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Ground-penetrating radar profiling in the Pasvik and Pechenga areas

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REPORT

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Summary:

As a part of a cooperation program between the Geological Survey of Norway (NGU) and the Russian Academy of Science, ground-penetrating radar (GPR) measurements have been performed in Pasvik and along the Rayakoski and Shuoni-Kuets profiles in Russia. The aims of the investigations have been; 1) locating conductive structures in bedrock, 2) finding dip of conductive structures, 3) indicating zones of resistivity anisotropy, 4) mapping of overburden thicknesses and composition and 5) delineation of structures in overburden and bedrock.

A steeply dipping conductive zone at a test site along Shuoni-Kuets (profile 4200) showed resistivity anisotropy. A vague indication of resistivity anisotropy could also be seen in parts of the Pasvik profile.

The bedrock reflector was difficult to recognize in areas with dry overburden, due to little or no contrast in relative dielectricity between dry overburden and bedrock.

The reflection configuration in the overburden was mostly hummocky or chaotic, indicating till. More fine-grained deposits (probably laminated fine sand/silt) were indicated at some places by a parallel reflection configuration. Dipping or flat-lying reflectors in bedrock probably represent cracks or fractures.

Keywords:	Malmgeologi	
Geofysikk	Løsmasse	
Georadar		Fagrapport

CONTENTS

1 INTRODUCTION

Profiling with ground-penetrating radar (GPR) has been carried out in three areas, one on the Norwegian side of the Russian-Norwegian border (Pasvik) and two on the Russian side (Rayakoski and Shuoni-Kuets). The work has been done as a part of the cooperation program between the Geological Institute, Kola Scientific Center of the Russian Academy of Science and the Geological Survey of Norway (NGU). The main purposes of the investigations have been;

- locating conductive structures in bedrock
- finding dip of conductive structures
- indicating zones of resistivity anisotropy
- mapping of overburden thicknesses and composition
- delineation of structures in overburden and bedrock

Earlier investigations in parts of the same areas comprise refraction seismics and slingram (Mauring & Rønning 1991), profiling with the 'Method of the Internal Sliding Contact' (MISC) and slingram (Rønning et al. 1993), deep geoelectrical studies (Zhamaletdinov et al. 1993).

The GPR measurements were carried out in the period 12th june to 20th june 1992 by Jomar Gellein and Jan S. Rønning from NGU. Participants from the USSR Academy of Science Dr. A.A. Zhamaletdinov, A. Tokarev and K. Dudkin carried out electromagnetic and magnetic profiling along the two profiles in Russia in the same period. Interpretation of GPR records was carried out by Eirik Mauring and Jan S. Rønning.

2 INSTRUMENTATION AND ACQUISITION PARAMETERS

Total length of the GPR profiles was about 4.4 km. In addition, 7 common mid-point (CMP) records were obtained for velocity analysis. One of these was unsuccessful. The location of the profiles is shown in map -01 and -02. Measurements were carried out using 'pulseEKKO IV' radar system (Sensors & Software Inc, Canada) with 50 MHz antennas and 400 V transmitter. Signals were stacked 128 times at each station. The antenna separation was 1 metre, and the recording time was 1024 ns. Other acquisition parameters are listed below (table 1).

Table 1. Acquisition parameters.

Location	Profile	Record id.	Sampl. int. (ns)	Position (m)	Step size (m)
Pasvik	PAS2	PAS2-A	0.8	2600-2649	0.5
Pasvik	PAS2	PAS2-B	1.6	2650-2700	0.5
Pasvik	PAS2	PAS2-C	1.6	2708-3000	0.5
Pasvik	PAS2	PAS2-CX	1.6	2800-3010	0.5
Rayakoski	82800	RA82800	1.6	82800-83009	1
Rayakoski	82800	RA83000	1.6	83000-83150	1
Rayakoski	82800	RA83150	1.6	83150-84001	1.8
Rayakoski	85400	RA85400	1.6	85400-86054	1
Rayakoski	85400	RA86055	1.6	86055-86094	1
Shuoni-Kuets	4200	SK4200	1.6	4200-4550	0.5
Shuoni-Kuets	4200	SK4200X	1.6	4200-4550	1
Shuoni-Kuets	4200	SK-TEST	1.6	0-89.5	0.5
Shuoni-Kuets	4200	SK-TESTX	1.6	0-46	0.5
Shuoni-Kuets	9400	SK9400	1.6	8700-9400	1
Shuoni-Kuets	13000	SK13000	1.6	13000-14000	1

