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GROUND PROBING RADAR EXPERIMENTS AT THE FOOTHILLS PIPELINE FROST HEAVE TEST FACILITY, CALGARY, ALBERTA

A-Cubed Inc.
Mississauga, Ontario

Earth Physics Branch Open File Number 83-13
Ottawa, Canada, 1983

Price/Prix: $ 75.00

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Abstract

This report presents the results of phase one of a test program using ground probing radar (GPR) at the Foothills Pipeline Frost Heave Test Facility in Calgary, Alberta. It contains a description of the field operations and presents the data in raw form along with topographic information collected at the time of the survey.

Résumé

Ce rapport présente les résultats de la phase I d'un programme d'essais d'un radar pour sonder les sols (GPR) a Calgary au Foothills Pipeline Frost Heave Test Facility. Il contient une description des opérations sur le terrain et présente les résultats bruts ainsi que l'information topographique recueillis lors du programme d'essais.

GROUND PROBING RADAR EXPERIMENTS
AT THE FOOTHILLS PIPELINE FROST HEAVE
TEST FACILITY, CALGARY, ALBERTA

Job. No. 52-5008

REF. DSS CONTRACT
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Distribution:

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Earth Physics Branch
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Mississauga

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1. INTRODUCTION

This report presents the results of phase one of a test program using ground probing radar (GPR) at the Foothills Pipeline Frost Heave Test Facility in Calgary, Alberta. It contains a description of the field operations and presents the data in raw form along with topographic information collected at the time of the survey.

The Frost Heave Test Site was established by Foothills Pipeline in 1974. It contains 5 short sections of 1.2 metre diameter pipeline which have been installed using several burial configurations. These pipes are continuously cooled to -10°C. with circulating refrigerated air in order to study the extent of freezing in the surrounding soils and to monitor frost heave activity as it pertains to the pipe installation.

During the experimental period, an extensive "frost-bulb" has grown around each of the pipes. The current GPR experiments described in this report were undertaken with the objective of ascertaining whether GPR techniques could detect the "frost-bulb" and provide some indication of the ice content in the bulb.

The work was carried out by A-Cubed Inc. personnel during March, 1983. This work comprised one or more radar profiles across all of the buried Sections of pipeline with each of three antenna systems. The antenna systems used were:

1. a 2 ns pulse length pair with a centre band frequency of about 300 MHz.

2. a 10 ns pulse length antenna pair with a centre band frequency of 200 MHz.

3. a 10 ns pulse length antenna pair with a centre band frequency of 100 MHz.

The objective of using these three antenna systems was to examine the depth of penetration/resolution tradeoff at various frequencies.

The work also included several CDP soundings which are used determine the EM wave velocities of the soil at the site. This information is necessary for computing depth estimates of the various radar reflection events.

The report concludes with two Appendices describing general radar principles and radar sounding techniques.

2. SITE DESCRIPTIONS AND SURVEY PROCEDURES

The survey was carried out under very good weather conditions. The recent warm weather had melted all snow and the ground was quite soft. Puddles were present in low areas.

2.1 Site Descriptions

The survey comprised one or more profiles run over five buried pipeline sections. Two panoramic views of the Test Facility are presented in Figure 2.1. The cross section models for each of the test pipes is given in Figures 3.2 - 3.6. The various test configurations have been reported by Carlson et al (1982)*. The following is a brief description of each of these configurations.

a) Deep Burial Test

A non-insulated pipeline section 1.2 m in diameter and approximately 12 m long was buried to a depth of 2.9 m (original surface to bottom of pipe). The pipe was covered with an original thickness of 1.65 m of silt. At present, the test consists of a berm approximately 2 m high which had a high silt component. The photos in Figure 2.2.1 show the berm and the placements of the radar line along with the numerous frost heave monitoring rods. Fortunately, a portion of the berm was clear of rods and a single radar survey line was readily laid out over the site.

b) Straight Gravel Test

A non-insulated pipe with a 1.2 m diameter was buried at a depth of 2 m from the original ground surface (to bottom of pipe) and mounted over a gravel pad 0.9 m thick. The pipe was covered with a layer of silt 0.75 m thick. The soil over the pipe is now about 0.3 m above the surrounding surface. At the time of survey the silt had thawed producing a very muddy surface on the radar survey lines. There were also some cobbles present on the eastern line. As seen in Figures 2.2.2 and 2.2.3, there was a large number of survey rods and sensors present which limited the positioning of radar

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*Carlson, L.E., Ellwood, J.R., Nixon, J.F., Slusarchuk, W.A., 1982: "Field Test Results of Operating a Chilled, Buried Pipeline in Unfrozen Ground", Proceedings of the 4th Canadian Permafrost Conference.

lines to two locations. These rods did not seem to severely affect the radar's data quality on the easternmost line. Several cables cross the west line (see photo) generated considerable clutter on the radar records.

c) Restrained Pipeline Test

A pipe similar to that buried in a) and b) above was buried to a depth of 2 m below ground surface (to bottom of pipe) and covered with 0.75 m of silt. The pipe was fitted with restraining devices at both ends to provide a constant hold-down pressure. The berm currently at the site is approximately 1.5 m in height. The hold-down units and the high density of heave rod permitted only one line to be located across this site. The line is shown in Figure 2.2.6 along with the location of the survey rods and a cable which ran across the line at the west end.

d) Insulated Gravel Site

This pipe is similar to that used in the Straight Gravel test section but it has a 15 mm thickness of polyurethane foam insulation around the pipe. The pipe is completely surrounded by gravel. There is a 0.75 m cap of silt on top of the gravel. (See Figure 3.4). The soil over the pipe is about .8 m above the surrounding terrain level. Once again, the large number of heave rods limited the choice of radar survey lines to three. One at the eastern end of the pipe and two towards the western end of the pipe. The site is shown in Figure 2.2.4.

e) Insulated Silt Site

The pipe and insulation are identical to that described for the insulated gravel site. The pipe was buried to a depth of 2 m to the bottom of the pipe. The burial trench was then filled with silt such that the top of the pipe was 0.75 m below surface. The soil directly over the pipe is currently 0.4 m above the surrounding terrain. Two radar lines were situated over this site although other instrumentation and heave rods occupied much of the central portion of the line. The site photo is shown in Figure 2.2.5.

2.2 Survey Procedures

After a preliminary review of the site, a series of profile lines were chosen where there would be minimal interference from survey rods and other objects. Where possible, more than one line was chosen on each pipe site. A summary of the line positioning is given in Table 2.2.1. Each line was chained and flagged at one metre intervals with '0' being the pipe axis. The distances were all measured conformable to the topography (secant chaining) so true horizontal intervals may be somewhat less than 1 m where there is considerable vertical relief. The corrected topography is plotted in the series of Figures 3.2 - 3.6.

In order to examine the depth of penetration and resolution tradeoff, three antenna configurations were employed on each line. These were a set of 2 ns pulse length antennas of 300 MHz. response and two sets of 10 ns pulse length antennas with 200 MHz and 100 MHz band centre frequency responses. All three antenna systems were bistatic with separations of 0.5 m centre to centre.

The antenna pairs were mounted with dipolar axes parallel on a wooden frame and were positioned approximately 3 cm above the ground. The antenna axes were positioned perpendicular to the direction of profiling. They were placed as low to the ground as possible to maximize coupling with the ground and to minimize the level of cultural noise from local radio and TV stations in the FM band, as well as scattering noise generated by the wide variety of metallic objects all over the test site.

The survey procedure itself consisted of dragging the antennas at a slow and constant rate along the line. At the same time the data was displayed on the control unit oscilloscope, recorded on a cassette tape and displayed in a grey scale format on an EPC graphic recorder. This real-time display allows the operation of the radar system to be constantly monitored and adjustments made to optimize the signal. As the antennas are profiled across a flag, the event is noted on the field records and recorded on tape as a brief signal interruption. These produce marker bands on the EPC records.

TABLE 2.2.1 - RADAR PROFILES

TITLE	BEARING	ORIGIN	SOL/EOL	NOTES
Deep Burial	NW-SE	Centre Line - 3m south of north survey peg	13.77m west 13.58m east	
Restrained	E-W	Centre Line - 0.8m north of south survey peg	10.71m west 9.64m east	
Straight Gravel (E)	N-S	Centre Line - 1.4m west of east survey peg	3.96m south 4.96m north	
Straight Gravel (W)	N-S	Centre Line at west survey peg	3.98m south 3.98m north	
Insulated Gravel (1)	N-S	Centre Line - 1m west of east survey peg	4.85m south 1.96m north	
Insulated Gravel (2)	N-S	Centre Line - 2m east of west survey peg	4.93m south 1.99m north	
Insulated Gravel (3)	N-S	Centre Line - .5m east of west survey peg	4.94m south 1.99m north	
Insulated Silt (1)	N-S	Centre Line - 2m west of east survey peg	4.96m south 1.99m north	
Insulated Silt (2)	N-S	Centre Line - 1.5m east of west survey peg	4.96m south 1.95m north	
Insulated Silt (2aE)	N-S	Centre Line - 2.5m east of west survey peg	4.96m south 1.95m north	100 MHz antennas
Insulated Silt (2bW)	N-S	Centre Line - 0.5m east of west survey peg	4.96m south 1.95m north	100 MHz antennas

Several CDP soundings were carried out in order to obtain a velocity model for the soils of the site. In this type of sounding every effort must be made to maximize coupling of the antennas to the ground. If this is not done spurious surface reflections and refracted air waves contaminate the record and mask surface returns. The antennas must be kept as close to the ground as possible. Unfortunately, the irregularity of some berm surfaces would not permit this for soundings perpendicular to the pipe axis.

CDP soundings parallel to the radar profiles were carried out on the restrained pipe section and the straight gravel section east line. CDP soundings perpendicular to the pipe axis were carried out on the insulated gravel pipe east line and insulated silt line 2. The results are tabulated in Table 2.2.2. The reader is referred to Appendix B for a more in-depth discussion of WARR and CDP sounding techniques. After all radar profiles and CDP soundings were completed, each station was surveyed with respect to the deep benchmark in order to provide detailed topographic information on each line. This information is necessary since the radar system yields depths to reflectors below surface independent of the topography. Thus a flat-lying reflector surface will mirror the topography above it. (See Appendix A). Topographic information allows for the correction of this phenomenon and eventually permits a picture of the subsurface reflectors in 'true' absolute section format. The accuracy of this picture is limited by the accuracy of the velocity model used to convert the measured two-way travel times to depths.

Table 2.2.2 - CDP SOUNDING RESULTS

TITLE	POSITIONING	VELOCITY	NOTES
RESTRAINED	parallel to radar profile. Centred at 0	0.07m/ns	perpendicular to pipe axis
GRAVEL	parallel to L1 centred at 0	0.144 m/ns	perpendicular to pipe axis. Antennas mounted on board due to extreme topographical variations, thus poor ground wave data. Reflection velocity.
INSULATED GRAVEL	Perpendicular to Line 1. Centred on Line 1 at 0.5 metres south	0.114 m/ns	parallel to pipe axis. Good ground wave data quality.
INSULATED SILT	Perpendicular to Line 2. Centred on Line 2 at 0.5 metres south	0.087 m/ns	parallel to pipe axis Good ground wave data quality.

3. PRESENTATION OF RADAR FIELD DATA

Post-field data processing permits the radar information to be modified and enhanced in a number of manners. A brief summary of the common types of signal processing and rationale for the processing is presented below.

The broadband nature of the radar system makes it sensitive to radio frequency noise from local stations. This noise is frequently a problem in urban areas with a high density of radio and TV stations. In addition to this, the radar signal is frequently scattered from nearby surface clutter and this too can mask the important subsurface data in the record. The scattered energy is usually dominated by the higher frequency components of the radiated signal. In some instances, these noise problems can be reduced by analog bandpass filtering of the data during replay. The bandwidth of the useful data is often small and bandpass filtering can successfully remove a great deal of very low frequency rumble and high frequency scattering noise in the data. Eliminating noise signals is very beneficial when using a limited dynamic range grey scale graphic record or for data display. The data presented here has been bandpass filtered and the band is noted on each section. Figure 3.8 demonstrates the effect of bandpass filtering on Line 2 of the Gravel Insulated section.

A very important aspect of the radar data is the tremendous vertical exaggeration of the data display. On the radar records, the horizontal position is the horizontal axis and the delay time to the reflector (see Appendix A) is the vertical axis. There is frequently a large scale difference between these two axes and on typical records of length corresponding to several tens of metres, the vertical axis may have a depth of only a few metres. Any significant slope in the subsurface structures will then be greatly exaggerated on the radar record and this makes interpretation more difficult. By contracting the delay time axis and expanding the position axis during playback one can produce a much more easily interpreted record. This has been done for the data presented here.

In addition to the above corrections, a D.C. bias is added to the signal to introduce a false shading which tends to suppress some of the noise and enhance the finer details of the data. The final result is a record which can be rapidly analysed.

Once all of the data has been played back in a consistent format, it is fully annotated from the tape notes and the original field records. The records are cut and mounted in manageable lengths and the section is located as accurately as possible on the site maps. Topographic information, when available, is compiled in graphic form along with the radar data.

The data presented in the series of Figures 3.2 to 3.6 consists of data from all three antenna systems with fid locations noted and has been augmented with travel time scales. The travel times are absolute measurements established when the radar controller is set up for any given survey. In addition to the raw data, the topographic information on each berm has been compiled and plotted. Finally, the site model for each line has been included as an interpretation guide. The scales on the topography and the model are not the same, however, the centre axes have been aligned in each case.

The positioning of each survey line is flagged on the accompanying small site map. The bandpass filter settings have also been included for each antenna system.

4. PRELIMINARY DATA INTERPRETATION

The radar data at most of the sites clearly shows the presence of the pipeline. The soil covering the pipes and most of the site has a high silt content. Such an environment results in high attenuation of the radar signals and severely limits the depth of penetration of current systems. Typical overburden conductivites reported from EM-31 measurements made by Geo-Physi-Con personnel were in the 30 mS/m range. In spite of the high loss soils, more subsurface features were observed than was anticipated before the survey.

The pipeline/frost bulb is clearly visible as a hyperbolic event on the insulated silt site and both of the gravel burial sites. There is little indication of the pipe/frost bulb at the restrained and deep burial sites, although some digital enhancement techniques might pull out these targets from below the noise level. Some proposed digital processing is discussed in section 5 of this report.

The advantages and limitations of the various antenna systems operating over different frequency bands are highlighted by the data. In general, the depth of penetration is highest on the low frequency (100 MHz) antenna units. The shallow features are strong reflectors but are only poorly resolved with the 100 MHz units. As the operating frequency is increased, the subsurface features are more and more clearly resolved but the depth of penetration decreases rapidly as well. In some instances, the pipeline/frost bulb is barely visible with the 300 - 400 MHz (2 ns) antenna unit.

The in-depth analysis of the hyperbolic pipefrost bulb event is beyond the scope of this report. At this juncture in time, the source of the radar event could equally well be the frost bulb or the pipe. In some instances there is a suggestion of a smaller hyperbolic event embedded within the larger one. In order to assess the information contained in the data, some numerical modelling of the pipe response should be carried out. Digital display and processing on selected lines will also allow a more in-depth examination of subtle features in the reflection hyperbolae.

A noticeable feature on many of the radar sections is the abrupt change in shallow stratigraphy at what appear to be the edges of the trench which was excavated during pipe installation. The variation of stratigraphy across the trench is not well known at this point in time. In addition, the radar appears to see a reflector in the 10 to 30 ns range which is ubiquitous over the site. This reflection is probably from the frost table on the site. Although the temperatures were well above freezing at the time of the field survey, the surface mud was only 10 to 20 cm deep and was usually underlain by a solid base which was thought to be unthawed soil.

While the whole site was littered with heave rods and other monitoring devices, interference with radar system peformance was not serious. By maintaining the antennas in close contact with the ground, very little energy was radiated into the air. This minimized the amount of energy available for scattering from metallic clutter on the surface.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The radar system worked very well over all the sites. A strong hyperbolic event characteristic of a 'point' or two-dimensional target is visible on nearly all records by all antenna systems. The range of antenna systems used has produced data which shows different information and this may be later combined to yield a more complete picture for each line.

Without more information on the original pipe installation, including up-to-date estimates (or measurements) of pipe positioning, it is difficult to ascertain how much actual frost bulb information is contained in the data versus other disturbed soil information. When such information becomes available, a better understanding of the data will be achieved. In addition, any information on the recent depth of the freeze/thaw interfaces would be extremely beneficial in resolving subsurface reflections.

Some digital processing of the multiple frequency data collected would be extremely beneficial. The preliminary analog bandpass filtering of the data hs already demonstrated that there is information concealed in the data which was not apparent from the field records. The raw unfiltered data has been recorded on tape and is ideally suited to this kind of investigation because positioning control is very tight and multiple frequency data has been collected.

In order to understand the detailed nature of the hyperbolic reflection events in the data, a forward modelling study should be carried out in order that the precise form of the buried pipe response can be predicted. This model would represent the response in a uniform medium. Deviations of the true response from the predicted response can then be used to infer information about the structure of the frost bulb around the pipes. This investigation is proposed as a component of Phase II of this project.

We recommend that two or three lines be selected for in-depth investigation. These will include:

1. digitization of data
2. deconvolution/correlation processing
3. enhanced graphics presentation
4. other types of filtering including 'hyperbolic stacking'

This investigation is essential to learn how much 'frost-ice' information is contained in the data. It would also help to further define the hardware requirements and refine the field techniques for future investigations with ground probing radar.

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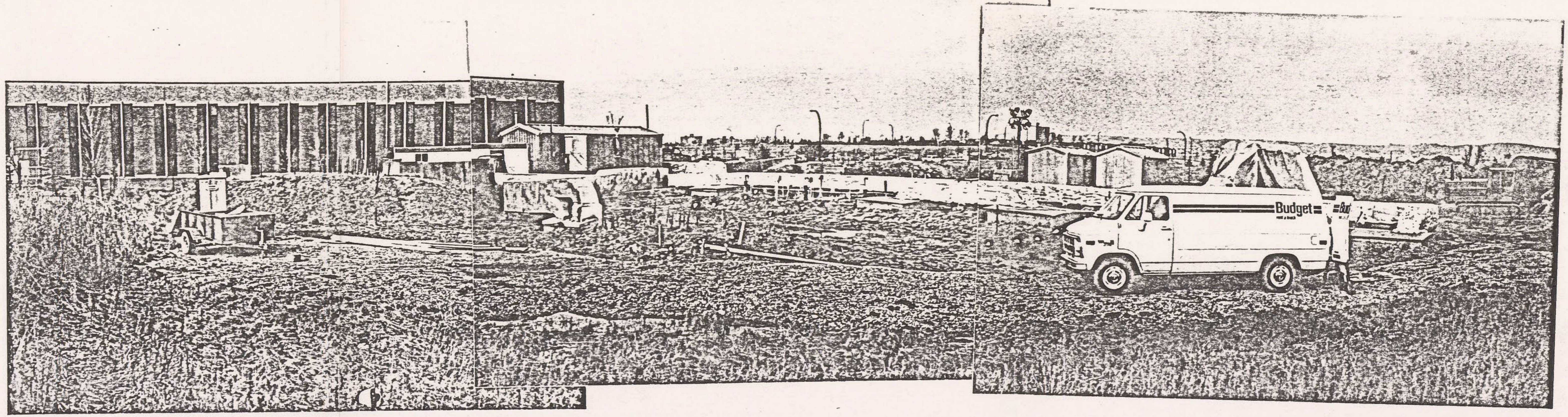
A3 A-CUBED INC.

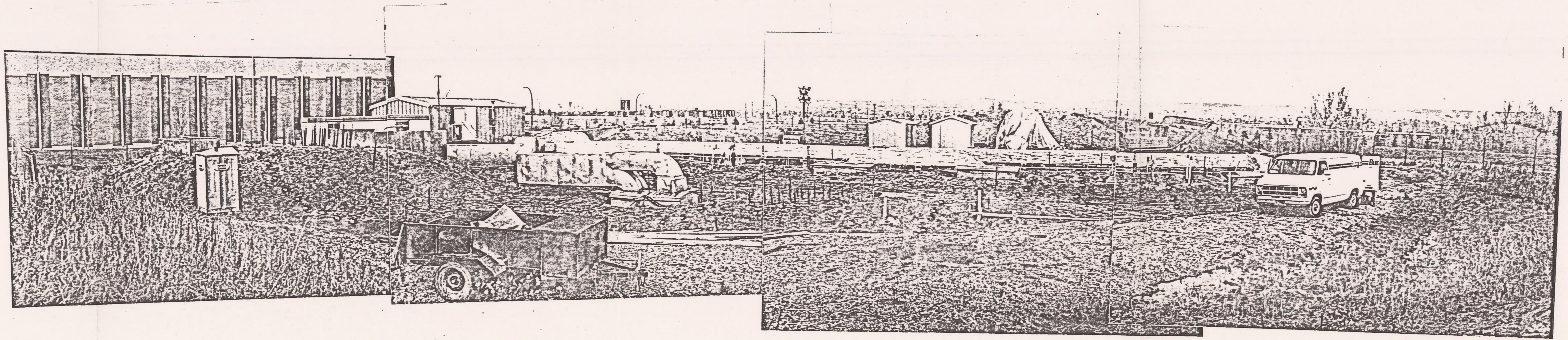
Fig. 2.1 PANORAMIC VIEWS OF FROST HEAVE TEST FACILITY, CALGARY

Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved: CV

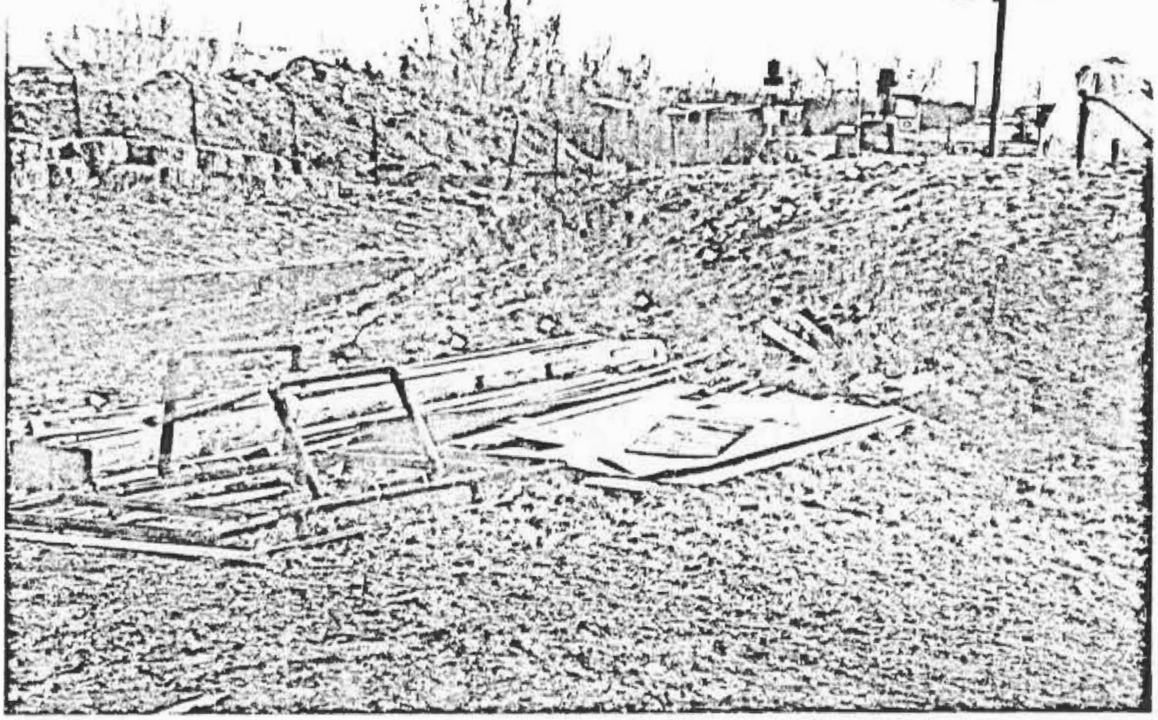


(a) View of site looking Northeast

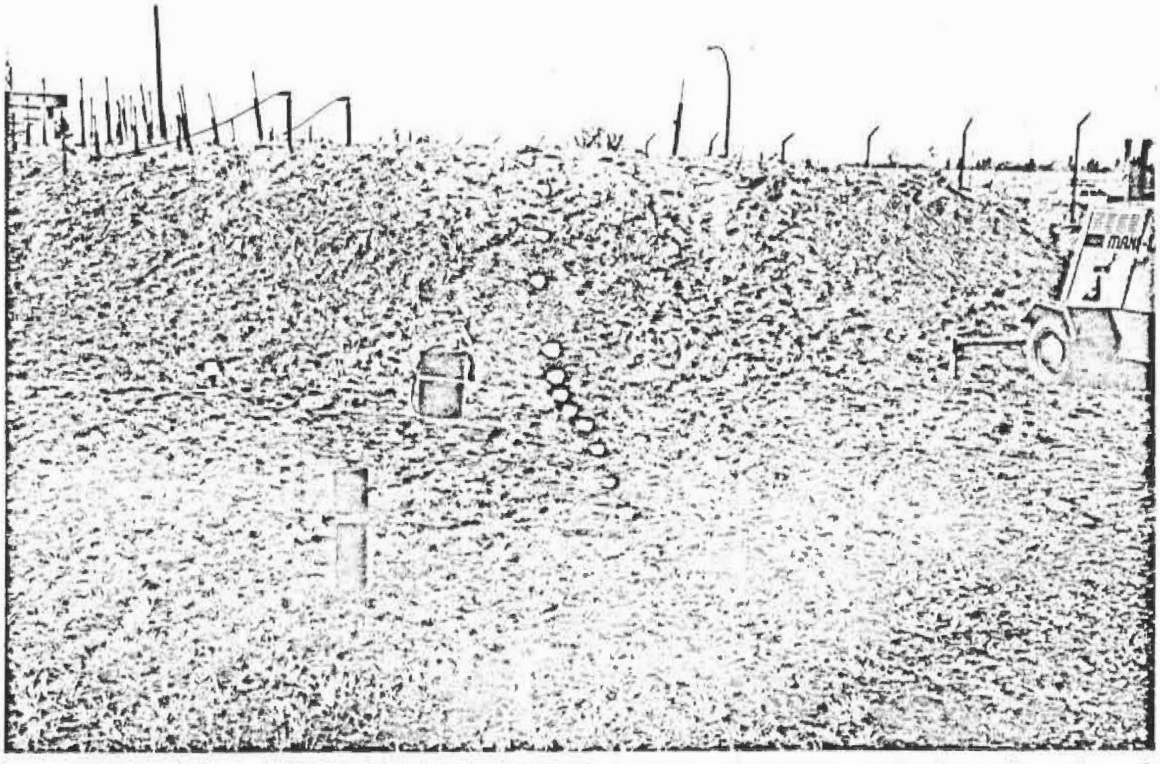
Radar Stations are white dots



(b) View of site looking North



(a) View of Western side of the Deep Burial line showing radar stations



(b) Eastern side of Deep Burial showing radar stations and deep benchmarks

A³ A-CUBED INC.	Title: Fig. 2.2.1 TWO VIEWS OF DEEP BURIAL SITE		
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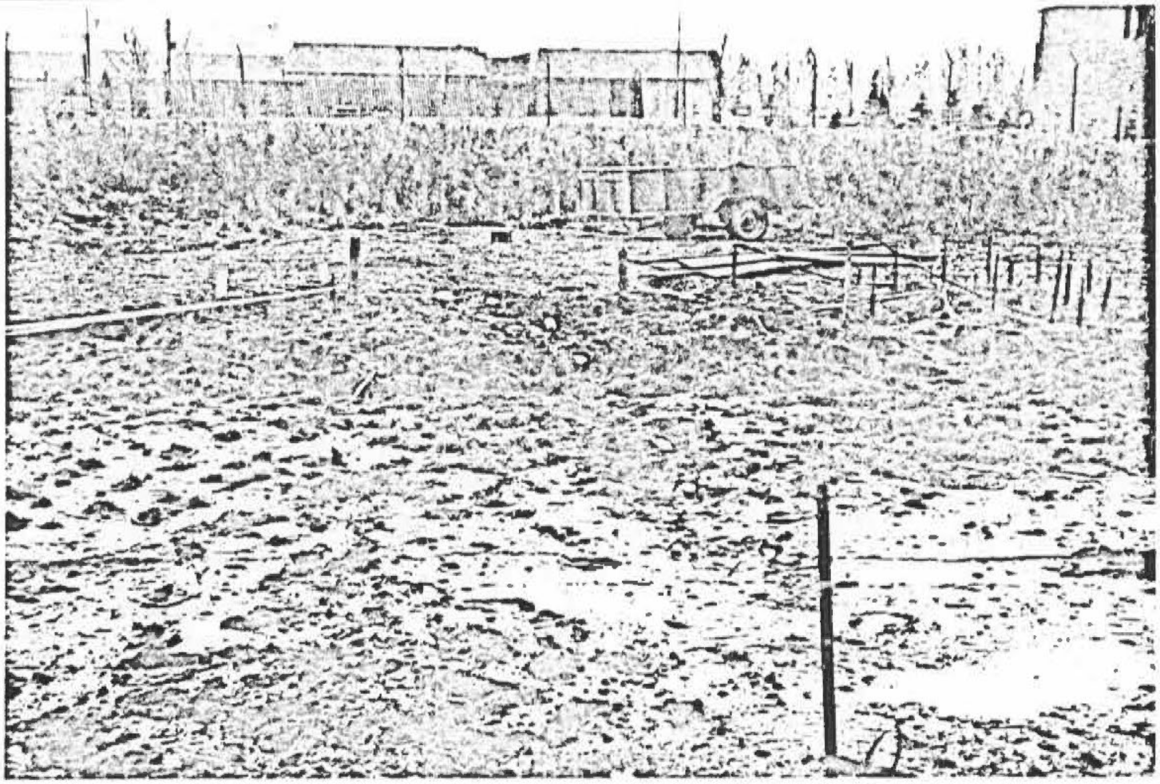
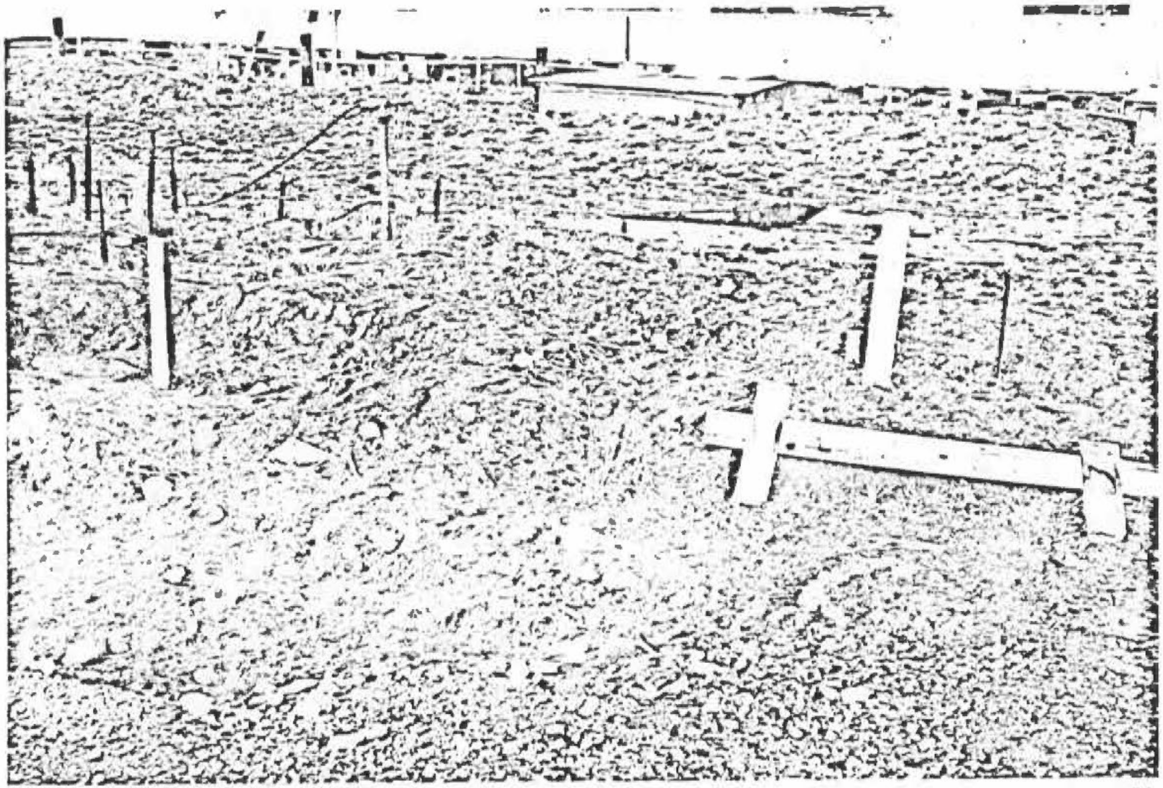
	Date:	Revision:	Approved: CV



