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SURVEY ARCHIVES

Ronne Ice Shelf
Spot Depth Seismics 94/95

Mark R. Johnson

BRITISH ANTARCTIC
SURVEY

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Ronne Ice Shelf Spot Depth Seismics 94/95

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This unpublished report contains initial observations and conclusions. It is not to be cited without the permission of the Director, British Antarctic Survey.

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SUMMARY

During the 94/95 field season seismic measurements of the ice- and water-column thickness were made at 15 km (average) intervals along a 2300 km traverse. This zig-zag traverse covered the southern and western Ronne Ice Shelf and the Evans Ice Stream; areas from which little seafloor data previously existed (See Figure 1).

Gravity measurements were made at each site and the strain rosette at Site 3 was re-measured.

PERSONNEL:

Mark Johnson	Glaciologist
John Sweeny	FGA

FIELD OPERATIONS DIARY

- 02 Dec Depart Rothera, visit Ed King near Fossil Bluff for explosives briefing and calibration of gravimeter
- 03 Dec Arrive with second load to input site S82 08 W050 45
- 04 Dec Third and final load arrives. Sledges and ski-doo's prepared
- 05 Dec Equipment prepared and test shots made
- 06 Dec Move to first waypoint Alpha and survey three sites at 15 km intervals
- 07-09 Dec Survey three sites per day at 15 km intervals reach end of first leg: Waypoint Bravo.
- 10-12 Dec Survey three sites per day at 15 then 20 km intervals as little change in seafloor topography and reach Charlie
- 13 Dec Survey three sites 20 then 15 km intervals
- 14 Dec Lie up
- 15 Dec Survey three sites at 15 km intervals and reach Delta
- 16 Dec Shallow refraction survey at site. Lie up
- 17-18 Dec Survey three sites per day with reduced intervals near ends of profile to maximise coverage of edges. Pass Echo
- 19 Dec Lie up
- 20 Dec Leave tent up and survey five sites around Foxtrot
- 21-22 Dec Survey three sites per day. Pass Golf and alter traverse to reach depot
- 23 Dec Refuel all jerries, make repairs to geophone cable and quality check downloaded seismic data
- 24 Dec Several sledge capsizes delay travel: survey two sites and onto next site Hotel
- 25 Dec Spot depth and shallow refraction surveys at this site
- 26 Dec-
-01 Jan Survey three sites per day. Hard going due to repeated sledge capsizes caused by troughs of soft snow. Turn 15 km short of waypoint Juliet, pass waypoint Kilo and reach Lima
- 02-03 Jan Lie up
- 04 Jan Survey four sites and reach Mike
- 05 Jan Survey three sites and depot science equipment for trip to patriot Hills for a resupply
- 06 Jan Arrive at Patriot Hills in time for dinner
- 07 Jan Received resupply
- 08 Jan Lie up
- 09-10 Jan Return to equipment depot and adjust sledge loads
- 11 Jan Survey three sites and reach November
- 12 Jan Survey three sites and repair ski-doo's suspensions
- 13 Jan Survey three sites and reach depot at Oscar
- 14 Jan Raise depot, refuel and make a shallow refraction survey
- 15 Jan Only survey one site before weather deteriorates
- 16 Jan Lie up
- 17 Jan Survey four sites and onto next site
- 18 Jan Survey one site at camp and lie up
- 19-21 Jan Lie up
- 22 Jan Survey four sites and on to next site Site 3/Quebec
- 23 Jan Leave tent up and travel towards Korff Ice Rise turn 1 km from coast

(heavily crevassed) and survey 5 sites at 9 km intervals

24 Jan Raise travel depot and lie up

25 Jan Lie Up

26 Jan Refuel jerries and measure/survey strain rosette

27 Jan Survey four sites

28-29 Jan Survey three sites and onto next each day. Pass Romeo and Sierra

30 Jan Survey one site at camp and lie up. Resited Tango to avoid crossing worst area on SAR images

31 Jan Survey four sites and turn before Tango having penetrated as far as possible into this crevassed region

01 Feb Lie up

02 Feb Weather clears late. Survey two sites. Shallow refraction survey at second site

03 Feb Survey four sites reach Uniform at second and turn to reach Uniform/Bravo

04 Feb Turn for Uniform/Charlie and survey four sites

05 Feb Survey four sites reach Uniform/Charlie at second and turn for Uniform

06 Feb Survey four sites and onto next

07 Feb Turn to place first site between Uniform and Victor and survey three sites

08-13 Feb Lie up

14 Feb Weather clears late. Survey two sites

15 Feb Survey four sites turn for Victor at first

16 Feb Survey four sites and reach Whisky. Shallow refraction survey at second site

17 Feb Survey four sites crossing area of minor crevassing for first 20 km

18 Feb Survey two sites turning to head back into Evans at first site since low on fuel. Stop when out of fuel!

19 Feb Prepare kit for uplift but no planes available

20 Feb Uplifted to Ski-Hi by single plane in two loads

21-22 Feb Await uplift to Rothera

23 Feb Return to Rothera via Fossil Bluff to calibrate gravimeter

25 Feb Second load arrives from Sky-Hi

1.INTRODUCTION

The measurement of the sub-ice bathymetry can only be achieved using seismic techniques since radar or sonar will not penetrate the sea water layer. Between 1976 and 1986 spot depth seismic data were collected by the Russian scientific consortium "Sevmorgeologija" over a large area of the Northern Filchner-Ronne Ice Shelf. However they failed to cover the areas south of Berkner Island and Henry Ice Rise and south and west of Korff Ice Rise which are believed to form interlinked troughs important to tidal flow patterns under the ice shelf.

To cover the maximum amount of the unsurveyed area a zig-zag route was chosen with spot depth seismic soundings to be made at approximately 15 km intervals. These would record the ice thickness and the sea-floor bathymetry.

Additional work includes obtaining gravity data at each site to improve the Geoscience gravity database, and re-measuring the strain rosette at Site 3.

2.EQUIPMENT

BISON 9024 SEISMOGRAPH

Performed well with no corrupted or lost data in the whole season. Experienced a few unrecoverable "hang ups" and error messages when initially turned on at temperatures below around -18°C but warmed quickly inside zarges box and proved reliable. The Automatic Gain Control (AGC) was applied to most records to display both the primary, and weaker multiple reflections clearly on a single printout. To retain information on the relative amplitudes of the reflections non-AGC records were also printed at intervals. Signal processing using the low-pass filter to reduce noise, particularly ground roll, sometimes proved useful but repeated printouts required a lot of paper.

GEOPHONE CABLE

The cable generally performed well although several times repairs had to be made to the take-outs. These suffered from the metal contacts either digging into or breaking loose from the worn supporting plastic causing poor contacts and bent wires. Some "cross-over" of the signal between channels was seen but was not significant to these results.

