Search for the Grounding Line near Schirmacher Oasis, East Antarctica

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Abstract

The Antarctic ice sheet is dynamic and continuously moving towards north under the influence of gravity. The portion of ice sheet, which floats over the sea, is called ice shelf. The loci of points where Land-Ice-Sea (L-I-S) meet, is called grounding line or hinge line. The grounding line is not fixed but keeps shifting in response to changes in environment. The location of grounding line is important in order to evaluate the dynamic processes occurring at the distal edge of ice sheet. During the course of 30th Indian Scientific Expedition to Antarctica, Ground-penetrating radar (GPR) instrument was used extensively as it is a non-invasive, time and cost effective, environmentally safe technique for high-resolution geophysical mapping that is effectively used in the Polar Regions for subsurface mapping. During the GPR data collection an-electromagnetic pulse (16-80 MHz) is transmitted into the ground along a survey line. This pulse is reflected back to the surface from subsurface interfaces where dielectric properties of different mediums change and is recorded. During the current expedition, data generated through these profiles has been used to demarcate the boundaries between land-ice-sea. In this GPR survey, approximately 34 line km of survey was conducted and GPR profiles were obtained including 31.5 line-km to the west of the Indian logistic convoy route and 2.5 line km in between the established Indian convoy route and easternmost margin of Schirmacher Oasis. All these traverses were taken by attaching GPR units to Arctic Truck. The L-I-S interface occurs at 70°51'S: 12°14'E at a depth of 340 m below the surface along a north-south stretch east of Schirmacher Range.

Keywords: Ice thickness, Grounding line, Ice shelf, Schirmacher Oasis, East Antarctica.

INTRODUCTION

The Antarctica continent covers an area of about 14.2 million sq. km with exposed land surface of less than 2 percent and the rest covered under the Polar ice sheet. The icy continent of Antarctica in the southern part of the Globe is unique in many respects. It is surrounded in all sides by the Southern Ocean which has Pacific, Atlantic and Indian Oceans as neighbours. The average annual precipitation is only ~15 cm (less than that in the Thar Desert of India). Though the average annual temperature is -25°C, it varies from 10°C in summer (especially on coastal regions) to – 65°C in winter. Because of this extreme cold condition it controls the world's climate to a major extent. Understanding of the dynamics of polar ice sheets and ice shelf is vital for realistic evaluation of climatic models. The Ice Shelf is a continuation of polar ice sheet that is moving away from the continent and floating over the Antarctic Sea. It varies in size and shape depending on the thickness of ice sheet in that region, rate of deposition of snow, the ocean currents and additional support of sea mounts as pillars rising from sea bottom. The icebergs floating in the Southern Ocean are detached from the ice shelf and they change their position in space and time [Shrivastava et al., 2011]. The Ice Shelf is cantilevered at the triple junction of land, ice and sea and floats freely over the sea on the other end. The loci of triple junction of Land-Ice-Sea (LIS) are referred as the grounding line or the hinge line. The Grounding line is not a fixed one. It keeps shifting its position owing to various factors including the flow of ice sheet and the ice shelf, even the collapse of the later. When an ice-shelf breaks up, the grounding line is exposed to increasing marine influence. The warming in the ocean may destabilize the grounding line and cause it to shift towards the shore side. The thickness of the ice sheet and the ice shelf at the grounding line is therefore an important factor. The average thickness of the ice cap is over 3.5 km and is maximum at the pole. Traditionally, drilling, echo sounding and microwave radar measurements were employed to gain information on the character of englacial and subglacial structures [Paterson, 1994]. The technological advancement in the field of remote sensing had been useful in providing information on the nature of ice shelf and its relationship with the continental ice sheet. Over the last three decades, radio-echo devices and radar systems are being utilized to study a variety of large-scale glaciological measurements. These systems are bulky (up to 40 m in length) and operating them in the rugged terrain at the glacier terminus is difficult. Radar systems operated from aircraft have provided some subsurface data, but the strong reflection from the air/ground interface limits the amount of energy entering the subsurface and affects the depth of penetration. The LIS interface is believed to pass all around the northern margin of Antarctica. Though the upper part of the snow/ice surface could be traced from the satellite imageries, the delineation of actual grounding line required information on the subsurface features beneath the ice. Ground Penetrating Radar (GPR) technology offers the facility to delineate and map the subsurface features in three dimensions that range from few metres [Swain and Chaturvedi, 2011] to deeper parts [Swain and Goswami, 2014]. The advantages of GPR include its nondestructive nature, higher resolution and rapid deployment. The thickness of a part of the Polar ice sheet to the south of Schirmacher Oasis by GPR was estimated by some workers in recent years [Dharwadkar et al., 2012; Gergan and Thayen, 2006; Sinharay, 2008; Swain and Chaturvedi, 2011; Swain and Goswami, 2014]. More observations were made by conducting GPR survey during 30th Indian expeditions to Antarctica (2010-2011) to search for the Grounding Line to the east of Schirmacher Oasis. The details regarding the expanse and thickness of the Polar ice sheet near Schirmacher Oasis, East Antarctica and the detection of the Grounding Line are presented in this paper.

