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RESULTS FROM THE RADIO ECHO-SOUNDING ON PARTS OF THE JOSTEDALSBREEN ICE CAP, NORWAY

by

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ABSTRACT

The paper describes instrumentation, navigation methods, and interpretation problems from radio echo-sounding on parts of Jostedalsbreen. A map of the subglacial topography is presented. Ice thickness ranges from 60 m to 600 m with most sections between 150 m and 300 m.

INTRODUCTION

During spring/early summer in 1981, 1984 and 1985, radio echo-sounding has been carried out on parts of the Jostedalsbreen ice cap in Western Norway (Fig.1). The soundings were made along 600 km of profiles, covering a total area of 60 km^2 (Fig.2). The purpose of the investigations was to map parts of the subglacial topography of the glacier and to establish sampling and navigation routines for efficient radio echo-soundings of other Norwegian glaciers.

METHODS

The instrument was a Mark II sounder, designed and constructed at the Science Institute, University of Iceland. It is a further development of the instrument described by Sverrisson et al. (1980). The analog presentation of the signals at a monitor is recorded on a photographic film.

Three different types of navigation were used. Only simple map and compass navigation was used in 1981 and the accuracy could not be calculated. For the 1984 survey, a stick-marked grid was established by means of a theodolite and an electronic distance meter. The grid for most of the area was 400 x 400 m and the accuracy of the x and y coordinates of each point is calculated to be better than 20 m. The setting up of such a grid proved to be very time-consuming and weather-dependent. For construction of the subglacial map, the surface z coordinates had to be taken from existing surface maps.

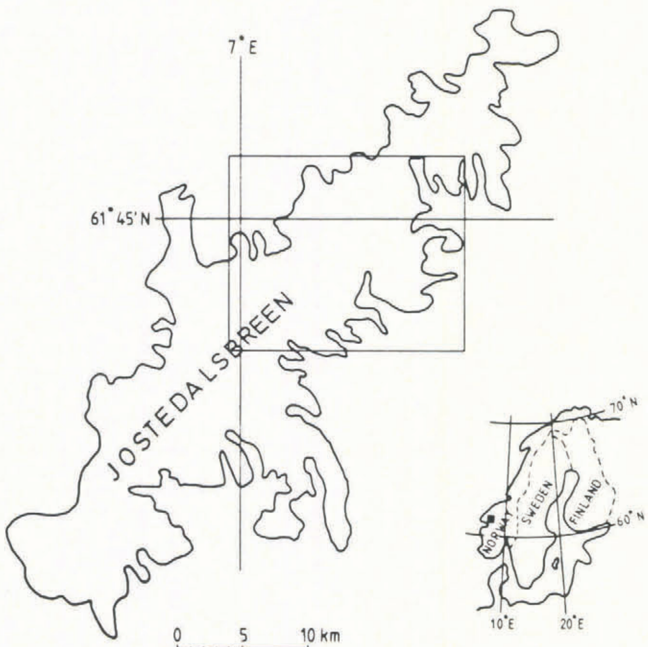

Fig.1. Location map of the investigated area.

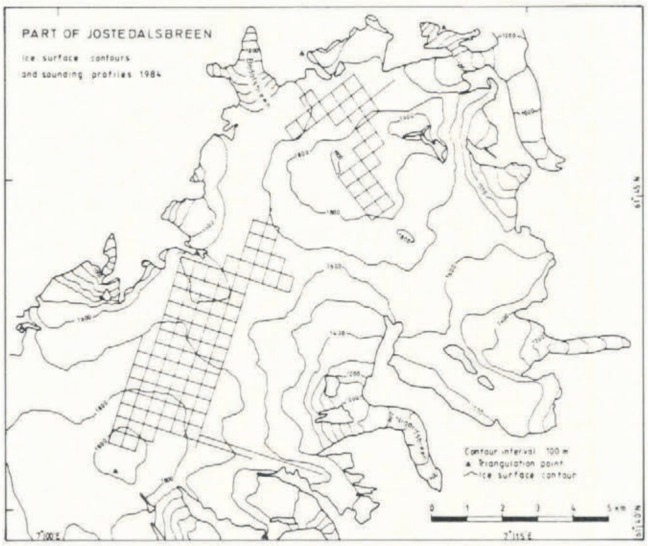

Fig.2. Ice surface contours and sounding profiles.

