Improvement in dating of the Dome Fuji ice core using O_2/N_2 (80-165 ka)

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The Dome Fuji ice core preserves valuable information on the climatic changes over the last 720 kyr, which enables to investigate forcings and mechanisms in the Earth's system. Precise ice core chronology is essential to determine sequences and durations of climate events, and to examine the phasing with forcings and other paleoclimatic records. Orbital scale variations in O_2/N_2 ratio of occluded air in the Vostok ice core are similar to those in local summer solstice insolation[1)]. By using this similarity, Kawamura et al. (2007) synchronized the O_2/N_2 variations in the Dome Fuji and Vostok ice cores with local summer insolation, and established chronology for the ice cores with accuracy generally better than ±2000 years (DFO-2006). However, it was recently pointed out by using detailed age matching between Dome Fuji, EDC and Chinese speleothem records that the DFO-2006 chronology around 90 kyr BP is too old by ~3 kyr[3)]. Possible cause of this error is dislocation of O_2/N_2 peaks because of large noise in the O_2/N_2 record. Recently, O_2/N_2 variations between 300 and 800 kyr has been reconstructed from EPICA Dome C ice core[4),5)], however, their records do not always show similar variation with local summer insolation. Thus, their O_2/N_2 record was not used for orbital tuning. These recent studies motivate us to examine the reliability of age markers based on the O_2/N_2 ratio of Dome Fuji ice core. In this study, we reanalyzed O_2/N_2 ratio in the first Dome Fuji ice core for 1200 –1974 m, which covers 80 –165 kyr BP.

Fractionation of O_2/N_2 ratio occurs from ice surface during storage[6)]. Because the first Dome Fuji core has been stored for about 20 years, we expect fractionated O_2/N_2 near the surface of ice. We thus tested different thickness of surface shaving, and found that shaving-off of about 1 cm of surface (and only using the inner part of the ice) is required for precise measurements for the ice samples below 1200 m depth. Because of this careful examination and improvement in methodology, our new O_2/N_2 data set on average do not indicate preferential loss of O_2. Reproducibility of O_2/N_2 ratio are ±0.425‰ for 1200 –1440 m, ±0.263‰ for 1440 –1640 m and ±0.088‰ for 1640 –1974 m, respectively.

We find large scatter in the new O_2/N_2 data between 1200 and 1440m (typical amplitude: ~6 –10 ‰). This depth range is just below bubble-clathrate transition zone where both air bubbles and clathrate hydrates were observed by microscopes. To investigate the cause of this scatter, we conducted a high-resolution continuous analysis at 2.5-cm resolution for 1399.030 –1399.484 m. The O_2/N_2 shows unexpected wave-like variation from -17 to -9 ‰with a wavelength of ~18 cm. The amplitude is comparable to the typical scatter in the O_2/N_2 data set from the discrete 11-cm samples. If we take 11 cm average of the high-resolution data, the average ratio only varies by ±~1‰, which is insufficient to explain the scatter in the discrete data. Our current speculation is that the wavelength and/or amplitude of the O_2/N_2 variations in other depths may be larger than those in the investigated section, and that O_2/N_2 of 11 cm samples can also vary by up to 10 ‰.

Our new Dome Fuji O_2/N_2 record confirms strong correlation with local summer insolation. Assuming no phasing between O_2/N_2 and insolation variations, O_2/N_2 data was smoothed by a low-pass filter with the cut-off period of 16.7 –10.0 kyr, and then tuned with local summer solstice insolation by peak-to-peak matching[2)]. Because the scatter in 1200 –1440 m does not reflect insolation signal, we rejected data points as outliers if they deviate from fitting curve by more than 3.3‰.

Compared with the DFO-2006 chronology, the new age scale (DF-2016) is younger around 90 and 130 kyr BP, while it is older around 150 kyr BP. There were sharp steps in annual layer thickness (calculated from depth –age relationship) at 94.2 and 150.3 kyr BP from DFO-2006[3)], but these unnatural steps disappeared in that from DF-2016. The DF-2016 and speleothem (U-Th) age scales agree within 1000 yrs. These results indicate that the revised chronology greatly improved from the DFO-2006 chronology.

To summarize, even though large O_2/N_2 fractionation occurs near the surface of the ice core over two decades of storage, the original O_2/N_2 ratio is preserved in the inner part of ice if it is stored at -50°C, and it can be precisely measured by sufficiently removing the ice surface. Accurate chronology can be constructed by orbital tuning of the high quality O_2/N_2 ratio from the Dome Fuji ice core with local summer insolation.

1) Bender, M. L., EPSL, 2002. 2) Kawamura et al., Nature, 2007. 3) Fujita et al., CP, 2015. 4) Landais et al., CP, 2012. 5) Bazin et al., CP, 2016. 6) Ikeda-Fukazawa et al., EPSL, 2005.

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