STUDY AREA

The Schirmacher Oasis is one of the smallest ice-free areas in Antarctica. It is situated on the Princess Astrid Coast in Dronning Maud Land in East Antarctica with an average elevation of about 100 metres above mean sea level. It is located between 70° 43'50" and 70° 46' 40" South Latitudes and 11° 22' 40" and 11° 54' 25" East Longitudes is a group of three visible ice-free landmass separated by different lakes (Fig. 1). The main part of the oasis is separated from a small landmass in the western part by a lake [Lake Zig-zag/ Lake E-1) and an island (Nadezhdy Island / Lanka Island) to the north by a lake (Lake Ozhidaniya / Lake E -10). The epi-shelf lakes are connected to the ocean that lies beneath the ice sheet [Swain and Chaturvedi, 2011]. This ice free landmass consists of rock exposures which include various types of bedrock, moraine covers, valleys displaying present and past glacier/meltwater activity, different types of lakes which are seasonally covered by a blanket of ice cover, seasonal and permanent cover of snow. All these landmasses together have been assigned the name Schirmacher Oasis having a length of 19.55 km trending ENE - WSW and maximum width of about 3.35 km covering an area of about 34 sq. Km. The elevation towards south and east are more and it has a slope of 6°- 7° towards north and 3° - 4° towards northwest (Fig. 2).

Fig. 1. *Schirmacher Oasis group of exposed rocky landmass are separated into three distinct zones by different lakes (Lake Zig-zag/ Lake E-1 separates one landmass towards west and Lake Ozhidaniya / Lake E-10 to the north separates Nadezhdy / Lanka island from the main Schirmacher Oasis).*

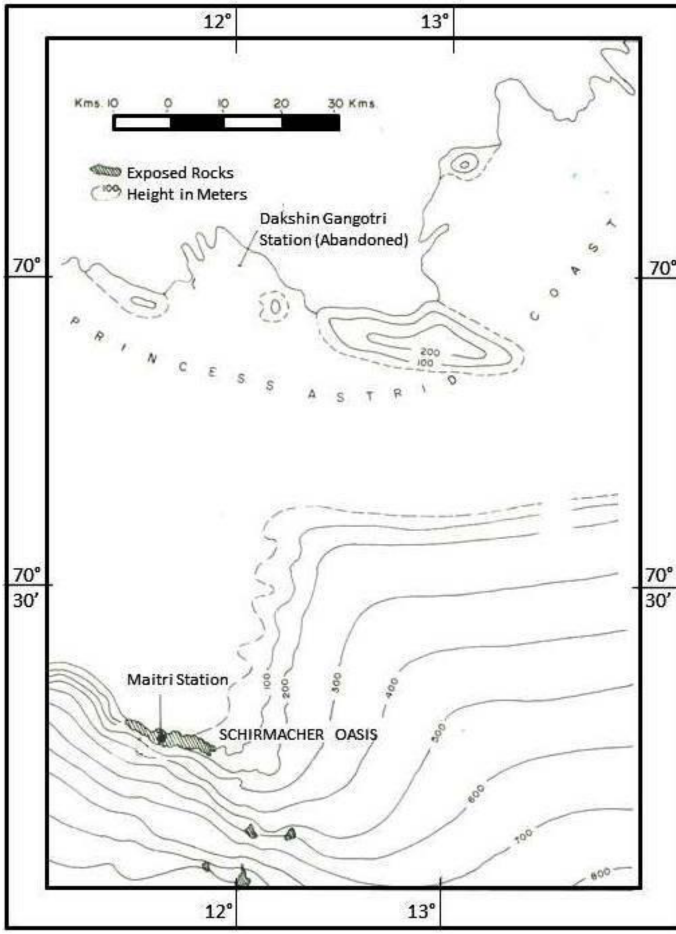

Fig. 2. Elevation of Schirmacher Oasis and its surrounding areas.

METHODOLOGY

The thickness of ice is detected through Ground Penetrating Radar (GPR) [Sinisalo et al, 2003; Swain and Chaturvedi, 2011; Swain and Goswami, 2014]. Ground Penetrating Radar (GPR) is a short-range pulse system for remote sensing which measures short-pulse electromagnetic (EM) reflections due to variations in the electrical properties of the different media. The EM wave spreads out and travels downward after being radiated from a Transmtting antenna. If it encounters a buried object or boundary with different electrical properties, then part of the wave energy is reflected back to the surface while the other part continues to travel downward. The wave that is reflected back to the surface is captured by a receiving antenna and recorded on a digital storage device for interpretation. A SIR-20 GPR system along with MLF antennae was used during the present studies. The SIR-20 GPR is capable of taking continuous subsurface profiles (100 and 200 MHz antenna) or can also take profiles in point mode (80-15 MHz MLF Antenna). However, a method was developed by Swain and Chaturvedi [2011] and modified by Swain and Goswami [2014] to carry out continuous GPR survey using MLF antennas. The propagation of radar wave through a medium depends largely on the dielectric permittivity, which is defined as the capacity of a material to store charge when an electric field is applied relative to the same capacity in vacuum.

Er = [c/v]2

Where Er is dielectric constant, c is velocity of light and v is velocity of electromagnetic wave passing through the medium. Under ideal conditions the depth of penetrations using MLF antenna with 15 – 80 MHz is 25 to 30 meters in Rocks ans soils, which increases manifold to around 350 meters in ice conditions. For specific purposes, the depth of penetration in ice condition can increase, but the resolution of the data deteriorates severely as it is governed by the equation $D = (2.32t)/\sqrt{Er}$, Where D is depth of target in cm, t is wave travel time in nanosec, 2.32 is a constant incorporating speed of light & conversion units and Er is dielectric constant of the medium. Reflections are created by an abrupt change in the electrical and magnetic properties of the material through which the electromagnetic waves travel. In most situations, magnetic effects are small. The greater the change in properties, the more signal is reflected. In addition to sufficient contrast in electromagnetic properties, sharp boundary between materials also aids in picking up GPR signals. GPR provides the highest lateral and vertical resolution compared to any surface geophysical method. However, for any measurement technique based on waves, wavelength is a limiting factor.