GEOPHONES

Seem highly resilient to the pressures of travel, planting and even freeze-thaw. Over the season three were damaged but these are probably all repairable.

GRAVIMETER

A "Master" Worden Gravimeter (No.556) was borrowed from the Geoscience department. To transport the gravimeter on the ski-doo a welded steel frame was built with the gravimeter held within a web of bungees and the whole assembly could be quickly mounted on the Alpine 2 Ski-doo. This was designed to isolate the meter from the vibrations and jarring of the ski-doo and seemed to perform well. The meter suffered from poor contacts between the tarnished brass of the lamp circuit and several times it was necessary to dismantle the bulb holder, resulting in a tare in the data. A tin of "Brasso" would be a useful addition to the gravimeter toolbox!

COMPUTERS

Two portable Toshiba PC's, a 3200 and a 1600 (as a spare), were used for downloading the seismic records from the BISON. Downloading was required only every two or three working days and took around four hours, including warming the PC and making two diskette copies of each file. An average file of around 6k samples took 0.37 MBytes of disk space and in total the 172 files saved required 70 HD diskettes per copy.

D.C. REGULATOR, BATTERIES AND GENERATOR

Initially a Melcher D.C. regulator was used to provide a stable 13 Volt supply from two (12 Volt 60 Ah Lead Acid "Tungstone") batteries producing 24 Volts in series. This would allow the continued operation of the Bison and computer even if the voltages of each battery dropped below 12 Volts. However the regulator could not provide enough current for the BISON printer at peak use and the Toshiba computer would only run at the "slow" clock-speed doubling the downloading time. The batteries were therefore reconnected in parallel and performed well. They were easily maintained at a voltage of over 13 Volts by charging them most days for a half to one hour.

A single deep cycle lead acid "leisure" battery was also taken as a spare and performed very well. This battery was far better designed to retain the acid which inevitably spilled when the sledges capsized, and it seemed to hold its charge well.

The ED300 Honda generator was completely reliable, efficient and quiet; using under 40 litres of petrol for the whole season.

NAVIGATION

All navigation and location of the sites was made using two Global Positioning Systems (GPS): The "Trailblazer" Magellan and the Garmin 75. The Magellan was mounted on the front (GA) ski-doo for navigating to each location whilst the Garmin was used to locate the final site of the seismic shot.

Both systems worked well although the Garmin had several features that were advantageous for this work: The display was larger, clearer and steered you back on course in a smoother manner; The plot display of the route taken and waypoints entered allowed quick checks for (human!) errors and the display of the satellite positions and the estimated position error ensured that the location could be recorded at the best moment. The positions recorded are generally accurate to within 120 m 2-D RMS. Of this 100 m 2-D RMS originates from the accuracy degradation introduced by the US Defense Department imposed Selective Availability program. It was reassuring to see that although the altitude error should be typically two three times the horizontal error (due to satellite geometry) this was never more than 100 m out.

On the down side both were frustrating to operate with mitts or cold hands (particularly the Magellan with its scrolling menus). The Garmin only had a one and half hour battery life (four alkaline batteries in the cold) and the Magellan could lose its satellite lock without warning the operator and indicate a change in course whilst searching for a new lock.

EXPLOSIVES

For all seismic reflection spot depth surveys a 4 m shot hole was drilled using a hand ice-corer and, after careful back-filling with snow and ice-cores, no blow-outs occurred. The signal/noise improvement over a charge buried at around 1 m was considerable particularly in the reduction of ground roll that would otherwise have obscured the primary ice-base reflection. A depth of four metres was chosen after several tests showed that beyond this little improvement was gained from the increasing effort. Very much less energy is required for the shallow refraction surveys and detonators buried at 20 cm or 50 g charges at 1 m were used as the sources.

The typical charge used for the spot depths was two primers: Two Miniseis (Total 200 g) seemed to be at least as powerful as two Trojans (Total 340 g). Around a quarter of the sites only required one primer and these tended to be located away from the coast but in relatively shallow water. In particularly disturbed areas such as near the southern edge of the Evans three charges were necessary on three occasions to pick up both the seabed and the more indistinct ice-base.

Multiple primer charges were joined by tape and the detonator wire was clove hitched around and taped to the primers. No misfires occurred.

Taken into the field:

178 Miniseis cast PETN primers (@100 g)
274 Trojan cast Pentolite 6 oz primers (@~170 g)
402 Nitro-Bickford "Daveydet" seismic electric detonators
on 5 m wires (July 1991)

Returned:

7 Miniseis cast PETN primers
137 Trojan cast Pentolite primers
0 Nitro-Bickford "Daveydet" detonators

No detonators were returned since only two planes were available for the uplift of the passengers, explosives and detonators; none of which may be flown together in any combination. 179 detonators were destroyed in the field.

ROTHERA ICD EXPLOSIVES INVENTORY (March 1995)

(Note: ICD contents only, see Ed King for full inventory. The ICD and Geophysics stocks are not packed separately)

Main Magazine

ANFO

18 boxes each containing 10 charges of 2.5 Kg Total 450 Kg
(180 Charges)

Miniseis P (100 g PETN)

1 box containing 7 primers Total 7

Trojan 6 oz Pentolite

Total 0

ALL ICD Trojan primers were used

11 extra Trojan primers were taken from the Geophysics stock

Red Annex

10 m lead detonators, ICI, 1988 Total 35

Grey Annex

5 m lead detonators, Nitro-Bickford, 1991 Total 520

3. OPERATIONS AND PROCEDURES

3.1. SPOT DEPTH SEISMIC REFLECTION SURVEYS

These parameters were kept constant throughout:

Shot depth	4 m +/- 0.1 m
Number of Channels	24
Geophone spacing	10 m
Shot offset	30 m
Sample interval	0.25 ms
Lo-cut analogue filter	4 Hz
Hi-cut analogue filter	1 kHz
Pre-amp gains	All high
Orientation	Along Profile

These parameters varied depending on the conditions and the ice and water column thicknesses:

Charge size	Usually 200 g (100 to 400 g)
Record delay	250 to 500 ms
Record length	1.5 to 2.5 s

For each survey the geophone cable was reeled out and the 24 geophones planted at offsets of between 30 and 260 m. In softer snow and when windy a "spade depth" hole was dug for each geophone to ensure a good contact with the ice and to minimize the noise. The four

metre shot hole was cored in-line 30 m from the first geophone and was ready for loading by the time the BISON had been set up and tested. Lashing/unlashing time was minimised by placing all the equipment on one half nansen sledge with the cable drum at the rear and, with practise, one site could be completed within an hour.

The objective was to be able to clearly pick or calculate the two-way-travel (TWT) times of the primary reflections from the ice (I_1) and sea bed (I_1W_1). Long record lengths were used to record both the primary reflections and any of the weaker multiples that might be detected. The I_2 (Ice column twice TWT time) or I_2W_1 (Ice column twice & Water column once) multiples in particular were often clearer than the I_1 primary itself and could be used to calculate I_1 after identifying the clearer I_1W_1 primary. The identification of the multiples was an important interpretation tool and particular care had to be taken when the I_2 arrival came near that of I_1W_1 .