(a) View looking south showing radar stations



(b) View looking northwest showing radar stations. Also site of CDP sounding

A-CUBED INC.	Title: Fig. 2.2.2 TWO VIEWS OF STRAIGHT GRAVEL EAST LINE		
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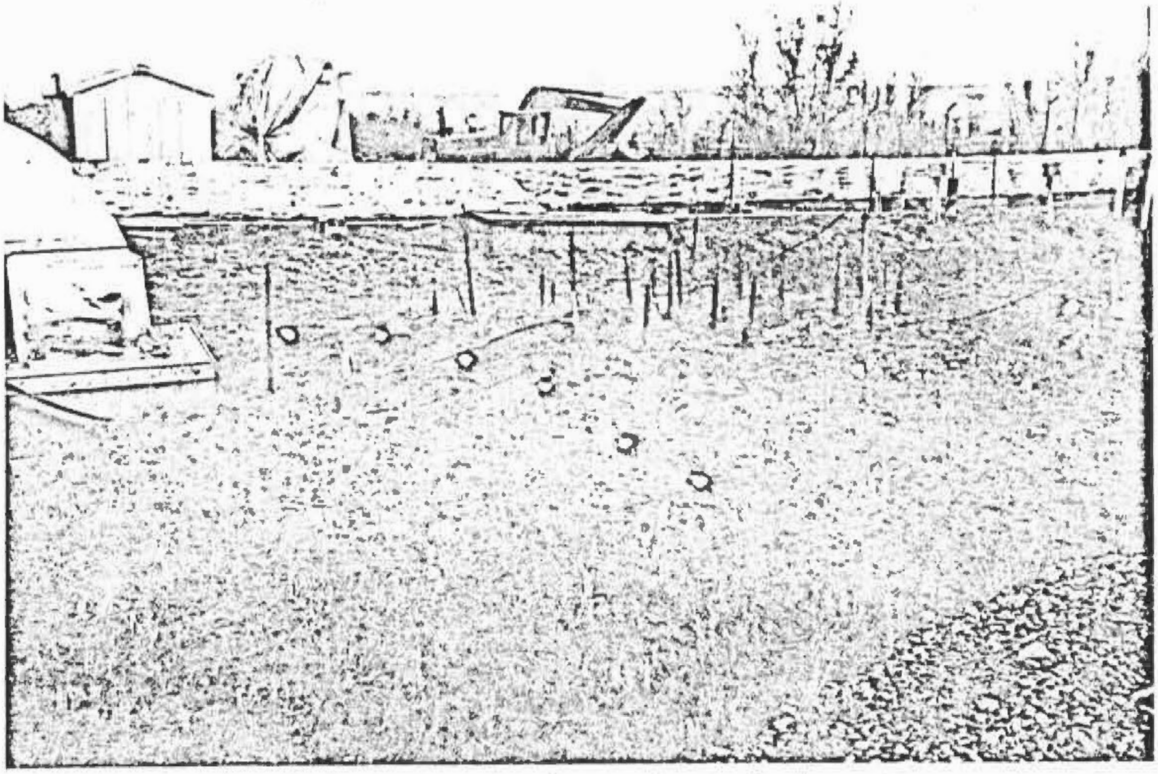
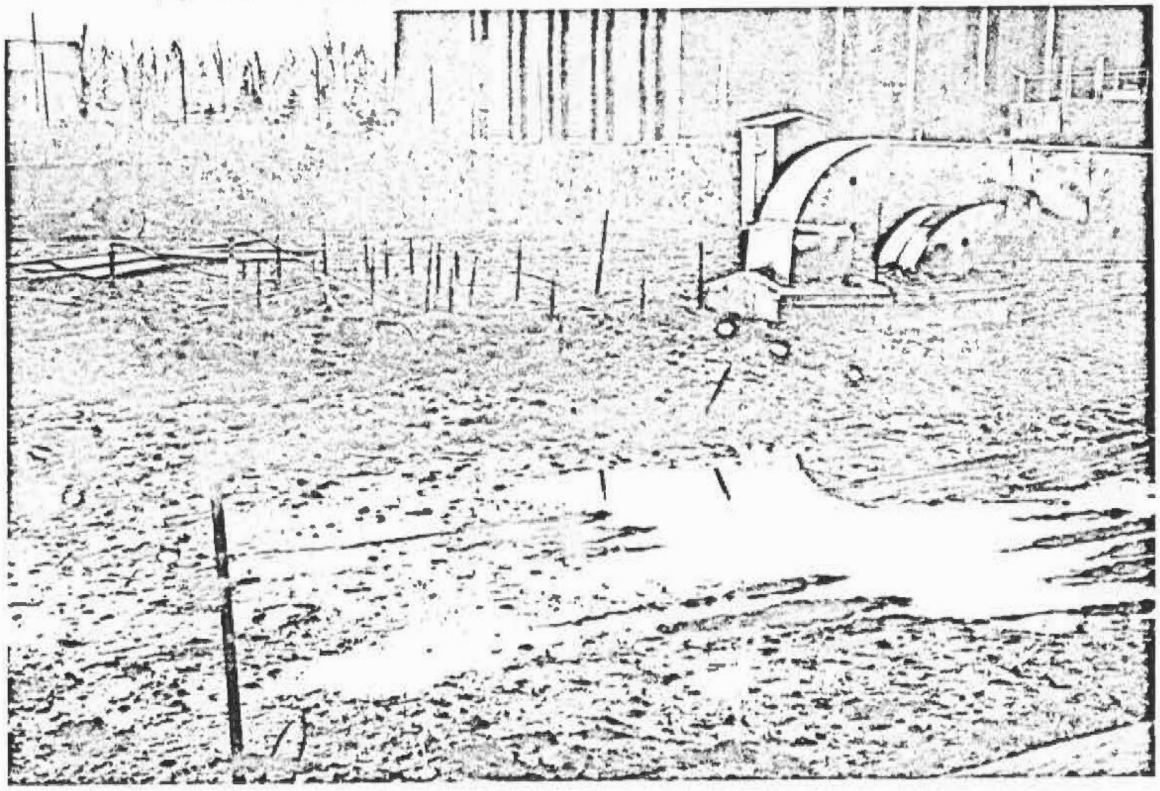
	Date:	Revision:	Approved: CV



(a) View looking Northeast showing radar stations



(b) View looking Southwest showing radar stations

A³ A-CUBED INC.	Title: Fig. 2.2.3 TWO VIEWS OF STRAIGHT GRAVEL WEST LINE		
	Scale:	Drawing No:	Job No:
	Date:	Revision:	Approved: CV

A-CUBED INC.

Title: Fig. 2.2.4 WIDE ANGLE VIEW OF INSULATED GRAVEL LINES		
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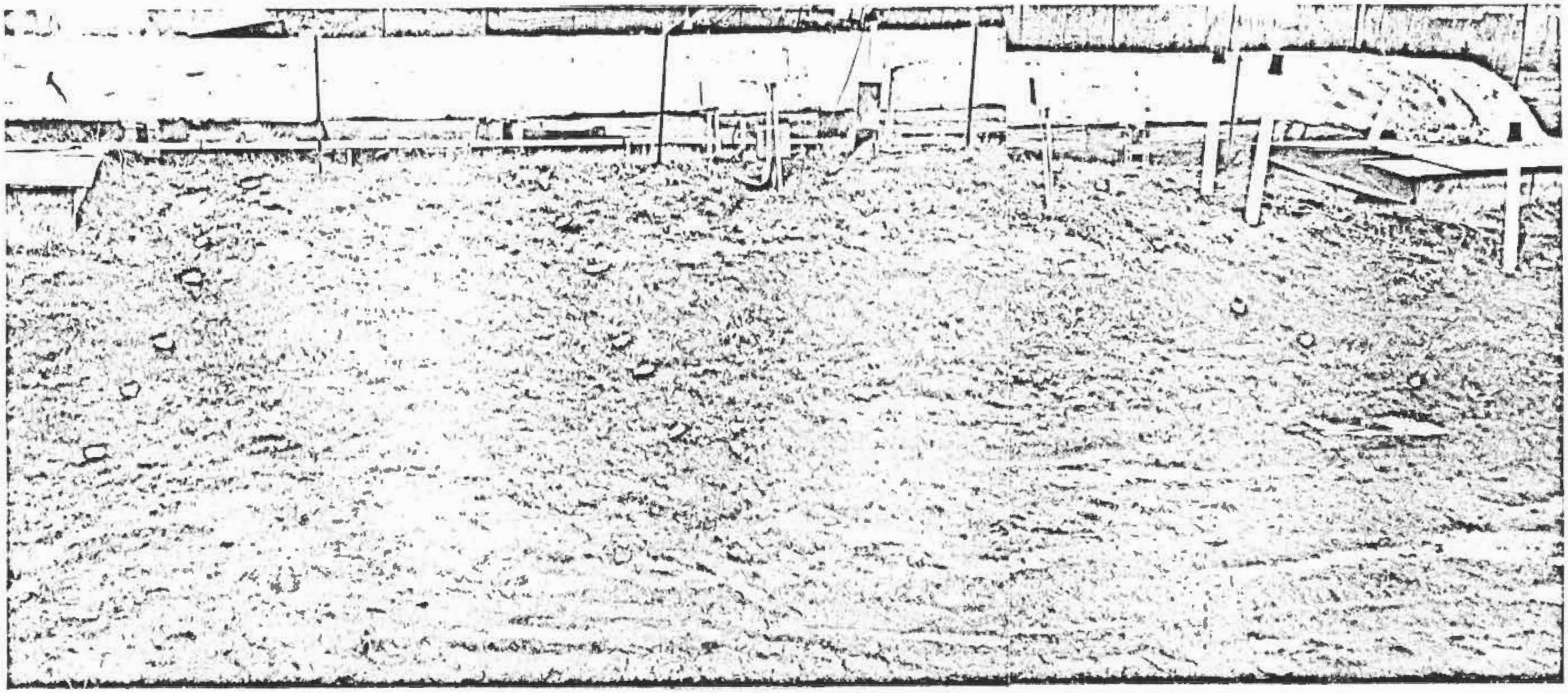
Date:	Revision:	Approved: CV

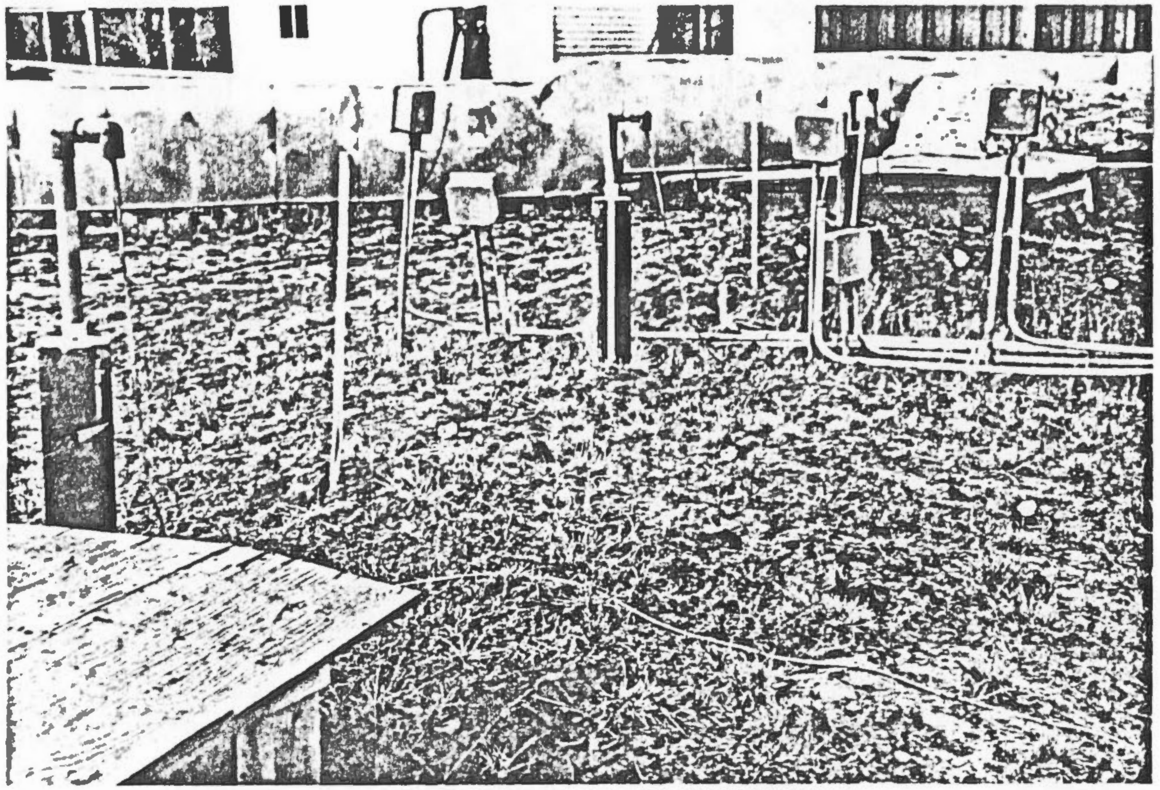


Wide angle view of Insulated Gravel Lines. View is looking North. Radar stations are white dots

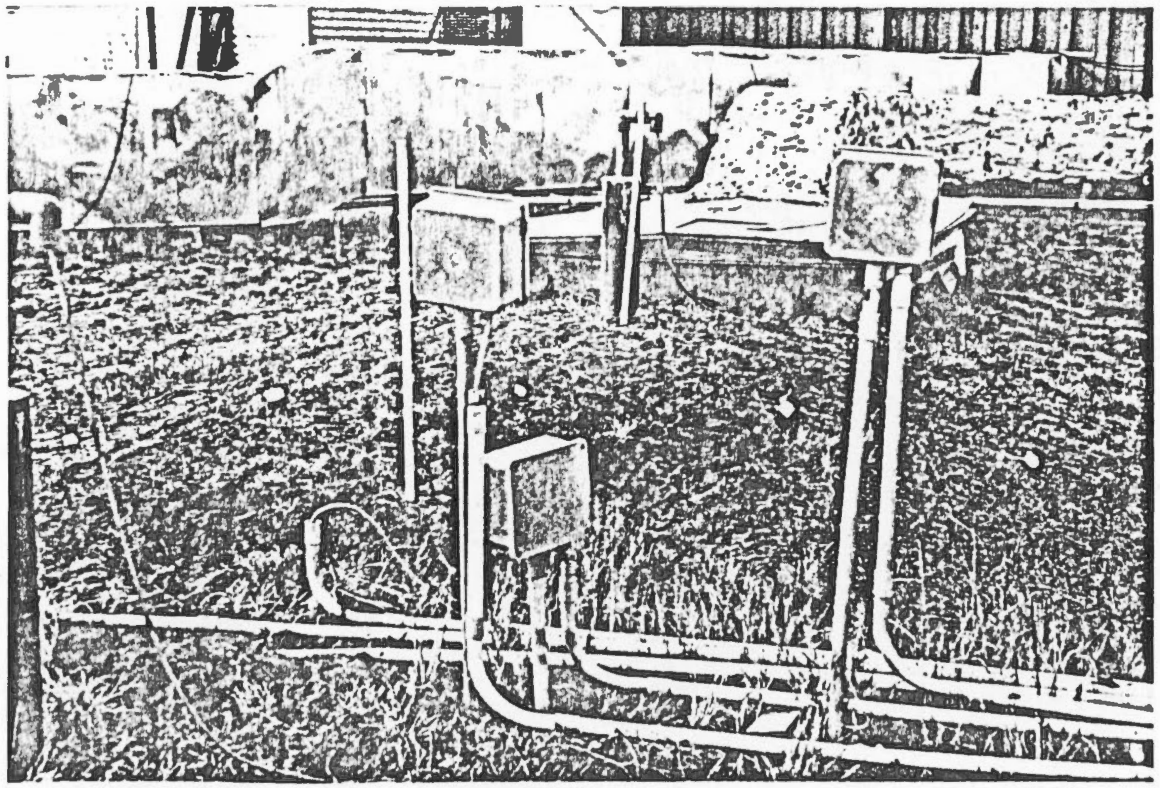
A³ A-CUBED INC.

Title:
Fig. 2.2.5 THREE VIEWS OF
INSULATED SILT MOUND

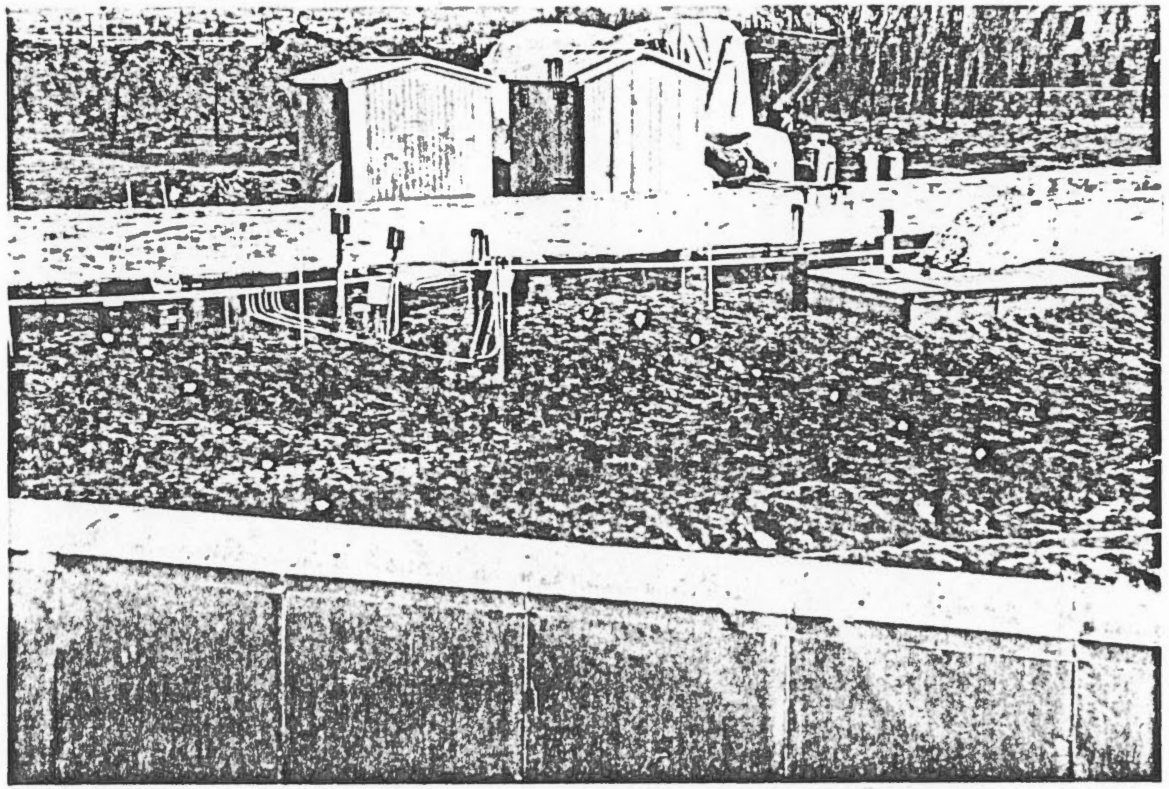
Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved: CV



(b) View looking west almost along pipe axis



(c) View looking west showing Line 2



(a) Wide angle looking Northeast showing both radar lines

A³ A-CUBED INC.

Title: Fig. 2.2.6 THREE VIEWS OF THE RESTRAINED SITE		
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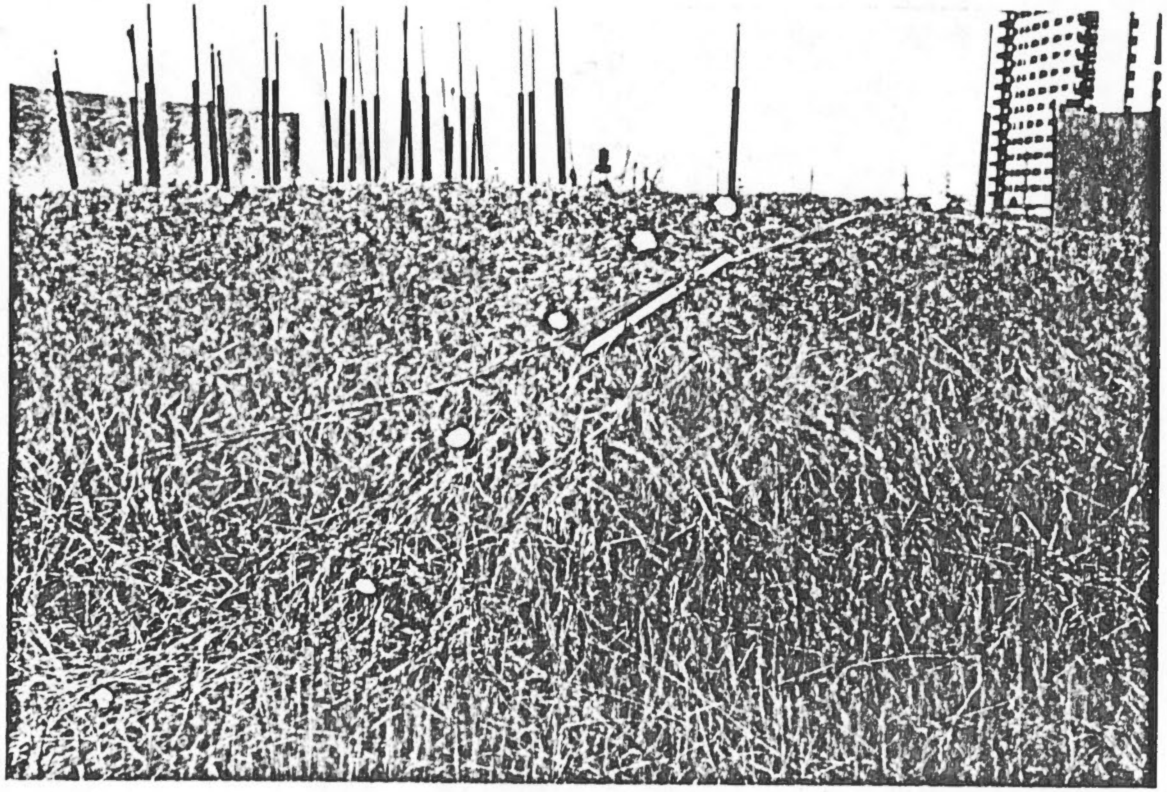
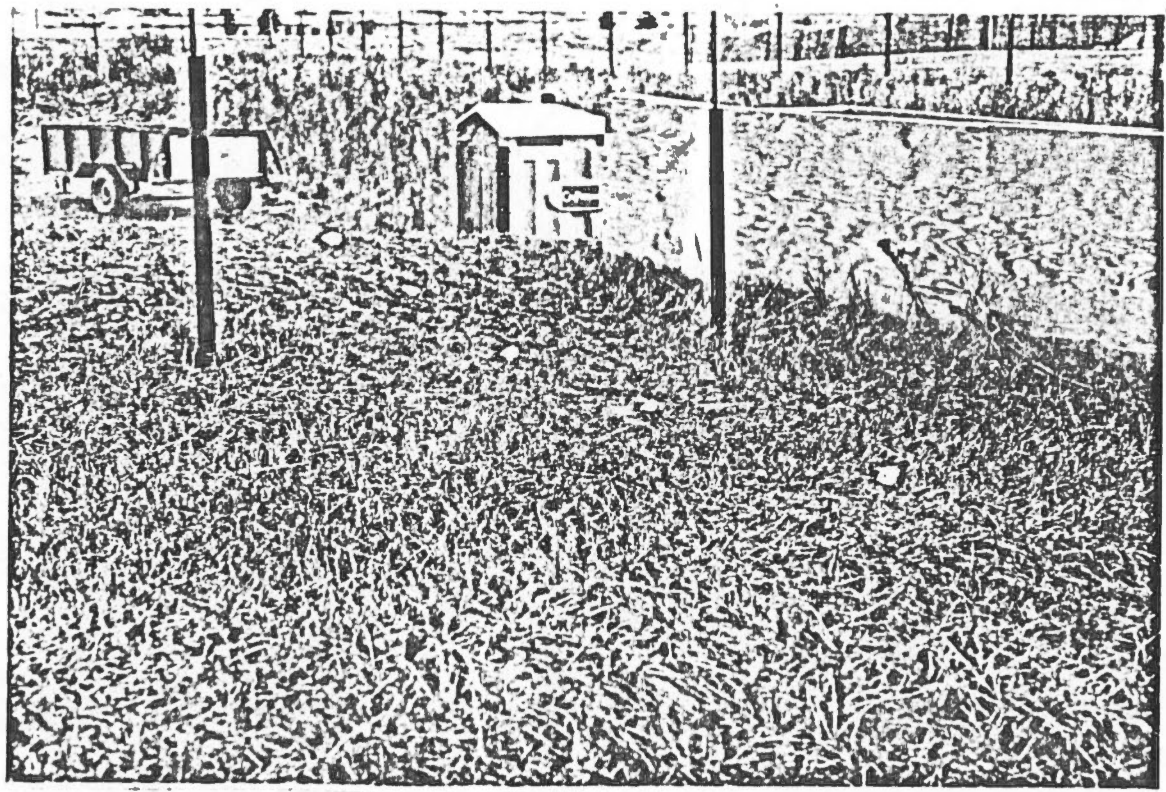
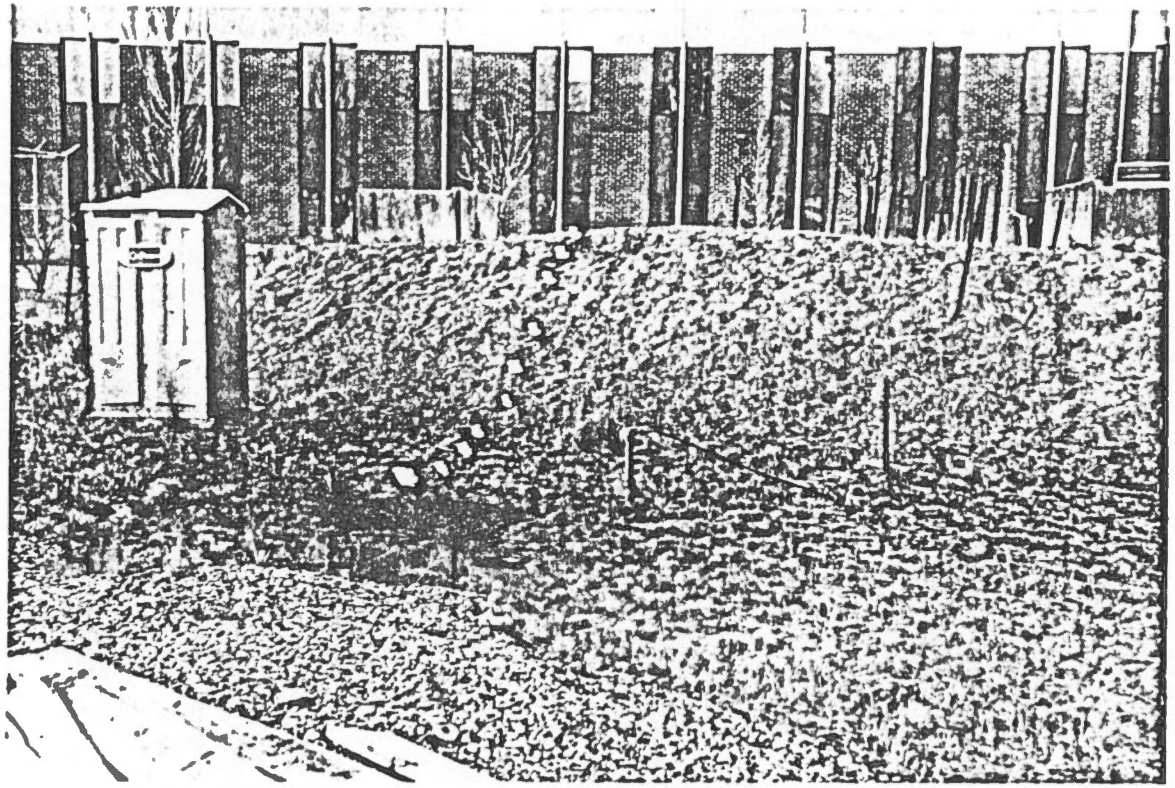
Date:	Revision:	Approved: CV



(b) Western side of mound showing line



(c) Top of berm with part of the radar line and survey rods



(a) View looking west showing Eastern half of line

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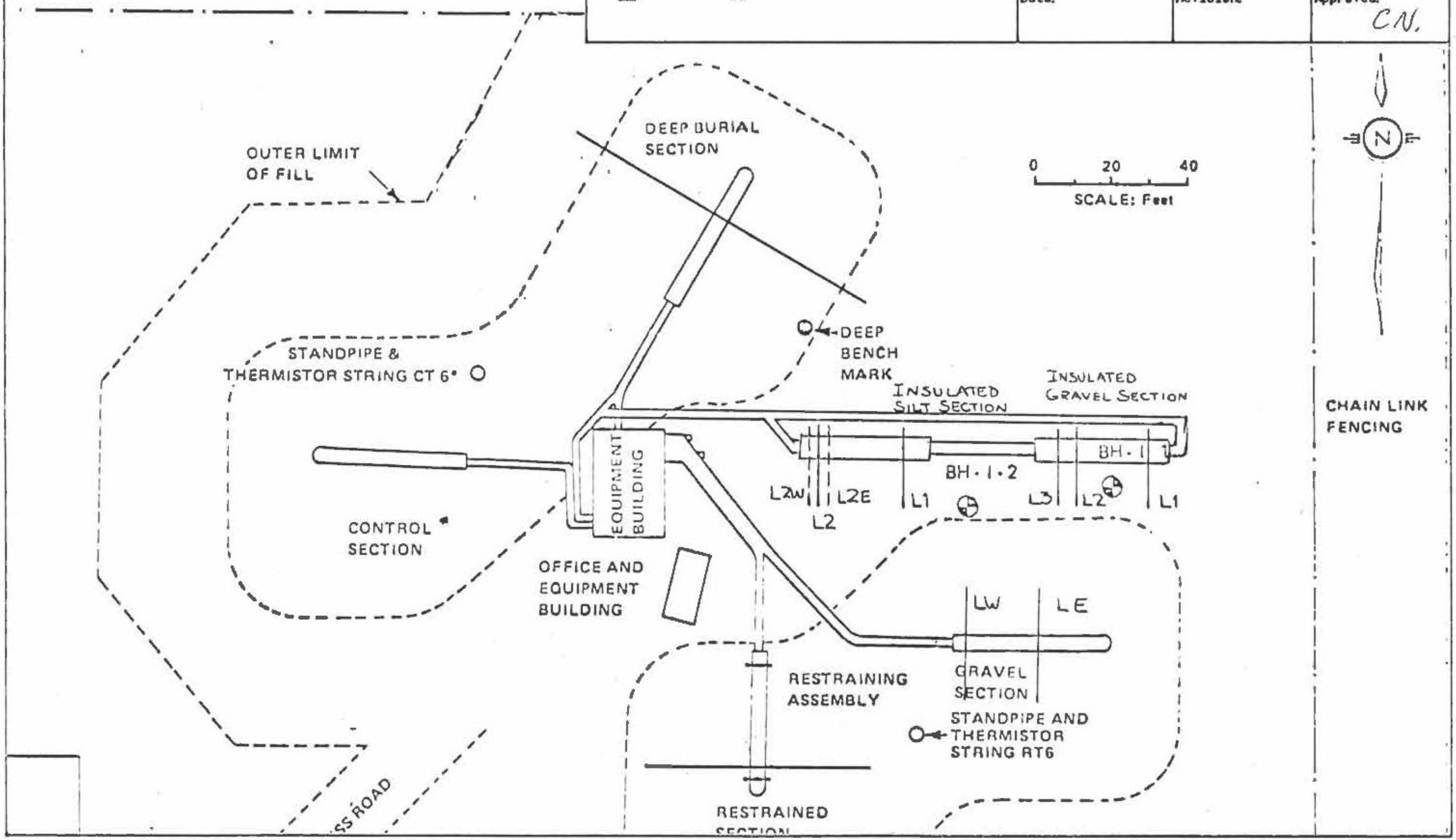
Title: FIG. 3.1 SCHEMATIC OF FROST HEAVE SITE WITH RADAR LINES		
Scale:	Drawing No: Fig. 3.1	Job No: 52-5008
Date:	Revision:	Approved: CN.



