Progress of glaciological research activities at the Dome Fuji station and its vicinity

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***Summary***

Ice cores from the Antarctic interior have provided valuable information on past climate changes. After the completion of deep ice coring at the Dome Fuji station in the 2000s, the Japanese Antarctic Research Expedition (JARE) has completed the transportation of all the ice core samples to Japan, providing samples for paleoclimatic studies over the last 720,000 years. JARE, in collaboration with international partners, has also been conducting field studies for locating a new drilling site for the oldest ice core in the Dome Fuji area. This information paper describes the recent field research and associated activities at the Dome Fuji station and its vicinity.

***1. Introduction***

In January 1995, the Japanese Antarctic Research Expedition (JARE) established the Dome Fuji Station (77° 19′  S, 39° 42′  E, 3,810 m above sea level) on the highlands of Dronning Maud Land. In the following three years, the expedition teams overwintered at the station and performed deep ice core drilling to a depth of 2,503 m; this project is referred to as the First Dome Fuji Project. Starting in 2002, the National Institute of Polar Research carried out another deep coring, referred to as the Second Dome Fuji Project, at the Dome Fuji station, to a depth of 3,035 m by 2007.

The next deep drilling (the Third Dome Fuji Project) is planned, and preparatory activities for locating old ice, including international collaborations, have been ongoing in the vicinity of the Dome Fuji station. The Third Dome Fuji Project aims to collect a deep ice core reaching back more than 1 million years to reconstruct past Antarctic environments and atmospheric greenhouse gases concentrations. It will provide crucial information on the mechanisms for the dominant periodicity of glacial-interglacial cycles, which was much shorter than that over the past approximately 800,000 years. The project is intended to be a direct contribution to the IPICS Oldest Ice Core Project, which states the need for multiple ice cores going back in time into the shorter glacial cycles. IPICS, the International Partnership in Ice Core Sciences, is an Expert Group of SCAR Physical Science Group, and is also supported by Future Earth PAGES (Past Global Changes) and IACS (International Association of Cryospheric Sciences). Implementation of this project is also directly connected to the SCAR Horizon Scan (5. How did the climate and atmospheric composition vary prior to the oldest ice records?) (Kennicutt et al., *Nature,* 2014).

***2. The Dome Fuji station***

Transportation of a part of the second Dome Fuji ice core was carried out in the 2018 - 2019 Antarctic summer season. With the success of this mission, all the Dome Fuji ice cores are now stored in Japan, mainly at the National Institute of Polar Research in Tokyo, and they will be provided for various paleoclimatic studies by ice-core communities, including international collaborations. Also, an extension of the casing in the second Dome Fuji deep borehole will be carried out in the 2020 - 2021 summer season, in order to maintain access to the precious 3,035-m-deep borehole for the future observations. The Dome Fuji station currently stores ice chip samples from the last deep drilling, and the station will continue to serve as storage for new ice cores, tools, and supplies for research activities around Dome Fuji. On the other hand, the current drill trench and living quarters of Dome Fuji station will not be suitable for the subsequent deep ice coring - the IPICS Oldest Ice Core project - because the melting of the ice-sheet bed at the site makes the collection of older ice core virtually impossible at the station and its immediate surroundings.

***3. Ice and snow observations, and preparatory activities for the subsequent deep drilling in the vicinity of Dome Fuji station***

Analyses of the Dome Fuji ice cores have provided vital information on the Antarctic and global paleoclimate, such as accurate ice-core chronology and atmospheric CO2 concentrations for multiple glacial cycles (Kawamura et al., *Nature,* 2007), surface temperature histories of Antarctic interior and Southern Ocean (Uemura et al., *Nature Commun.,* 2018), the so-called bipolar seesaw in multiple glacial periods (Dome Fuji Ice Core Project Members, *Sci. Adv.,* 2017; Buizert et al., *Nature,* 2018), and past variations of aerosols and biological activities (Iizuka et al., *Nature,* 2012; Goto-Azuma et al., *Nature Commun.,* 2019; Oyabu et al., *J. Geophys. Res.,* 2020).

