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IMPULSE RADAR SOUNDING OF FOSSIL ICE WITHIN THE KURANOSUKE PERENNIAL SNOW PATCH, CENTRAL JAPAN

by

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ABSTRACT

The impulse radar was found to be useful in surveying the internal structures of wet snow patches in mountain regions. Radar profiles revealed that the thickness of the perennial ice was 30 m, possibly the thickest in Japan. An unconformity widely extended nearly parallel to the surface at the depth of 2 to 9 m and divided the ice into two parts.

1. INTRODUCTION

The Kuranosuke snow patch is located in the Mt. Tateyama (3015 m) region in the Northern Japanese Alps, where the snow accumulation in winter is about 15 m and the snow melt in summer is nearly the same. It has been known that moulin-like vertical holes appear once every few years after the firn has melted. Yoshida and others (1983) investigated these holes in detail and considered that there had been crevasses or cracks in the snow patch in the past.

In the present work, the internal structure and the bottom topography of this snow patch were investigated to understand the mechanism of its formation.

2. DIRECT OBSERVATION OF THE PERENNIAL ICE STRUCTURE

M. Yoshida entered into a vertical hole (Y in Fig.1) and observed the stratification and the grain size of the perennial ice in October 1979. The vertical cross-section of the hole and the stratification are illustrated in Figure 2(a). The hole was 19 m deep. The dip of the layer boundary changed from 10° near the surface to 30° near the bottom. The thickness of the layers became narrower with increasing depth. The grain diameters were measured and found to be 10–40 mm near the bottom.

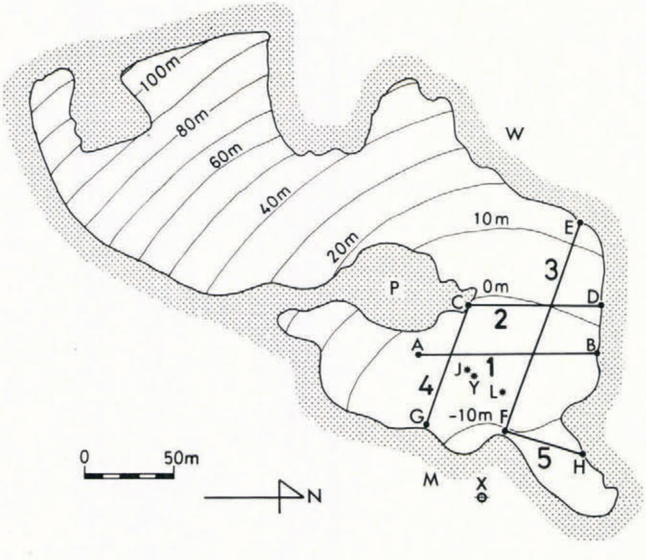

Fig.1. Topographic map of Kuranosuke snow patch. Symbols: 1–5: measuring lines; A–H: end points of lines; J, L and Y: vertical holes; M: end moraine; P: pro-talus rampart; W: cirque wall.

The same observations were carried out at two holes, J and L in Fig.1, in September 1980. The surface of the perennial ice at that time was 1 m lower than that in October 1979. It was seen at both holes that the dip of the boundary layer abruptly changed across the gravel layer at the depth of 4 m.

Some core samples were taken in August 1980 to examine the stratification and the grain size profile. The results for one of them are illustrated in Fig.2(b). In this figure, granular snow covering the perennial ice is not shown. The level of the ice surface was approximately the same as that in October 1979. The stratification was quite different between both sides of the gravel layer at the depth of 5 m. Furthermore, the grain diameter of the upper ice was nearly uniform and approximately 1.5 mm, while that of the lower ice was widely scattered and there were large grains up to 30 mm. These suggest this gravel layer is an unconformity. This was also identified in the other core samples.

It is reasonable to consider that the gravel layers at a

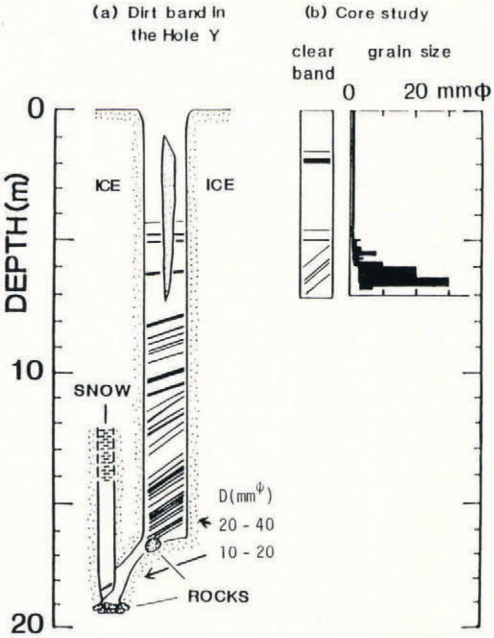

Fig.2. Stratification and grain-size profile.

depth of 4 m, observed in the holes J and L, are identical with the unconformity found in the core samples. In the case of the hole Y, it was impossible to confirm from the observational results whether the dirt layers at the depth of 5 or 7 m were the unconformity. The radar profiles described later suggest the layer at depth of 7 m to be the unconformity.