3 INTERPRETATION OF GPR RECORDS

The interpretation of reflection events on the GPR records is difficult in the surveyed areas. Several records display chaotic reflection configurations that can be attributed to a wide variety of geological settings. Lack of additional information (e.g. regional quaternary and bedrock maps) makes the interpretation highly subjective. Until additional information becomes available, the interpretation must be considered preliminary.

3.1 Velocity analysis

Velocity analysis was carried out by CMP-measurements at one location in Pasvik, two locations in Rayakoski and three locations in Shuoni-Kuets. The results are presented in table 2.

Table 2. **CMP velocity analysis. Zero offset reflection times are in nanoseconds. Velocities are in metres/nanoseconds.**

CMP id.	Time	Velocity	Time	Velocity	Time	Velocity
CMPPAS1	200	0.1				
RACMP1F	50	0.14(?)	150	0.09(?)	470	0.08(?)
RACMP2F	70	0.09(?)				
SKCMP1F	220	0.07				
SKCMP2	200	0.11				
SKCMP4F	100	0.11	180	0.10-0.11		

In general, the quality of the CMP records was poor, and the velocities depend on the position of the water table. As a result, an average velocity of 0.10 m/ns is used for converting two-way traveltime in the time sections to depths.

3.2 **Pasvik**

GPR measurements were carried out on a road along profile PAS2 between position 2600 and 3010 (map -01). The profile is separated into four records, which are shown in map -03. PAS2-A, PAS2-B and PAS2-C were recorded with the antennas perpendicular to the bedrock strike direction, whereas PAS2-CX was recorded with the antennas parallel with the bedrock strike direction. Thin overburden is indicated by exposures near the profile. Along parts of the profile, the road has been built up about 2 metres above a lake, indicating the expected position of the water table on the records.

Earlier investigations with MISC and slingram (Rønning et al. 1993) have revealed a highly conductive zone in bedrock between position 2800 and 3000. The conductive zone is thought to represent graphite- and sulphide-bearing schists.

Record PAS2-A, PAS2-B and PAS2-C

The top of bedrock is probably represented by a sharp, horizontal reflector at 80-90 ns on PAS2-A. A prominent reflector can be seen from position 2650, dipping in the profile direction. An equally distinct reflector is dipping towards 2700. Both are interpreted as being bedrock reflectors. On PAS2-C, top of bedrock is probably seen as a weak reflector at 110 ns between position 2720 and 2785. A strong reflector between position 2795 (110 ns) and 2925 (80 ns) is also believed to be the bedrock reflector. Reflectors underneath the bedrock reflector display a mostly chaotic reflection configuration, sometimes with crossing reflectors that probably represents fractures in bedrock. Intra-bedrock reflectors between 2735 and 2925 are weak, short and dipping. From position 2800 the reflectors are mostly horizontal. The transition from dipping to horizontal reflectors may be due to a slight rotation of the profile direction. From position 2925, the sediment cover is probably thin, as the reflectivity becomes stronger and the reflectors more distinct. Strong, dipping reflectors at 2930 and 2950 are probably representing cracks/fractures in bedrock. Depositional type can not be delineated on the basis of GPR records. The penetration is fair to good in the area of conductive bedrock (2800-3000).

