one meter of ice covers over 20 kyr, Chung et al. 2023), so diffusion processes may make it difficult to interpret the paleoclimatic record. The modeling in Chung et al. (2023) shows that an ice core at North Patch could offer a middle ground (Fig. 2). This ice sheet is around 3200 m thick, resulting in lower age density, but there also appears to be little-to-no basal melting, leaving the oldest ice intact.

Outlook
The DELORES radar system is not the highest resolution available, therefore, it would be beneficial to apply newer radar systems to North Patch in order to confirm the findings in our study. The logistics of constructing a drill site at North Patch would be eased due to its proximity to the French-Italian Concordia station. Despite this, the age modeling suggests that the ice-core age-depth relationship at North Patch would be very different to those of EDC and Beyond EPICA (Fig. 2).

All that remains to be determined is who will choose to exploit this great opportunity to extract the (up to 2 Myr-old) Oldest Ice available at North Patch.

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