The relative strength of the ice base reflection depends on how close the ice-ocean interface is to the ideal abrupt planar boundary. A weak ice bed reflection partially obscured by the remnants of ground roll made many records difficult to interpret. Most difficulty was experienced near the shear margins and grounding lines where the ice bed reflection tended to be weaker and noise came from natural acoustic energy (often so loud it could be heard at the surface) and out of plane reflections from fractures (crevasses and tide cracks). Figure 2 shows an example of a clear reflection record (No.0074 at K6). The Non-AGC record shows the relative strength of the primary reflections and reversed polarity of the I_1 arrival (c.f. the I_1W_1 arrival) due to the large velocity inversion (decrease with depth) at the ice-ocean interface. With the AGC applied the I_2 , I_1W_2 and I_2W_1 primaries can be clearly identified. The ground roll appears as slow moving event of high amplitude and low frequency that has largely decayed before the I_1 arrival.

The two-way-travel times to the ice and sea bed could be picked to an accuracy of ± 0.75 ms on most records although this depends on the record quality. To convert these times to depths the velocity within the various mediums must be calculated. The average velocity for the top 100 m of unconsolidated snow (firn) was found from the refraction surveys to be on average 2894 ms^{-1} . The velocities used for the ice column below 100 m, 3805 ms^{-1} , and the water, 1470 ms^{-1} , are taken from Smith and Doake 1994. The surface elevation has been calculated using the equation for hydrostatic equilibrium of the ice (D. G. Vaughan et al 1995). Figures 4 and 5 illustrate four typical depth profiles: 4a) Profile A to B showing the rise in the sea-bed 40 km south of Berkner Island; 4b) Profile F to G showing the shallow water column thickness south of Henry Ice rise; 5a) Profile Korff to R showing the deep flat channel between Korff Ice Rise and Fowler Peninsular and 5b) Profile U to V showing the gentle U-shaped sea-bed at the mouth of the Evans Ice Stream.

3.2. SHALLOW REFRACTION SURVEYS

Shot depth	20 cm and 1 m
Number of Channels	24
Geophone distance from shot	1,2.5,5,7.5,10,12.5,15,20,25,30,35,40,45,50,60,70,...140,150 m and 150,160,170,...370,380 m
Sample interval	0.1 ms

Charge size	1 or 2 Detonator(s) and 50 g of Miniseis PETN
Record delay	0 ms
Record length	0.25 and 0.5 s
Lo-cut analogue filter	4 Hz
Hi-cut analogue filter	1 kHz
Pre-amp gains	All high

The main objective of this work was to find the average travel time correction for the low velocity layer of firn over the ice. The velocity of a seismic wave in the bulk of the ice is near constant, but it rises rapidly within the top unconsolidated layers; gradually approaching the bulk value by a depth of around 100 m. The firn-ice transition giving rise to the velocity depth function depends on the surface temperature and accumulation of the area.

The first arrivals are measured for two shots at short, 1 to 150 m, and long, 150 to 380 m offsets. An example of a long offset refraction record is shown in Figure 3 and the first arrivals are seen between 70 to 150 ms.

An in-house program employing The Wiechert-Herglotz Inversion with Abels Integral Equation was used to reduce the time/distance data to a velocity/depth function. This also gives an average velocity for the top 100 m of the ice which was used to correct the travel time to depth conversion for the slower firn. The variation in the average velocity over the five refraction surveys made at D2, H1, O1, T4 and V7 was under 5%; producing an error in the firn correction of under 1m.

3.3.GRAVITY SURVEY

The gravimeter reading was recorded at each site and two examples of gravimeter profiles are shown in Figure 6. Since the ice-surface elevation is nearly constant the uncorrected result is largely a function of the seabed topography, proportional to the elevation of the sea-bed. This aided the initial interpretation of some of the noisier seismic reflection records.

During the lie up at Site 3 hourly gravimeter readings during the day were made to form a gravimeter tidal record. These are shown with the predicted tides from the Proudman Oceanographic Laboratory Tidal Model (personal communication from A. V. Robinson 1995) in Figure 7. Although the amplitudes are different (N.B. Not to scale) the phase and frequency match appears to be very good. Unfortunately the record is too short to allow a reliable harmonic analysis.

3.4.STRAIN ROSETTE SURVEY

At Hot Water Drilling Site 3 the (four pole) strain rosette was remeasured using a 100 m steel tape and a TH2 Zeiss theodolite. Two distances were measured, a short and a long arm, and all angles from each glacio-pole. The results are given in the Appendix.

4.CONCLUSION

While in the field 152 spot depth seismic surveys were made and a total distance of over 2800 km was travelled by ski-doo. Since the route was so open the camp had to be moved each day but the generally favourable weather allowed good progress throughout the whole season.

Although the results conform to the general trends estimated by Dave Vaughan for the "Map of Subglacial and Seabed Topography" there are significant variations from this conception. The data will be published and incorporated into the existing dataset for the Filchner Ronne Ice Shelf.

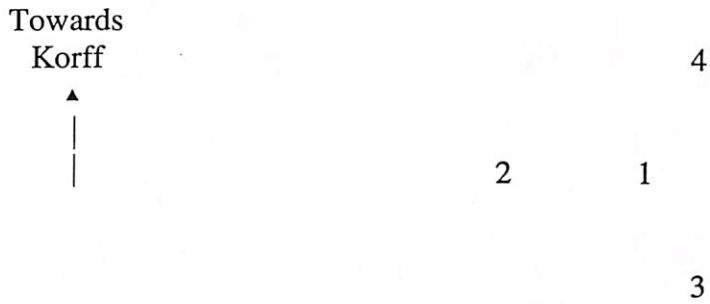
A 150 m rise in the sea-bed 50 km south of the southern grounding line of Berkner Island divides the southern trough into two and may split and direct the tidal flow. This will be highly significant to the results of the 96/97 hot water drilling season at the northern and southern limits of this trough. The southern trough in the region between the Henry Ice Rise and the coast appears to be skewed northwards: deepest just 20 km south of the Henry coastline. There is evidence to support that the underwater ridge (aligned with waypoints T, U and UB) is a continuation of the Fowler Peninsular but importantly, this remnant of the ridge does not block the western trough. The Evans appears to deepen upstream to the south and west to a maximum depth of over 1500 m and not to the north and east as previously thought.

ACKNOWLEDGEMENTS

Many thanks in particular to John Sweeny and also to all the Support Staff at Rothera, the Air Unit and the ever patient Radio Shack Crew.
Keith Nicholls, Andy Smith, Dave Vaughan, Chris Doake, Ed King, Keith Makinson and Allan Robinson for all their assorted help in Cambridge.