The grain size of the ice was very different on opposite sides of the unconformity. According to Tusima's (1978) experimental formula on the recrystallization rate of ice grains immersed in water, the formation age of the lower ice is at least 1000 years if it has recrystallized without non-hydrostatic stress. It is interesting to know the kind of climatic and stress conditions under which the ice has been formed.

3. RADAR SOUNDING

3.1. Procedure

Radar echo-sounding for the bottom topography and the internal structure of the perennial ice was carried out in September 1983. The topographic map of the snow patch at that time is shown in Fig.1. No vertical hole appeared in that year. The level of the snow patch's surface was close to that in October 1979. The soundings were made along five lines, 1-5, as shown in Fig.1.

The impulse radar used in the present investigations was a model KSD-2A developed by KODEN Electronics Co. Ltd. The main feature of the equipment is summarized in Table I. The equipment consists of eight blocks: two antenna units (for 140 and 400 MHz), a control unit, an oscilloscope for A-scope, an image processor unit, a coloured CRT unit for B-scope, a cassette data recorder and an engine generator.

The 140 MHz antenna was set on a snow boat and moved along measuring lines at as constant speed as possible. The control unit and the data recorder were carried by an investigator. The monitoring units were unconnected during traverse because of easy movement. Echo data recorded on cassette magnetic memory tapes were reproduced on A- and B-scopes and analyzed after returning to the laboratory. Digital image processing techniques were also used.

3.2. Dielectric constants of snow and ice

The dielectric constant of wet snow depends on its density and water content and the frequency of the electromagnetic wave used for measurements. The constant, however, was not measured. Then, the permittivity of snow was taken to be 4.0, which was derived from our permittivity measurements using the same equipment on various types of snow cover (Yamamoto and others 1986). According to the theoretical formula of Yamamoto and others (1984), this value is realized in snow having the wet density of 0.53 Mg/m^3 and the water content of 15 weight%.

The dielectric constant of ice also depends on its density and water content and the frequency. It is, however, shown from both a theoretical consideration and an impulse radar measurement at the ice body formed within a lava cave called "Fuji fuketu", that 3.2 (the permittivity of pure ice at very high frequency) can be used for this purpose (Yamamoto and others 1986). Under these approximations, we suspect that the error of the estimated depth of interfaces is within 10%.

3.3 Observation results

A radar profile along line 1 is shown in Fig.3. In the figure, the horizontal line (ss) at the travel time of 0 ns shows the surface of the snow patch. The snow/ice interface (si) is observed at depths from 1 to 3 m. The strong intensity from the unconformity (u) described above is seen at the depths from 4 to 8 m. It is reasonable to consider that the gravel deposited on the unconformity gives rise to strong reflection. The bottom of the ice body is bounded by the foot of a pro-talus rampart at distances from 0 to 35 m and that of a cirque wall from 70 to 100 m. The slope of the cirque wall is so steep that its echo is very weak. The strong echo from bedrock is observed at distances between 25 and 90 m. It becomes deeper under the pro-talus rampart and the cirque wall, since the permittivity of the detritus is higher than that of ice. In this figure, the maximum depth of the snow patch is approximately 30 m at a distance of 70 m. It is possibly the thickest perennial ice in Japan. No echo shows that fossil ice is buried under the pro-talus rampart and/or cirque wall.

In Fig.3, at least three interfaces (a, b, and c) are distinguished in the ice body under the unconformity. Simple geometrical analyses show that they are not ghost echoes from the pro-talus rampart, the cirque wall and the end moraine. It is reasonable to consider that these interfaces are gravel layers, since such strong echoes cannot occur due to other layer boundaries. In the cross-section of Fig.3, the unconformity and gravel layers form a south-facing slope.

