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Ice Thickness and Subglacial Topography Studies by Ground Penetrating Radar during the XX Indian Antarctic Expedition

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Abstract

Ground Penetrating Radar (GPR) has proved to be a versatile tool for mapping of glacial ice thickness and related studies over the years. During the XX Indian Antarctic Expedition pulse EKKO IV GPR operating at center frequency of 12.5 MHz was used to measure the ice thickness of polar ice sheet to the south of Schirmarcher Oasis, Queen Maund Land in Eastern Antarctica. The GPR profiling of 8.3 km was carried out between Vetehiea and Tallaksenvardan nunataks. The general bedrock topography is gently undulating, 1520 m wide depression in the bed rock is marked by a sudden break in slope at 4700m and 6220 m due south of Vetehiea, where the thickness of ice is more than 440m, indicating a deep graben structure in the bed rock. The extension of southern edge of this graben was traced 700m due NW from Tallaksenvardan and two kilometer due west of Vetehiea Tallaksenvardan GPR survey line, with this it is established that the alignment of graben is due NE-SW. This alignment is parallel to number of fault escarpment and shear zones in Schimarchar Oasis. GPR survey also conducted to estimate the thickness of the shelf ice and snow over the buried Dakshin Gangotri Station. The thickness of snow over the Dakshin Gangotri Station is 15 to 20 meters and thickness of ice in the vicinity of station is 145 to 150 meters.

Keywords: Antarctica, Ground Penetrating Radar, Ice thickness, Bedrock Topography, Graben.

Introduction

Glaciers and Ice sheets play an important role in understanding of past and present change in climate as they respond and preserve natural and anthropogenic environmental events. National Center for Antarctic and Ocean Research (NCAOR) in an effort to strengthen their systematic studies of polar environment, invited Wadia Institute of Himalayan Geology to conduct Ground Penetrating Radar (GPR) studies of polar ice to identify a suitable zone close to the Indian Antarctica Research Station, Maitri for detailed further studies. GPR has emerged as a convenient and quick geophysical technique for the study of glacier ice, especially for the preparation of glacier ice thickness maps. The first measurements of polar ice thickness by radar reflections were carried out buy Jiracek and Bentley in January 1965 at South Pole Station (Jiracek 1967, Drewry 1971). They investigated the subglacial topography between the Southern Trans-Antarctic Mountains and South Pole. There are three groups of sub glacial topography, one comprising lowland areas, and the other two of highland regions. One of these highland regions are with relatively smooth and regular topographic surface but dissected by deep valleys, and the other showing a very rugged mountainous terrain (Drewry 1975). In a recent effort, all the available ice thickness measurements on Antarctica were compiled into a single database and housed at the British Antarctica Survey Cambridge UK (Matthew et al., 2001). This database includes over 1,400,000 km of airborne radar sounding profiles and around 250,000 km of ground based radar and seismic traverse. During this expedition GPR profiling was also carried out to estimate the thickness of shelf ice and snow over the buried first Indian Antarctic station, the Dakshin Gangotri.

GPR profiling of polar ice was carried out between two Nunataks for a distance of 8.3 km. starting from south of Vetehiea (70. 47.85 S, 11.32.45 E) and ending at north of Tallaksenvardan (70.51.58 S, 11.32.45 E). This area is to the south of Schirmarcher Oasis, Queen Maund Land in East Antarctica (Fig. 1). Airborne radio echo sounding (RES) of