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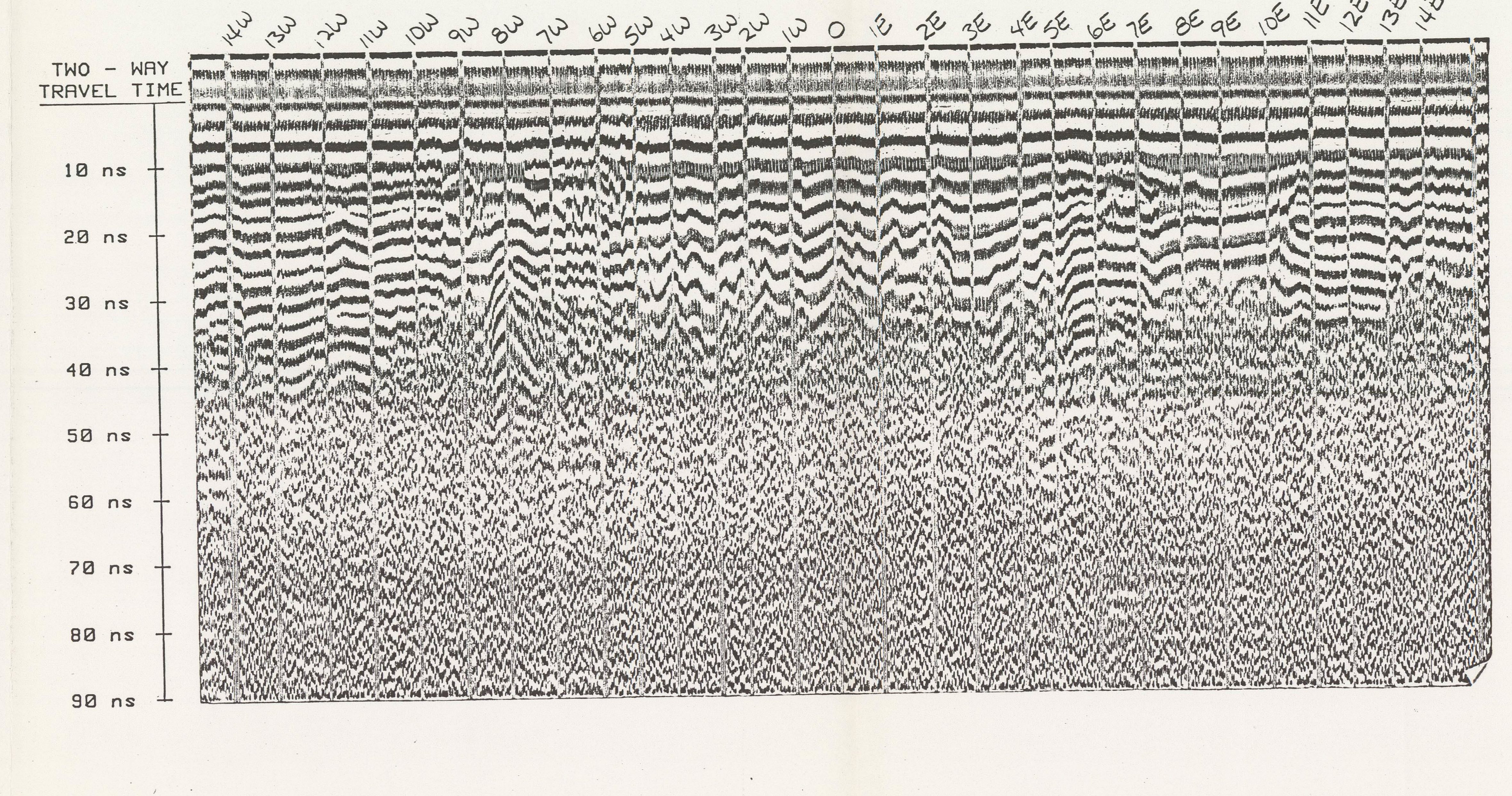
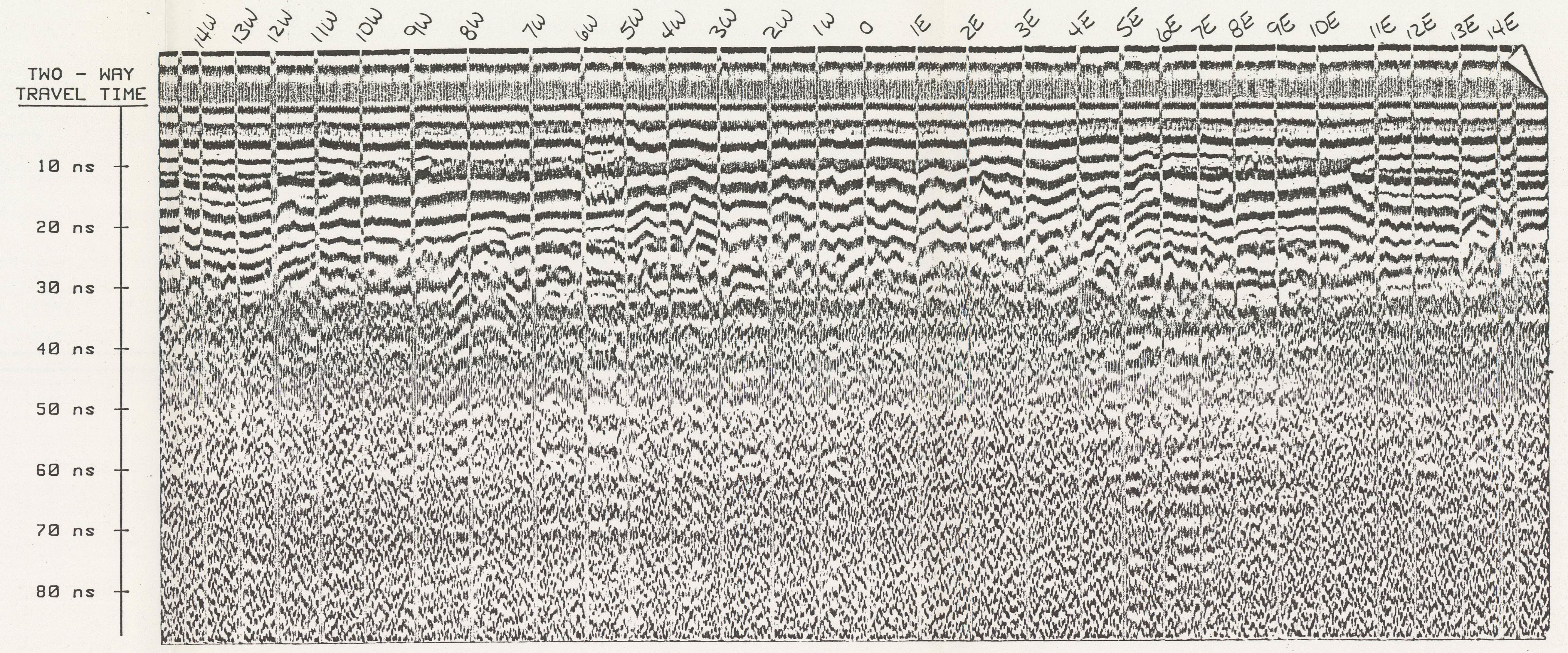
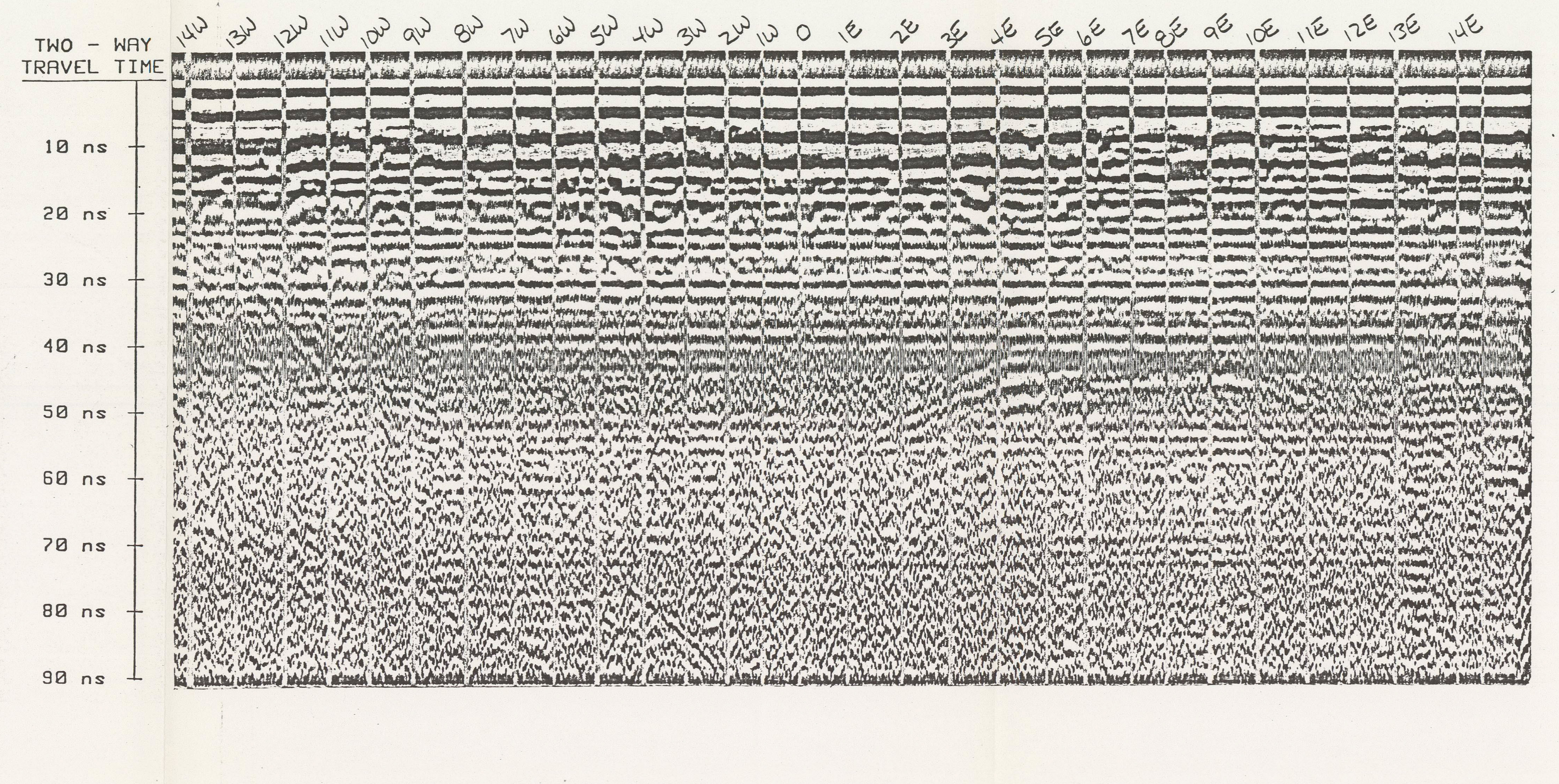
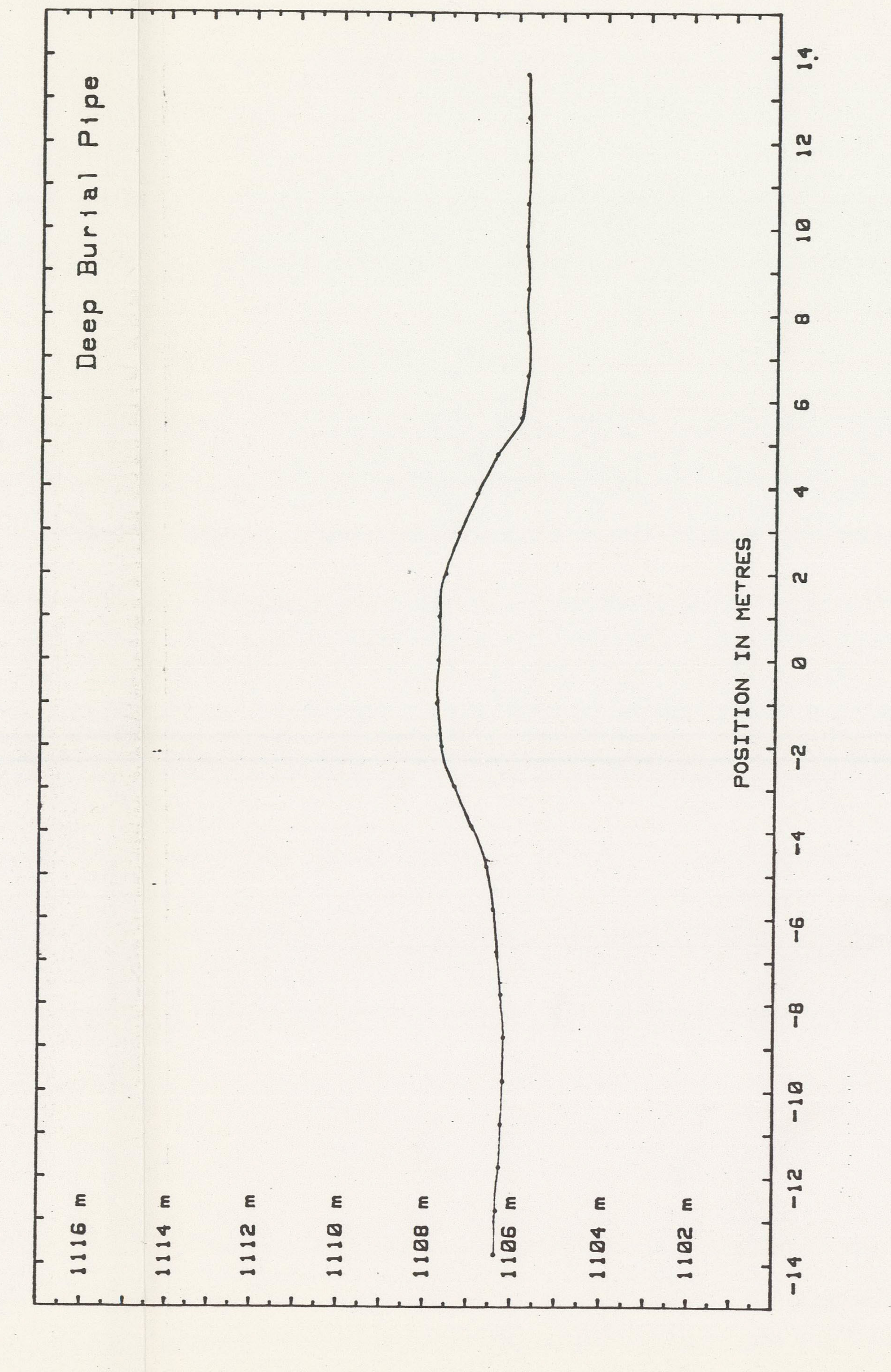


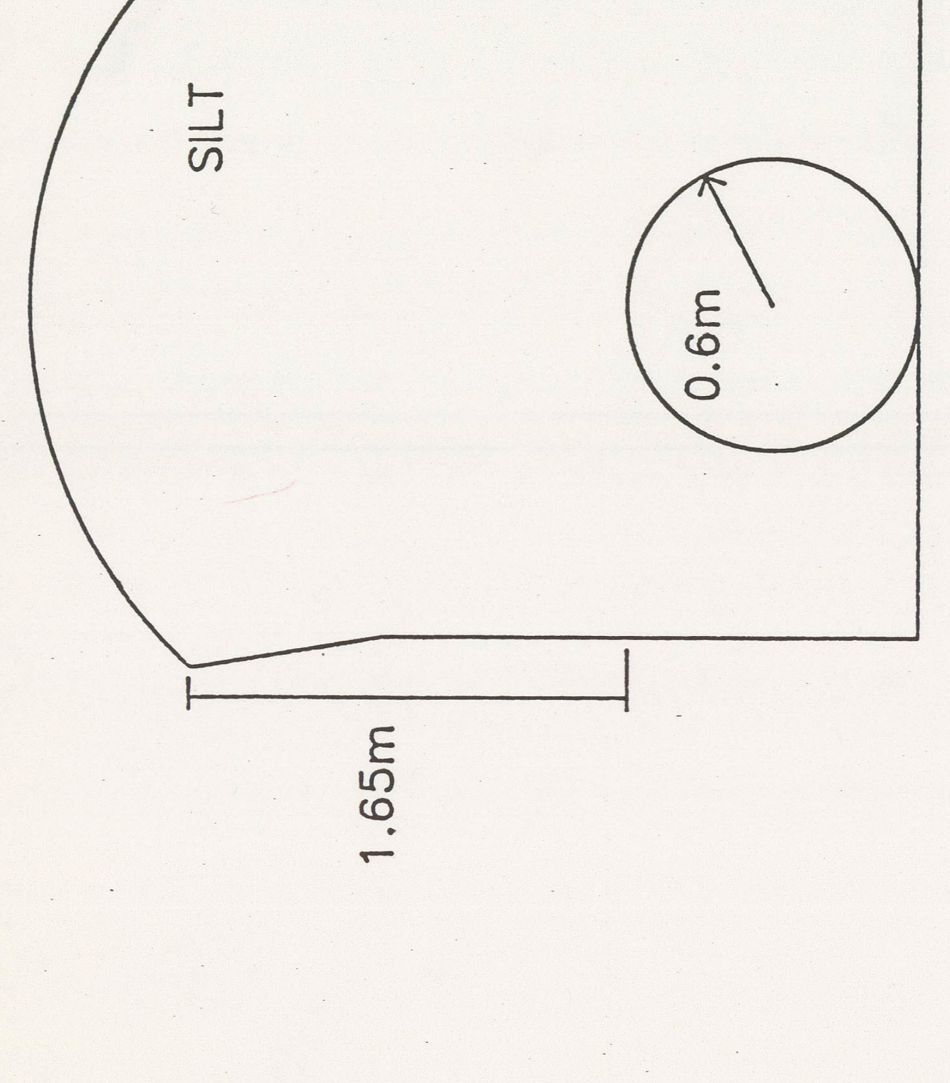




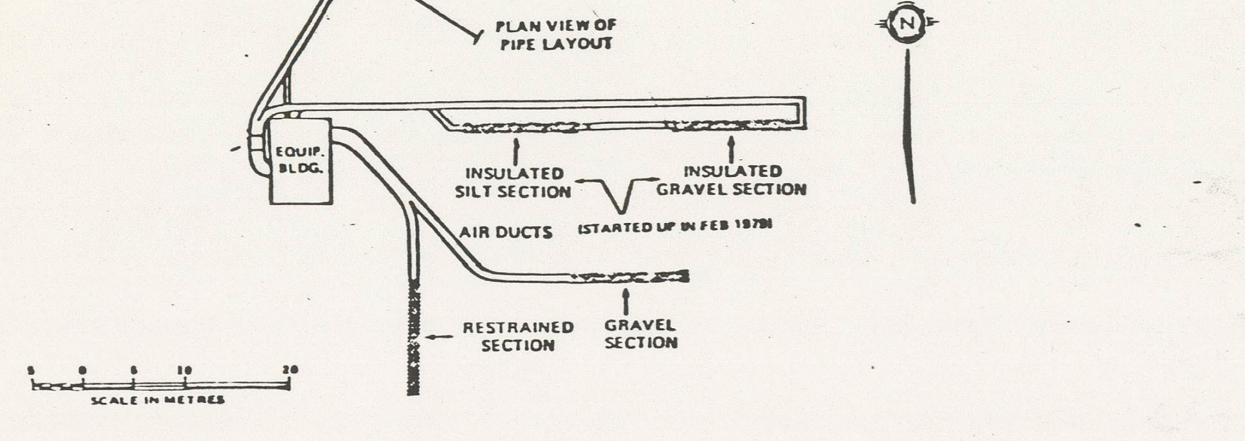
TOPOGRAPHY



DEEP BURIAL SECTION MODEL
CROSS SECTION



A-CUBED INC.	Title: Fig. 3.2 DEEP BURIAL PIPE		
	Scale:	Drawing No:	Job No: 52-5008
	Date:	Revision:	Approved: CV



NOTES

1. See the map above for line location.

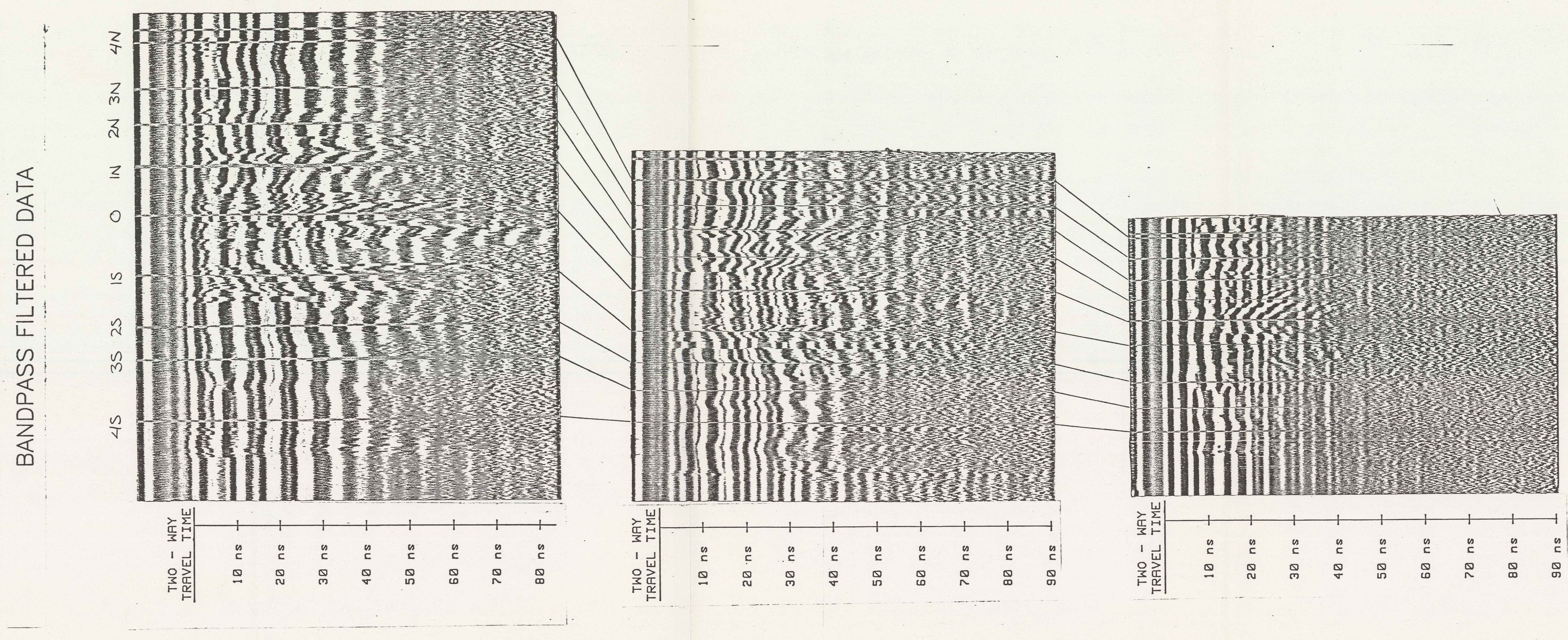
2. Data Sections presented left to right in the following order with filter settings:
100MHz Antennas filtered 420 to 480 Hz
200MHz Antennas filtered 420 to 480 Hz
300MHz Antennas filtered 420 to 480 Hz

3. All distances are in metres.

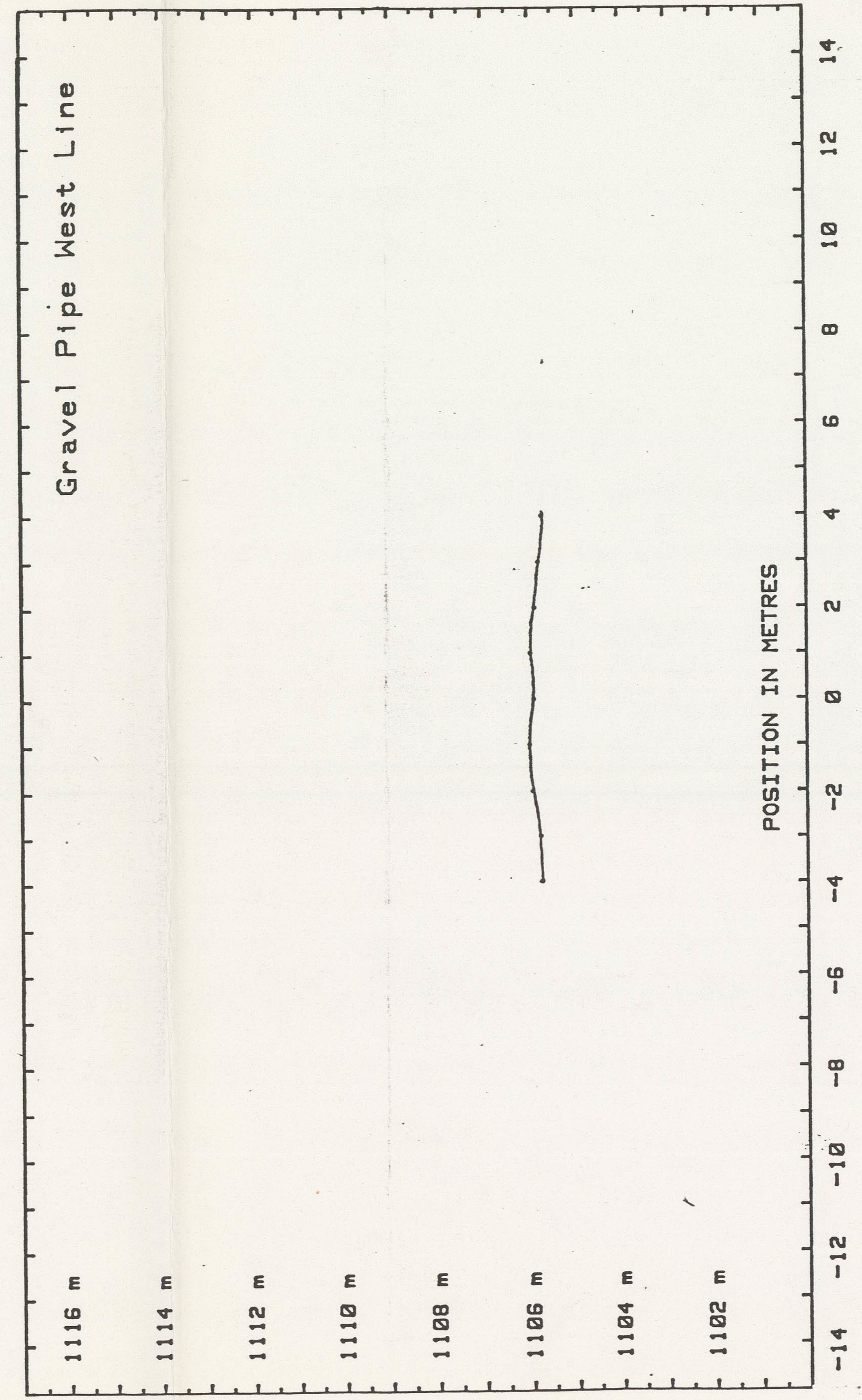
4. Topography and Model diagrams are not drawn to the same scales.

5. Zero position corresponds to pipe axis.

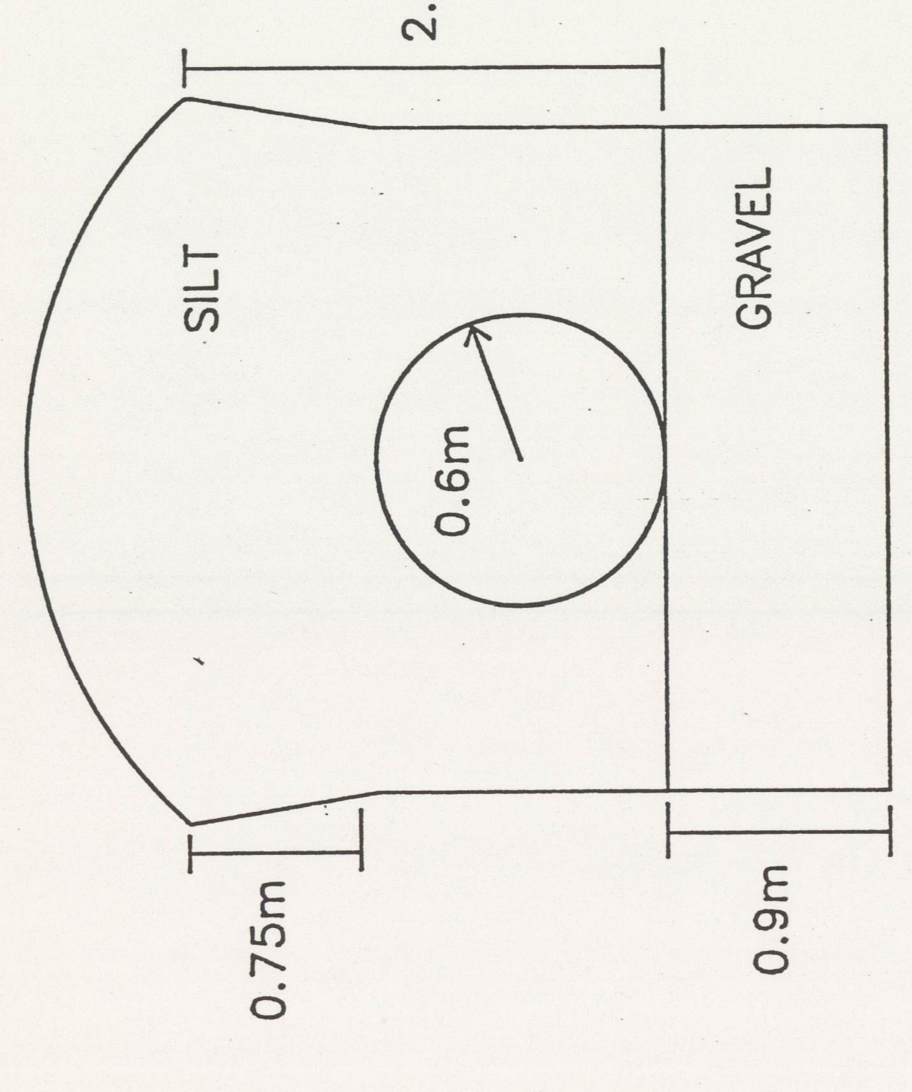
BANDPASS FILTERED DATA



TOPOGRAPHY



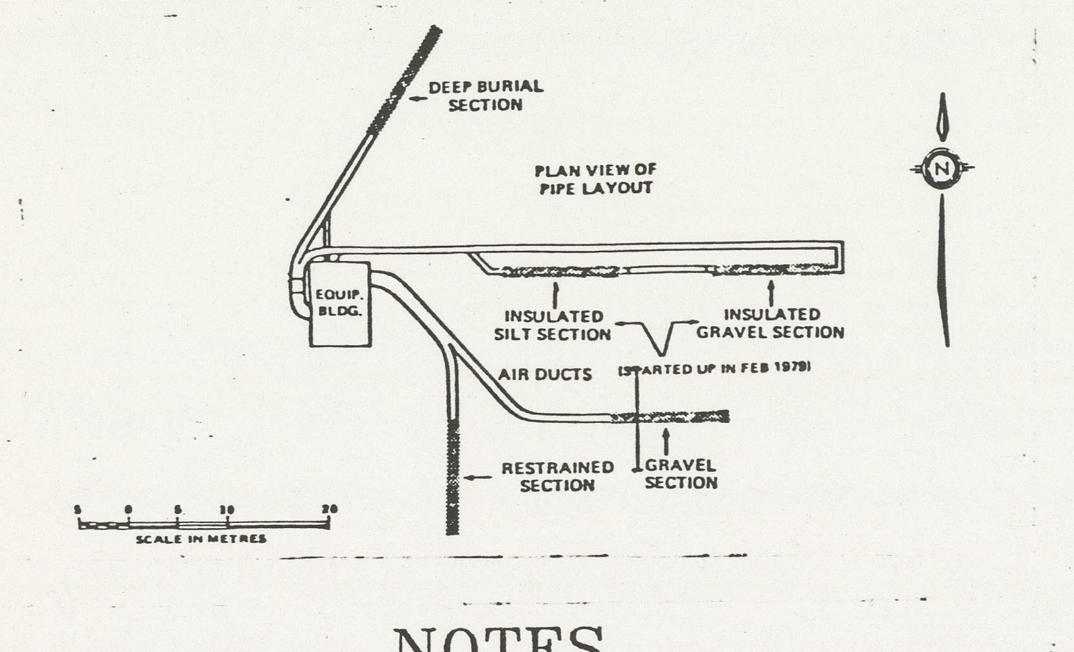
STRAIGHT GRAVEL MODEL CROSS SECTION



A-CUBED INC.