Record PAS2-CX

The measurements were carried out along parts of 'PAS2-C', but with the antennas orientated perpendicular to the profile direction. The main purpose with these measurements was to see if there was any resistivity anisotropy in bedrock in this area. Then, the depth of penetration should be different between position 2800 and 3000 on 'PAS2-C' and 'PAS2-CX'. There seems to be a slight difference between position 2880 and 2890, probably indicating resistivity anisotropy within bedrock.

3.3 Rayakoski

GPR measurements were carried out along the Rayakoski profile in the areas 82800-84000 and 85400-86094. The profile segments are named '82800' and '85400' respectively. These two segments are separated into five records. Earlier investigations (Rønning et al. 1993) show a strong magnetic anomaly (>800 nT) from 82800 to 82900, which is probably due to diabase in this area.

Profile 82800

The records for this profile are shown in map -04 (record RA82800, RA83000, RA83150). The profile is expected to cross the Northern boundary of the Pechenga greenstone belt, where the Ni-productive graphitic schist was missing (Zhamaletdinov et al. 1993).

Between position 82820 and 82855 the reflectivity is weak. The depth of penetration is fair, because a reflector can be seen at about 300 ns between 82847 and 82855. This reflector is dipping along the profile direction between 82855 and 82870 (down to 400 ns). Between 82855 and 82960 the record is dominated by horizontal and parallel reflectors down to 200 ns. Between 82960 and 83030 it is characterized by good penetration (down to 700 ns) and strong reflectivity. Several parallel reflectors are dipping from 83030. The reflection configuration is chaotic in this area. A reflector at 500 ns possibly represents bedrock. From position 83030 to position 83330, we see horizontal, parallel reflectors down to 200 ns, resembling the reflection configuration between position 82855 and 82960. Poor penetration could be due to a possible presence of fine-grained material in the overburden, or it could merely indicate shallow depth to bedrock. Horizontal reflectors can also be seen between position 83510 and 83690. It is believed that parts of the record showing horizontal reflectors are representing areas with overburden. Between position 83330 and 83510 and between 83690 and the end of the profile, the record is dominated by a chaotic reflection configuration with strong reflectivity. In these areas, the sediment cover is probably thin. Linear, dipping events in the record, e.g. between 83195 (150 ns) and 83240 (400 ns) and between 83510 (250 ns) and 83555 (550 ns), have a velocity corresponding to the propagation velocity of EM-waves in free air. These events are therefore reflections from objects on the surface.

Profile 85400

This profile is covered by the records RA85400 and RA86055 and these are shown in map - 05. The records are characterized by a chaotic reflection configuration. Horizontal reflectors can be seen between position 85400 and 85550. In the rest of the record, several dipping reflectors can be seen. Penetration is in the area between 300 and 400 ns. At several locations along the profile (e.g. 85550, 85730 and 85790), bedrock exposures could be observed during profiling. There are good reasons to believe that bedrock is shallow along most of the records. Dipping or flat-lying reflectors can represent fractures or structures in bedrock. Graphite can be seen in outcrops at 85730 and 85790. The presence of this does not seem to have any influence on the depth of penetration. It is suggested that the graphite mineralization is too disseminated to cause energy absorption.

3.4 **Shuoni-Kuets**

Measurements have been carried out in three profile segments along the Shuoni-Kuets road (4200, 9400 and 13000).

Profile 4200

This profile traverses a geological feature known as the 'Ni-productive belt' (graphite- and sulphide-bearing rocks) (Rønning et al. 1993). It is recognized on the MISC profile as a low resistivity zone ($\rho<10$ Ωm) between position 4360 and 4470. It is also associated with a medium anomaly between 4360 and 4560 on the slingram profile (Mauring & Rønning 1991). This zone was studied in detail with GPR at a test site c. 120 m west of the Shuoni-Kuets road. GPR measurements were also carried out along the road from position 4200 to 4550. In both areas measurements were carried out with the antennas approximately perpendicular to and parallel with the bedrock strike direction.