APPENDIX

Strain Rosette Measurements:



Travel
Depot

Angles:

123	30° 0' 47.8"	431	30° 3' 51.2"
421	29° 48' 59.6"	132	32° 26' 51.7"
423	59° 49' 47.4"	432	62° 30' 43.0"
241	30° 9' 13.3"	214	120° 22' 33.5"
143	27° 41' 41.9"	413	122° 16' 8.9"
243	57° 49' 18.0"	213	117° 21' 17.5"

Distance 1-2 840.386 m (Tape temp=-8.5°C)

Distance 2-3 1386.473 (Tape temp=-9.0°C)

Exposure of poles:

1) 2.263 m 2) 2.970 m 3) 2.166 m 4) 2.527 m

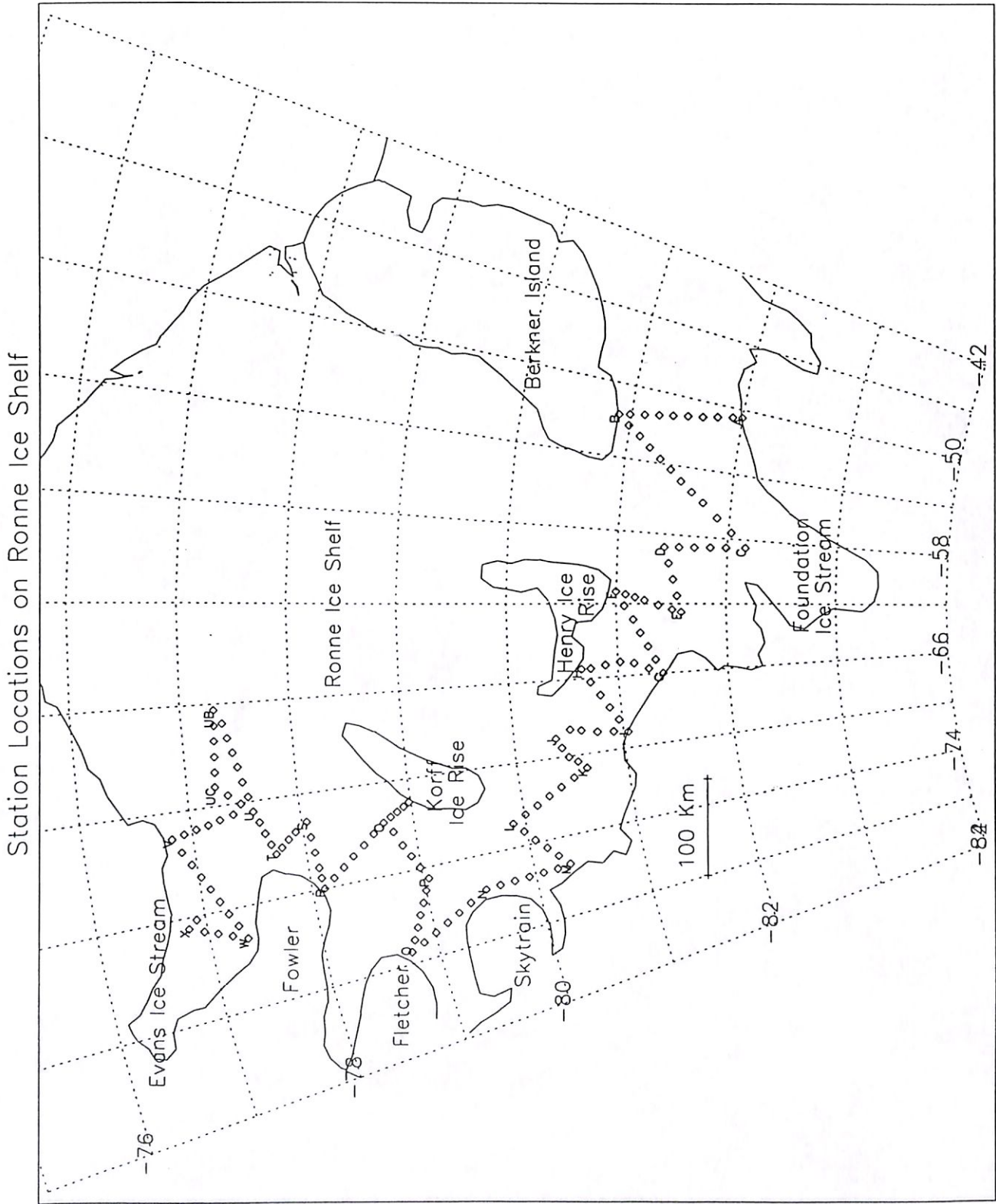


Figure.1: Location Map

Figure.2: Reflection Profile Record No. 0074 @ K6

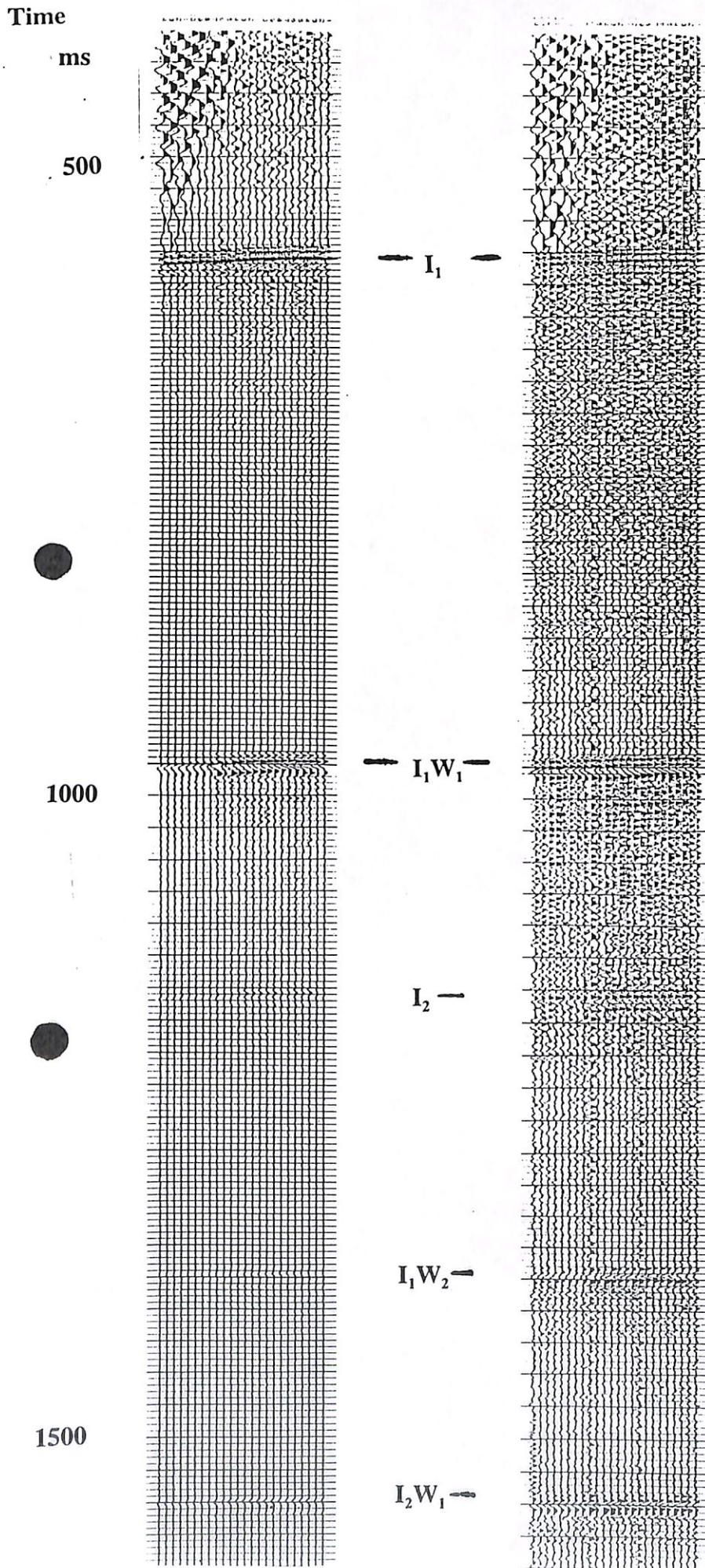
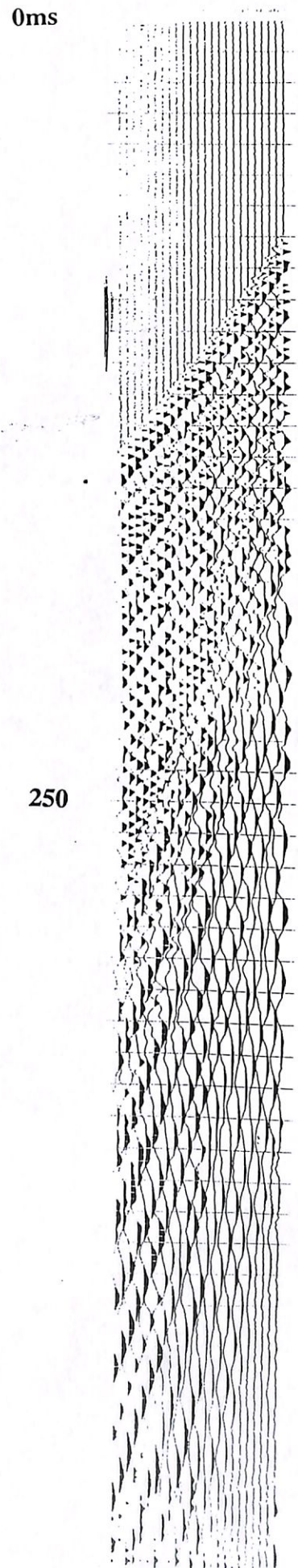