TABLE I. THE MAIN FEATURE OF A KODEN IMPULSE RADAR, MODEL KSD-2A (FACILITIES NOT USED IN THE PRESENT INVESTIGATIONS ARE NOT DESCRIBED)

Antenna system and type	monostatic bow-tie type
Transmission pulse	
Pulse shape	monocycle sinusoidal
Pulse width	6 ns
Centre frequency	140 MHz
Peak power	50 W
Pulse repetition rate	50 kHz
Receiving system	
RF gain	40 dB
LF gain	40 dB with the sensitivity time control
Display	
A-scope	
B-scope (colour CRT)	
Image processing	smoothing, space filter, correlation, Rosenfeld method, difference method
Data record	
Medium	cassette magnetic memory tape
Available input	echo, synchronous, displacement, voice signals

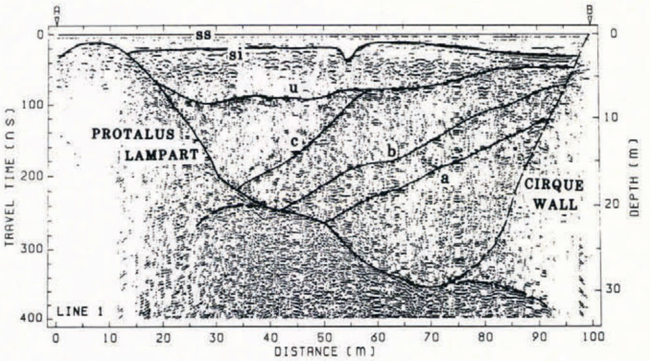

Fig.3. Radar profile of line 1. Symbols are explained in the text.

Radar profiles of lines 2-5 were also analyzed. The details have already been described elsewhere (Yamamoto and others 1986). Figs 4 and 5 show the estimated sections of the internal structure and bottom topography of the snow patch under lines 2 and 3, respectively. The unconformity is raised 5 m near the distance of 20 m of line 2 (Fig.4). Three gravel layers (d, e and f) were distinguished from the radar profile of line 2.

Line 3 was set approximately parallel to the fall line. The snow/ice interface, the unconformity and five gravel layers were identified as shown in Fig.5. The depths of these interfaces in Fig.5 coincide with those in Figs 3 and 4 at the points of intersections between lines 1 and 3, and between lines 2 and 3. Figs 3, 4 and 5 show that the unconformity is widely extended, nearly parallel to the snow patch surface and at depths from 2 to 9 m. The radar profiles of lines 4 and 5 showed that the unconformity did not exist under these lines.

4. DISCUSSION AND CONCLUSIONS

The impulse radar was found to be useful in surveying the internal structure of wet snow patches.

The stratification of vertical hole Y, and the radar profile at the distance of 35 m along line 1 agree well with each other. The unconformity and the gravel layers in the radar profile coincide in depth with thick dirt layers.

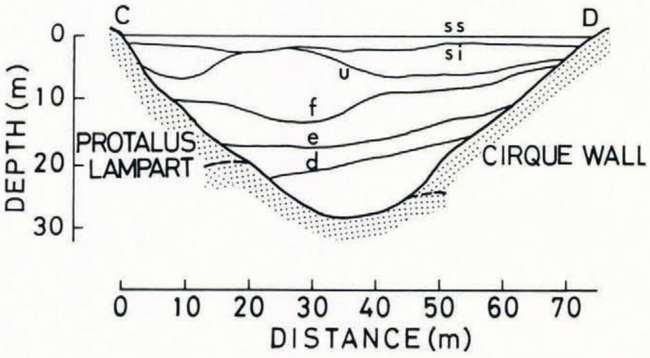

Fig.4. Estimated structure under line 2.

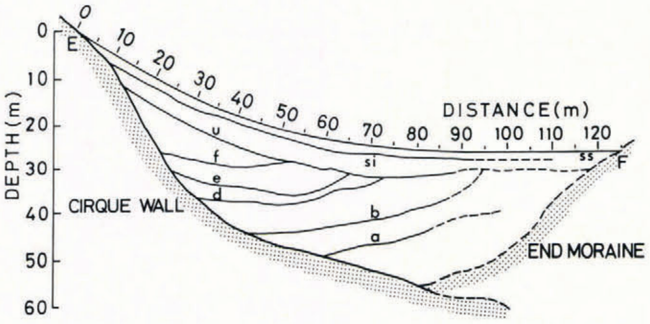

Fig.5. Estimated structure under line 3.

The unconformity bent under line 2. It is reasonably explained that the bend was caused from enhancement and reduction of snowmelt due to deposition of detritus on the surface of the snow patch (Yamamoto and others 1986). This process plays an important role in the layered structure formation of the snow patch.

The radar stratifications and the grain-size profile show that there exist two ice bodies of different age, separated by an unconformity. It is possible to infer that the lower ice is old glacier ice, although there is no active glacier at present in Japan. The ice might have been prevented from surface melting by the heavy snow accumulation in the winter and the thick debris cover. Furthermore, bottom melting might have been small due to the existence of permafrost, which is conceivable, as this location is close to the lower limit for discontinuous permafrost. Core samples will be taken to determine the formation age of the bottom ice to confirm the above.

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