$\lambda = v/f$. where λ is wavelength, v is velocity of wave and f is the frequency.

Measuring objects smaller than the probing wavelength can be difficult. If the target's physical cross- section area is large as compared to the wavelength, the ratio between the physical and acoustic size is independent of the wavelength. In the opposite case, the acoustic size is highly dependent of the wavelength. Resolution of GPR is usually between one-half and one-third of the wavelength of transmitted signal.

The GPR method is site specific in its performance depending upon the surface and subsurface conditions. Performance specifications include information about reflections, depth of investigation, resolution, interferences, calibration, quality control, precision and bias. Depth of observation usually, (i) decreases as frequency (of the antenna) increases. (ii) decreases as water and clay/salt content increases. (iii) decreases as scattering increases. (iv) increases as transmitter power increases.

Deployment in the field

The GPR system comprises a Subsurface Interface Radar (SIR) with a Toughbook, GPS, Survey wheel, cables and various antennas of 15, 20, 35, 40, 80, 100 and 200 MHz frequency. All these components draw power from a 12 V battery. As batteries drain out quickly in the extreme cold conditions of Antarctica, power was drawn directly from the vehicle using suitable fabrication done at the Maitri station. For dragging the antennas on the ice surface, a Y-shaped bar was fabricated and connected to the backside of the vehicle using a D-shackle. The antennas are then attached to the connector with the help of fabricated wooden boards, so that there is no influence of the metal body on the antenna. The SIR instrument and the Toughbook are kept inside the heated cabin of the vehicle, so that the desired temperature is maintained. The GPR instrument and the antennas were connected by a long cable.

The Multiple Low Frequency (MLF) antenna with 15, 20, 35, 40 and 80 MHz frequency has a different setting than the shielded 200 MHz antenna. MLF antenna is unshielded and has separate Transmitter and Receiver systems requiring additional power for transmission. That was provided through a 12V vehicle battery. A four meter long wooden trolley was prepared for keeping the Transmitter and Receivers at 1, 2 and 3 meters apart as and when required for modifying the frequency of the antenna when the MLF elements are extended to 0.6, 1.2, 1.8, 2.4 or 3 m on both sides [Swain and Goswami, 2014). No metallic parts were used and a survey wheel was attached to the 100 and 200 MHz antenna structures for dragging behind the vehicle and Multiple Low Frequency (MLF) antenna. All antennas were tested on snow surface near the Maitri station before commencement of the work.

Another system of MLF antenna deployment was fabricated during 1st Indian Scientific Expedition to South Pole and 30th Indian Scientific Expedition to Antarctica by using GPR system in the snow vehicle named Arctic Truck. The Transmitter (Tx) of the GPR – MLF system was fixed in the rear side of the vehicle by placing inside a wooden chamber (Fig. 3). The survey wheel is attached to the Tx and can be dragged with the vehicle. The Receiver (Rx) was fitted to the front panel of the vehicle by placing inside of a wooden chamber (Fig. 3). The wire connecting the Tx and Rx was fixed above the vehicle in order to avoid any wear and tear. The GPR system was kept inside the vehicle. 12V power was supplied to the system from the vehicle. As the distance between Tx and Rx was fixed, continuous GPR data could be obtained during survey. The elements of the MLF Tx and Rx were extended to 0.6, 1.2, 1.8, 2.4 or 3 m on both sides to obtain a desired frequency of 80, 40, 35, 20 and 15MHz [Swain and Goswami, 2014].

Antenna frequency	Samples/ scan	Bits/ sample	Scans/ sec	Scans/m
15 MHz	512	16	30	12 - 20
20 MHz	512	16	36	12 - 20
35 MHz	512	16	39	12 - 20
40 MHz	512	16	42	12 - 20
80 MHz	512	16	56	10
200 MHz	512	16	80	10

Fig. 3. *GPR survey using the snow vehicle (Arctic Truck) with fitted Transmitter (Tx) and a Receiver (Rx) inside a wooden box at the rear side and front side respectively. Tx is attached with a survey wheel towards the rear side of the vehicle.*

The dielectric constant for ice was computed by velocity analysis using the common midpoint (CMP) survey and was kept at 3.0 [Dharwadkar et al., 2012]. During the course of survey, the range (time for which the radar listens for reflected signals) was changed depending on the location of survey and target depths. About 34 linear km of profile data has been collected in 2010-11 during 30th ISEA, including 31.5 line-km to the west of the Indian logistic convoy route and 2.5 line km in between the established Indian convoy route and easternmost margin of Schirmacher Oasis (Fig. 4). The acquired data was processed using the RADAN 6.0 and 6.5 software. The use of digital enhancement techniques was kept to a minimum in the processing of the GPR profiles. Generally, variable gain and a high/low pass frequency filters were applied to the data. GPR signals propagate extremely well through ice and produce long diffraction tails from point-source reflectors.