Figure.3: Long Offset Refraction Profile

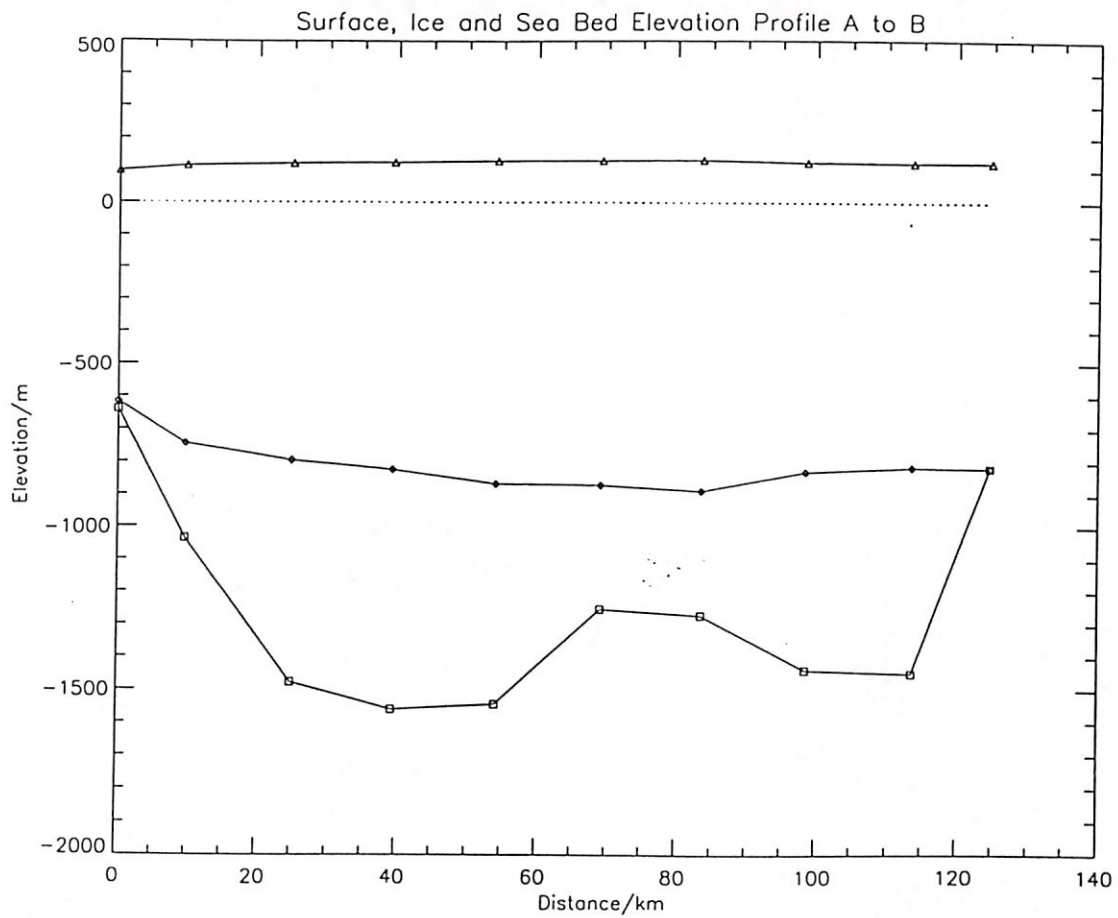
No. 0054 @H1



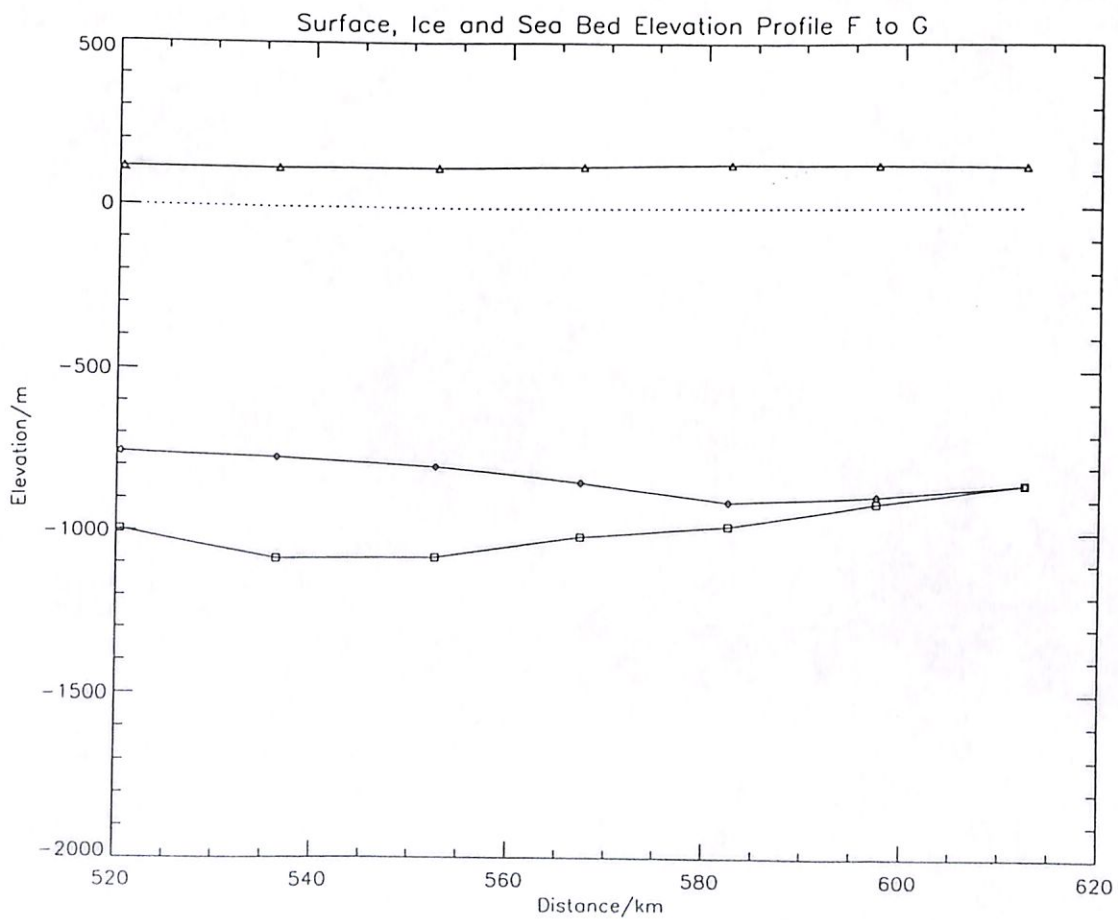
a) Without AGC Primary Reflections only

b) With AGC Multiples and Primaries