Test site

Approximately 120 m west of the Shuoni-Kuets road, in the vicinity of 4200, a test site was selected primarily for the study of depth of penetration and resistivity anisotropy. A test profile which traverses exposed diabase/graphitic schists was measured with the antennas perpendicular to (record 'SK-TEST') and parallel with (record 'SK-TESTX') the bedrock strike direction. Fig. 1 shows outcrops of fractured diabase in the area. Fig. 2 is a close-up view of a graphitic schist exposure, showing thin banding with iron oxidation.

Fig. 1: Exposed bedrock at the beginning of profile SK-TEST.

Record SK-TEST

The record is shown in map -06. The recording was carried out with the antennas perpendicular to the bedrock strike direction and with a step size of 0.5 m. Penetration is very variable, but in parts very good (700-800 ns at position 35). From position 0 to 20, the record shows high reflectivity, probably due to fractured bedrock (see fig. 1). Between position 21 and 30 the penetration is poor (loss of energy), with the exception of a few traces where reflections can be seen down to 400-500 ns. Between position 20 and 30 the graphitic schist is exposed (see fig. 2). The presence of graphite is probably causing the poor penetration. The zone of poor penetration is almost vertical, suggesting steeply dipping bedrock. A chaotic reflection configuration representing structures in bedrock, can be seen from position 30. Good penetration is evident from a dipping reflector between position 35 and 45 at 600-800 ns. The dipping reflector from position 40 (150 ns) to position 60 (450 ns) is interpreted as the bedrock surface. The moderate penetration between position 60 and 90 (300-400 ns) indicates either a thin sediment cover or energy loss due to fertilized ground.


Fig. 2: Exposure showing banding with iron oxidation.

Record SK-TESTX

The record is shown in map -06. The profile is measured along 'SK-TEST' to position 46. The recording was carried out with the antennas approximately parallel with the bedrock strike direction. Areas 0-21 and 30-46 exhibit the same features as 'SK-TEST'. Between position 21 and 30, the penetration is negligable, whereas 'SK-TEST' shows good penetration on several traces in the same area. This shows that the energy loss between position 21 and 30 is different when recording with the antennas perpendicular to and parallel with the bedrock strike direction. This indicates a resistivity anisotropy in this area, which is also indicated by resistivity measurements (Zhamaletdinov et al. 1993).

Record 4200

The GPR record (SK4200) is shown in map -06. Measurements were carried out with a step size of 0.5 m and antennas perpendicular to the bedrock strike direction. Along parts of this profile (between position 4260 and 4370) refraction seismics has been carried out earlier (Mauring & Rønning 1991). The results from these measurements showed a depth to bedrock between 11 and 15 metres. Seismic velocities indicated till as the main overburden constituent.

Even though the bedrock position is known, the bedrock reflector is difficult to recognize on the GPR record, probably because the overburden is dry. This normally gives little or no contrast in relative dielectricity between bedrock and overburden, the result being that very little energy is reflected from the bedrock/overburden interface. Possible bedrock can be followed as an undulating reflector from position 4200 (150 ns) to position 4305 (300 ns). Intermediate bedrock reflector positions; 4215 (150 ns), 4225 (200 ns), 4240 (200 ns), 4255 (260 ns), 4290 (150 ns). From position 4325, bedrock cannot be seen on the GPR record due to bad penetration. Underneath the bedrock reflector, dipping structures (25-30°) can be seen, probably representing fractures/schistosity in bedrock. Reflectors above bedrock display a hummocky or partly chaotic reflection configuration to position 4325. From position 4325, the reflection configuration is parallel, with reduced penetration. From position 4325 to position 4440, only a very weak reflector can be seen at 140-160 ns. It is suggested that sediments in this area are mostly fine-grained, probably representing marine sediments, as the area is below the upper marine limit (M. Thoresen, pers. comm.). Above the suggested marine sediments, a sequence of parallel reflectors can be seen between 4480 and 4550. These are dipping in the profile direction, and can represent laminated fine sand/silt. Above the sequence, reflectors exhibiting a more chaotic reflection configuration can be seen from position 4505, indicating coarser deposits (aeolian/fluvial).