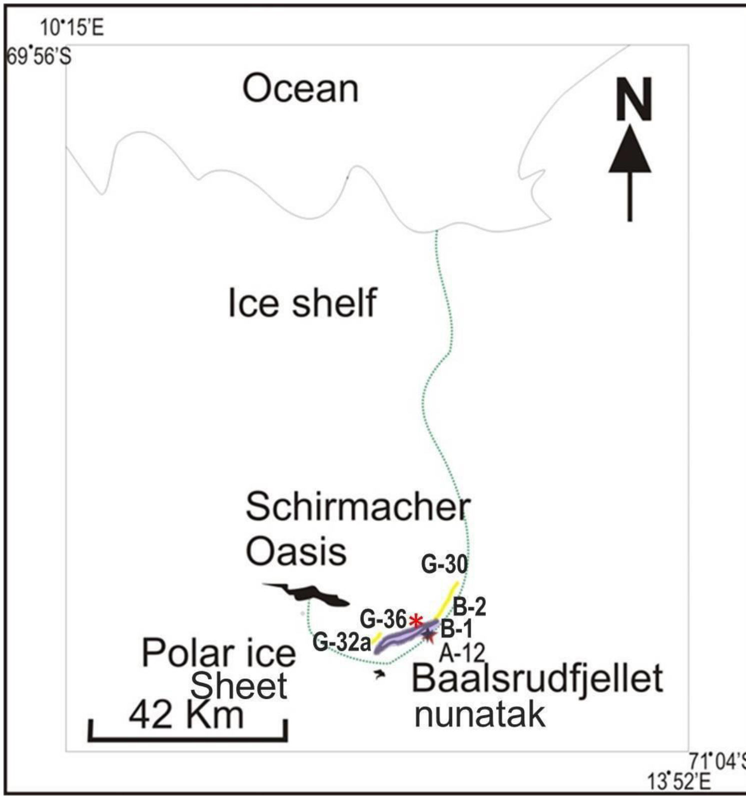

Fig. 4. *Route map of GPR traverses taken (purple line) during 30th expedition along with topographic profile from Baalrudfjellet Nunatak to the ice shelf edge. GPR traverse taken during 29th ISEA is shown by yellow lines.*

RESULTS AND DISCUSSIONS

GPR survey carried out during 2008-09, from the Baalsrudfjellet Nunatak to 12 km northeastward till A-12 point showed that the ice-bedrock interface increased from 0 m to about 380 m at point A-12. Another 2 line km of GPR survey towards ice shelf margin near new India Bay showed that the ice-sea interface varied from 28 m near the shelf margin to 70 m at 2 km from the ice shelf margin [Dharwadkar et al., 2012]. During the 29th expedition, 15 line Km of GPR survey was carried out including 12.5 line km beyond A-12 point of the Indian logistic convoy route towards north and 2.5 line km in between the established Indian convoy route and east tip of Schirmacher Oasis (Fig. 4).

GPR Survey:

A total distance of 2.5 Km was surveyed along the line 70° 48' 42" S: 110 48' 4" E - 70° 45' 37" S: 120 3' 04" E from WSW to ENE direction. Initially, MLF antenna with 80 MHz frequency was used for GPR survey followed by 35 MHz frequency. Data collection parameters with 35 MHz frequency antenna are given in Table 1.

Table 1. Data collection parameters with MLF antenna with 35 MHz frequency during 30th ISEA.

S. No.	Parameter	Data
1	Configuration type	Custom
2	Channels	1
3	Samples/scan	512
4	Scans/sec	25
5	Dielectric constant	3
6	Scans/unit (in this case, m)	4
7	Unit (in this case, m)	5 m per mark
8	Transmit rate	100 KHz
9	Transmitter	1
10	Receiver	1

Initially, the two-way travel time range of GPR with this arrangement was kept at 1000 ns, which is equivalent to 80 m depth. Though there is no interface between the underlying bedrock and ice could be seen, but the internal characteristics of polar ice cap with variation in the snow layers with a strong interface between the overlying ice and the buried moraine materials could be observed along this line. Snow depth gradually decreases from 12 m to 0 m within a distance of 60 m, thus the slope of the snow boundary with the ice to be 110 towards WSW. The moraine materials could be observed at a depth of 40 m from the surface (Fig. 5). From 305 m from the starting of the profile, snow-ice interface shows a slope of 130 towards NNE, which has continuous layers of moraine materials underneath it upto 46 m at a horizontal distance of 500 m. Another GPR survey taken with similar set up in this area shows signatures of buried frozen lake at a depth of 38 to 48 m from surface along this 500 m profile. Ice -water column depth could be observed at a depth of 38 m at the starting to 46 m at a horizontal distance of 470 m (Fig. 6). Though this interface is between ice and water column, but the confinement of the water column and the very nature of frozen lake at a shallower depth with land-ice interface observed in the GPR profiles ruled out the possibility of Land-Ice-Sea interface. Bedrock and ice interface could be seen at a depth of 80 m at a horizontal distance of 135 m from the starting of the profile, which has a gentle slope of 50 towards WSW.

However, on further survey, the depth of the ice-bedrock interface increased to more than 80 m (the permissible depth window with the current set up). Data collection parameters were changed thereafter and arrangements were made to carry out GPR survey with 35 MHz frequency. The profile shows that within a horizontal distance of 500 m, the bedrock-ice interface varies from 150 m to 250 m, with a slope of approximately 110 towards ENE (Fig. 7). After 2.5 Km of survey, more areas could not be explored at that time, because of the rigorous melting and opening of the large number of melt water channels.