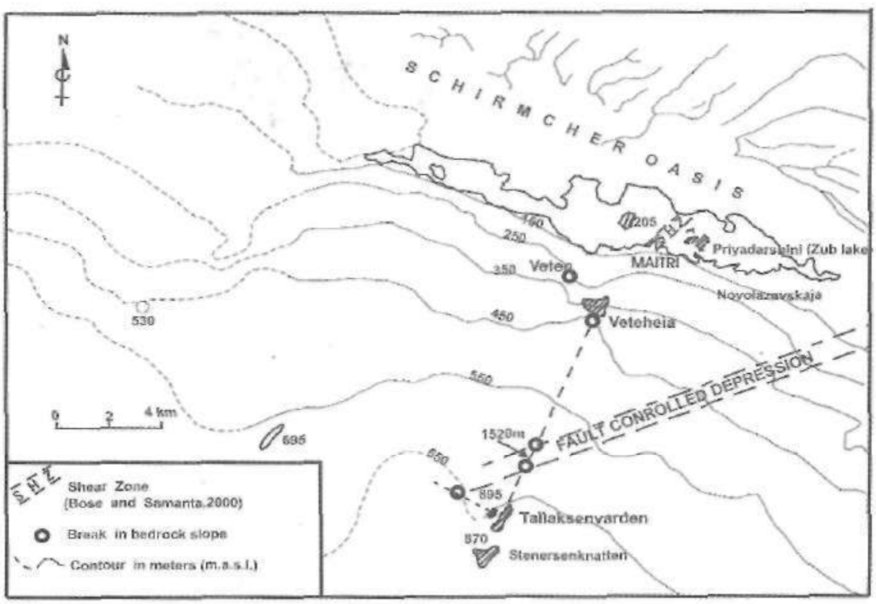

Fig.l: Location map of GPR survey profiles and the position of subglacial graben

Dronning Maund Land region was carried out by the Belgian Antarctica Expedition during 1968-69 (long.0.57' 58"to 3.28' 52" East and lat.70.30'8" and 71.26'58" South, Van and Decleir 1975). Authors have not been able to access any published account of ground based radar traverses or airborne RES of the area under study, our accessibility to many of other published works are limited due to language problem. Survey line extending from Vetehiea to Tallaksenvardan, along which GPR survey was carried out almost coincides with a polar ice divide, demarcating two distinct ice flow directions, one flowing due NW and other due NE. One of the major objectives of this study was to map the subglacial topography beneath the polar ice, and decipher the tectonic setup of the region, which could prove useful in selection of a suitable location for ice core drilling. Results of GPR survey conducted to estimate the shelf thickness and snow depth over the sunken Daskshin Gangotri station established in 1983 are also discussed.

Pulse EKKO IV GPR and Survey Design

Pulse EKKO IV GPR of Sensors & Software, Canada was used for the study. The pulse EKKO IV GPR is a lightweight, portable, all digital ground penetrating radar system. It consists of six components, namely a pair of identical antennas, a transmitter electronics unit, a receiver electronics unit, a control console and a laptop. The pulse EKKO IV operative center frequency is achieved by mounting the appropriate antenna on the system. All other parameter settings for the profiling are accessed via laptop that provides the user interface, graphical data display and data storage.

To achieve greater depth of penetration to map the ice- bedrock interface, 12.5 MHz central frequency antennae were deployed and a 2.4 ns pulse signal through a 20 kw transmitter was used for the sounding. Selection of antennae pattern in GPR survey is the important component of the survey design and data interpretation as antenna radiation pattern indicates the magnitude of electromagnetic (EM) energy flows in specific direction from antenna. The target positioned in a direction where there is a large amount of radiated power is more likely to generate a detectable response than one which is in a direction of little or no radiated power. Annan and Cos way (1992) proposed a simplified beam model for survey design application. This model is described as an elliptical cone, which extends downward into ground beneath the exciting or receiving antenna and anything inside the cone is illuminated or energized. The electrical field is treated as being aligned with the long axis of the beam footprint. There are several other antenna configuration possible, based on the objective of the sounding (Annan and Cosway 1992). In this work prime objective was to detect the bedrock ice inter-phase. When the long axis of footprint of beam is oriented parallel to the survey line, it reduces the lateral reflections, and get stronger reflection from straight below. GPR survey between Vetehiea and Tallaksenvardan nunataks (Fig.l), a distance of 8.3km was carried out with antenna separation of 8m and a step size of 2m in reflection mode to obtain GPR profiles. Longitude, latitude and elevation data along the survey profile were generated at an interval of 100 meters by the GPS.