For the 1985 survey, a mobile, radio-navigation system was used (Motorola MRS III miniranger controlled by an HP microcomputer). The mobile system measured the distance from four transponders, placed at fixed points with determined coordinates. The position was calculated by a least-squares algorithm and resulted in map coordinates with a standard deviation less than 3 meters. A Digiquartz pressure sensor was used to measure the elevation of each point in the track. The pressure recordings were adjusted for air pressure variations every day. The advantage of this was a more exact surface z coordinate than the map could provide. Jostedalsbreen is thought to be a temperate glacier. Watts et al. (1975) and Watts and England (1976) demonstrated that internal scattering from water-filled cavities in the ice was a major problem in radio echo-sounding of temperate glaciers. The frequency of the sounder has to be low enough to ensure that most of the inhomogeneities caused by water have a smaller extent than the wavelength. The frequency window of the sounder is 0.1 − 10 MHz and the centre frequency is 8 MHz, determined from the length of the antenna; $f = c/(4 \cdot h \cdot \sqrt{\epsilon})$, where h is the half length of the antenna, c is the speed of light and ϵ is the real part of the effective permittivity. (Ferrari and others, 1976.) The instrument gave good results for ice thicknesses down to 600 m.

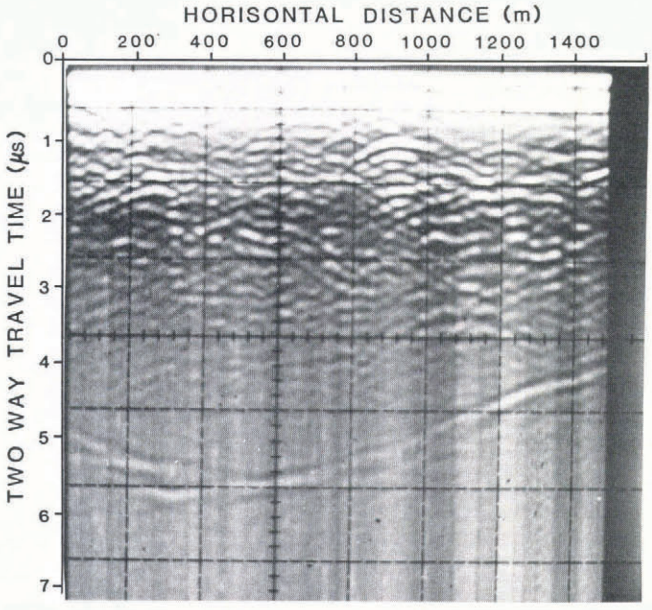

Fig.3. Bottom reflection of good continuity and sufficient amplitude.

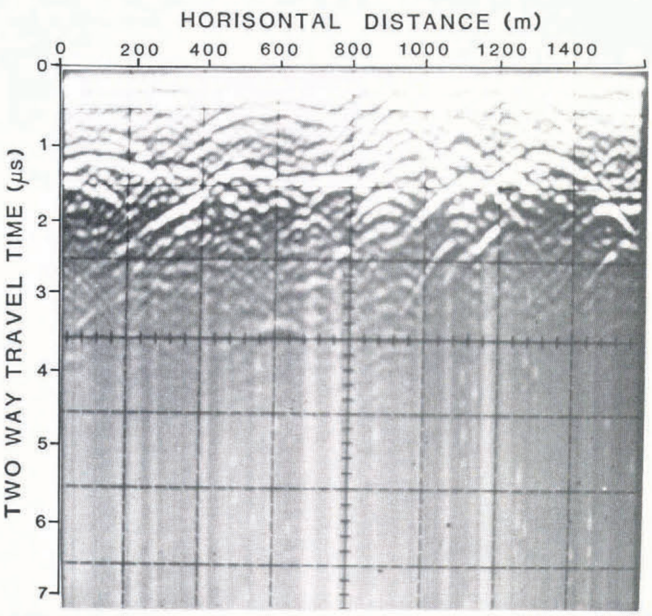

Fig.4. The bottom reflection is hidden by diffraction hyperbolae. Each hyperbola originates from one reflection point.