Title: Fig. 3.3.1. GRAVEL PIPE WEST LINE

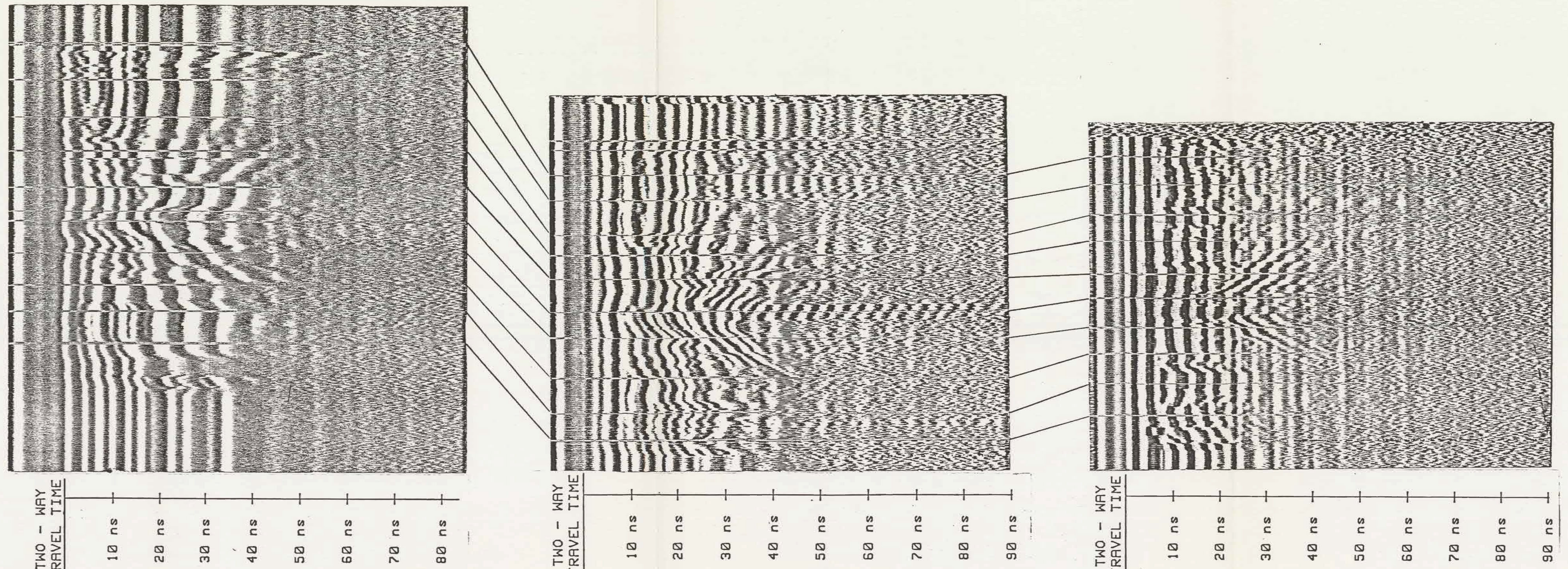
Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved: CV



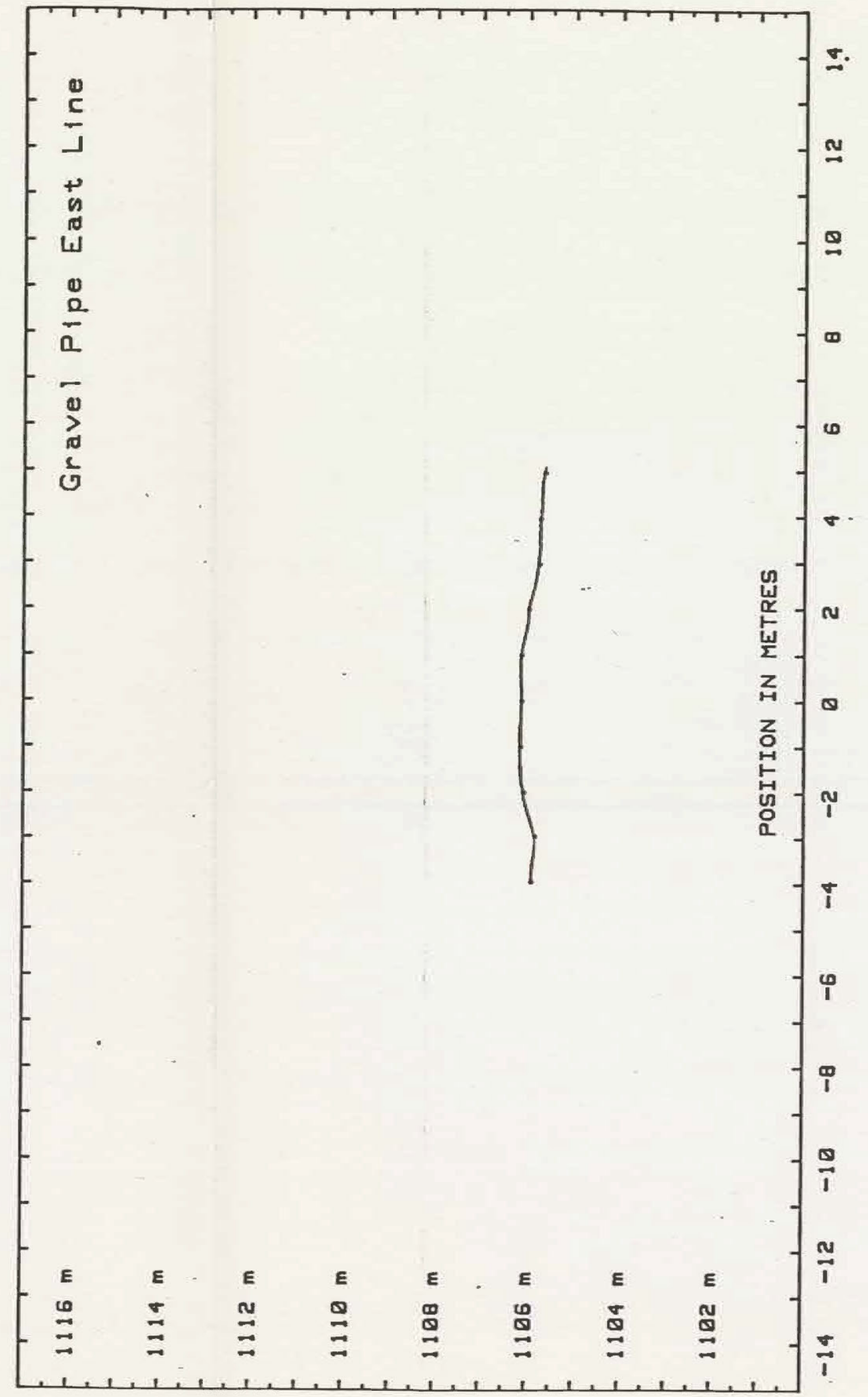
NOTES

1. See the map above for line location.
2. Data Sections presented top to bottom in the following order with filter settings:
   100MHz Antennas filtered 400 to 500 Hz
   200MHz Antennas filtered 380 to 420 Hz
   300MHz Antennas filtered 400 to 600 Hz
3. All distances are in metres.
4. Topography and Model diagrams are not drawn to the same scales.
5. Zero position corresponds to pipe axis.

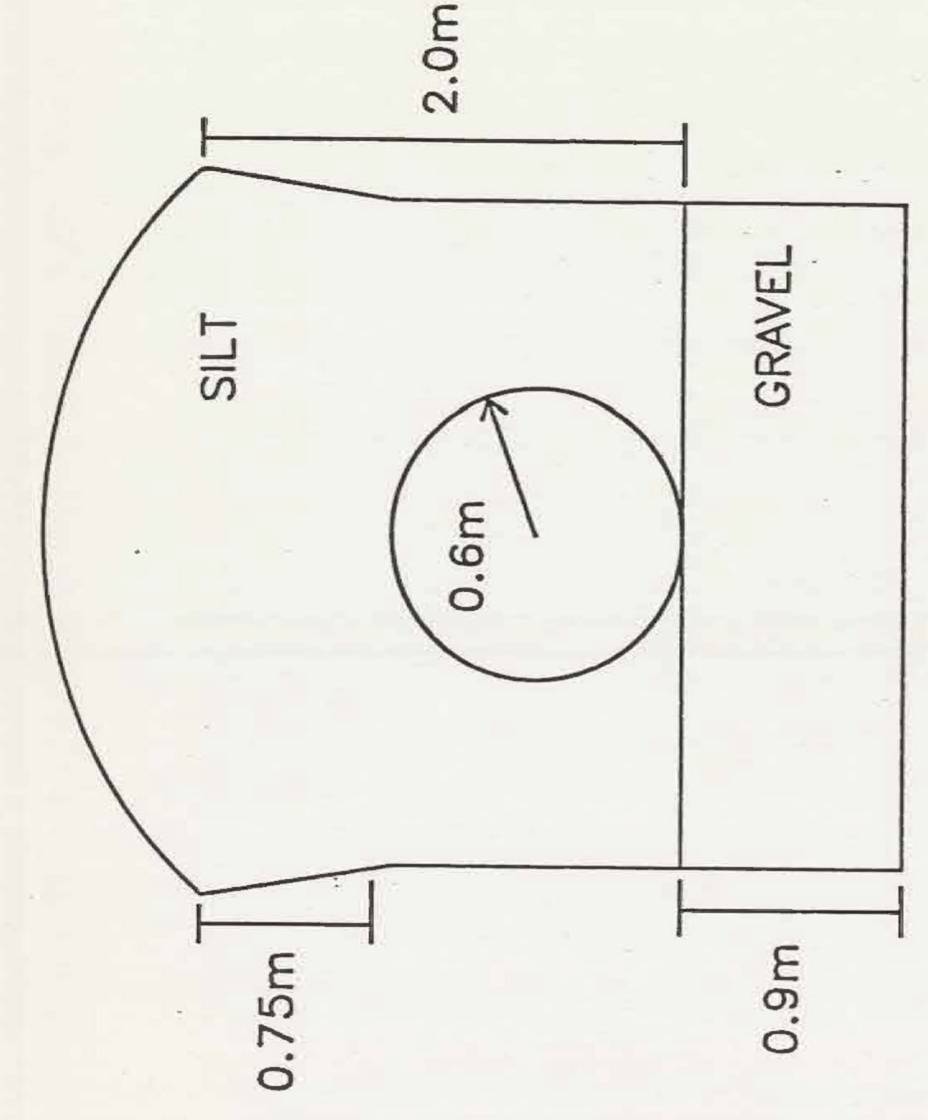
BANDPASS FILTERED DATA



TOPOGRAPHY



STRAIGHT GRAVEL MODEL CROSS SECTION



A-CUBED INC.

Title: Fig 3.3.2. GRAVEL PIPE EAST LINE

Scale: —

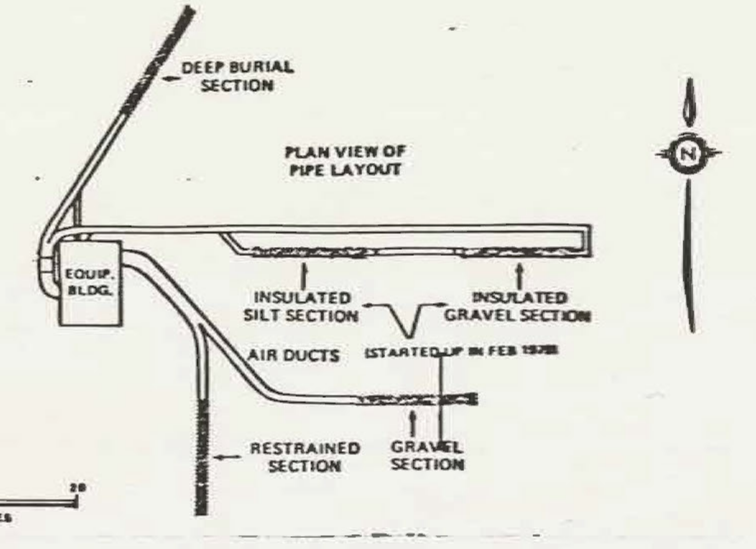
Drawing No:

Job No: 52-5008

Date:

Revision:

Approved: CV



NOTES

1. See the map above for line location.

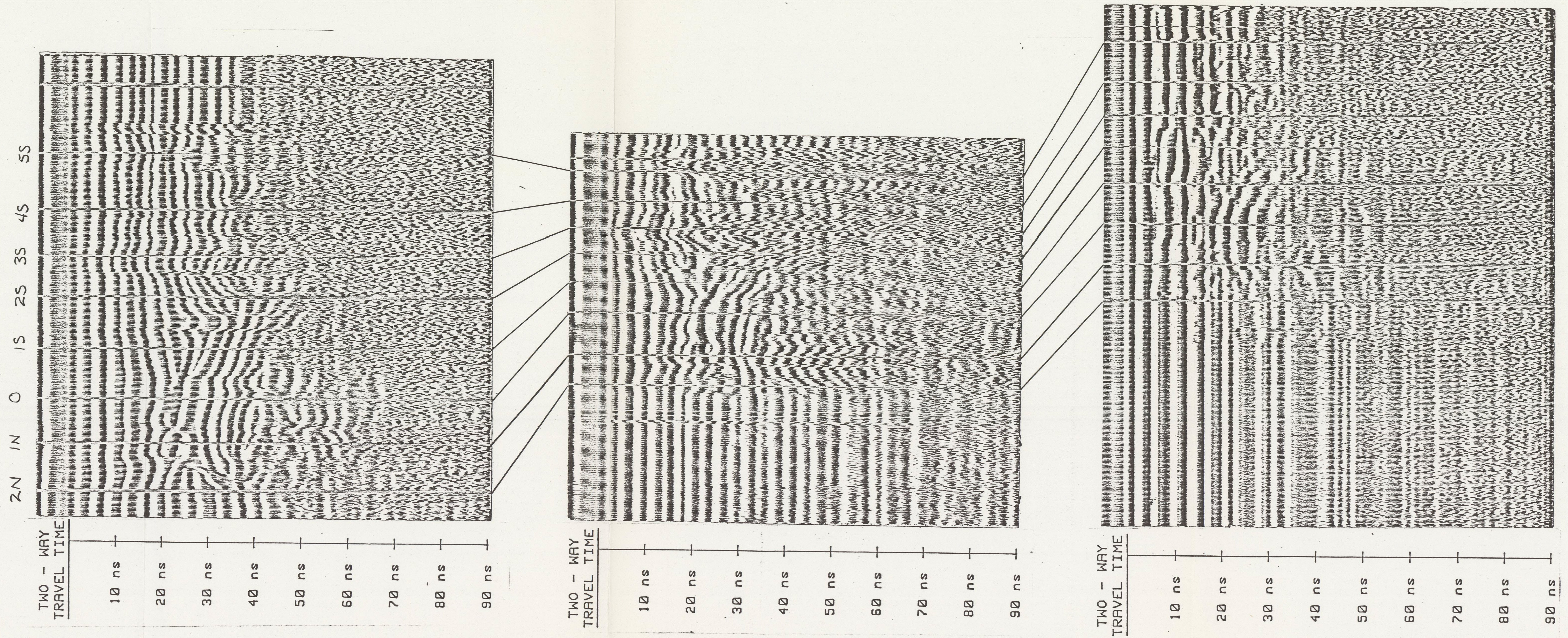
2. Data Sections presented top to bottom in the following order with filter settings:
   100MHz Antennas filtered 300 to 500 Hz
   200MHz Antennas filtered 380 to 420 Hz
   300MHz Antennas filtered 440 to 600 Hz

3. All distances are in metres.

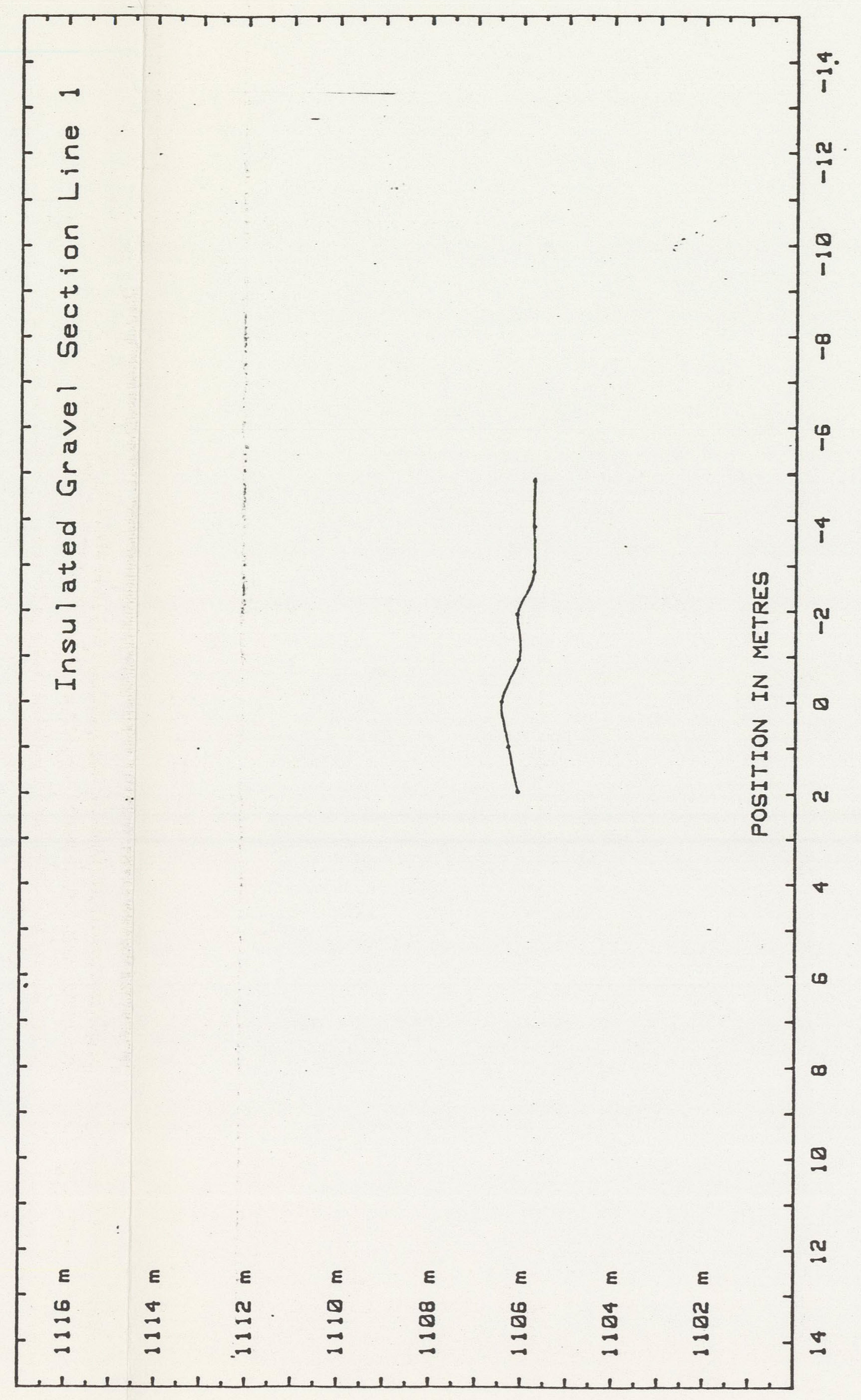
4. Topography and Model diagrams are not drawn to the same scales.

5. Zero position corresponds to pipe axis.

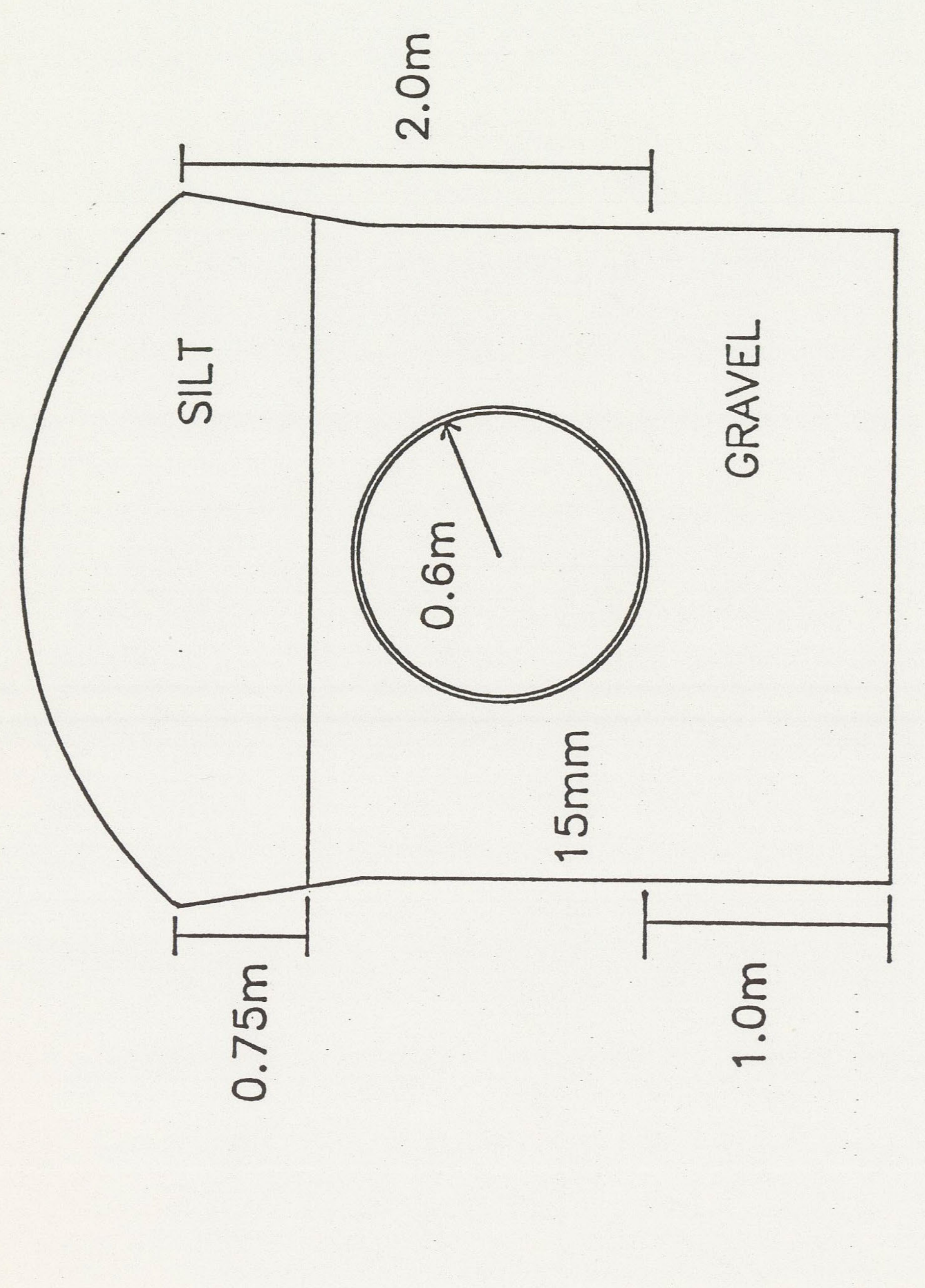
BANDPASS FILTERED DATA



TOPOGRAPHY

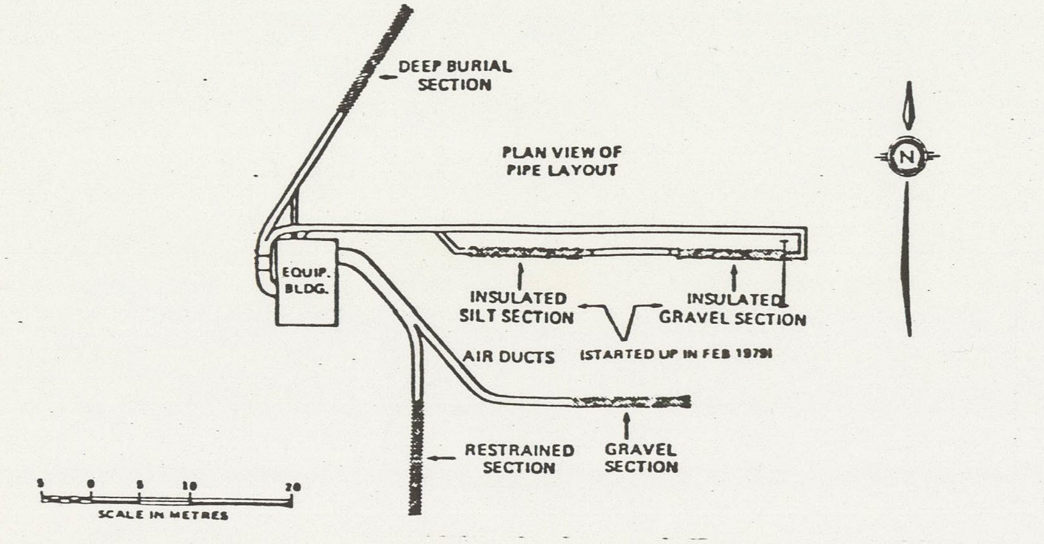


INSULATED GRAVEL MODEL CROSS SECTION



A-CUBED INC.

Title: Fig. 3.4.1. INSULATED GRAVEL PIPE LINE 1		
Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved:



NOTES

1. See the map above for line location.

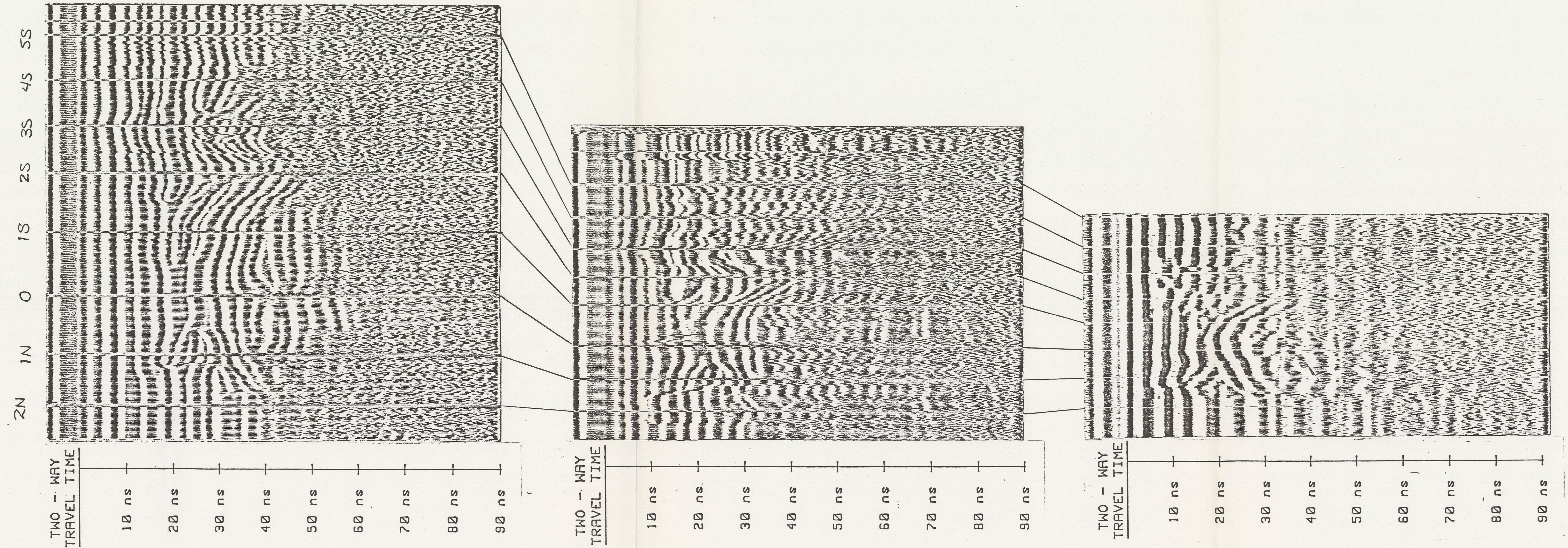
2. Data Sections presented top to bottom in the following order with filter settings:
100MHz Antennas filtered 420 to 480 Hz
200MHz Antennas filtered 380 to 420 Hz
300MHz Antennas filtered 440 to 500 Hz

3. All distances are in metres.

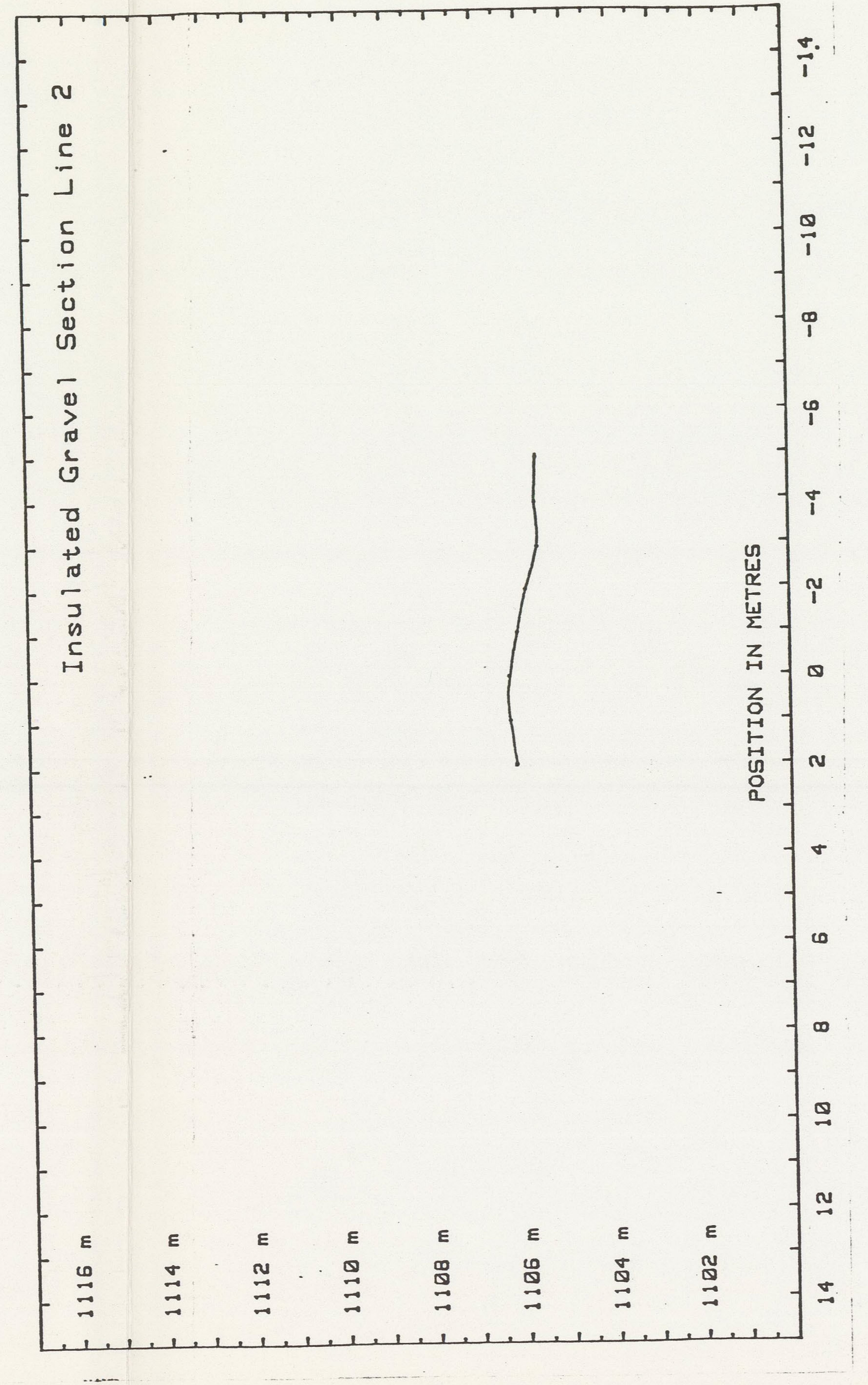
4. Topography and Model diagrams are not drawn to the same scales.