The studies of the Dome Fuji ice core have also revealed that the base of the ice sheet has been melting, and this is the reason for the bottom age of the second Dome Fuji ice core (approximately 720,000 years) being significantly younger than expected under the assumption of a frozen bed. On the other hand, recent modelling studies have suggested that ice of over 1 million years may exist in the Antarctic interior, including areas around Dome A, Dome C, and Dome Fuji (e.g., Fischer et al., 2013). This, together with the advantage of the existing Dome Fuji ice core with the known depth-age relationship, makes the Dome Fuji area appropriate for further glaciological surveys using contemporary techniques combined with ice-sheet modelling, for mapping old ice.

Toward these goals, JARE has conducted surveys around Dome Fuji in two consecutive summer seasons (59th JARE in the 2018 - 2019 season and 60th JARE in the 2019 - 2020 season). The JARE 59th Dome Fuji field team, consisting of ten personnel and six snow vehicles with sleds, started a ground traverse from Syowa Station in early November, and conducted three months of activities that included a ground-based deep sounding radar survey over a total distance of nearly 3,000 km, and shallow ice coring at three locations, within a radius of about 100 km around the Dome Fuji station. Installation of an automatic weather station, and in situ observation and sampling of surface snow along the routes, were also conducted.

After the analyses of the JARE 59th field data, the target area for further surveys was narrowed to the southern side of the Dome Fuji station, where the ice sheet is found to be thinner, and the surface mass balance is found to be smaller than at Dome Fuji. The JARE 60th Dome Fuji field team, consisting of ten personnel (five scientists and five logistics personnel) and six vehicles, hosted the Japan-U.S.-Norway international glaciological survey, in which two scientists from Norwegian Polar Institute and high-resolution ice radars from two U.S. universities joined the JARE team at about the midpoint toward Dome Fuji, using a Twin Otter aircraft operated by the British Antarctic Survey (the incoming and outgoing flights were both funded by the Beyond EPICA project). The international team put a base camp about 50 km south of the Dome Fuji station, and its activities included detailed ground-based radar surveys, a 142-m ice coring with firn air sampling to approximately 100 m, and in situ snow observations. The data collected during the two field seasons will be analyzed in collaboration with international collaborators, including those in the United States, Norway, and France, and the outcomes and ice-sheet modelling results will be combined to make the decision on the Oldest Ice Core drilling site in the vicinity of the Dome Fuji station.

All JARE 64th inland activities during the 2021 - 2022 season were unfortunately cancelled because of the COVID-19 pandemic. The next Dome Fuji field activity was carefully planned in JARE 63rd (the 2021 - 2022 season) to recover the delay. It successfully conducted two traverses to Dome Fuji, extended the casing pipe of the Dome Fuji borehole as explained above, carried out an ice radar survey for finalizing the drill site selection, and transported fuel and materials to the Dome Fuji station.

In JARE 64th (the 2022 - 2023 season), the Dome Fuji field team will make a trench for deep drilling and ice-core processing, which are in the design stage but have the same basic structures as those for the last two Dome Fuji projects. It is a 3-m-deep, 4-m-wide trench with a length of several tens of meters, with a tentlike ceiling above the snow surface where the deep drill sites, and a flat ceiling elsewhere. The drilling site will have living and sleeping modules, a workshop module, and a generator housing, all on sleds. Drilling of a shallow ice core, reaming of the shallow hole, and installation of casing pipes will also be conducted if time allows after the construction of the drill trench.

***4. Next deep drilling (the Third Dome Fuji project)***

The third Dome Fuji deep drilling will be carried out between 2023 and 2027. Deep drilling, bedrock sampling, deviation drilling, and borehole logging will be performed in the four consecutive summers starting in the 2023 - 2024 summer. Each summer activity at the drilling site is expected to last for about two months. For the deep drilling, an electromechanical drill will be used with borehole liquid to prevent borehole closure.