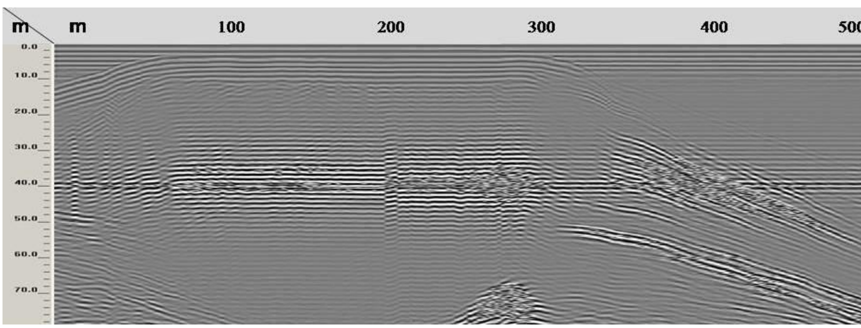

Fig. 5. *GPR profile with 80 MHz frequency showing snow-ice and ice-moraine material interface at a depth of around 35 – 40 m.*

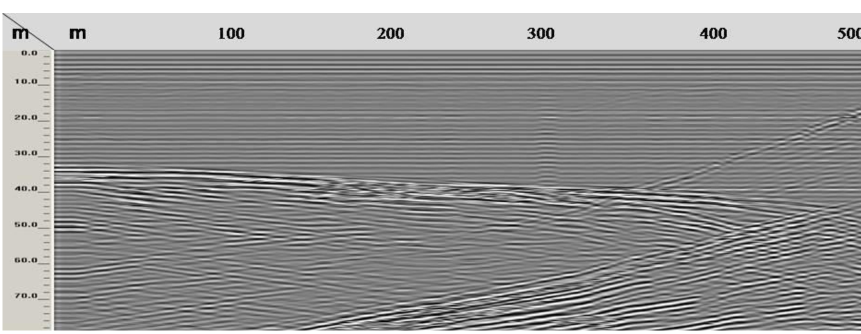

Fig. 6. *GPR profile with 80 MHz frequency showing bedrock-ice and ice-frozen lake water column interface at a depth of around 35 – 40 m.*

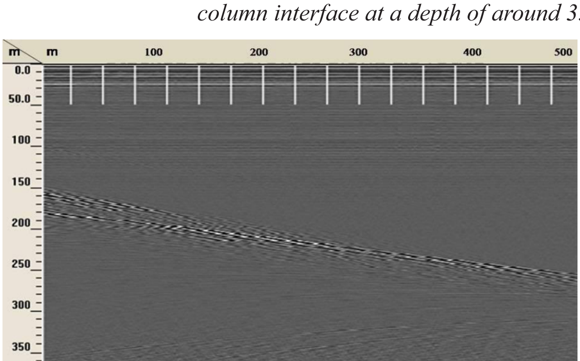

Fig. 7. *GPR profile with 35 MHz frequency showing bedrock-ice interface at a depth of around 150 - 250 m.*

More areas were explored after subsiding of melt water channel openings and GPR survey was conducted with the set up as discussed above. A 2 km profile generated from the point 70° 53.044' S: 11° 57.087' E towards NE shows ice-bedrock interface at a depth of around 300 m from the surface (Fig. 8). The resolution becomes very poor and thus MLF antenna with 20 MHz frequency with the data collection parameters given in Table 2. A series of traverses were taken between the points 70° 53.044' S: 11° 57.087' E and 70° 49.163' S: 12° 20.877' E passing through the point 70° 51.090' S: 12° 14.429' E, lying 2.5 km west of the Indian logistic convoy route. With the new set up, the survey was carried out and a 2 km profile was generated, which shows that the upward convex subsurface structure in the bedrocks is observed at a depth of 300 - 340 m (Fig. 9). The bedrock-overlying ice interface is thus observed to be at a depth of 320-330 m (Fig. 10) in a 2 km long GPR profile along SW-NE direction. After the initial 4 kms of traverse, bedrock-ice interface shows a shallower nature of ice thickness reaching the depths of 320 m at the starting to 250 m at the shallowest position along this profile, which is equivalent to a two-way travel time of 4000 ns and 3200 ns respectively (Fig. 11). The interface at the end of the profile shows a depth of 280 m below the surface. Rigorous melt water channels presence and spreading of the elements up to 2.4 m on both sides of the vehicle lead to numerous signal problems and are reflected in the profiles generated afterwards (Figs. 11. 12 and 13). Presence of deep-seated water attenuated the signal and is reflected in the profile in terms of a strong basal interface between the ice and bedrock (Fig. 12). This profile shows the bedrock-ice interface at a depth of 280 – 300 m up to a horizontal distance of 1300 m. After this the bedrock shows a slope of 150 towards NE, over which another interface marking the presence of sea-ice interface could be observed at a depth of 300 m. Another 2 km long GPR profile taken beyond this point also show similar interface between sea and ice at a depth of 300 – 340 m. Several profiles thus created with GPS attachment can be seen in 3-D view, having length, width and thickness (Figs. 14, 15, 16, 17 and 18). This leads to the markings of grounding line near 70° 51.090' S: 12° 14.429' E (Fig. 19) at a depth varying from 300 to 340 m as the ice over it has a change in the elevation.

Table 2. Data collection parameters with MLF antenna with 20 MHz frequency during 30th ISEA.