Figure.4: Surface, Ice and Sea Bed Elevation Profiles

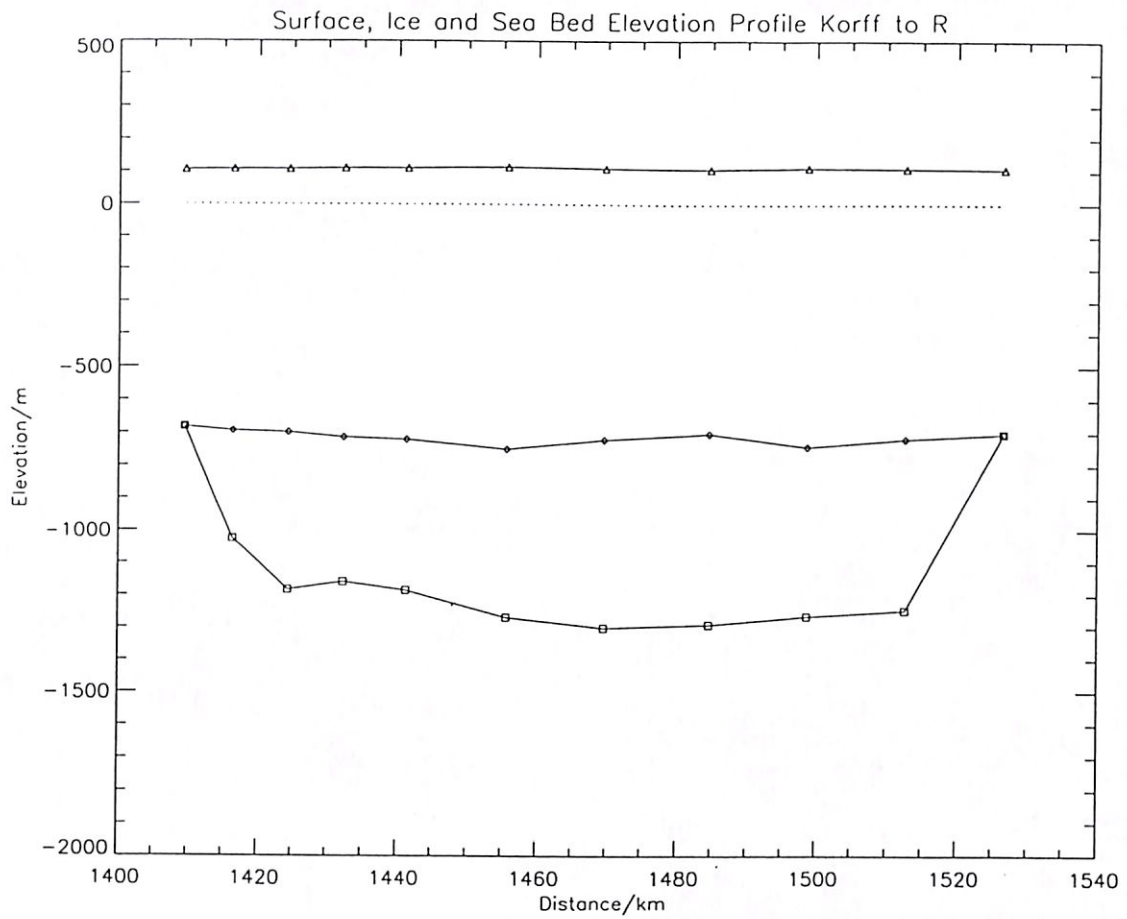


a)Profile A to B

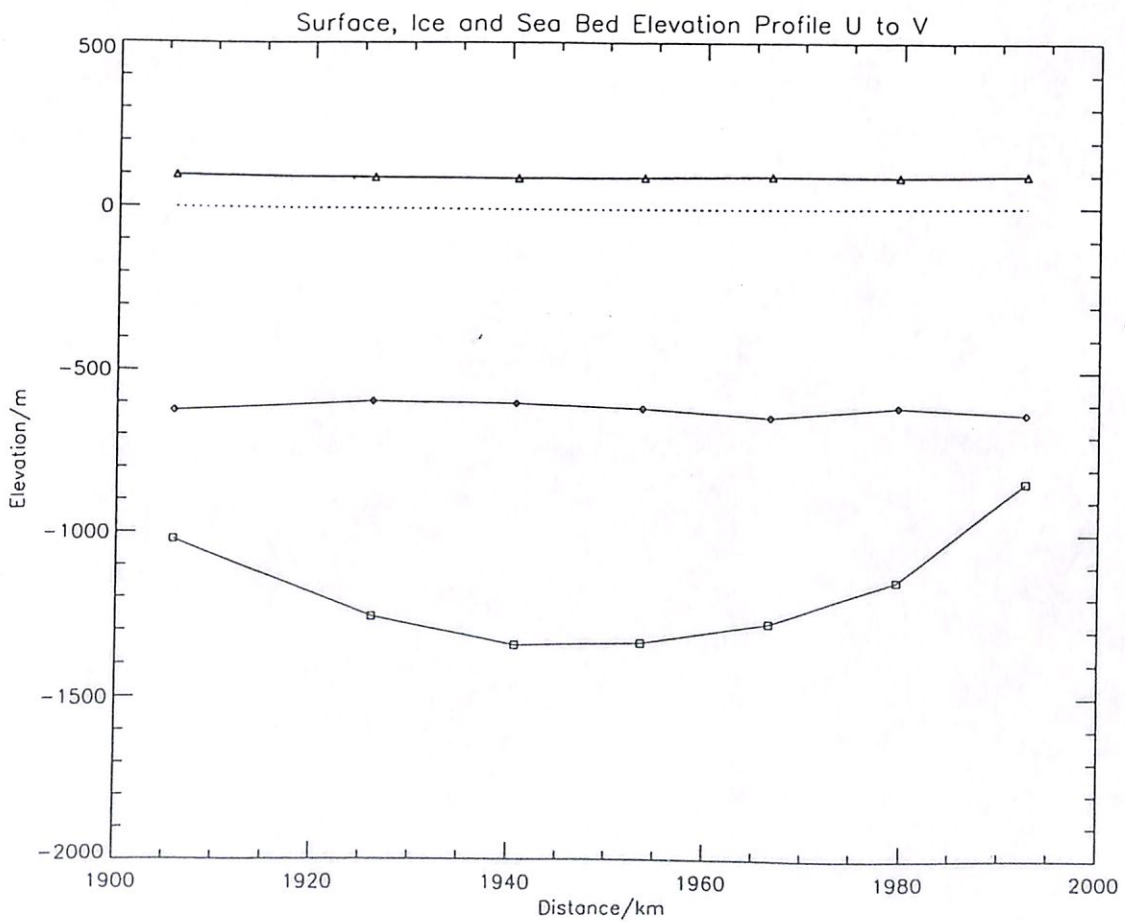


b)Profile F to G