Results and Discussions

GPR data collected were processed and plotted using EKKO IV software (Fig. 2). Propagation velocity of electromagnetic waves in ice was taken as 0.16 m/ns for calculation of ice thickness. Thickness of polar ice sheet at the staring point of GPR profiling on the southern edge of Vetehiea is 5 to 7m. Ice thickness increases gradually due south along the survey line. Bedrock ice interface slopes at an angle of 20° till 800m from the starting point, then it suddenly flatten out to 6 to 8 degrees. After this break in bedrock slope, bedrock surface has undulating features. The ice thickness increased to 320 m at 1400 m along the profile line from the starting point and it increases to 380 m at 2700m and at 4700 m bedrock slopes towards south and gradually gains the thickness of 440m. From this point onwards pulse EKKO IV GPR with the investigating team could not detect the ice bedrock interface as it was beyond the capability of the system. It is inferred that the thickness of polar ice is more than 440m thick due south along the survey line towards Tallaksenvardan. The bedrock ice interface was again encountered at 6220 m point along the profile line from starting point and 2080m due north from Tallaksenvardan. The sudden increase of ice thickness between 4700m to 6220 m is being interpreted as a 1520m wide graben like depression beneath the polar ice.

Vetchefa
(!<P 47.85' S.il^0 32.45" E)

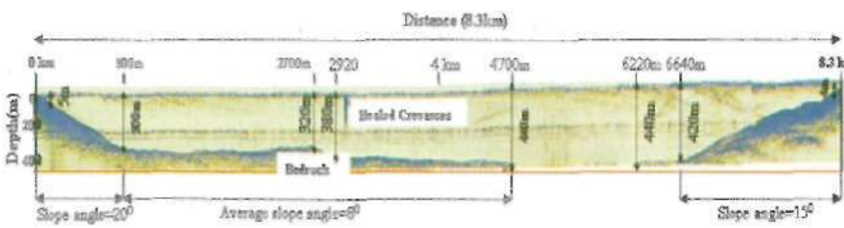

Fig. 2: 8.3 km GPR profile between Veteheia and Tallaksenvarden Nunatak, Dronning Maud Land, East Antarctica.

Western extension of southern edge of fault controlled depression was traced to 700m NW of Tallaksenvardan 1.5 km SW from the Vetehiea - Tallaksenvardan GPR survey line (Fig. 1). With this finding the direction of the depression is established as NE - SW. The direction of this structure is almost parallel to the shear zones mapped by Bose and Samata (2000) and fault traces mapped by Ravindra (1999) in Schirmarcher Oasis. The subglacial topography is relatively smooth and dissected by deep rift like valley, very similar to those described by Drewy (1975) and Damm (2004) from Eastern Antarctica and Oates Land Antartica. The bedrock slope increase sharply to 15 degrees at 6800m and remains more or less constant till end of survey line at 8300m northern edge of Tallaksenvardan nunatak. A healed crevasse at 2920 m from starting point has been identified by the sudden change in the reflection pattern in the profile. Many reflections from surface cracks in polar ice between 3000-5000m are seen in the profile. Two crevasses are identified by their typical hyperbolic reflection pattern, one at 3050m and another at 3700m.

Internal Layers of Polar Ice

All along the 8.3 km GPR profile, multiple reflections from the surface layers till a depth of 25-30 meters were clearly visible. These reflections are from the metamorphosing of firn layers. Due to low temperature regime in Antarctica, snow densification is governed by pressure melting and takes long years to transform into glacier ice> Such reflectors are deeper towards the central part of the profile where the cap ice has maximum depth. Near Vateiah nunatak, the internal surface layers dip towards the central part of the Trostadhallet ice cap and near the Tallaksenvarden nunatak, the layers are dipping towards the nunatak. Figure 3 shows the best presentation of reflections from these internal

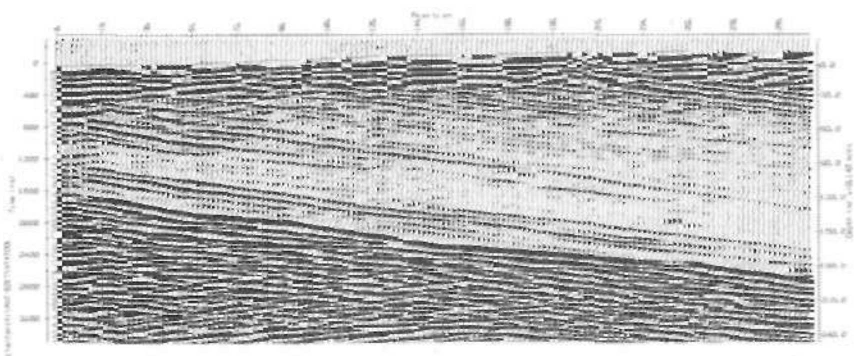

Fig. 3: Part of 8.3 km profile processed to enhance the reflections from internal layers of polar ice.

layers. This is close to the Veteiah Nunatak and shows many major layers in the glacier ice up to the bedrock with all of them dipping towards the center of the bedrock depression.