5. Zero position corresponds to pipe axis.

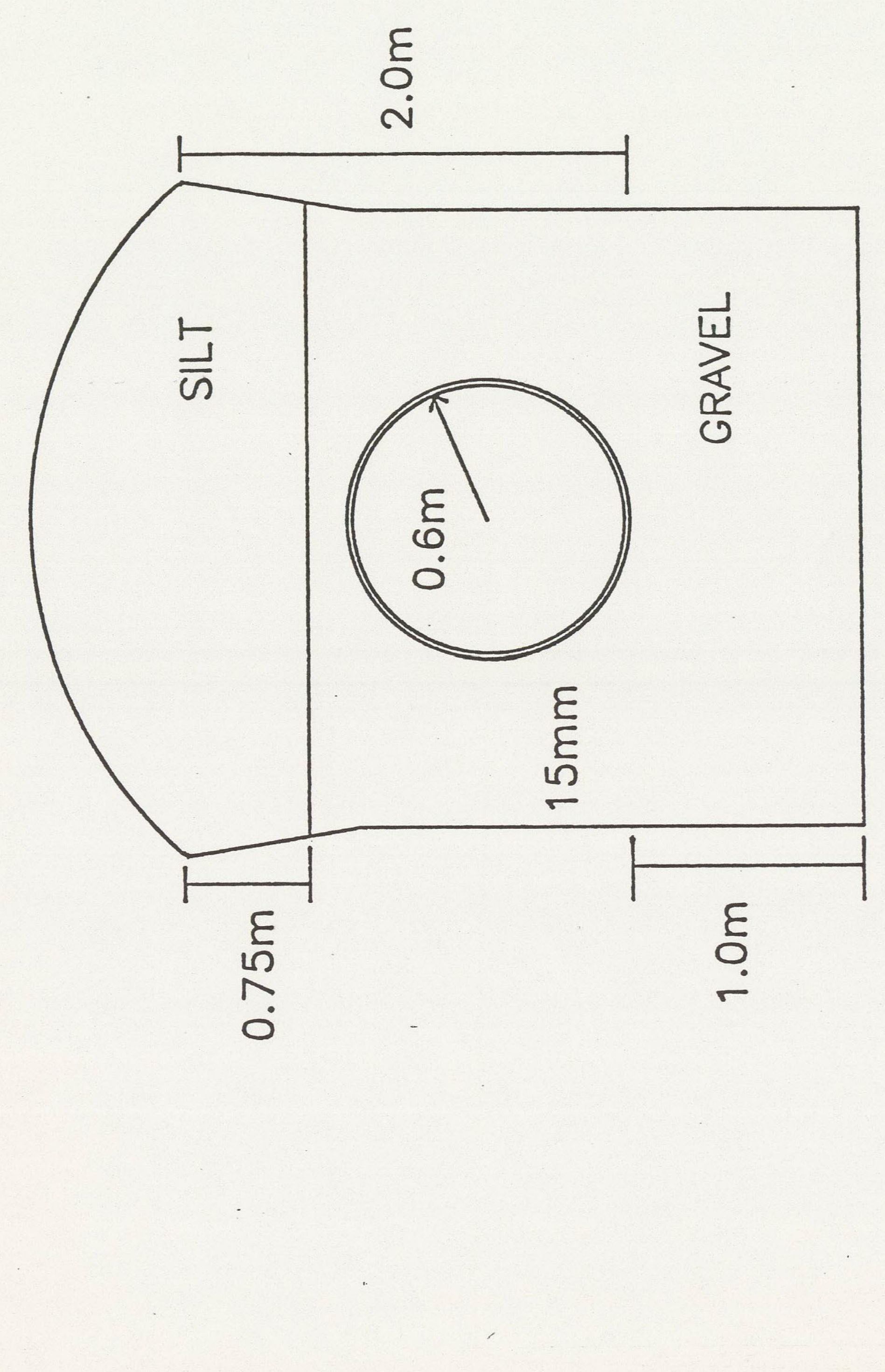
BANDPASS FILTERED DATA



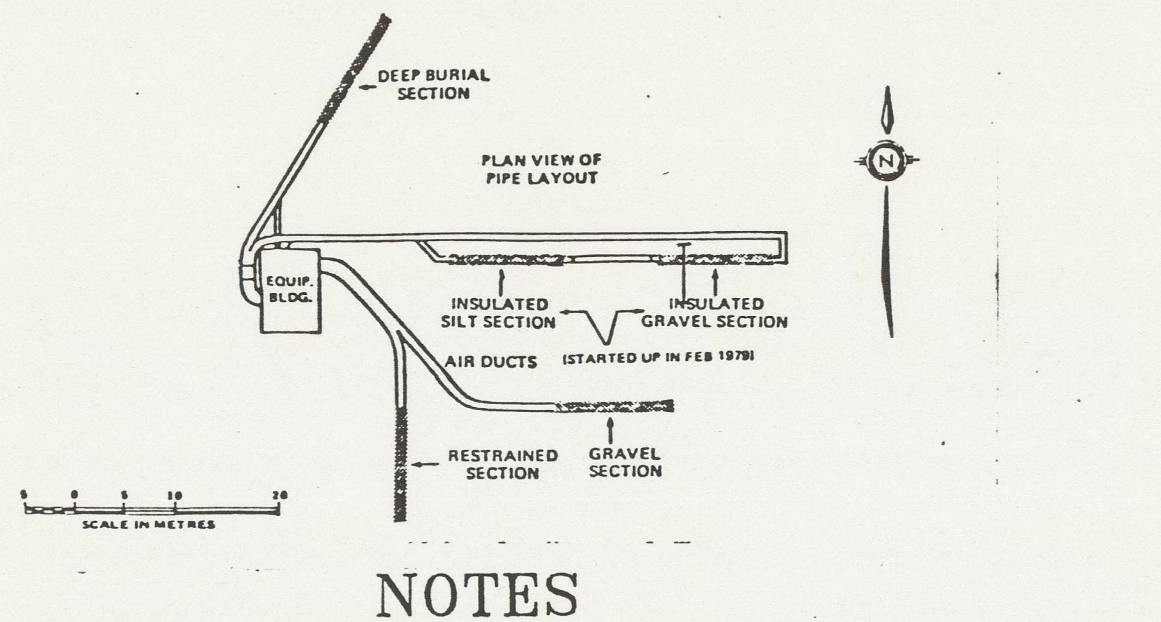
TOPOGRAPHY



INSULATED GRAVEL MODEL CROSS SECTION



A-CUBED INC.	Title: Fig. 3.4.2. INSULATED GRAVEL PIPE LINE 2		
	Scale:	Drawing No:	Job No: 52-5008
	Date:	Revision:	Approved:



NOTES

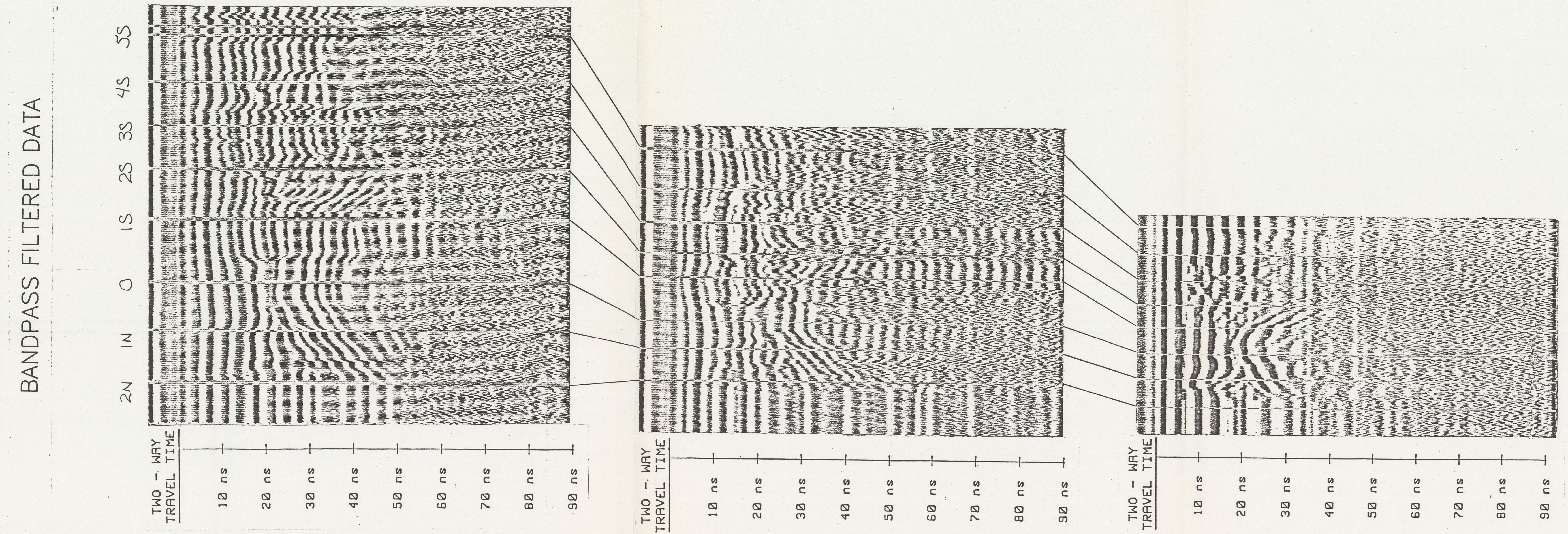
1. See the map above for line location.

2. Data Sections presented top to bottom in the following order with filter settings:
100MHz Antennas filtered 420 to 480 Hz
200MHz Antennas filtered 420 to 480 Hz
300MHz Antennas filtered 350 to 400 Hz

3. All distances are in metres.

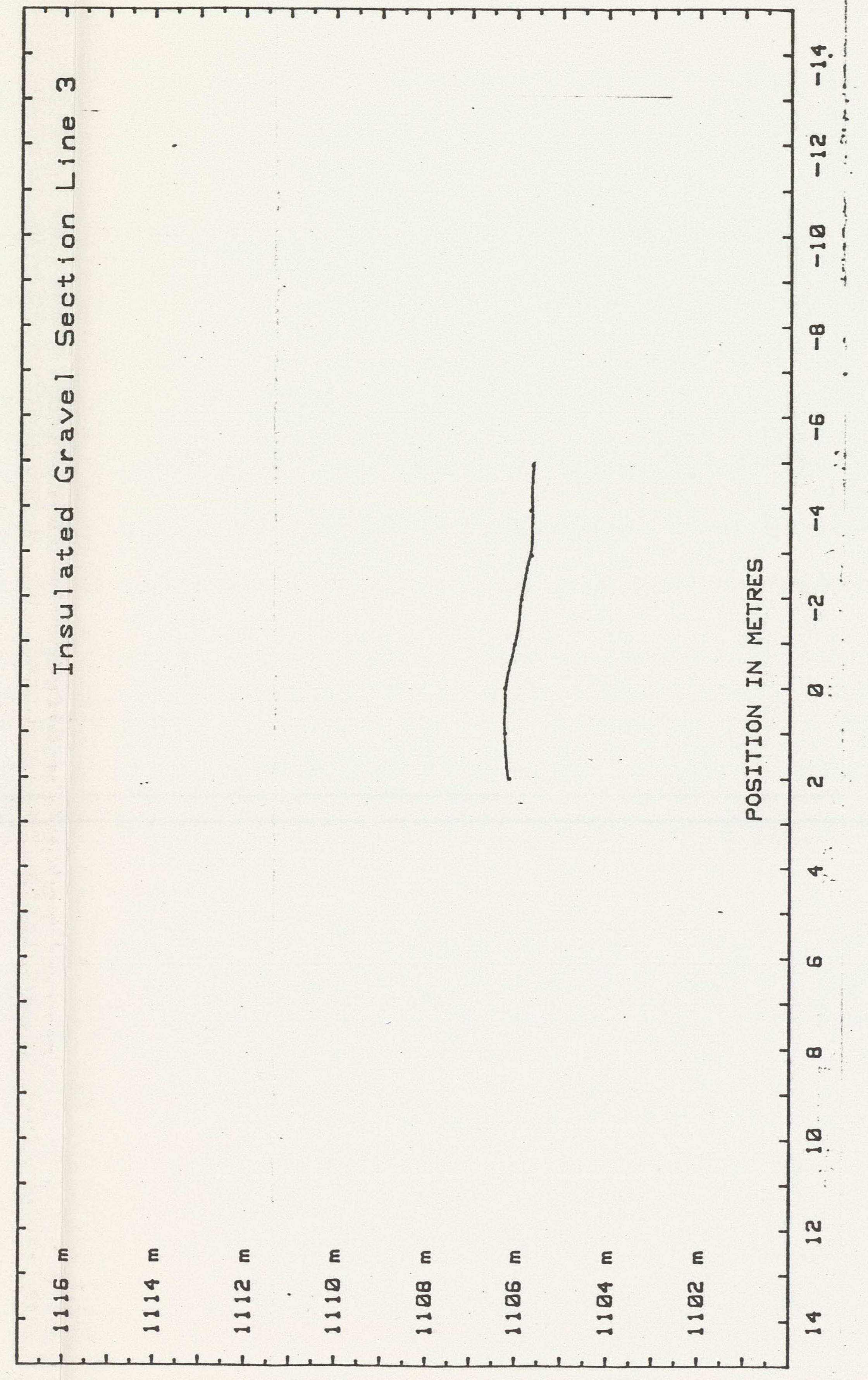
4. Topography and Model diagrams are not drawn to the same scales.

5. Zero position corresponds to pipe axis.

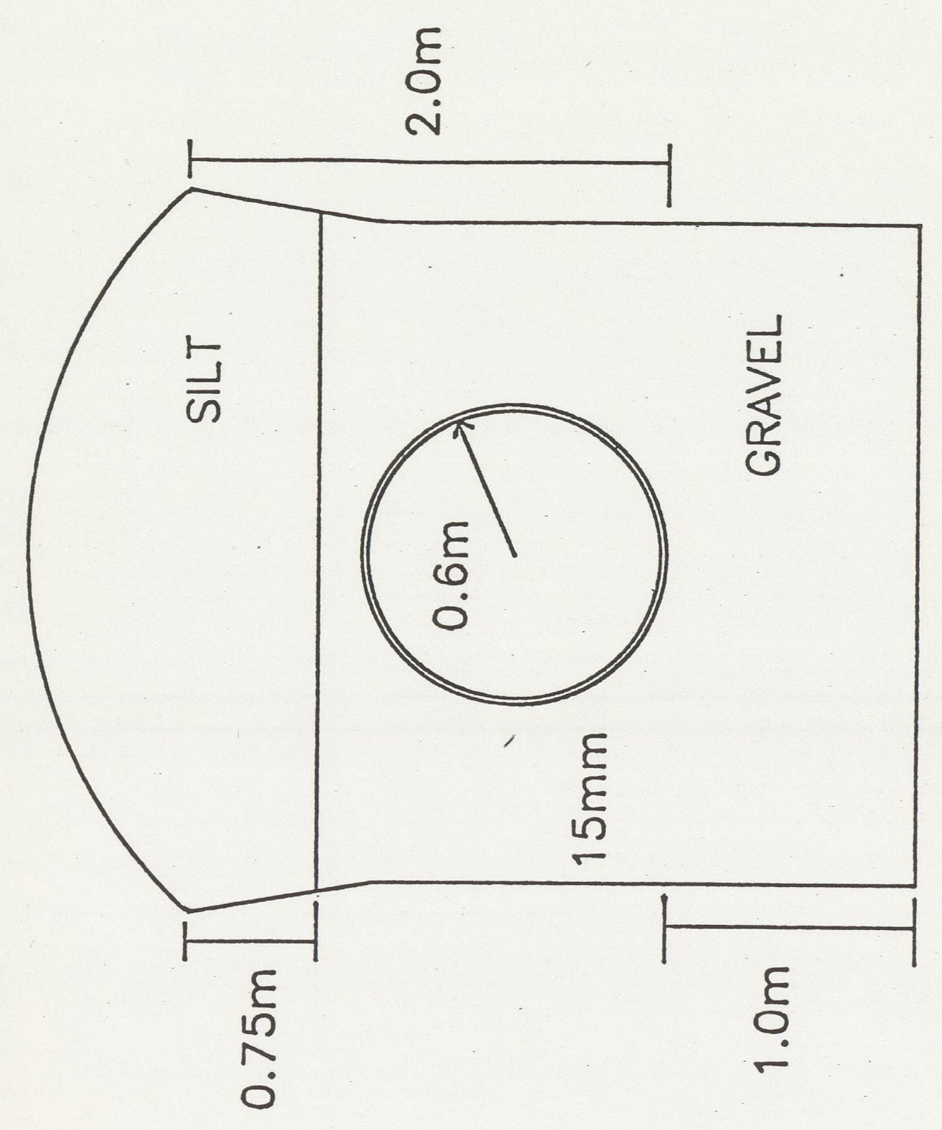


BANDPASS FILTERED DATA

TOPOGRAPHY

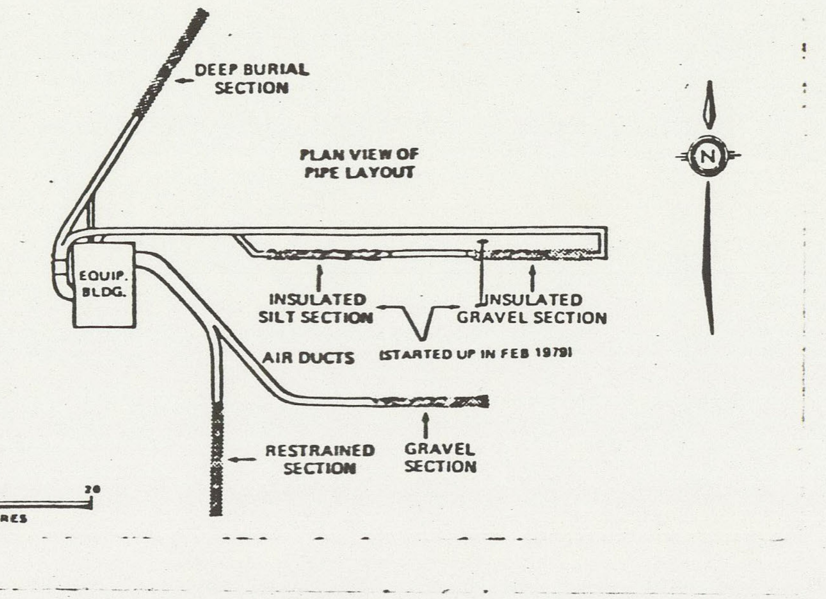


INSULATED GRAVEL MODEL CROSS SECTION



A-CUBED INC.

Title: Fig. 3.4.3 INSULATED GRAVEL PIPE LINE 3		
Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved:



NOTES

1. See the map above for line location.

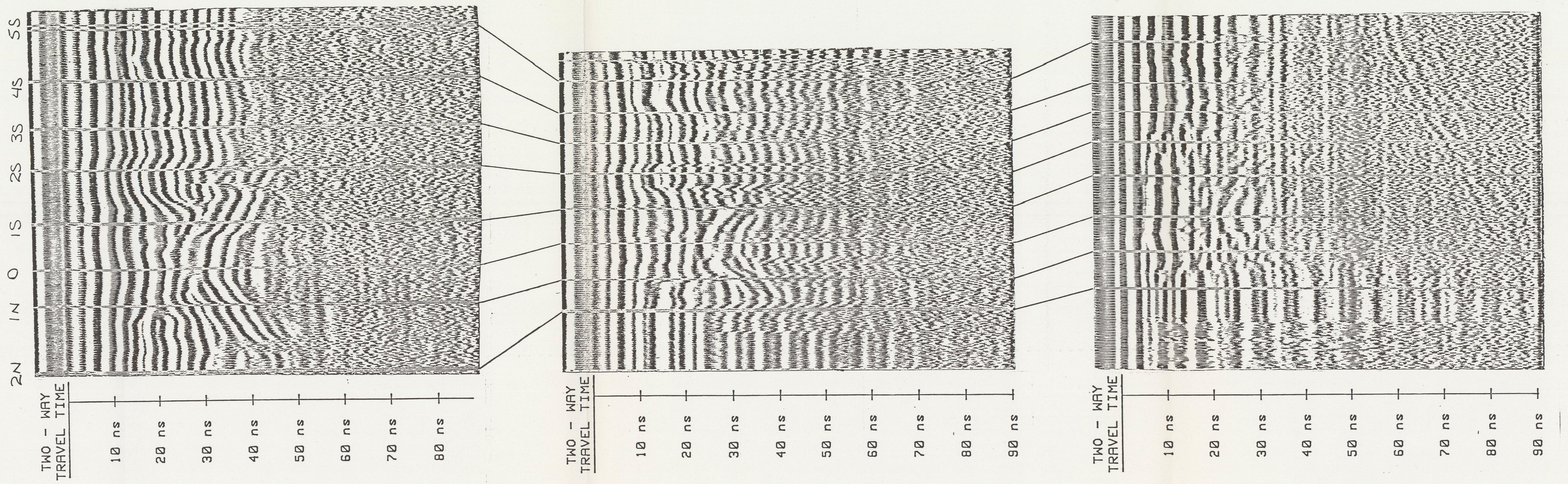
2. Data Sections presented top to bottom in the following order with filter settings:
100MHz Antennas filtered 420 to 480 Hz
200MHz Antennas filtered 380 to 420 Hz
300MHz Antennas filtered 400 to 480 Hz

3. All distances are in metres.

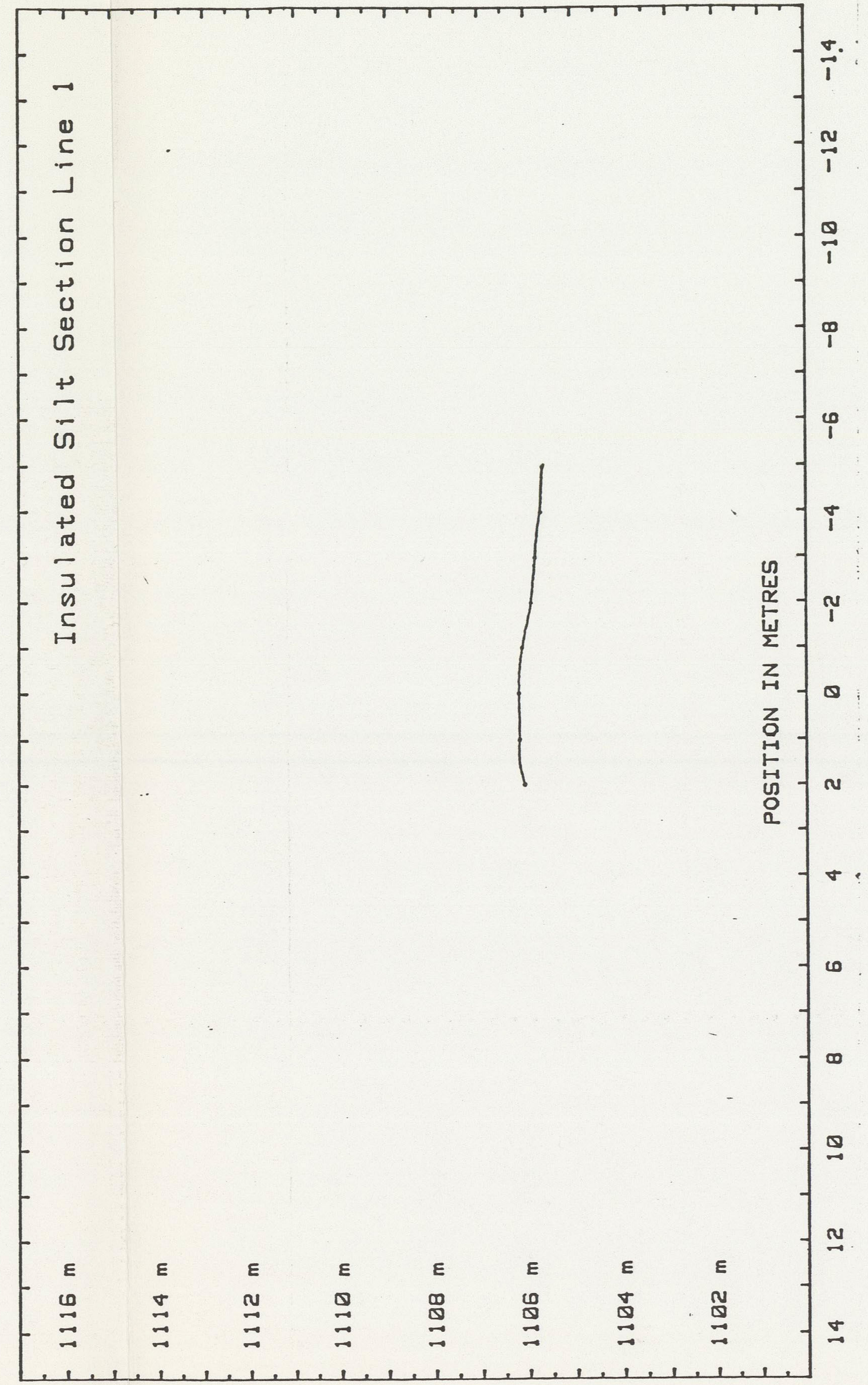
4. Topography and Model diagrams are not drawn to the same scales.

5. Zero position corresponds to pipe axis.

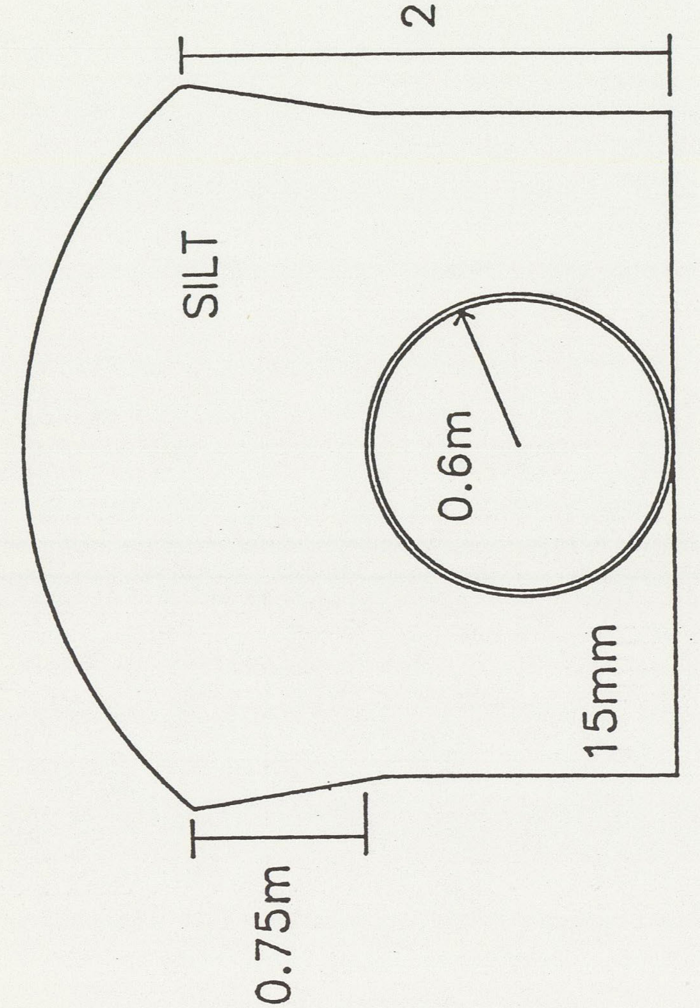
BANDPASS FILTERED DATA



TOPOGRAPHY



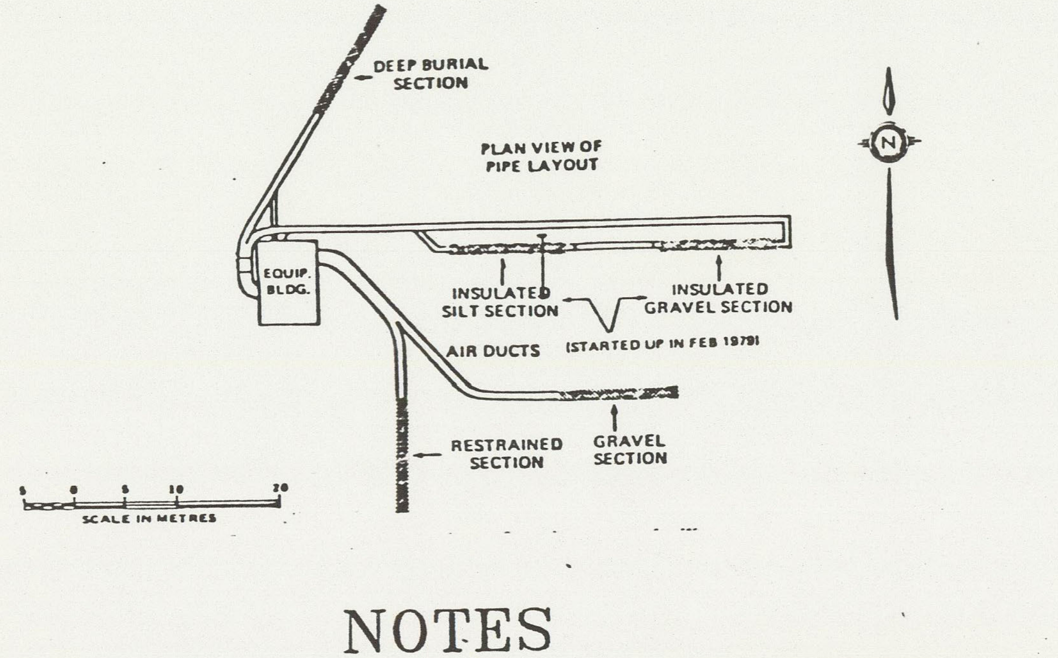
INSULATED SILT MODEL CROSS SECTION



A-CUBED INC.

Title: Fig. 3.5.1 INSULATED SILT PIPE LINE 1

Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved:



NOTES

1. See the map above for line location.

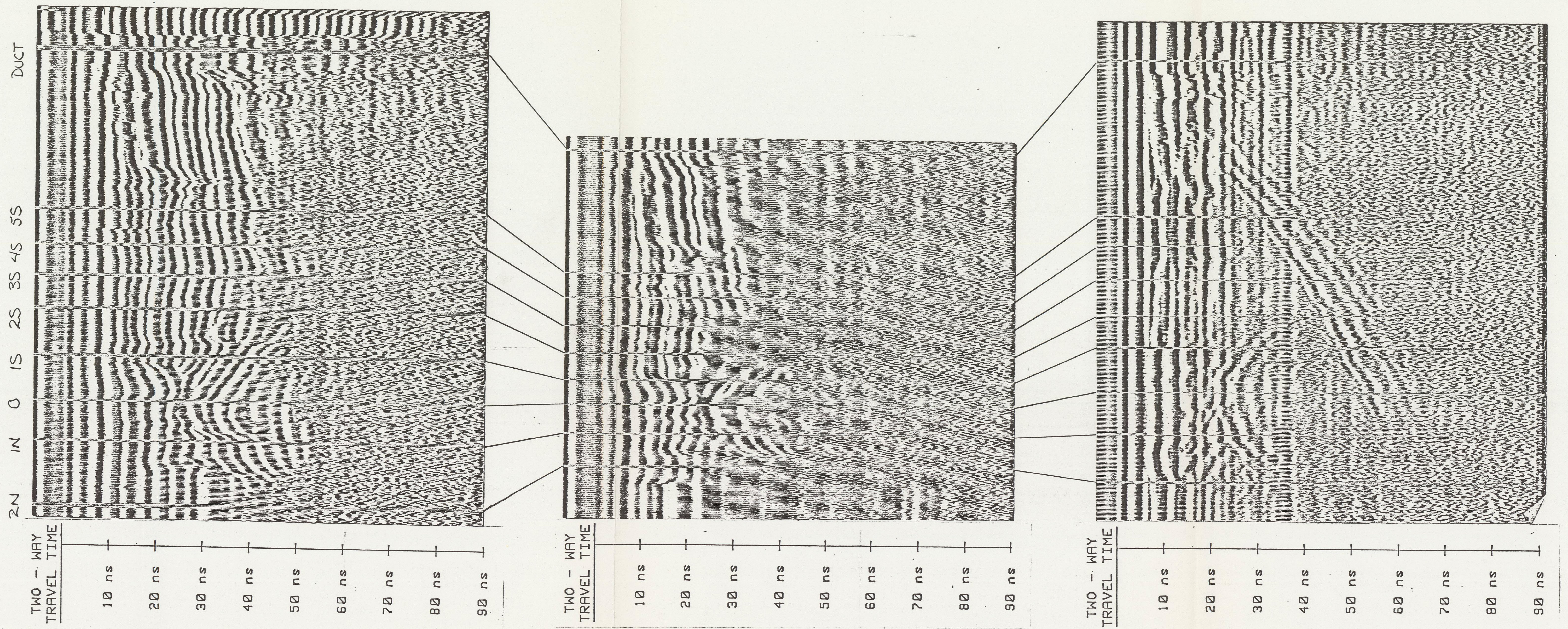
2. Data Sections presented top to bottom in the following order with filter settings:
100MHz Antennas filtered 420 to 480 Hz
200MHz Antennas filtered 380 to 420 Hz
300MHz Antennas filtered 400 to 500 Hz

3. All distances are in metres.

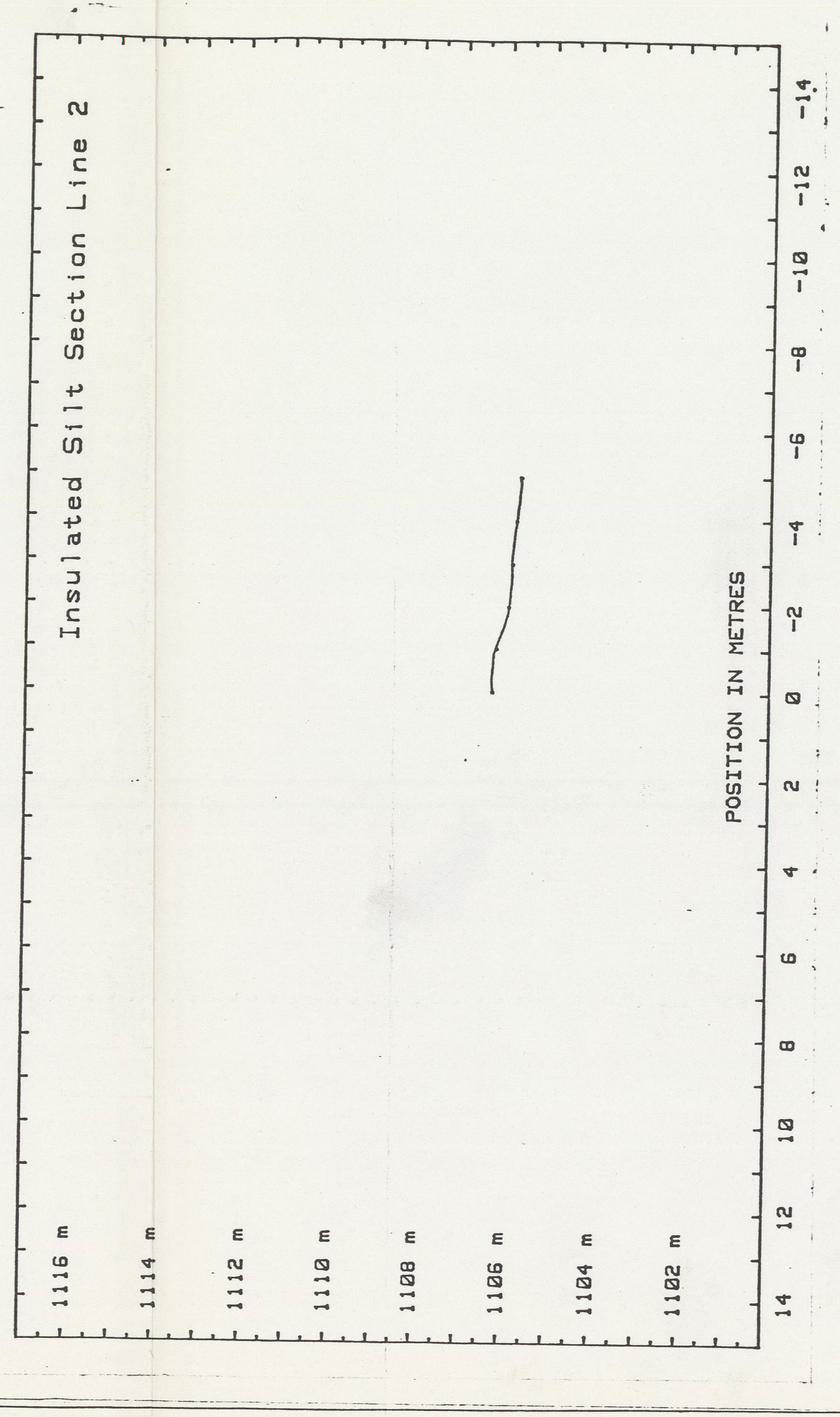
4. Topography and Model diagrams are not drawn to the same scales.