S. No.	Parameter	Data
1	Configuration type	Custom
2	Channels	1
3	Samples/scan	1024
4	Scans/sec	25

S. No.	Parameter	Data
5	Dielectric constant	3
6	Scans/unit (in this case, m)	1
7	Unit (in this case, m)	5 m per mark
8	Transmit rate	25 KHz
9	Transmitter	1
10	Receiver	1

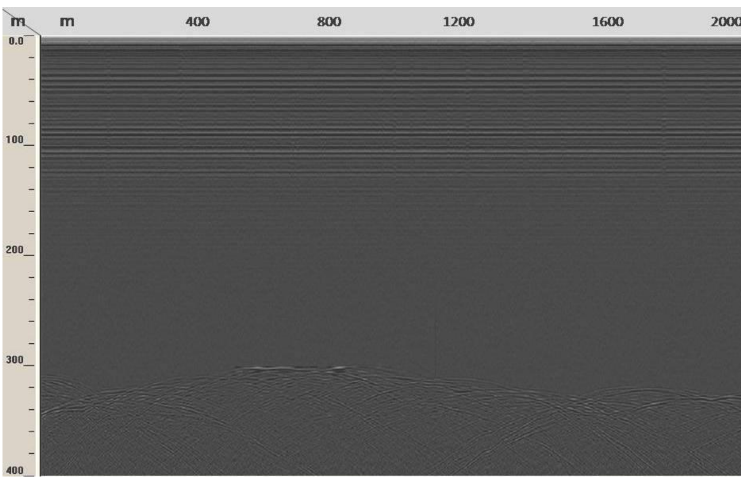

Fig. 8. *GPR profile with 35 MHz frequency showing bedrock-ice interface at a depth of around 280 - 320 m.*

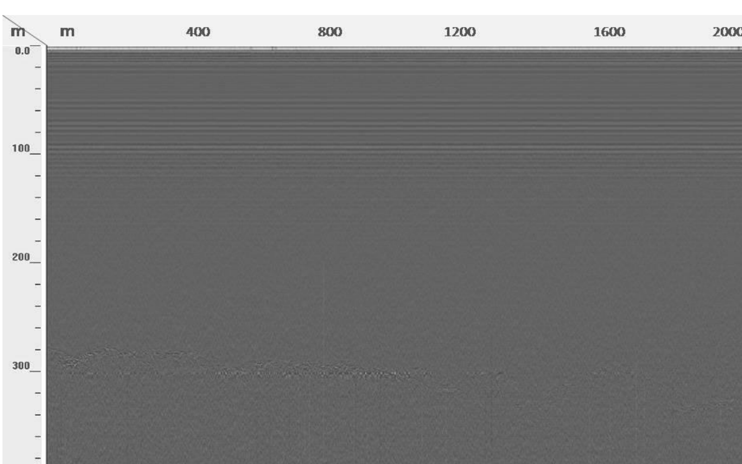

Fig. 9. *GPR profile with 20 MHz frequency showing bedrock-ice interface at a depth of around 300 - 340 m.*

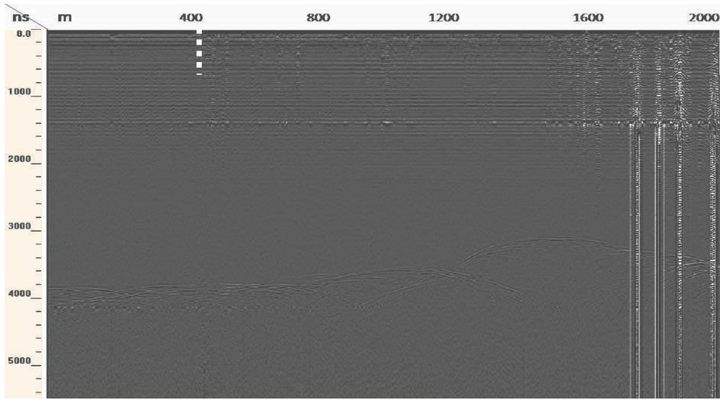

Fig. 10. *GPR profile with 20 MHz frequency showing bedrock-ice interface at a depth of around 340 m*

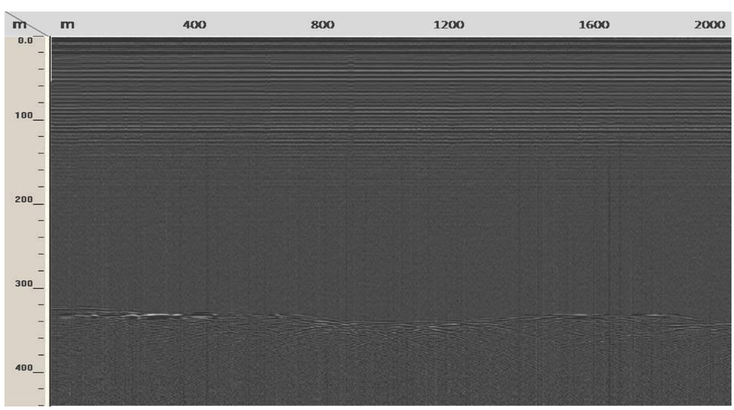

Fig. 11. *GPR profile with 20 MHz frequency showing bedrock-sea interface at two way travel time range of 3200 -3800 ns. Melt water channels influence the profile.*

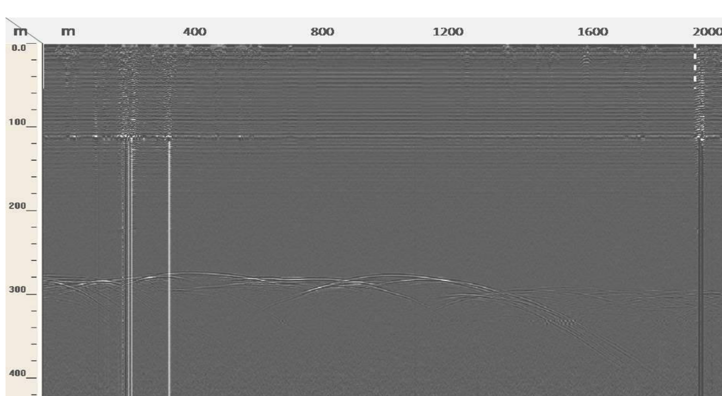

Fig. 12. *GPR profile with 20 MHz frequency showing bedrock-ice and ice-sea interface at a depth of 280-300 m.*