GPR Sounding at Dakshin Gangtori Station

GPR surveys in reflection mode was conducted to determine the snow and ice cover over the buried /sunken Daksljin Gangotri (DG) station. An independent survey along a hundred meter survey line was conducted to estimate the thickness of shelf ice in the vicinity of DG. The profiles were processed and plotted (wiggle trace format) using pulse EKKOIV software. Figure 4 shows snow and ice cover over the DG station and hanger to be 15 to 20 m thick and the thickness of the ice shelf to be 175 to 180 m.

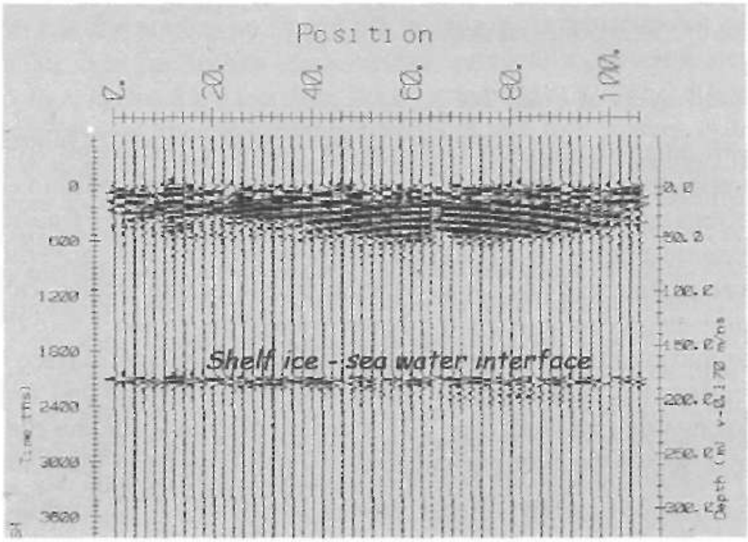

Fig. 4: GPR profile of Antarctic Shelf showing reflections from shelf ice -sea water interface and reflections from buried Dakshin Gangotri Sation (staked parabolas). Snow above the DG station is around 20m.

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References

Annan, A.P., and Cosway S.W., 1992, Simplified GPR beam model for survey design. Extended Abstracts of 62nd Annual International Meeting of the Society of Exploration Geophysicist New Orleans, Oct.25-29, 1992.

Bose S., and Samata S.K., (2000), Polyphase Deformations in the Precambrian Rocks of the Central Parts of the Schirmarcher Hills East Antartica, Seventeenth Indian Expedition to Antarctica, Scientific Report 2000 Department of Ocean Development, Technical Publication No. 15, pp 73-90.

Damm V. (2004) Ice thichness and Bedrock Map of Matusevich Glacier Drainage System (Oates Coast) Terra Antartica, 11(1), pp. 85-90.

Drewry D.J. (1971) Subglacial morphology between the Transantarctic Mountains and the South Pole. In: R.J. Adie, ed. Antarctic Geology anf Geophysics. Olso, Unversitetsforlaget. pp. 693-703.

Drewy, D.J., (1975), Terrain units in Eastern Antarctica. *Nature,* 256, pp 194-195.

Ravindra Rasik (1999), Geomorphology of Schirmacher Oasis East Antarctica Proc. Symp. Snow, Ice and Glaciers March 1999, *Geol. Surv. Ind. Spl. Pub.* 53, pp 379-390.

Jiracek, G.R., (1967), Radio sounding of Antarctic Ice. Geophys and Polar Res. Center, Univ. of Wisconsin-Madison, Res. Rep. pp 67.

Matthew B. Lythe, David G Vaughan and the BEDMAP Consortium, 2001, BEDMAP: A new ice thickness and subglacial topographic model of Antartica, *Jour, of Geophysical Research,* Vol. 106, No B6, pp 11, 335-11351.

Van Autenboer, T and Decileir, H, 1975, Jelbartisen-Trolltunga, Dronning Maund Land, Antartica, radio-glaciological survey. Dat Report. Professional Papers, 1975, No 1.