5. Zero position corresponds to pipe axis.

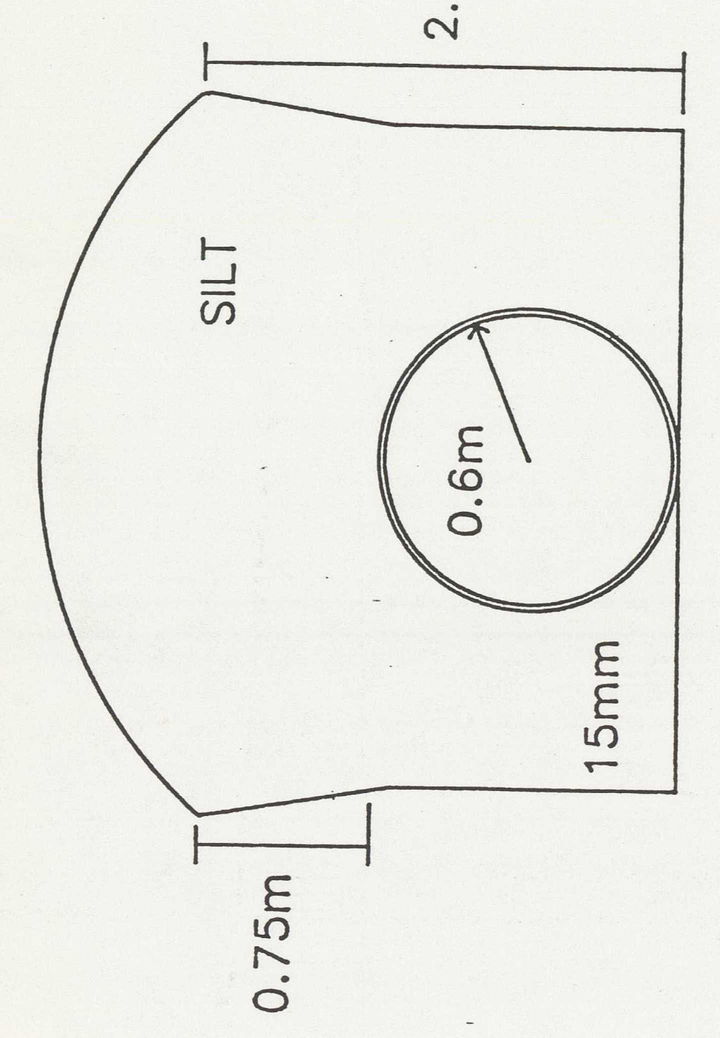
BANDPASS FILTERED DATA



TOPOGRAPHY

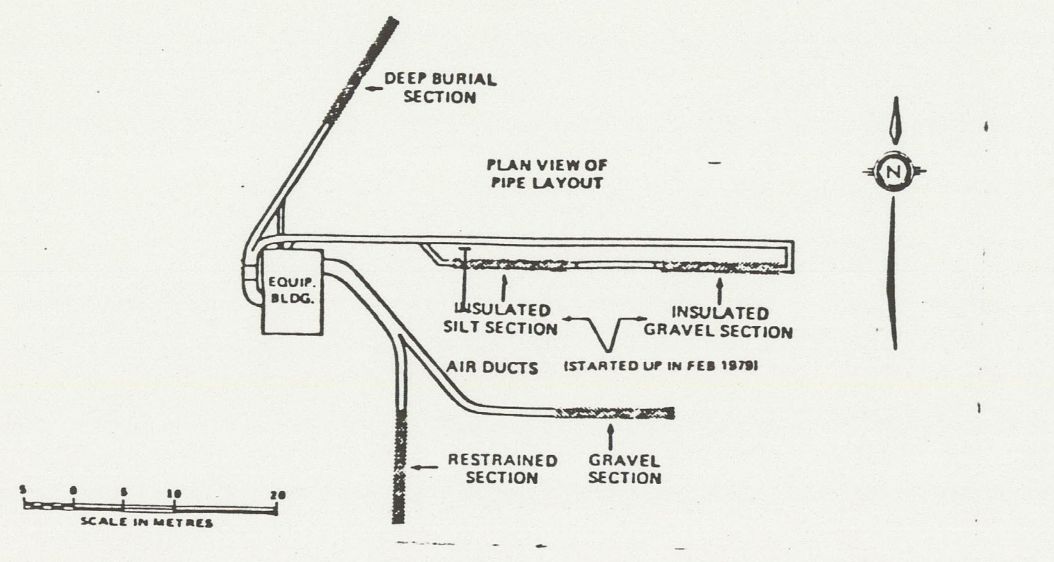


INSULATED SILT MODEL CROSS SECTION



A-CUBED INC.

Title: Fig. 3.5.2 SILT INSULATED PIPE LINE 2		
Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved:



NOTES

1. See the map above for line location.

2. Data Sections presented top to bottom in the following order with filter settings:
100MHz Antennas filtered 420 to 480 Hz
200MHz Antennas filtered 380 to 420 Hz
300MHz Antennas filtered 400 to 500 Hz

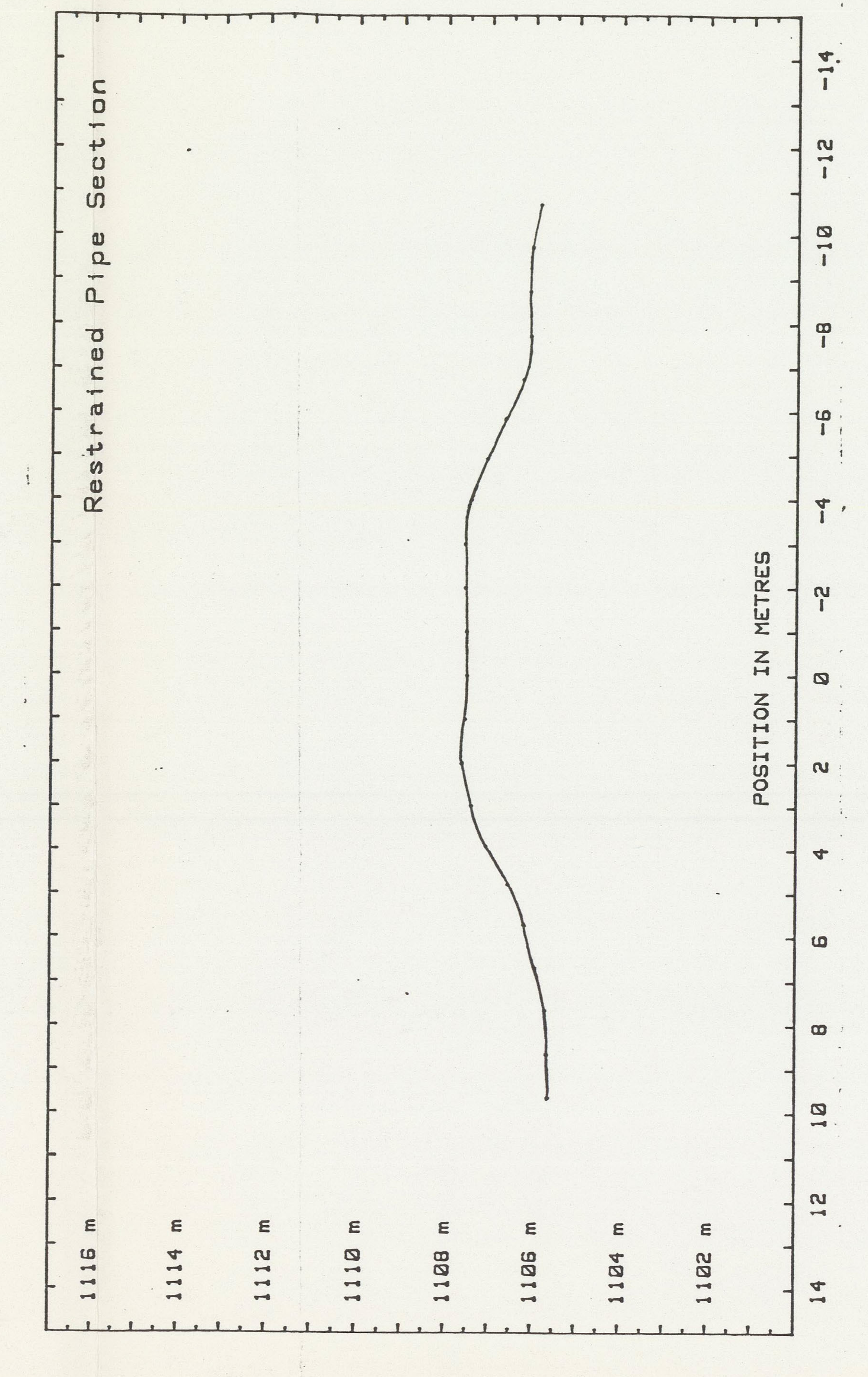
3. All distances are in metres.

4. Topography and Model diagrams are not drawn to the same scales.

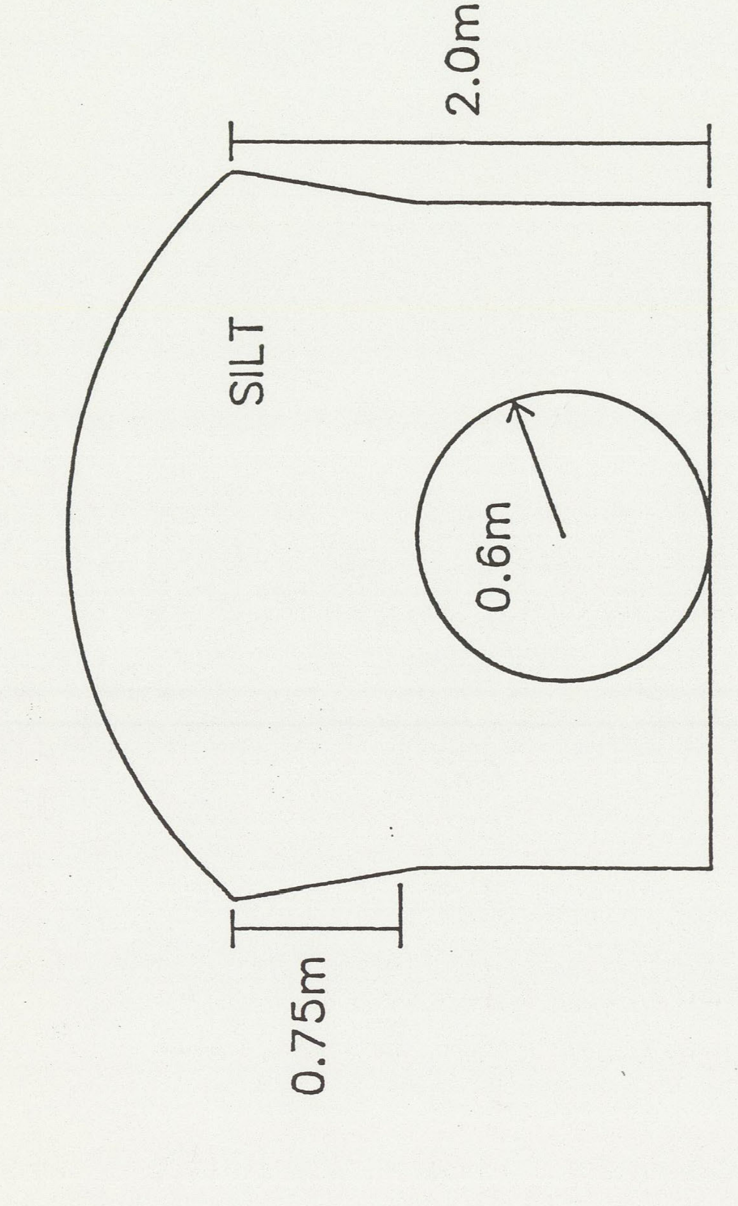
5. Zero position corresponds to pipe axis.

BANDPASS FILTERED DATA

TOPOGRAPHY

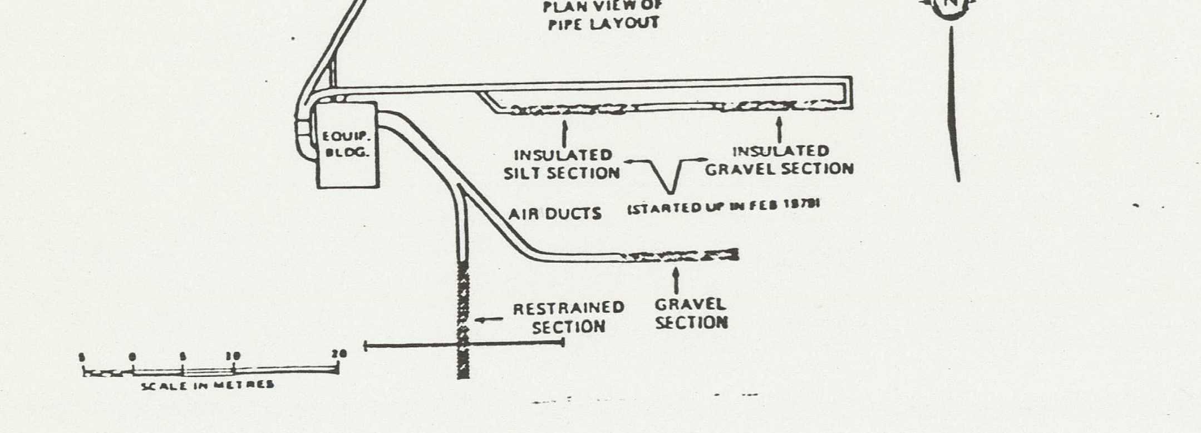


RESTRAINED SECTION MODEL CROSS SECTION



A-CUBED INC.

Title: Fig. 3.6 RESTRAINED PIPE		
Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved:



NOTES

1. See the map above for line location.

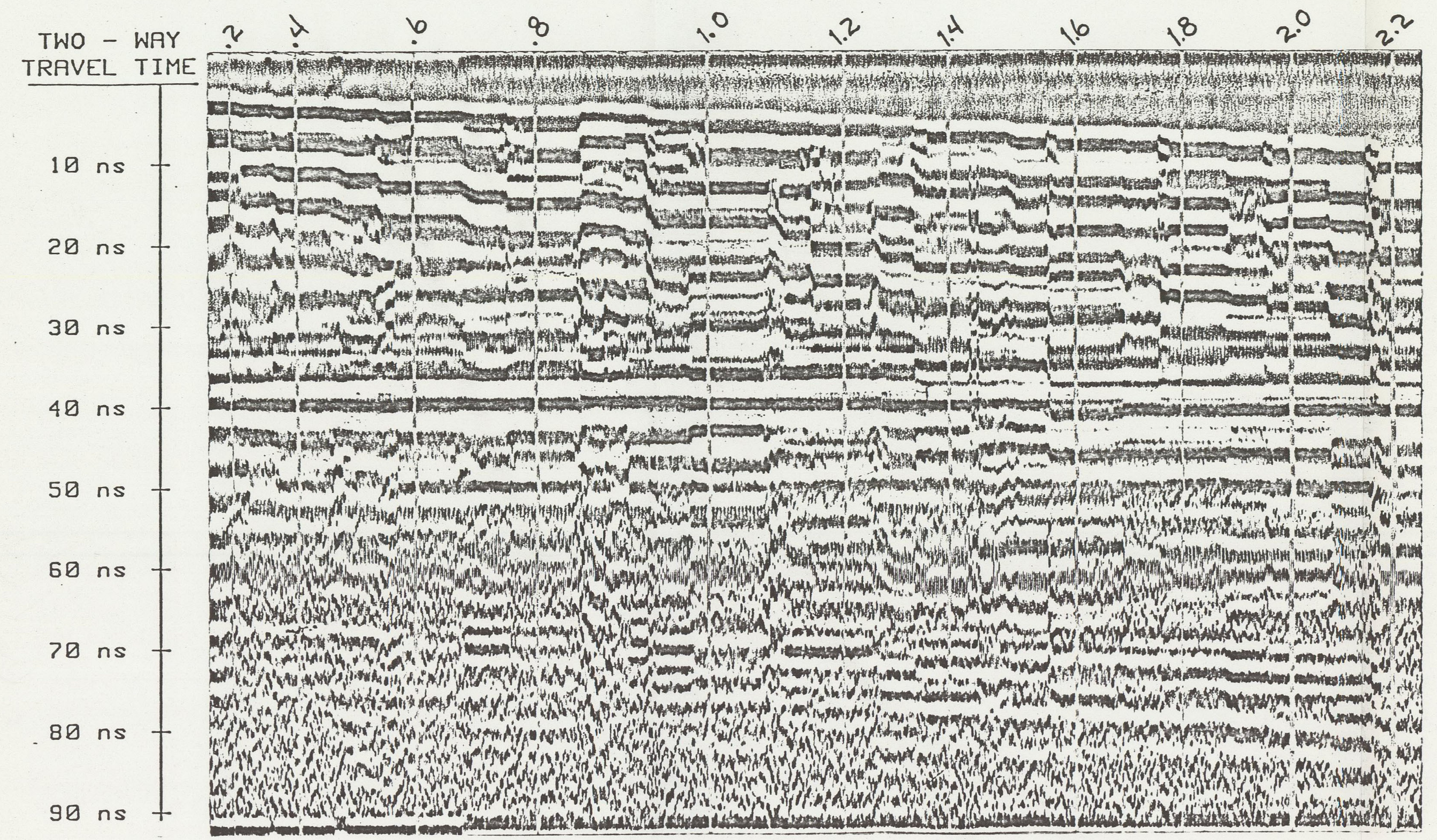
2. Data Sections presented left to right in the following order with filter settings:
   100MHz Antennas filtered 300 to 500Hz
   200MHz Antennas filtered 380 to 420 Hz
   300MHz Antennas filtered 400 to 500Hz

3. All distances are in metres.

4. Topography and Model diagrams are not drawn to the same scales.

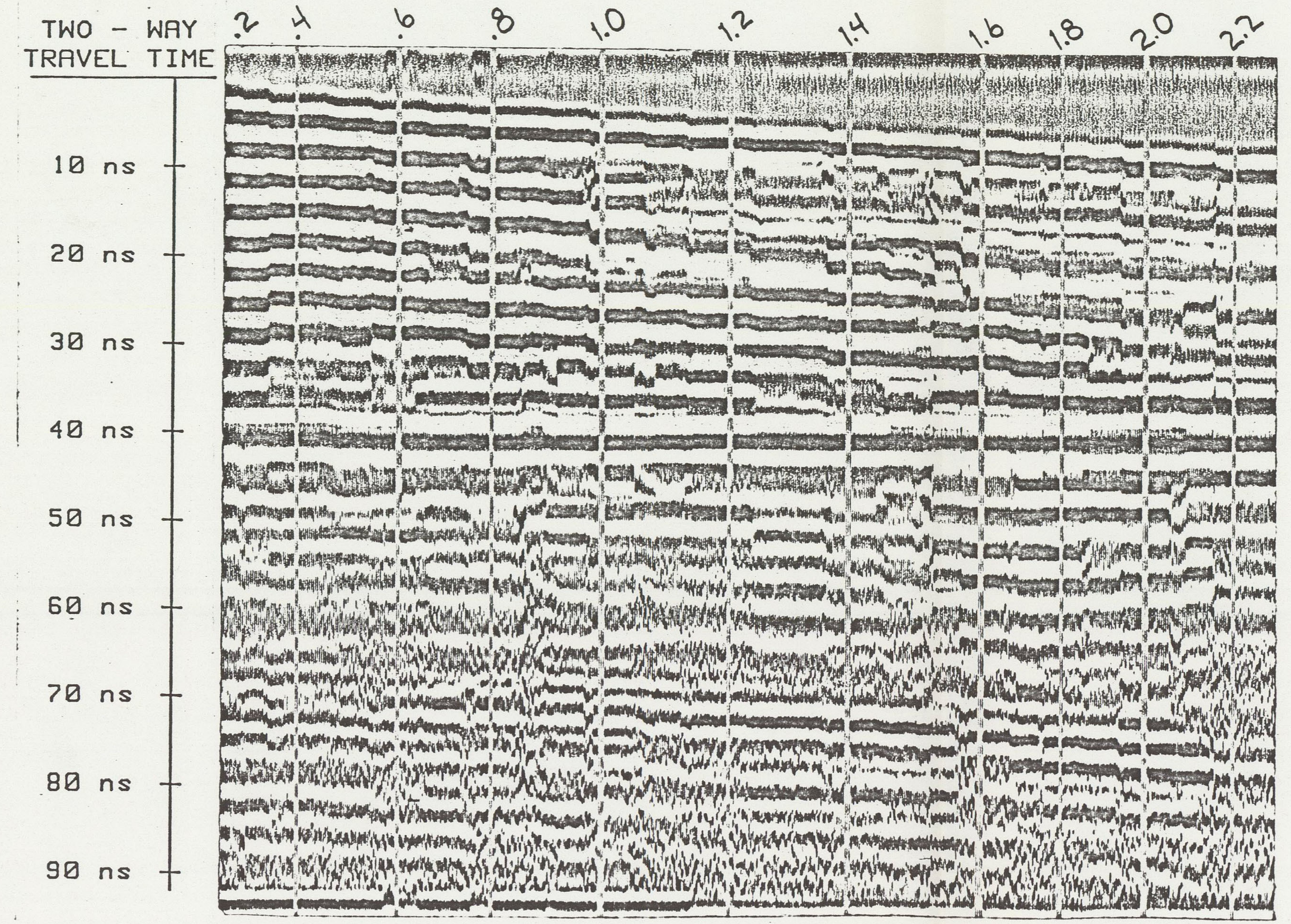
5. Zero position corresponds to pipe axis.

COMMON DEPTH POINT (CDP) SOUNDINGS



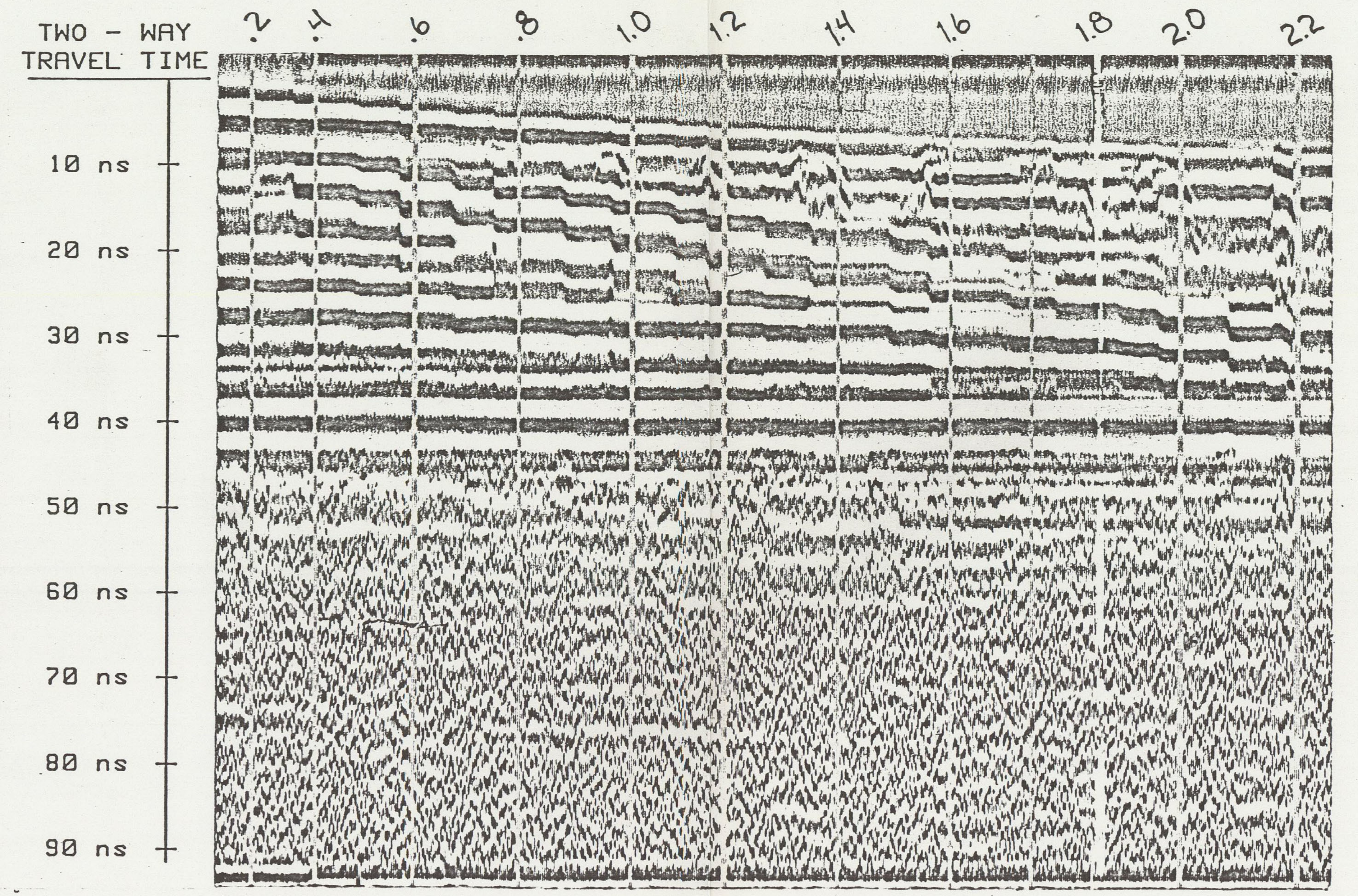
RESTRAINED PIPE SECTION

CDP Sounding parallel to Radar profile: centred at the zero line over the pipe axis.
Bandpass Filtered 380 to 420 Hz.



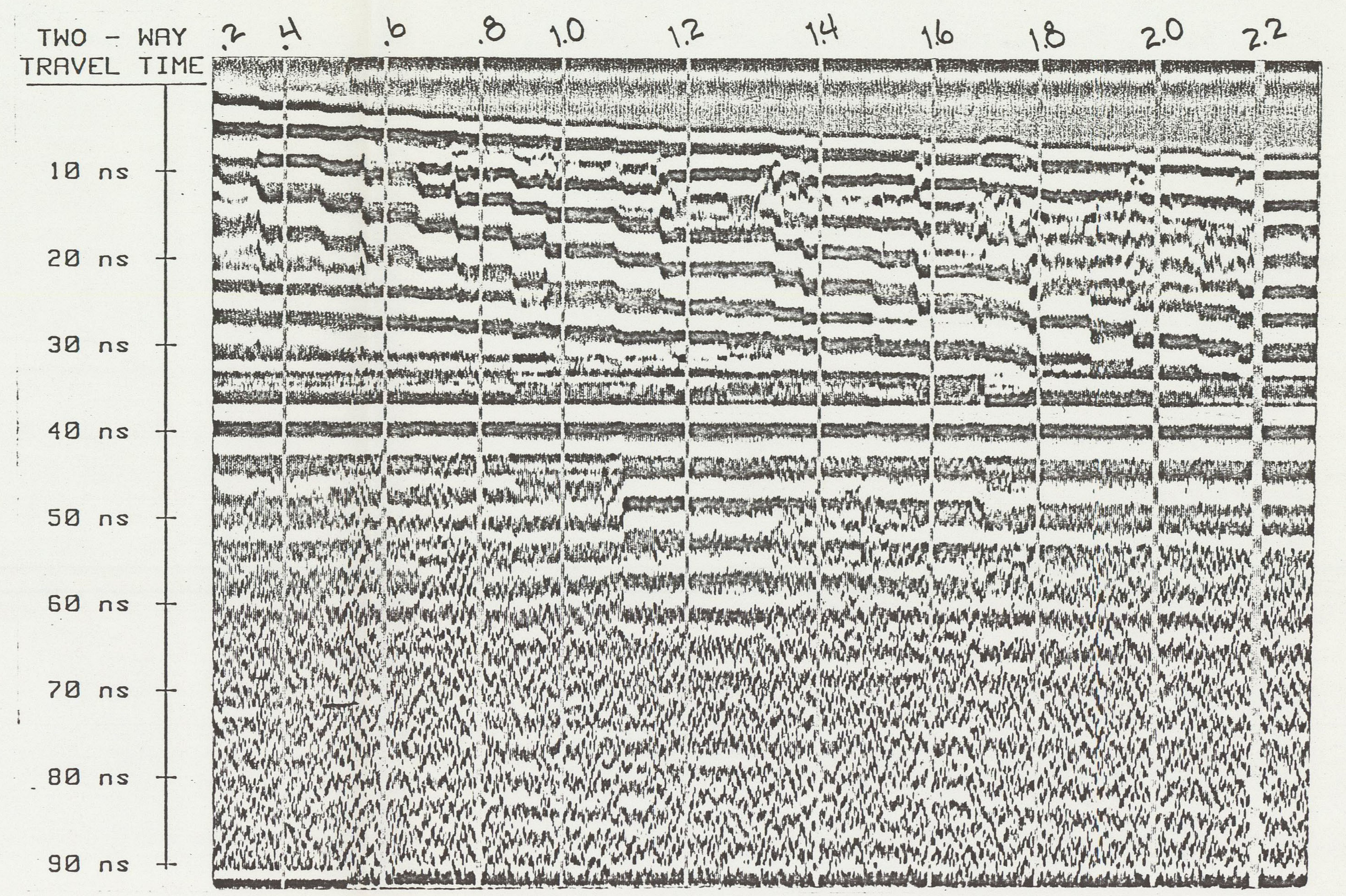
STRAIGHT GRAVEL SECTION

CDP Sounding parallel to Radar profile: centred at zero on Line 1.
Bandpass Filtered 380 to 420 Hz.