Figure.5: Surface, Ice and Sea Bed Elevation Profiles

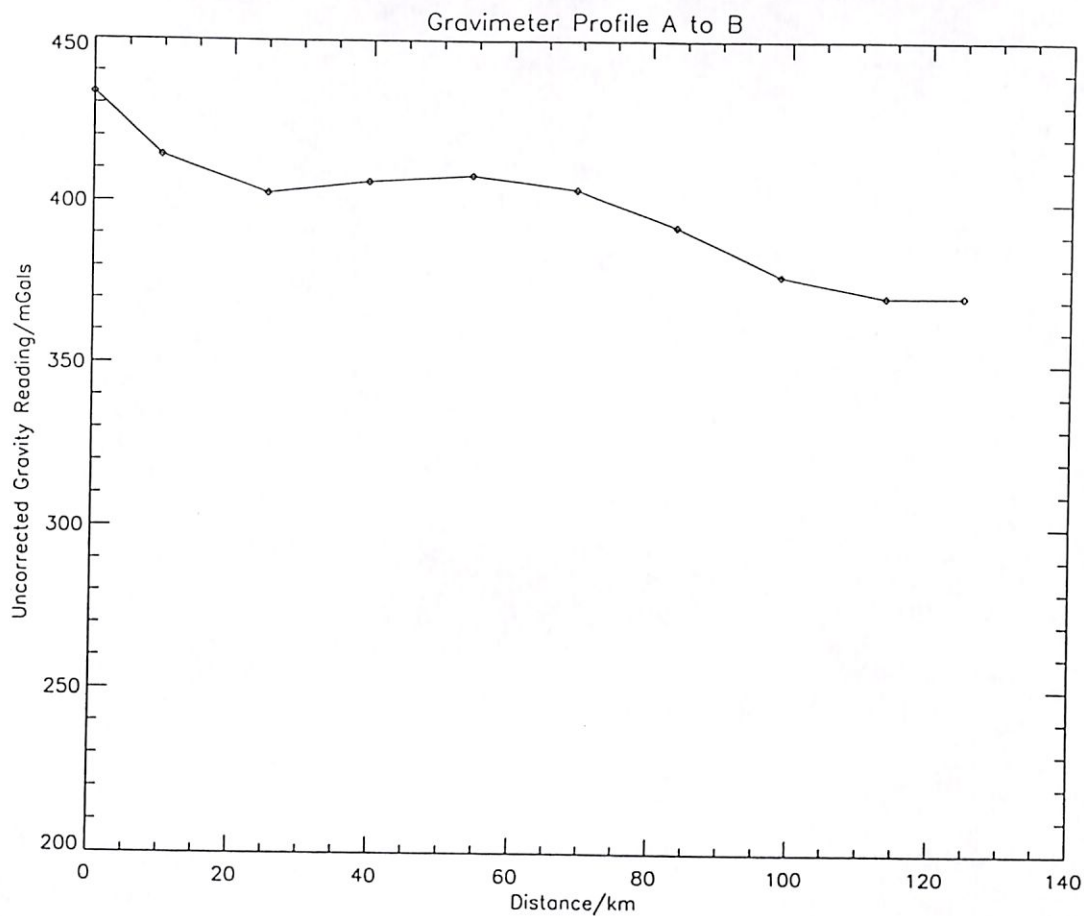


a)Profile Korff to R

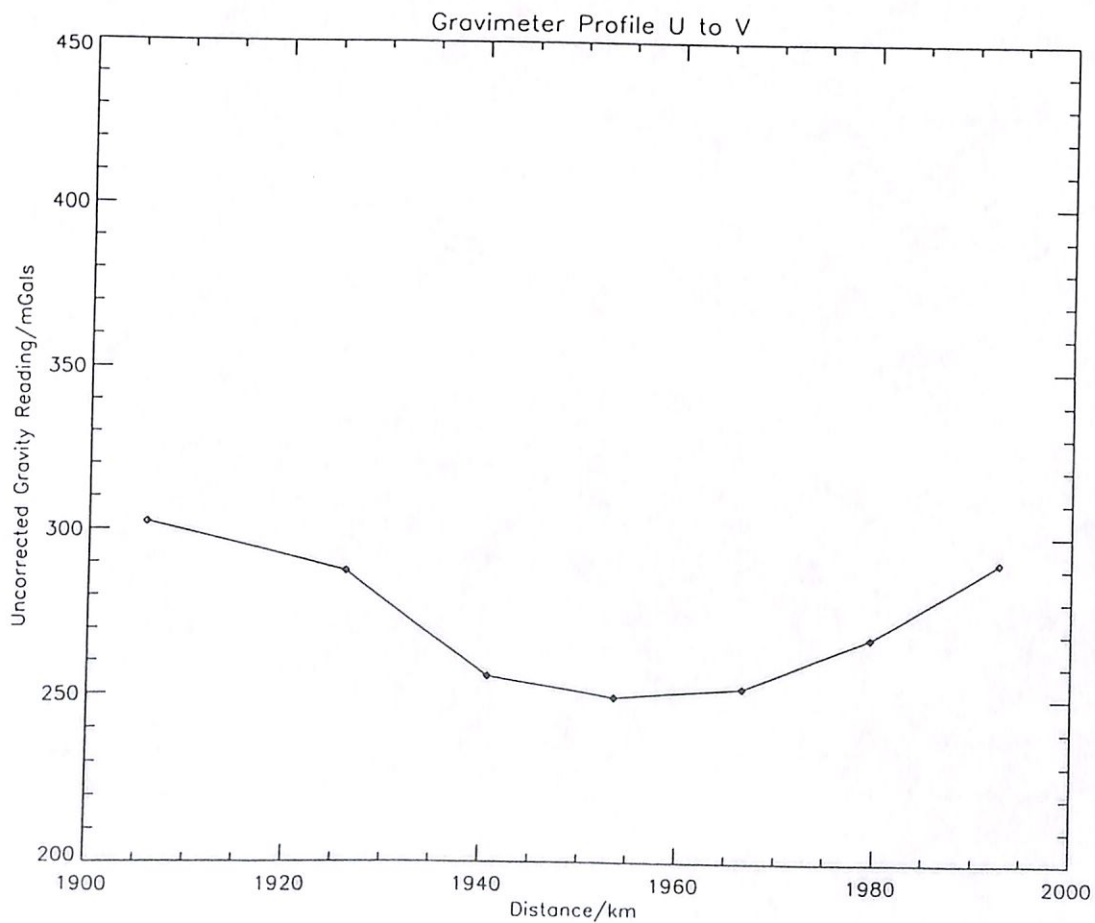


b)Profile U to V

Figure.6: Uncorrected Gravimeter Profiles



a)Profile A to B