Record 4200X

The profile is the same as 'SK4200', only with a step size of 1 m and the antennas parallel with the bedrock strike direction. The record (SK4200X) is shown in map -06. The record displays the same features as 'SK4200', only with a poorer delineation of reflectors due to higher step size. The penetration is the same. Recordings with antennas perpendicular to or parallel with the bedrock strike direction do not indicate areas with resistivity anisotropies.

Profile 9400

In this area, there is a low resistivity zone from earlier MISC-measurements ($\rho<1\ \Omega m$) in bedrock from position 8800 to position 9150 (Rønning et al. 1993). In addition, three medium to strong slingram anomalies are indicated at position 8880, 8960 and 9025 (Mauring & Rønning 1991).

The record (SK9400) is shown in map -07. Between position 9020 and 9320, refraction seismics have been carried out earlier (Mauring & Rønning 1991). Depth to bedrock is interpreted to be 12-14 metres between position 9020 and 9090, decreasing to 6 metres between position 9090 and 9110. From position 9110 to 9320, depth to bedrock is in the order of 3-6 metres. The bedrock reflector is not readily seen on the GPR record, probably because the overburden is dry. This gives very little contrast in relative dielectricity at the overburden/bedrock interface. Anyway, reflectors at the following positions are interpreted as being bedrock reflectors; 8730-8765 (100-200 ns), 8935-8980 (150-200 ns), 9080-9120 (300-100 ns). The high seismic velocities in the overburden (1820-2000 m/s) are probably representing highly consolidated till. The GPR record is characterized by a chaotic reflection configuration, where single reflectors can be followed across just a few traces. Between position 9120 and 9400 the reflectors are probably representing mostly structures in bedrock. In this area, the reflectivity is strong. Between position 9020 and 9090 the reflectors represent structures in the overburden sediments. The reflectivity is weaker in this area. In the area 8700-9020, strong reflectors can be seen to rise towards the terrain surface. Depth to bedrock is not known in this area. It is therefore difficult to tell whether the reflectors are representing structures in bedrock or overburden or the bedrock reflector itself. The low resistivity zone between 8800 and 9150 is not recognized on the GPR record, as one would expect reduced penetration here.

Profile 13000

Between position 13200 and 13300, earlier investigations (Rønning et al. 1993) reveal a magnetic anomalous (600-700 nT) and low resistivity zone ($\rho<1$ Ωm). Slingram measurements (Mauring & Rønning 1991) revealed weak anomalies at 13180 and 13310.

The record (SK13000) is shown in map -08. A wavy, weak and irregular reflector between position 13110 and 13450 at 50-200 ns probably represents the bedrock surface. The overburden thickness in this area is in the order of 2.5-10 metres. Elsewhere, the record is quite uniform in terms of reflectivity (strong) and reflection configuration (chaotic), resembling a pattern which is common for reflections from within bedrock. Outcrops could be seen at several locations along the profile. Dipping reflectors in the areas 13500-13660 and 13900-14000 probably represent cracks/fractures in bedrock. Anomalous zones indicated by other methods are not seen on the GPR records.

4 CONCLUSION

As a part of a cooperation program between the Geological Survey of Norway (NGU) and the Russian Academy of Science, ground-penetrating radar (GPR) measurements have been performed in Pasvik and along the Rayakoski and Shuoni-Kuets profiles in Russia. The main purposes of the investigations have been; 1) locating conductive structures in bedrock, 2) finding dip of conductive structures, 3) indicating zones of resistivity anisotropy, 4) mapping of overburden thicknesses and composition and 5) delineation of structures in overburden and bedrock.