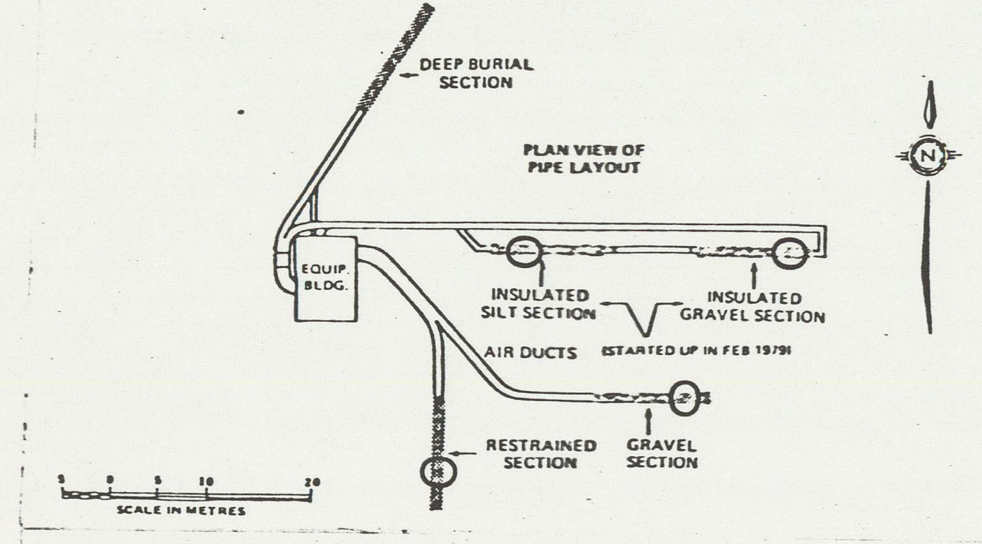
INSULATED GRAVEL SECTION

CDP Sounding perpendicular to the Radar profile: centred on Line 1 at a point 0.5 metres south of the pipe axis.
Bandpass Filtered 380 to 420 Hz.



INSULATED SILT SECTION

CDP Sounding perpendicular to the Radar profile: centred on Line 2 at a point 0.5 metres south of the pipe axis.
Bandpass Filtered 380 to 420 Hz.



NOTES

1. SEE THE MAP ABOVE FOR CDP SOUNDING LOCATIONS.
2. FID MARKERS ARE CENTRE TO CENTRE ANTENNA SEPARATIONS IN METRES.
3. THE CENTRE OF THE ANTENNA ARRAY REMAINS FIXED IN SPACE AS THE TWO ANTENNAS ARE MOVED APART.

A^3 A-CUBED INC.	Title: Fig. 3.7 CDP SOUNDINGS	
Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved: C.V

RAW FIELD DATA

BANDPASS FILTERED DATA

Positive and negative peaks are black.
No DC bias added.

Filter Setting: 200 – 1000 Hz
Positive peaks only are black.
DC bias added.

Filter Setting: 200 – 600 Hz
Positive peaks only are black.
DC bias added.

Filter Setting: 250 – 500 Hz
Positive peaks only are black.
DC bias added.

Filter Setting: 300 – 600 Hz
Positive peaks only are black.
DC bias added.

Filter Setting: 400 – 500 Hz
Positive peaks only are black.
DC bias added.

A³ A-CUBED INC.

FIG. 3.8 ANALOGUE PROCESSING OF RAW DATA
INSULATED GRAVEL LINE 2 AT 100 MHz

Scale:	Drawing No:	Job No: 52-5008
Date:	Revision:	Approved: CV

APPENDIX A

GENERAL RADAR SOUNDING PRINCIPLES & EQUIPMENT

GENERAL RADAR SOUNDING PRINCIPLES AND EQUIPMENT

A.1 Basic Concepts

The concept of using radar to penetrate the ground has been in existence for more than 30 years. The initial ground probing radar work came about from the fact that altimeters on aircraft used in ice capped Arctic areas would penetrate through ice sheets. This discovery led to the exploitation of the radar idea for mapping ice thickness in these areas. The idea of using radar in non-ice materials found little acceptance since the majority of the Earth Science community felt that the depth of penetration would be so minimal as to be useless.

In actual fact, there are a number of geological environments where ground probing radar can be used with great success. In general, the higher the ground resistivity, the better the chances of utilizing a ground probing radar system. As a result, the ground probing radar systems have evolved for addressing particular geological problems. One of the first areas addressed after that of sounding through ice was the utilization of radar in boreholes drilled into salt domes or in salt mines themselves. Salt is highly resistive when it is dry and, as a result, is an excellent dielectric material through which to propagate radio signals. Work in the early 1970's suggested that frozen soils should be transparent to radar signals. Field measurements in permafrost areas have verified this. Further work showed that significant penetrations could be obtained in sand and gravel materials. In coarse grained soils where the ground water is very fresh, penetrations of up to 30 and 40 metres have been achieved with ground probing radars on a routine basis. The whole state of the art at the moment is undergoing constant evolution with new and better equipment being developed. Certainly the ground probing radar techniques are still in their infancy as geophysical tools.

The basic concept of ground probing radar is very simple. An antenna is used to generate an electromagnetic radio frequency pulse. This signal radiates outwards from the antenna and if any changes in electrical character of the material through which it is propagating are encountered, some of the energy is reflected back towards the transmitter. Thus, after a certain amount of delay time, some energy is returned to the antenna. In "conventional" radar systems, this can be used for ranging the distance to specific targets. Ground probing radar works on exactly the same principle. A pulse of energy is generated at the ground surface on a simple antenna. Part of the energy is radiated into the ground and it propagates with the EM wave velocity of the ground. This wave propagates more slowly than the waves in air and also suffers some attenuation due to ohmic losses in the soil or rock through which it is propagating. Changes in stratigraphy, water content or rock type can cause some of the energy which is propagating outwards from the antenna to be reflected back again. By monitoring this return radiation as a function of position one can then map features beneath the ground surface.

Figure A-1 illustrates the general concept. In this schematic diagram two antennas are used, one for transmitting the signal and one for detecting the returning signal. In principle the same antenna that transmits the signal could be used to receive the energy. In practice, it has turned out that utilizing two antennas is usually more practical for ground probing radar. This is certainly not the case for special applications, however, and a single antenna can be used quite effectively. For illustrative purposes, the schematic situation in Figure A-1 is translated into a radar record shown in Figure A-2 which displays the radar signals as a function of delay time versus position. The transmitter is assumed to generate a wiggle pulse at time zero. This appears on the receiving trace always at time zero and is shown as such on Figure A-2. Simple structures generate various types of signatures, as illustrated by the events arriving later in time. The results shown here are typical of those observed in actual field data.

A ground probing radar system has two initial requirements. The first is obtaining fieldworthy hardware which can generate the appropriate electrical or electromagnetic signals and then receive and record them. The second is to make the system portable, such that it can be transported over the ground in a continuous manner. Although it has not been stressed so far, continuous profiling records are extremely helpful to interpretation. By profiling, one obtains a continuous record of stratigraphy and other subsurface features, so that there is no difficulty in correlating events from place to place. Since the wavelengths and the scales of the measurement are quite often small, typically on the order of a few metres, it is essential that very close spatial sampling of the signals be made. As a result, it turns out to be most practical to make continuous observations of the ground, rather than to make discrete observations.

A.2 Hardware

The equipment involved in a ground probing radar system is very simple in principle. The unit consists of three main elements, namely, the transmitting unit, the receiving unit and the recording and display units. A simple block diagram of ground probing radar hardware is shown in Figure A-3.

The transmitter unit is a pulse generator which outputs a short duration (1 - 20ns) voltage pulse onto a broadband antenna. The receiving unit consists of a receiving antenna (which may be the same one as used for the transmitter) which acquires reflected signals and the radio frequency electronics which measure signal amplitude versus delay time after the transmit pulse.

In order to put the timing problem into perspective, it is necessary to consider the propagation velocities of EM waves ub typical materials. In air, electromagnetic energy propagates at a speed of 0.3m/ns. The slowest geologic material commonly encountered is water and it has a speed of propagation of about one tenth that in air. Any other geologic material normally falls in the range of one half to one quarter of the propagation speed in air.

It is therefore imperative that timing mechanisms be available to resolve times down to the order of one nanosecond if spatial resolution of the order of a fraction of a metre are going to be achieved. Initial ice probing radar had great success using very simple techniques. The spatial resolution required was much less, typically only tens of metres and probing to depths of several kilometres. As a result, the timing requirements were an order to two orders of magnitude slower than is required for current ground probing radar applications. Recording techniques that evolved for the ice application were various photographic techniques for recording oscilloscope beams. Typical times involved were in the microsecond range and this was feasible with existing technology.

In order to achieve the same thing with very shallow ground probing radar, typical times that have to be analysed are in the nanosecond range. The advent of the sampling head oscilloscope principle made a major step forward in the ground probing radar technology. The sampling head oscilloscope allowed very high frequency signals to be analysed as long as the excitation signals were repetitive in nature. The sampling head uses the repetitive nature of a signal to sample successive repetitions of the signal and generate an audio frequency facsimile of the high frequency signal. This principle is embodied in all of the ground probing radar systems currently operating.

It is beyond the scope of this note to give any details on the sampling head principles other than to provide a brief outline of how it works. A repetitive signal is generated and a window is placed at some delay time with respect to the start of the signal. Each repetition of the signal is associated with a different delay. By systematically increasing the delay with respect to the start of the signal, it is possible to obtain a sample of signal at any given delay time with respect to the start of the signal. If the delay is increased linearly with time a replica of the high speed signal can be generated which has a time base proportional to the rate of delay increase. Time base expansions of 10^6 to 10^9 can be easily achieved in this manner.

In the sampling head oscilloscope the excitation signal is generated on a routine basis and the sampling head window is slid at a locked rate with respect to the transmitted signal or periodic signal. This is done in an analog manner such that an analog trace is generated which is equivalent to the original high frequency signal but has its time base expanded by several orders of magnitude.

In the ground probing system a typical repetition rate for the transmit pulse is in the range of 50 to 100kHz. A secondary timing ramp slews the sampling head window across the received waveform such that one whole record of data is generated in some fraction of a second, typically anywhere from .01 second up to 1 second. There are a number of interplays in this whole timing network. One is the maximum delay after the transmit pulse to which the window moves before the cycle repeats. This is the time range or window setting for the radar system. Typically, this would be anywhere in the range from 10ns to 1000ns. This time range in nanoseconds is swept out in the equivalent scan time which is in the range of .01 to 1 second. As an example, a radar trace corresponding to a window setting or full range setting of 500 nanoseconds swept out in half a second would correspond to a time base expansion of 10^6.

The ground probing radar normally used by A-Cubed Inc. works on this basic principle. The transmitter rep rate is 50kHz. The scan time for a single sampled record is normally 150 milliseconds. Full scale window ranges can be adjusted from 20 nanoseconds up to 1000 nanoseconds.

The preceding gives some idea of the electronics involved in measuring the signals. A crucial element of the ground probing radar system is the antenna system. Antennas, by their very nature, tend to be narrow bandwidth devices. For ground probing radar purposes, the ideal transmit signal is one which has a very broad spectral content, typically being flat over a decade or two in frequency. Similarly, the receiving antenna should be able to respond to the same signal with a flat frequency response. In practice, such antennas are just not achievable. This is not totally without some consternation on the part of antenna designers who talk about log periodic and other similar antennas. Unfortunately, these are just not practical for ground probing applications. The main reason is that the characteristics of the antennas vary, depending on the type of ground on which the antennas are placed. If they are raised too high above the ground surface, then the coupling to the ground is reduced and the radar signals are attenuated. The which are used most often for ground probing radar are resistively loaded dipoles. These antennas are not very efficient but they do provide reasonable bandwidth in a simple robust package. They are also lightweight and practical to construct which is a big advantage as well. The typical ground probing radar antenna is is a flared, planar structure with discrete resistive loads placed on it. To a certain extent the antenna is a crude approximation to the biconical antenna.

A third, and not irrelevant, aspect of the radar hardware is the manner in which the data is displayed or recorded. Ground probing radars generally use a grey scale recorder to display the radar data. Various types of audio frequency tape recorders are used to record the analog signals coming in at the control unit for future replay, signal processing, data enhancement, etc. The volume of data is extremely high and analog recording is the only practical means of recording the data for posterity. Only in very special situations can digital signal recording be utilized effectively.

One of the biggest difficulties with the ground probing radar to date has been the means of displaying the data in an effective manner. As mentioned previously, graphic or grey scale recording units are utilized for this. In general, such devices have a limited dynamic range for the signals they can display. In an ideal setup, the maximum dynamic range that can be presented visually is on the order of 20dB. In practice, half of this dynamic range is achievable on a routine basis. On the other hand, the radar records themselves typically have a dynamic range of about 60dB for the signals coming out of the sampling head. It is therefore an essential component of the radar system to attempt to do dynamic range compression on the signal. The second factor which is important is modifying the various grey scale recorder settings in order to present the data in a most effective form, allowing the human eye to select discrete features and follow trends in otherwise noisy data. Figure A-4 shows the relationship between a radar trace and the equivalent graphic recorder display.

One of the most effective ways of achieving a dynamic range compression with ground probing radar data is to utilize the delay time aspect of the data. In general, the longer the delay time, the further the signal has propagated through the ground and the more attenuation from geometric spreading of the wavefronts and from ohmic losses the wave has suffered. One can therefore apply a differential gain to the received signals versus time. In other words, a very small amplification is given to signals which come at very short times after the transmit pulse and an increasing amount of amplification is given to signals which come later and later in time after the transmit pulse. This is available in all ground probing radar systems which are currently operating. While the above analysis is generally true, there are always exceptions to this rule. Quite often one can have one strong refelector in an otherwise decreasing amplitude section. Therefore the adjustment of time gain in setting up the radar system to start with is always a very critical aspect of the system adjustment in a survey.

Other factors which enter into data display are those of enhancing the grey scale recording level such that the eye can more readily discern individual features in the record and maximize the dynamic range. Invariably, ground probing radar records have a significant amount of noise or clutter associated with them. Part of this noise is just system noise which is an inevitable fact of life in any system. The second source of noise can be external, spurious radio frequency interference which generates a general hash background noise on the record. The third source of noise is actual geologic structure itself, or geologic noise. In the latter case, the noise is generated by energy reflected from geologic features or structures which are not of importance in a particular application. It is therefore necessary to be able to distinguish between the desired subsurface reflections and those which come from other structural features or geologic features in the section. Various types of band pass filtering, zero level suppression, biasing on the data and other factors can be utilized to enhance the visual presentation of the data. In general, just about every site has a different set of problems and data presentation cannot be generalised. It requires experience, insight and understanding of the data and the noise sources in order to present the data in the most palatable form for the eye to understand.

A.4 Practical Field Considerations

As outlined in the hardware section above, there are a number of aspects of the hardware which have to be considered in order to get good clean data. The same goes for the actual operation of the system in the field. There are a large number of variables in a radar survey operation and it is important that these various settings of the hardware components of the system as well as the survey procedure be tailored to the particular application under investigation.

The objective of the radar survey is to map subsurface structure by generating a pseudo section which displays radar reflection signals as a function of delay time and a function of position along the surface. To achieve this, one has to be able to display radar signals versus delay time and position in a systematic, coherent manner. In the preceding discussion of the hardware the sampling head approach of generating audio frequency facsimiles of the radar signals is utilized to generate the amplitude of the radar signal versus delay time. The field procedure is the important factor in determining the other axis, namely the display of these records versus position. In practice, a field record which is as close to the ideal record should be sought. This involves moving the radar system over the ground at a systematic and constant rate. In practice, this is very difficult to achieve because there are always obstacles which have to be overcome. In the past, one of the simplest but greatest obstacles was just the antennas themselves. Manufacturers of these systems would make huge, very heavy antennas which were almost impossible to transport except on a paved surface. The real world normally requires one to carry these antennas through bush, through tunnels and various other inhospitable environments while moving at a regular pace.

Another obstacle to getting continuous records at a uniform pace is the actual electronic hardware itself. To date, radar systems have been encumbered by huge and power-hungry tape recorders and graphic display units. These in turn require a number of people or vehicles to transport the equipment. In the system currently utilized by A-Cubed Inc., efforts have been made to try and minimize the weight factors in the equipment. Initial prototype gear utilizes an audio cassette tape recorder and very lightweight antennas. In addition to the actual movement of the system over the ground, it is also important to be able to monitor the precise position of the antennas with respect to the ground. This involves profiling on a grid or line with a known chainage along it. In practice, the best way this can be achieved is to put an audio track on the tape recorder which is also recording the radar data. In this manner, comments can be recorded in parallel with the actual radar data. If the line has been chained at equally marked intervals then these chainage locations can be recorded on the tape along with any major topographic features.

One of the most difficult problems in the ground probing radar field is the actual setup of the radar system on a site. In general, it is impossible to predict beforehand the exact nature of the stratigraphy in an area and the strength of the signals which will be observed. In addition, it is also almost impossible to predict exactly how far one will be able to look into the ground as a function of delay time of the signal. It is therefore necessary, in setting up on a site, to run a number of test lines and calibrate the system to the specific site and the specific problem at hand. This is done by running the radar system on several different range settings and gain settings, and adjusting until the particular feature which is being sought is enhanced by the radar and other spurious or geologic noise features are suppressed as much as practical by the system.

Maximum coupling of energy comes from keeping the antennas as close to the ground surface as possible. In profiling mode on rough terrain this is often difficult. The additional benefits of keeping the antenna(s) close to the surface versus the speed of production in a survey are difficult factors to trade off. In general, however, the antennas should be kept within a tenth of a wavelength of the ground surface in order to maximize energy coupling into the subsurface.

There are several common antenna configurations. In normal production work the transmitting and receiving antennas may be one and the same or, more often, two separate units. In the first case the system is called a monostatic system, whereas in the second it is a bistatic system. Normal procedure for sounding to depths of several tens of metres involves using two antennas typically separated by a metre to 3 metres centre to centre with dipole axes parallel. In theory this is not of any consequence; in practice, however, it is extremely important in that the sampling head receiver normally has a finite dynamic range. From experience a 2 metre separation achieves the best tradeoff in dynamic range versus target resolution in most instances. The effect of using finite antenna separation is that it reduces the resolution of very shallow targets. It is therefore very important to decide how deep the targets which are being sought are and what is the most practical antenna separation to use for these targets. Figure A-5 and A-6 show some typical profiling configurations for the antennas in actual field operation.

A third aspect of field procedures is the actual selection of the operating frequency of the radar. In general, the bandwidth of the antenna systems are quite limited. As a result, it is imperative that the characteristics of a radar target be well defined before the survey work begins. In general, the smaller and shallower the target, the higher the operating frequency should be. With typical ground probing radar systems various antennas are utilized which work on the same principle but have different centre operating frequencies. Normally, A-Cubed Inc. operates two antenna systems, one which has a centre frequency of 100MHz and another one which has a centre frequency of around 350MHz. The higher frequency antennas are good for high resolution and shallow penetration. Features which are a few centimetres in extent and at depths of one to three metres are resolvable with this type of antenna. For deeper structure the 100MHz antennas, which typically have resolutions of on the order of one quarter to one half metre and can have penetrations of up to 30 or 40 metres, are utilized.

In any site situation it is imperative that the system performance with different frequencies be assessed. In some instances the responses are predictable, in others quite unpredictable responses can be obtained. Much of the unpredictability of the radar responses comes from the total lack of knowledge of the detailed ground structure. Fine scale geologic stratigraphy can have a tremendous impact on the performace of the radar. As a general rule, depth of penetration increases as the frequency of the radar system is decreased. On the other hand, the spatial resolution of the radar system decreases as the frequency decreases as well.

A.5 Data Interpretation

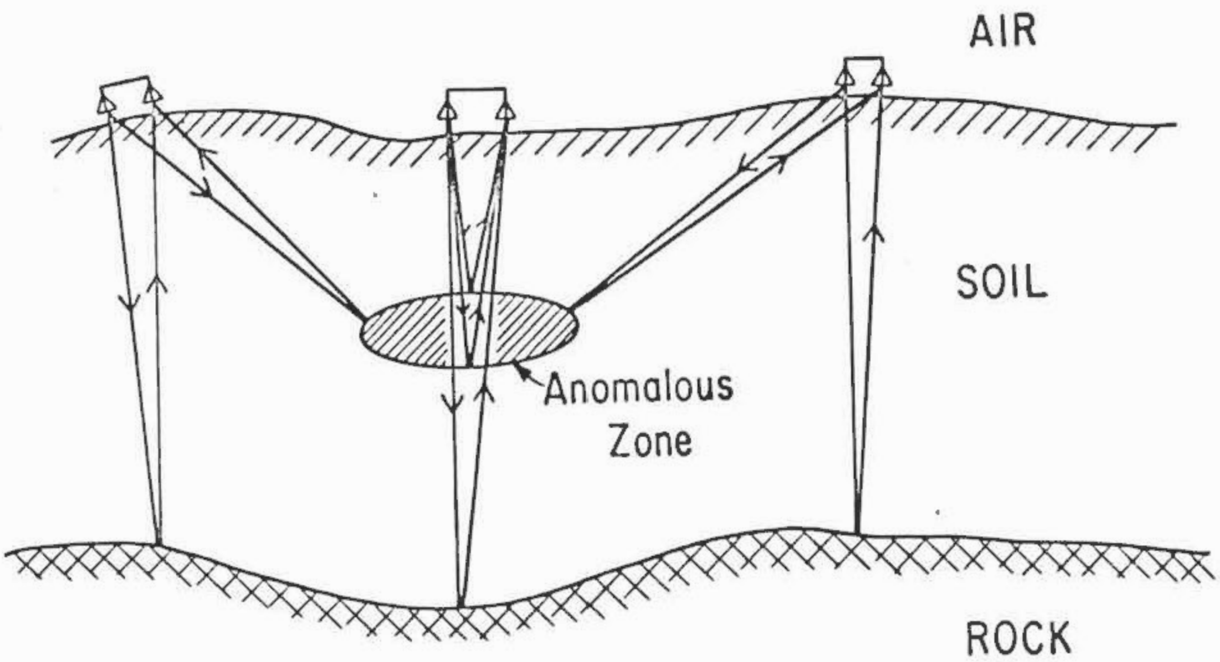
The output of a radar survey is a set of continuous sections which show radar reflections versus delay time on one axis and horizontal position on the other axis. The objective of the exercise is to remap the radar reflections into their true spatial positions under the ground. This involves two aspects of analysing the data. One is just utilizing this record as a delay time picture. In this case, each event has a known delay time associated with it and a certain spatial position. The delay time is converted to a distance by knowing the velocity of the material through which the wave has propagated. The result then is a section which gives horizontal position versus depth in the ground. In practice, the depth in the ground is only an approximate value since the velocity of propagation in the ground is usually unknown. Experience with radar data to date however, suggests that fairly accurate predictions of propagation velocity can be made with very little effort.

With a little care a fairly representative section of the ground can be regenerated from the radar delay time section. A great deal of additional information is also present in the radar record, but requires considerable effort to extract. This information comes in the amplitude of various reflected events as well as the wave shape or spectral content of the reflected events. With high fidelity recording systems it is sometimes possible to estimate the polarity of the reflection signal and to be able to discern variations in the character of the reflection signals which indicate variations in the actual geologic target. In practice, analysis of these second order features of the record are hampered by idiosyncrasies of the actual radar hardware. The radar systems have considerable non-linearity in their amplitude components. In addition, considerable distortion of the waveform occurs in various aspects of the sampling head portion of the receiver. As a result, it is usually very difficult to get any kind of quantitative estimates out of the amplitude and wave shape of the return signals. The experienced interpreter, however, can readily identify features in the records which have unique character and utilize these unique characteristics in order to infer something about the conductivity of a geologic structure or the contrast in material properties at the boundary. A typical example of good ground probing radar data is shown in Figure A-7. This figure displays the radar section in a grey scale format, Figure A-8 gives the corresponding geological interpretation based on borehole control and other information at the site.

A-CUBED INC.

Title:
GROUND PENETRATING RADAR
-SCHEMATIC DIAGRAM

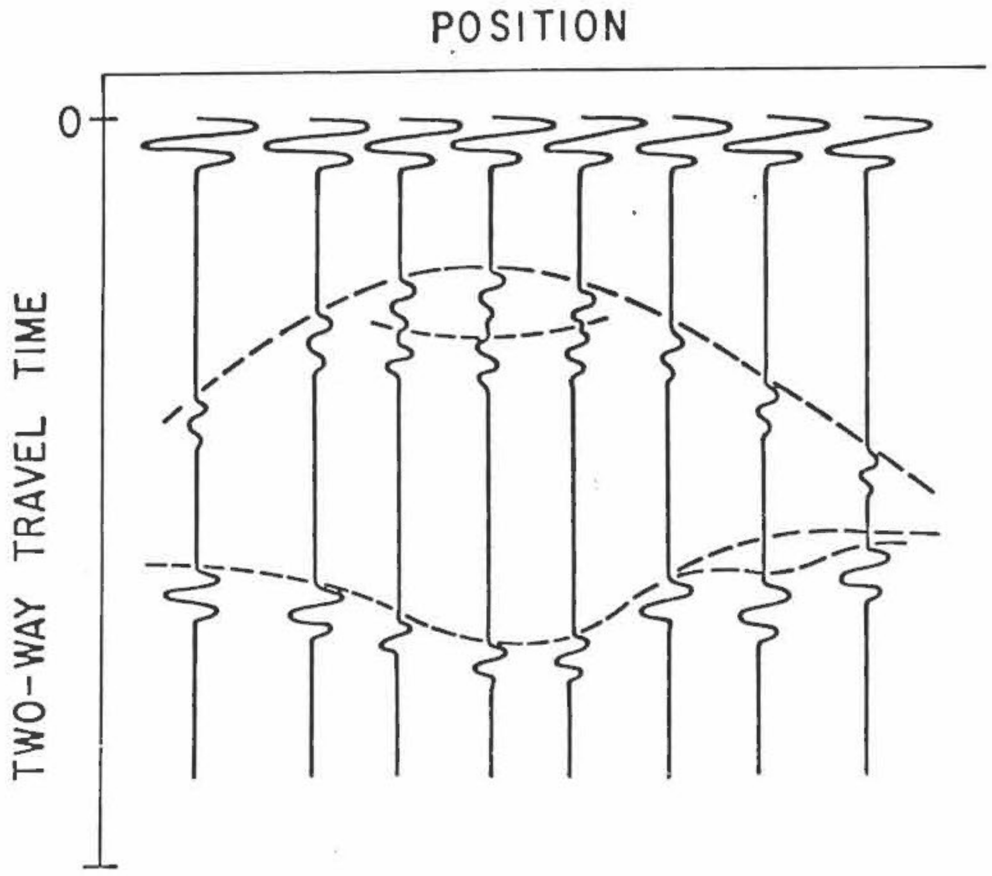
Scale:	Drawing No:	Job No:
	FIG. A-1	52-5001
Date: 12/01/83	Revision:	Approved:



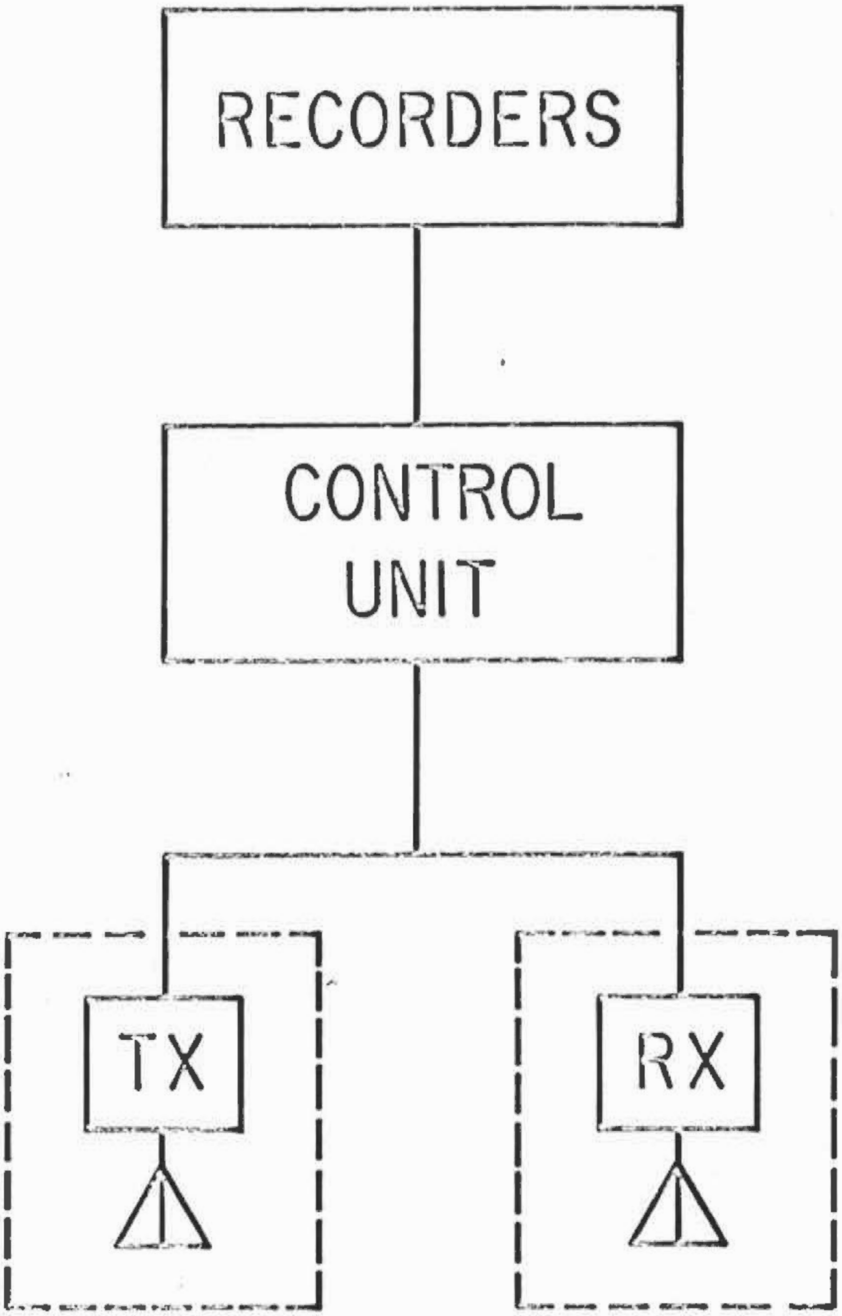
A³ A-CUBED INC.