b)Profile U to V

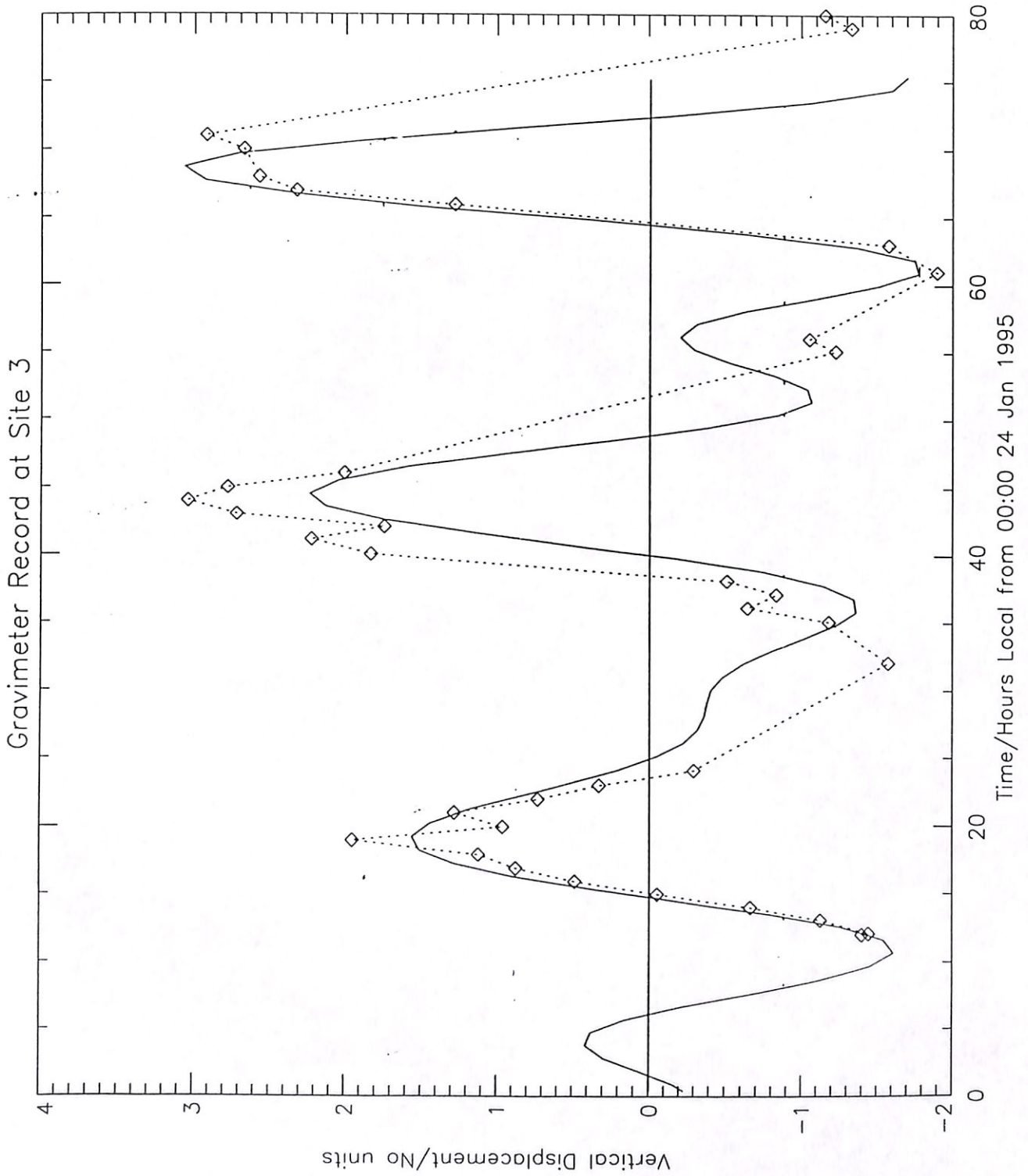


Figure.7: Site 3 Tidal Record: Solid Line-Modelled Tide
Dashed Line-Gravimeter Readings

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