Within the 'Ni-productive belt', a conductive structure could be seen at the test site along Shuoni-Kuets (profile 4200) as a zone of reduced penetration. It is suggested that the conductor is steeply dipping. In the same area, GPR measurements with antennas perpendicular to and parallel with the bedrock strike direction gave different penetration, indicating resistivity anisotropy. A vague indication of resistivity anisotropy can also be seen in parts of the Pasvik profile. In Rayakoski, the presence of graphite bearing rocks (in exposures) had no effect on the penetration.

Mapping of overburden thicknesses was difficult in areas with dry overburden. In these areas, even with depth to bedrock from refraction seismics available, the bedrock reflector could hardly be recognized on the GPR records. This is caused by little or no contrast in relative dielectricity between dry overburden and bedrock. Where bedrock appeared in water saturated zone, the bedrock reflector could sometimes be seen.

The reflection configuration in the overburden was mostly hummocky or chaotic, indicating till. More fine-grained deposits (probably laminated fine sand/silt) were indicated at some places by a parallel reflection configuration. Dipping or flat-lying reflectors in bedrock probably represents cracks or fractures.

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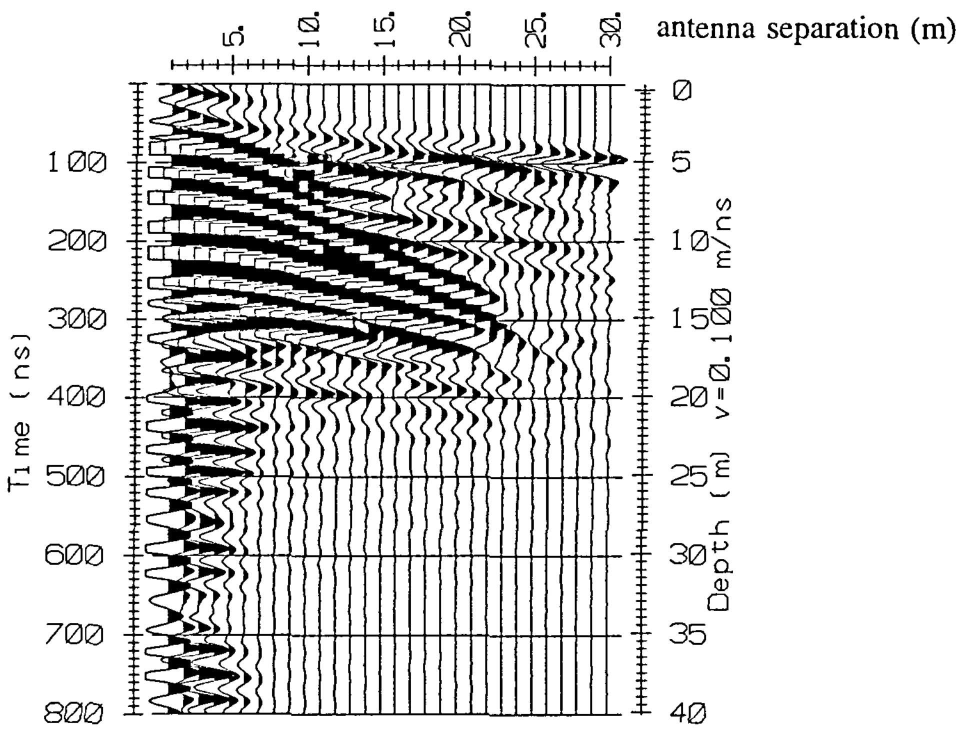
CMP-record CMPPAS1