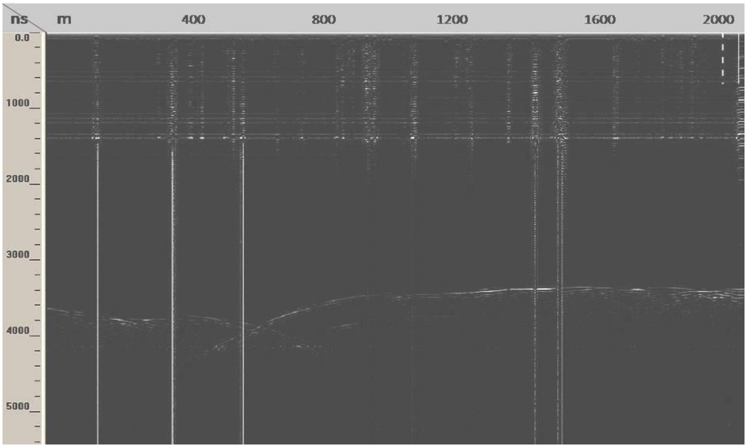

Fig. 13. *GPR profile with 20 MHz frequency showing ice-sea interface at two way travel time range of 3600 - 3800 ns. Melt water channels influence the profile.*

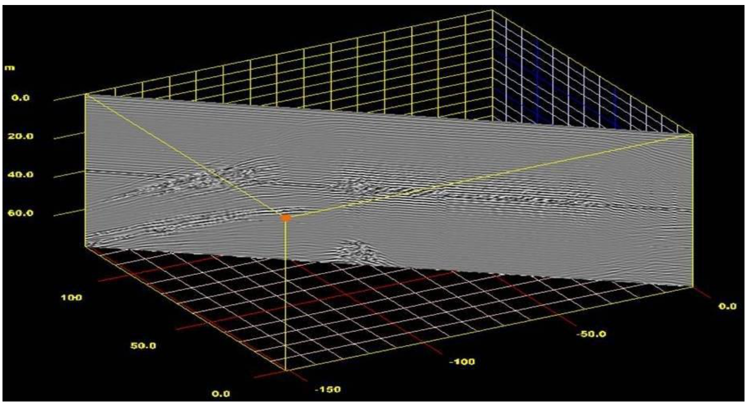

Fig. 14. *3-d view of a GPR profile showing bedrock-ice interface.*

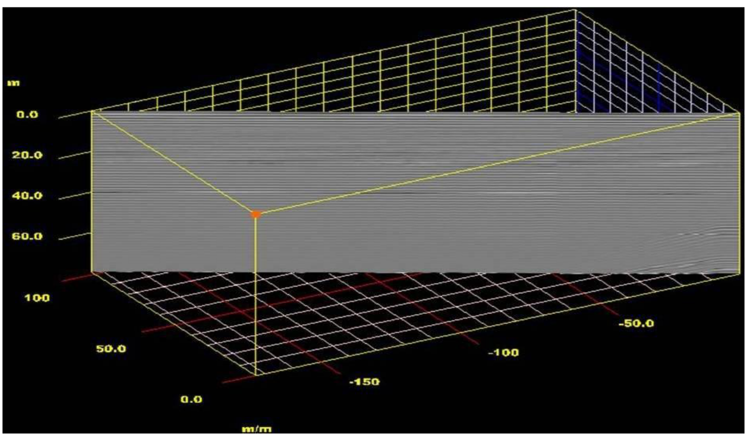

Fig. 15. *3-d view of a GPR profile showing snow-ice and ice-moraine material interface.*

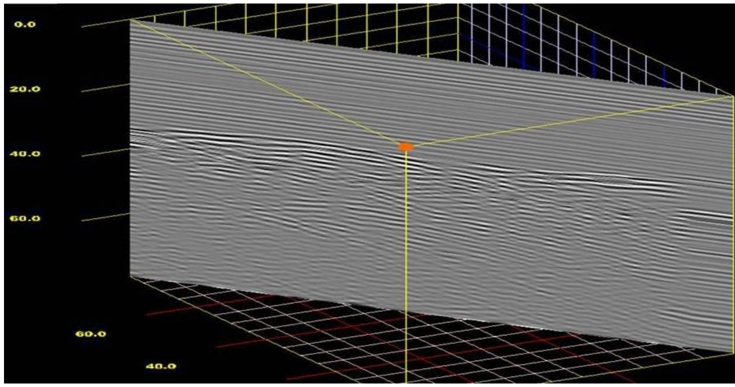

Fig. 16. *3-d view of a GPR profile showing bedrock - ice and ice - frozen lake water column interface.*

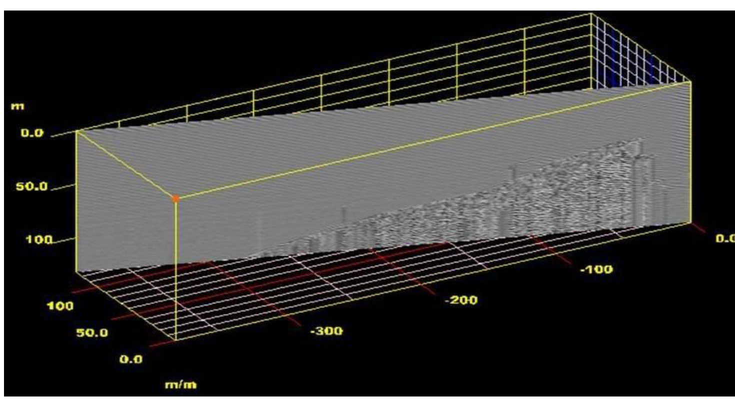

Fig. 17. *3-d view of a GPR profile showing frozen lake water column-ice interface.*