Title:
RESPONSE OF RADAR SYSTEM TO
GEOLOGY OF FIG. A-1

Scale:	Drawing No:	Job No:
	FIG. A-2	52-5001
Date: 12/01/83	Revision:	Approved:



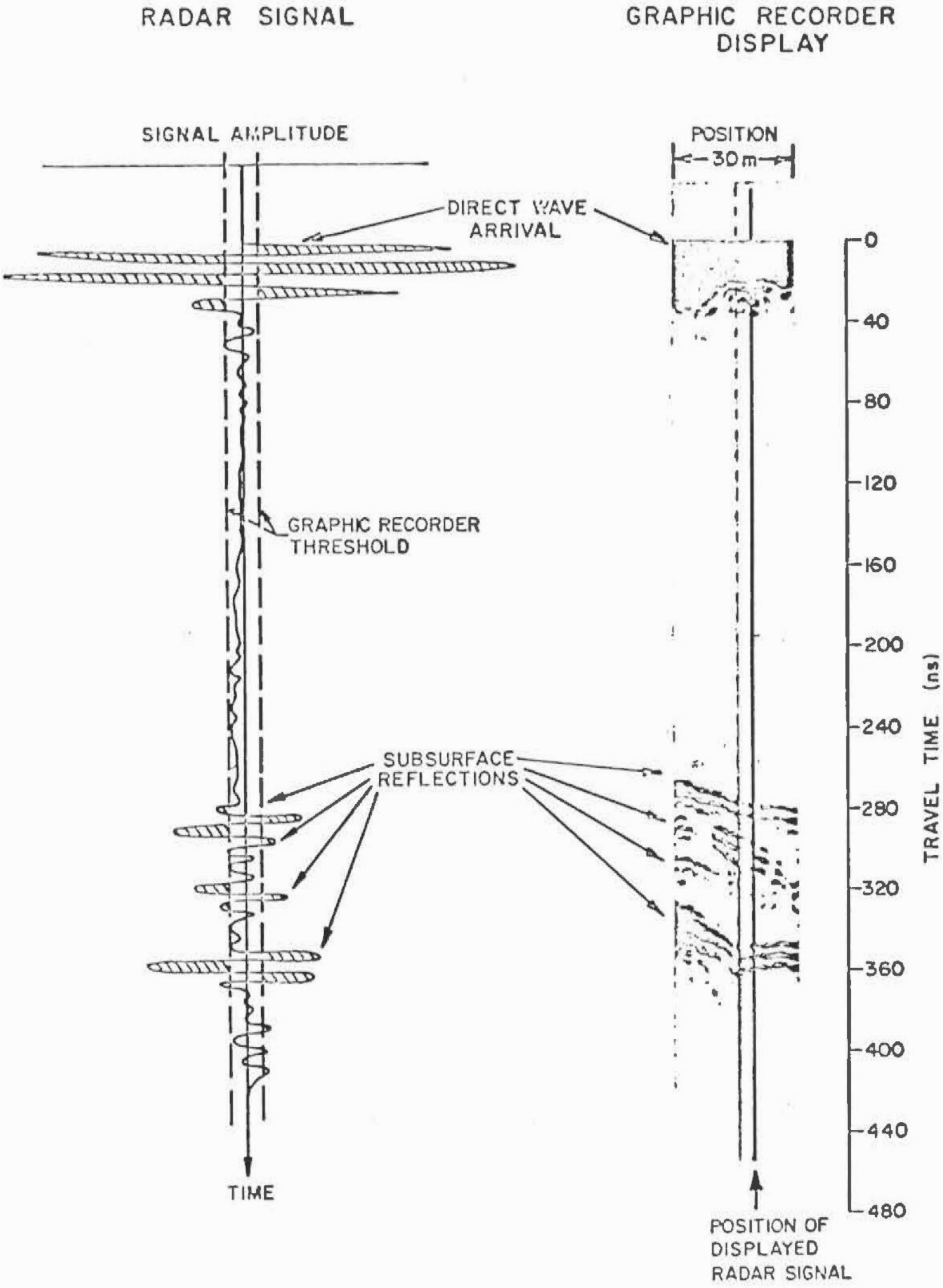
A³ A-CUBED INC.	Title: RADAR SYSTEM HARDWARE BLOCK DIAGRAM		
	Scale:	Drawing No: FIG. A-3	Job No: 52-5001
	Date: 12/01/83	Revision:	Approved:



RADAR SYSTEM
BLOCK DIAGRAM

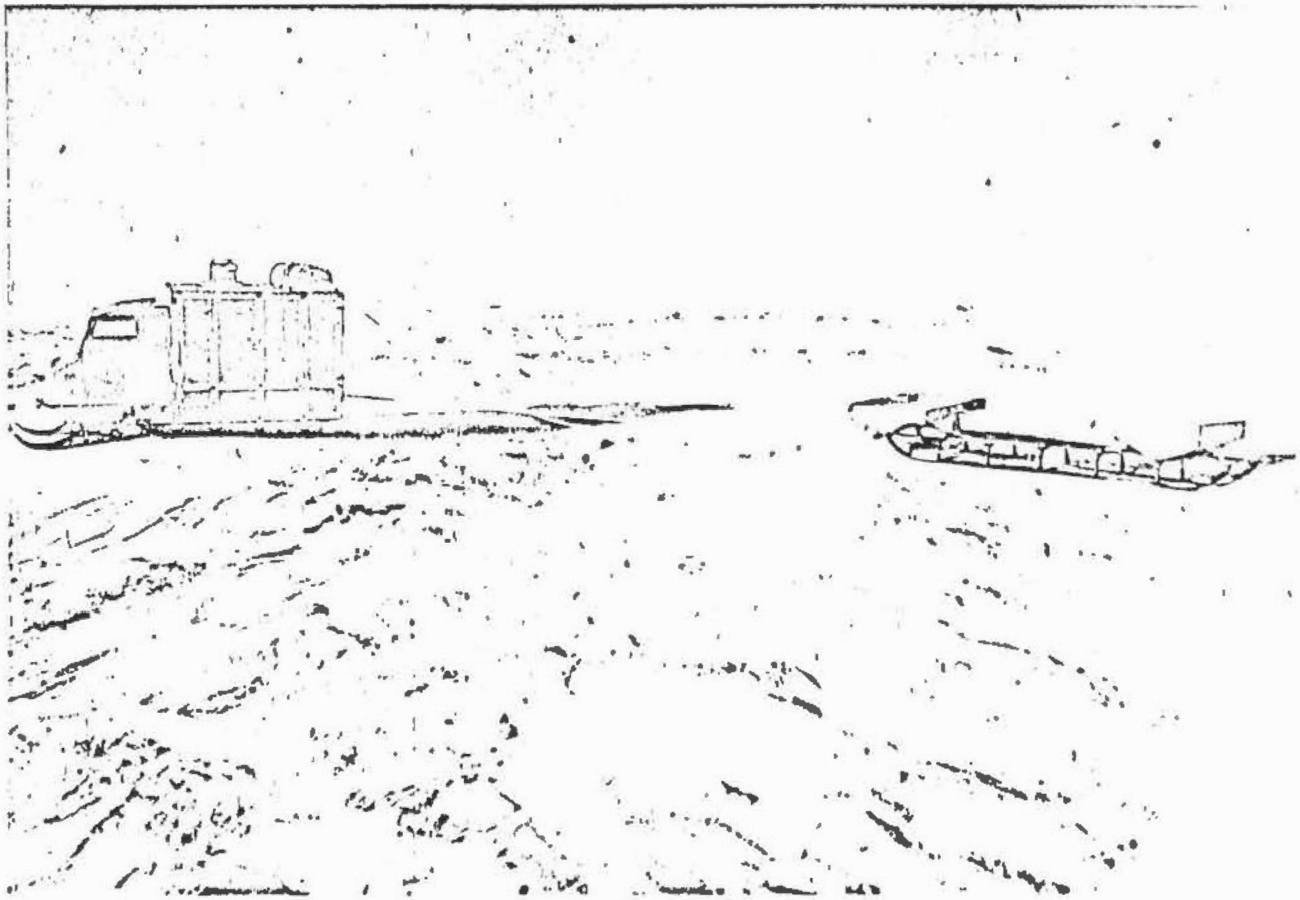
A-CUBED INC.

Title: WIGGLE TRACE AND GRAPHIC RECORDER EQUIVALENT		
Scale:	Drawing No: FIG. A-4	Job No: 52-5001
Date: 12/01/83	Revision:	Approved:



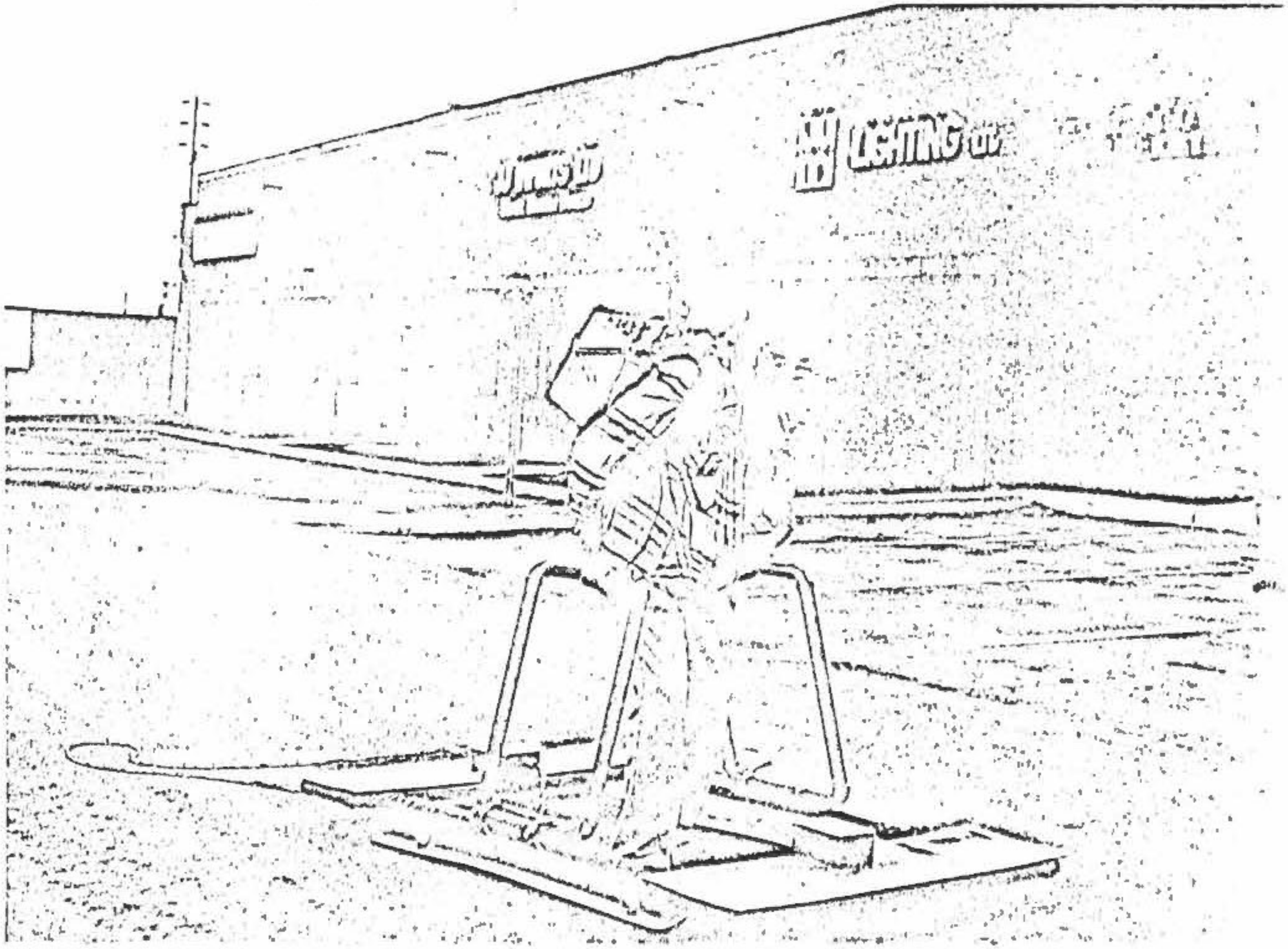
A-CUBED INC.

Title: TYPICAL TOWED ANTENNA CONFIGURATION		
Scale:	Drawing No: FIG. A-5	Job No: 52-5001
Date: 12/01/83	Revision:	Approved:



A-CUBED INC.

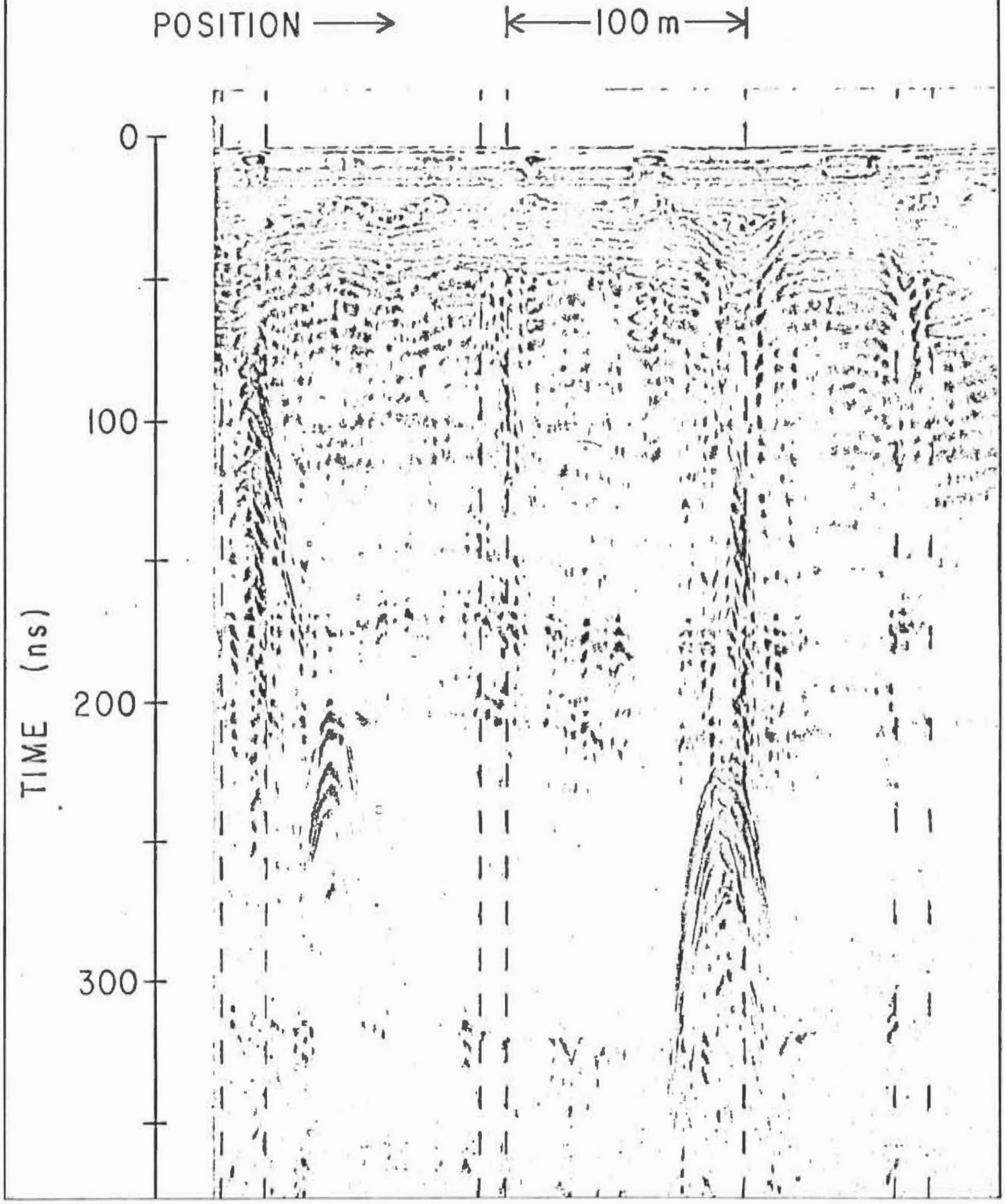
Title: TYPICAL PORTABLE ANTENNA CONFIGURATION		
Scale:	Drawing No: FIG. A-6	Job No: 52-5001
Date: 12/01/83	Revision:	Approved:



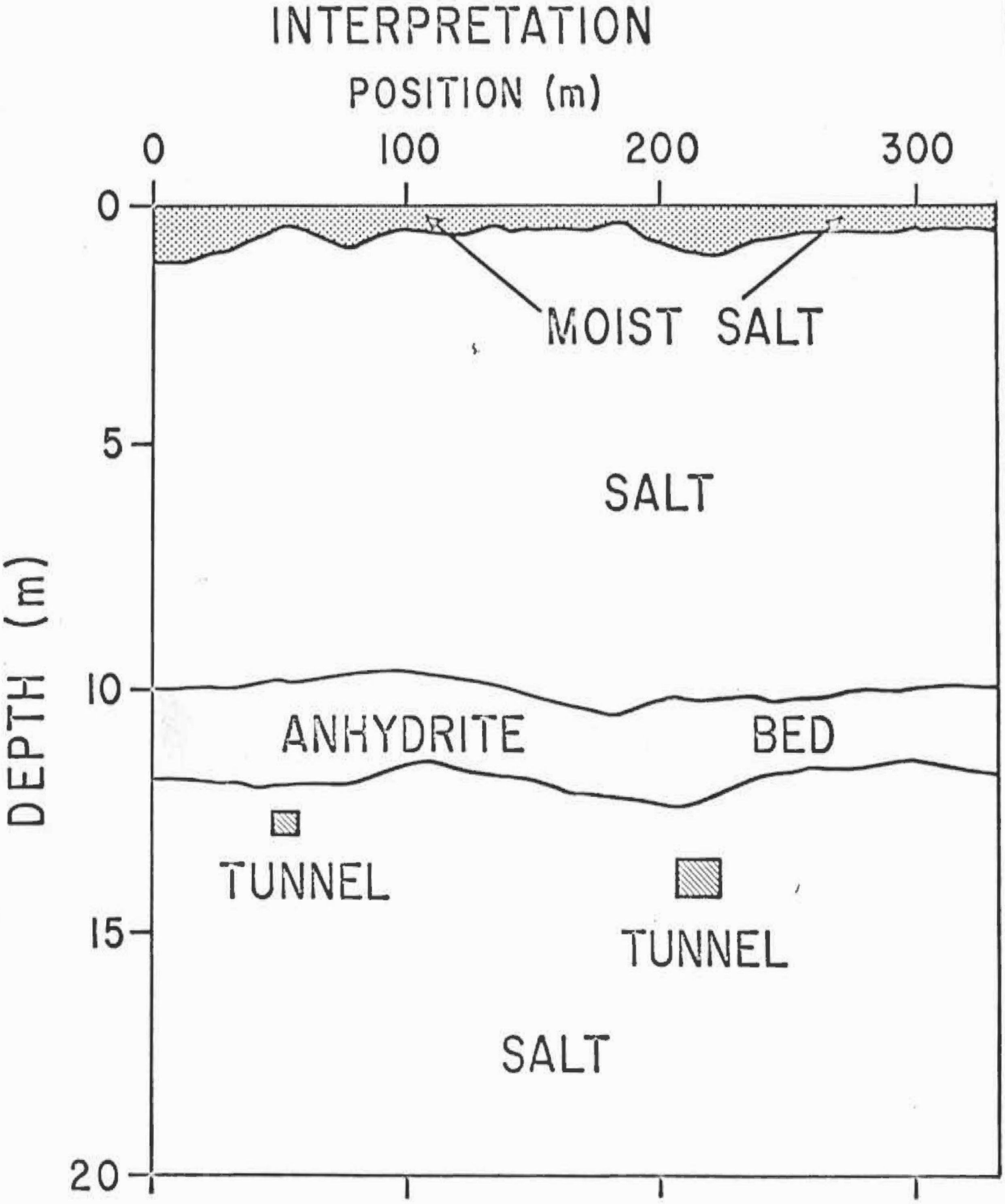
A³ A-CUBED INC.

Title: EXAMPLE OF A RADAR SECTION GRAPHIC RECORDER DISPLAY
Scale:
Drawing No: FIG. A-7
Job No: 52-5001
Date: 12/01/83
Revision:
Approved:

RADAR PROFILE OF A TUNNEL FLOOR



A³ A-CUBED INC.	Title: GEOLOGICAL SECTION FOR FIGURE A-7		
	Scale:	Drawing No: FIG. A-8	Job No: 52-5001
	Date: 12/01/83	Revision:	Approved:



APPENDIX B

CDP AND WARR PRINCIPLES & INTERPRETATION

CDP AND WARR PRINCIPLES & INTERPRETATION

B.1 CONCEPTS

In order to interpret ground probing radar data and infer depths to subsurface features, it is essential that the velocity structure in the ground be determined. Common depth point (CDP) and wide angle reflection and refraction (WARR) soundings are means by which the velocity versus depth structure in the ground can be determined. The two methods are very closely related and in flat lying stratigraphy the same results are obtained from both. In areas of dipping stratigraphy or undulating stratigraphy, the CDP methods have some advantage over WARR soundings.

The electromagnetic wave propagation velocity in a material is determined primarily by the dielectric constant when the material has a relatively low electrical loss. In media where displacement currents exceed electrical conduction or loss currents by an order of magnitude, then the propagation velocity is totally determined by the dielectric constant of the material. Table B-1 summarizes the wave propagation characteristics for radar signals. The phase velocity and the attenuation in the medium are related to the electrical properties of the medium. Table B-2 gives some typical values for the dielectric constant and electrical conductivity of materials which have been observed from experience with the radar system.

In soils, the propagation velocity is primarily a function of the water content of the soil. The higher the water content the higher the dielectric constant. The relationship between water content and dielectric constant is

$$K = 2.26 + 0.176\theta + 0.0106\theta^2$$

where K is the dielectric constant and θ is the volumetric water content of the soil.

This empirical relationship is derived from analyses of the propagation velocity in a wide range of soils at varying water contents and water salinities. The work was carried out jointly by the Geological Survey of Canada, Energy Mines and Resources, Canada, and the Soil Sciences Research Institute of Agriculture Canada.

The preceding discussion has given some basic information about the propagation characteristics of radar signals in the ground. CDP and WARR sounding methods provide a means of measuring these properties in the field. The propagation velocity is measured by varying the travel path to a given target in a known manner. The variation of travel time as a function of the propagation path is directly a function of the propagation velocity in the material. In CDP and WARR soundings, the propagation path to a target is varied by changing the antenna geometry. The velocity determination is identical to that utilized in the seismic industry where refraction methods are used to measure velocity versus depth and where normal move-out velocities associated with various reflectors at depth are utilized to estimate velocity versus depth.

TABLE B-1

SUMMARY OF RADAR WAVE PROPAGATION PARAMETERS IN LOW LOSS MATERIALS

Phase Velocity

$$v = \frac{c}{\sqrt{K}} \quad >>> \quad \frac{0.3}{\sqrt{K}} \qquad \text{m/ns}$$

Attenuation Coefficient

$$\alpha = \tfrac{1}{2} \frac{\sigma}{\sqrt{K}} Z_0 \quad >>> \quad 1.64 \frac{\sigma}{\sqrt{K}} \qquad \text{dB/m*}$$

Parameter Definitions

c = 3×10^8 m/s - speed of light

Z_0 = 377 ohms - free space impedance

K - material dielectric constant

σ - electrical conductivity

*units of conductivity are in milliSiemens/m.

TABLE B-2

DIELECTRIC CONSTANT AND ELECTRICAL CONDUCTIVITY OBSERVED IN COMMON GEOLOGIC MATERIALS

MATERIAL	K	σ (mS/m)
Air	1	0
Distilled Water	80	0.01
Fresh Water	80	0.5
Sea Water	80	3000
Dry Sand	3-5	0.01
Fresh Water Saturated Sand	20-30	0.1-1.0
Limestone	4-8	.5-2
Shales	5-15	1-100
Silts	5-30	1-100
Clays	5-40	2-1000
Granite	4-6	.01-1
Dry Salt	5-6	.01-1

B.2 FIELD PROCEDURES

Both CDP and WARR soundings methods assume that there are a number of reflecting targets in the ground which are relatively flat-lying. Two antennas are used to measure the travel time for a signal to propagate from the transmitter down to the reflecting horizon and back to the receiving antenna. The assumption of relatively flat-lying stratigraphy permits the assumption that the path travelled to the reflecting horizon by the radar wave and then the path back to the receiving antenna is well defined and varies in a uniform manner as the antenna separation is varied.

In the CDP soundings the two antennas are simultaneously moved equal distances away from a common centre point. The reason for the name, common depth point, is that for all intents and purposes the energy propagated into the ground and returned by a reflector is always reflected from the same point on the reflector surface. This has some impact when soundings are being made on a rough or significantly dipping horizon. Field operations involve careful handling of the cabling between the transmitting and receiving antennas. In addition, a controlled measurement of the antenna separation is required. Normal procedure for a CDP sounding is to place the transmitting and receiving antenna side by side on the ground surface centred over the common depth point of the sounding. The antennas are then pulled apart in a continuous manner with markers being placed on the radar record at equally spaced locations to show separation from the centre point.

In practice, it has been found that an alternate way of doing CDP soundings is to move smoothly between each fixed antenna separation and then stop the antennas at that fixed point for a short period of time before continuing on with increasing the separation. The resulting record looks like a staircase of events rather than a continuous smooth curve. The reason for using the staircase approach is that it allows one to digitize the data for later analysis on a computer. If the antennas are moved continually then it is more difficult to digitize the radar records at precisely known spatial intervals. The spacing interval of stops or position markers is typically .5 to 2m. The scale of the problem dictates the spatial parameters of the sounding. In practice, the antenna separation should be increased to the point where the angle of incidence of the waves on the deepest reflector is in excess of 60°. At least 10 controlled spacing markers should be recorded.

WARR soundings are carried out in almost exactly the same manner. The only difference in such soundings is that one of the antennas is put in a fixed location and the other antenna is moved away from it in exactly the same manner as in a CDP sounding. The advantage of a WARR sounding is that it is logistically much easier to carry out. Only one antenna is moved, only one wire has to be controlled in carrying out the survey and only one spatial measurement has to be made.

The disadvantages of the WARR sounding are that the reflection point on the subsurface reflectors moves as the receiving antenna moves. As a result, the travel path can vary as the reflection point moves around on the undulating surface of the reflector. In order to compensate to some degree for this problem it is important that WARR soundings be reversed. Normally if the antennas are moved apart to a maximum distance, X, then the fixed antenna should be moved to a position of X/2 metres from its original point and the sounding done in the reverse direction. In this way, two-fold coverage over the target is obtained and some of the ambiguity caused by topography on the subsurface reflector can be eliminated from the sounding data.

Figure B-1 shows the general features of a CDP or WARR sounding. Signals propagate between the transmitter and receiver over a number of different paths. Depending on which event or ray is followed, different parts of the ground are sounded. If several layers are present in the ground and are apparent on the WARR record then it is possible to determine interval velocities for each such zone in the ground. The problem is much like that of peeling an onion. First the velocity of the near surface material is determined, next the velocity of each subsequent layer is inferred utilizing the previously inferred velocity.

In carrying out the actual sounding in the field there are a number of factors which should be observed. First, any spurious surficial features, such as the survey vehicle, which can generate radar responses should be removed from the area of the sounding, if possible. If this is not possible then the sounding should be relocated as far as possible from any of the cultural features and other things which can possibly contribute energy to the return signal. While in practice it is possible to distinguish reflections from surface features by the fact that the velocity appears to be that of air rather than some lower velocity, sometimes the clutter on the record is so large that one cannot resolve the subsurface features.

One of the most critical aspects of carrying out CDP and WARR soundings is the management of the cables which interconnect the transmitter and receiver. This is one of the largest sources of noise and can totally contaminate a sounding record. All possible efforts should be made to keep the wiring connections running perpendicular to the axis of the dipole antennas used for the sounding. This minimizes the coupling between the antennas and the wires, and hence the scattered radiation from the interconnecting cabling. Normally this requires a considerable amount of manpower in order that tangles and disruptions during antenna separation do not occur.

B.3 SIMPLE INTERPRETATION PROCEDURE

The bulk of the required information for interpreting a CDP or WARR sounding is given in Figure B-2. There are two types of waves which can arrive at the receiving antenna. Namely, direct waves and reflected waves. Direct waves are waves which travel directly between the transmitter and the receiving antenna. There are two paths for these waves; one which travels straight through the air and the other one which travels straight through the ground. The airwave travels at the speed of light in air, whereas the groundwave travels with the propagation velocity of the shallow near-surface material of the ground. On a WARR or CDP record both of these events appears as straight line arrivals. A CDP or WARR record is a chart which has horizontal distance on one axis and travel time on the other axis. The slope of this line is directly related to the propagation velocity for the direct waves. In fact, the slope is inversely proportional to the propagation velocity. On records where both events are clearly discernible it is normal procedure to measure the velocity of the groundwave by reference to the measured velocity on the airwave. This usually eliminates any positioning ambiguities. Since the speed of light is well known, it therefore provides a way of measuring the antenna separation in instances where there is some erratic behaviour or uncertainty in the actual antenna separation data. Field interpretation is normally carried out by measuring the slopes of the direct airwave and the direct groundwave. The slope then gives the square root of the dielectric constant of the material. When detailed work is done in the office it is often more desirable to fit the arrival data with a least squares fit to come up with some estimate of not only the slope but the uncertainty in the slope.

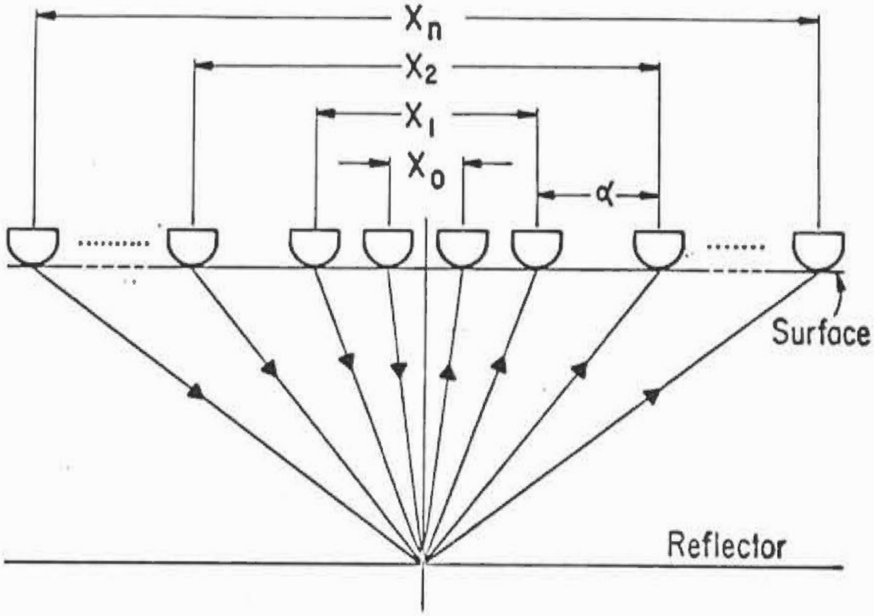
For reflection events, the distance-travel time relationship is hyperbolic. The normal procedure for interpreting reflection events is to plot the arrival time versus antenna separation on what is known as a T^2-X^2 plot. Plotting travel time squared versus separation squared yields a straight line relationship with a slope which is inversely proportional to the square of the propagation velocity in the material. The intercept for the reflector provides a depth estimate for the reflector.

The depth estimate to a reflector and the propagation velocity to that reflector combine to give a travel time which may be subtracted from the travel time to deeper reflectors to yield their velocities and depths in turn as well. This "Stripping" process will eventually yield a subsurface velocity/thickness model for layered stratigraphy.

A³ A-CUBED INC.

Title:
ANTENNA CONFIGURATION FOR
CDP OR WIDE ANGLE SOUNDINGS

Scale:	Drawing No:	Job No:
	FIG. B-1	52-5001
Date: 12/01/83	Revision:	Approved:



X_0 — minimum antenna separation determined by antenna size.

$X_n = 2\alpha n$

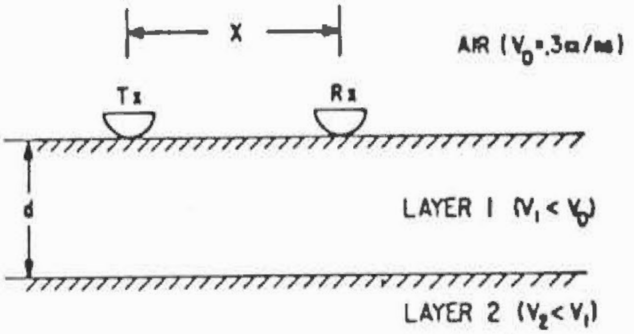
α = distance an antenna is moved between soundings.

A³ A-CUBED INC.

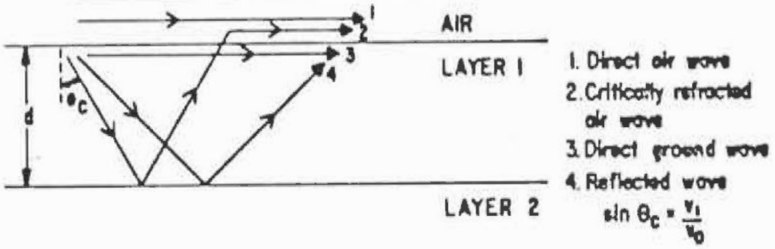
Title:
RAY PATHS AND TRAVEL-TIMES
FOR RADAR SOUNDINGS

Scale:	Drawing No: FIG. B-2	Job No: 52-5001
Date: 12/01/83	Revision:	Approved:

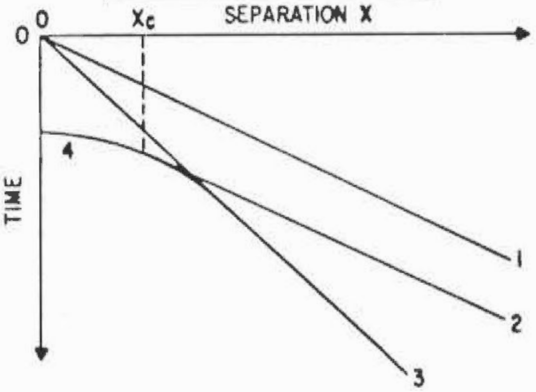
LAYERED EARTH MODEL



FIRST ORDER RAY PATHS (NO MULTIPLES)



IDEALIZED RADAR RECORD



A-CUBED INC.

Title:
EXAMPLE OF A WARR SOUNDING

Scale:	Drawing No:	Job No:
	FIG. B-3	52-5001
Date:	**Revision:**	**Approved:**
30/12/82