INTERPRETATION

One of the most difficult problems in radio echo-sounding of temperate glaciers is the shallow reflections. For two-way travel time up to 2 µs, several strong reflections were observed. These reflections are thought to be caused by internal water pockets. They are strong enough to obscure the bottom reflection and make the interpretation difficult (Fig.4). The reflection coefficient of an ice-water interface is 0.7 while it is 0.2 for ice-rock and −0.3 for ice-air. The values of the relative permittivity that we used are: for ice, 3.24 (Paren, unpublished), for water, 80 (Egner and Eriksson 1955) and for rock, 6.88 (Segalstad 1984).

The reason for the negative reflection coefficient for the ice-air interface is that the wave reflecting from a medium with less conductivity suffers a phase change of 180 degrees.

During the measurements, the polarity of the antenna was changed now and then to see which phase gave the best reflections. This polarity change gave different results in various parts of the glacier. This may be caused by dispersion and special physical characteristics of the glacier ice and/or ice-bedrock interface. However, a systematic study of this phenomenon has not yet been made.

In order to avoid following sideswipes, or other erroneous reflections, the profiles were interpreted in closed traverse loops assuming that the bedrock reflecting horizon is the only continuous one. However, in some places, only sideswipes were recorded and had to be used as an indicator of the depth. In such cases, a careful evaluation of the surrounding bedrock topography was the basis for a determination of which sideswipe should be used, or if some sort of interpolation had to be used. Migration techniques were used to transfer time reflectors of high inclination to bedrock topography.

The wave speed through the glacier has not been measured, but a constant speed of 169 m/µs has been used. This value was suggested by Robin et al. (1969) for pure, crystalline ice. No correction was made for higher speed in the upper, firn part of the glacier. The thickness of the firn is thought to be less than 30 m. Measurements by hot water drilling equipment in two boreholes, spaced 2 km apart, gave a firn thickness of 18 m in both holes. The zone of interchange from firn to ice was rather sharp and could be estimated to only a few decimeters. The interpretation of the profiles, as well as the construction of the subglacial map, was done manually. The average depth difference in crossing profiles can be used as an estimate of the interpretation error. This is approximately 30 m, while the interpretation error of a single reflector would be less than 15 m. The minimum ice thickness that can be sounded is approximately 60 m and is determined by the pulse length. The surface z coordinates are taken from existing glacier maps, constructed from 1966 air photographs. The subglacial map is shown on Fig.5.

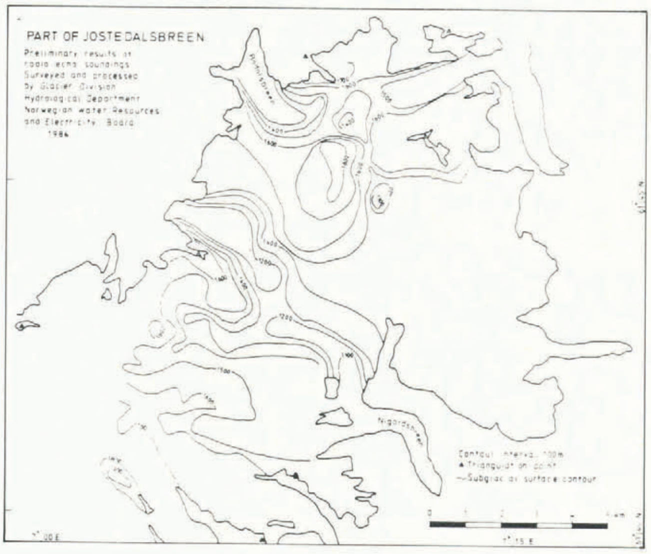

Fig.5. Map of subglacial topography. The interpolated contours are in some places directed by surveys from 1981.

CONCLUSION

The general ice thickness of the measured area is between 150 m and 300 m. Deviations from this are mostly found on the tops of the local ice caps, where thickness tends to be more like 50–100 m. Further, in areas of large relatively flat surface, where the thickest ice is found, the depths vary between 400 m and 600 m.

Exact x, y and z (surface) coordinates proved to be as important as the depth soundings in obtaining good results.

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