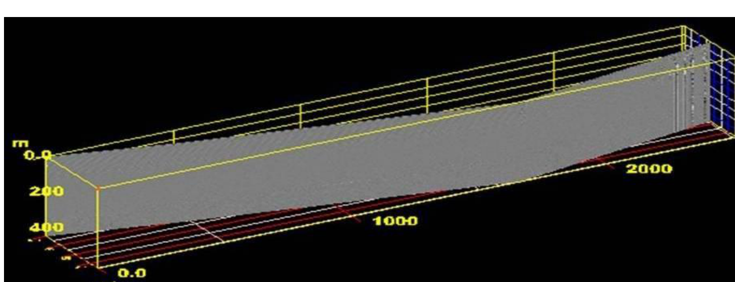

Fig. 18. *3-d view of a GPR profile showing bedrock-ice interface with melt water channels influencing the profile.*

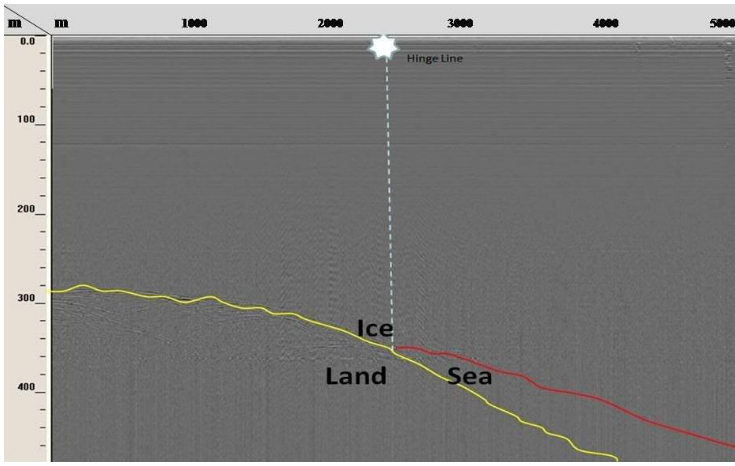

Fig. 19. *GPR profile showing Land-Ice-Sea interface, (hinge line or grounding line)*

CONCLUSIONS

The Antarctic ice sheet acts as a repository of past climatic transformations and together with the ice shelf, plays an important role in influencing the global climate. Antarctic ice sheet is thickest at the South Pole and constantly flows outwards under the influence of gravity. Differential GPS measurements on the velocity and principal strain rates of Antarctic ice sheet carried out in the south of Schirmacher Range show an average velocity of 6.21 + 0.01 m per annum towards the north-northeast [Sunil et al., 2010].

There is a continuous buildup of ice in the interior of the Antarctic continent and simultaneous destruction at the periphery along the ice shelf. Ice shelf varies in size and shape depending on the thickness of the ice -sheet in a particular region. It forms a continuation of polar ice sheet that has moved away from the continent and is cantilevered on one end at the triple junction of land-ice-sea while the other end floats over the sea. This makes the thickness of Polar ice sheet one of the important factors that controls the configuration of the ice shelf beyond the loci of this triple junction (Land-Ice-Sea interface) commonly referred as the grounding line.

Ground Penetrating Radar has emerged as an important geophysical tool for assessment of the state of ice shelf and identification of subsurface features beneath in the Polar Regions. The main appeal of this tool is its non -destructive nature, low cost and time effective operation. GPR produces an accurate picture of the subsurface in two and three dimensions. The contrast between the dielectric permittivity of ice, bedrock and ocean water provides the basis for use of GPR for delineation of the interfaces below the ice cover. A project was taken up by Geological Survey of India to locate the places through which Grounding

Line passes through to the east of Schirmacher Oasis. During the course of work in 28th ISEA, it was observed that the ice thickness increases rapidly from 0 m near the northern edge of Baalsrudfjellet Nunatak (where rocky outcrops are exposed) to 380 m near the reference point A-12 (of convoy route) (Fig. 4). This location is about 20 km from the edge of Baalsrudfjellet Nunatak. The surface elevation profile shows that the topographic height also decreases rapidly from 457 m above mean sea level (MSL) to about 100 m above MSL at A-12. The subsurface data obtained during 29th expedition shows that the ice thickness increases from 380 m near A-12 to about 500 m near G-30 (70°44.979' S: 12° 29.121' E) that lies between convoy reference points B1 and B2 and is located about 12 km north- east of A-12 with variation in the ice thickness in between these. Convex nature of the bedrock has been observed in one profile north of the grounding line during 29th expedition. This structure is about 500 m long and 30 m higher than the background in this part. However, this structure could not be termed as subsurface mound due to its smaller dimensions. A possible loci for L-I-S was detected at latitude 70°51.090'S and longitude 12°14.429'E that gets expressed as a steeply sloping land-ice interface juxtaposed against gently sloping sea-ice interface (Fig. 19). This juxtaposition is observed at 340 m below the ice sheet that was later confirmed in a closely spaced profile line generated during 30th expedition.

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