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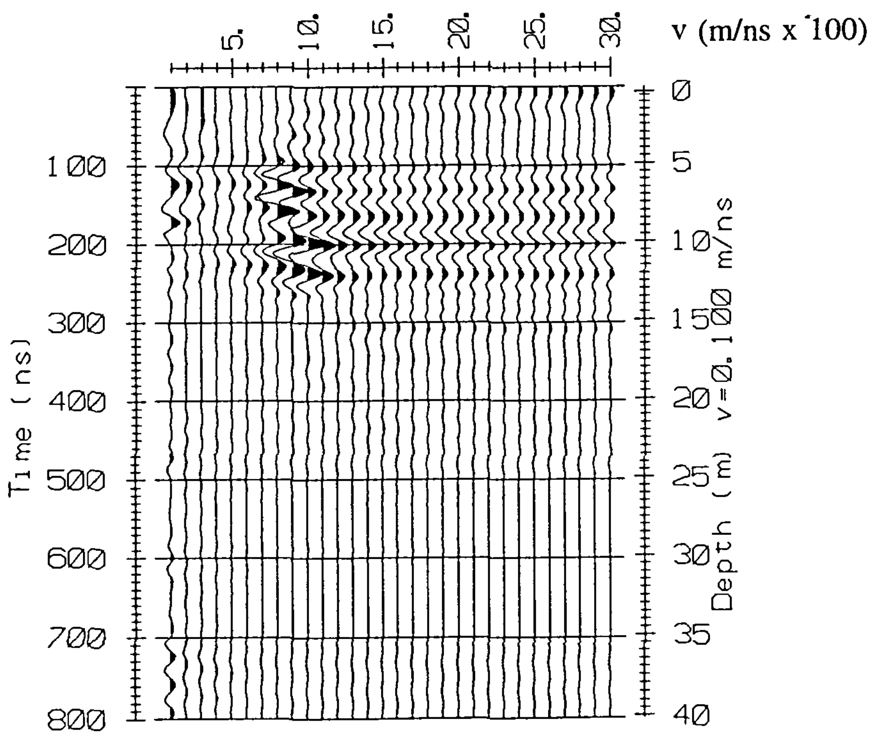

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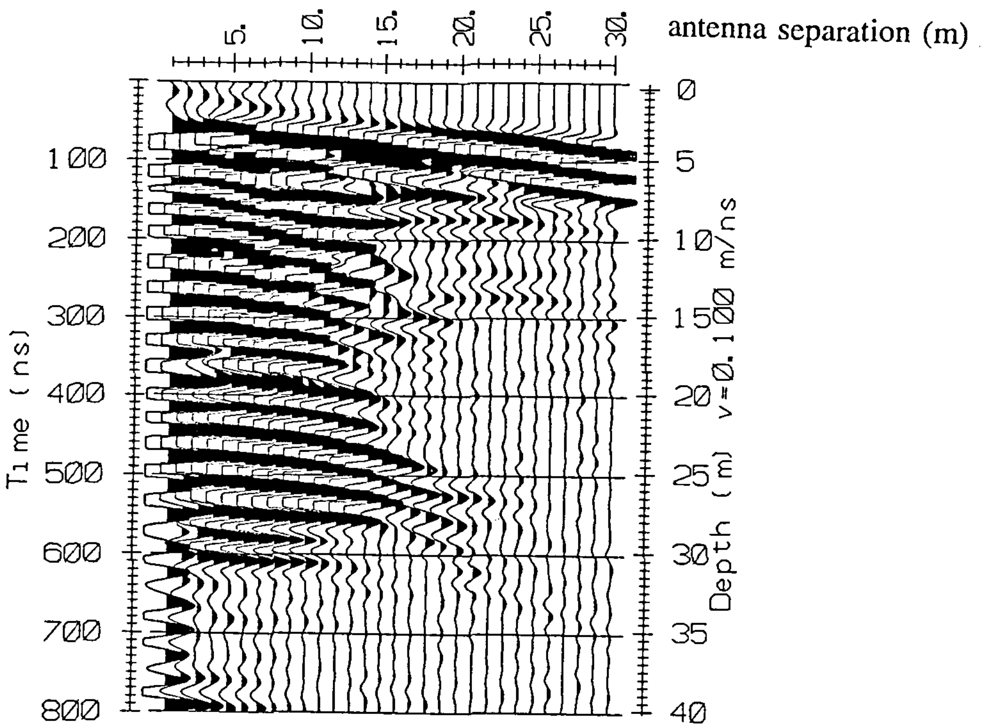

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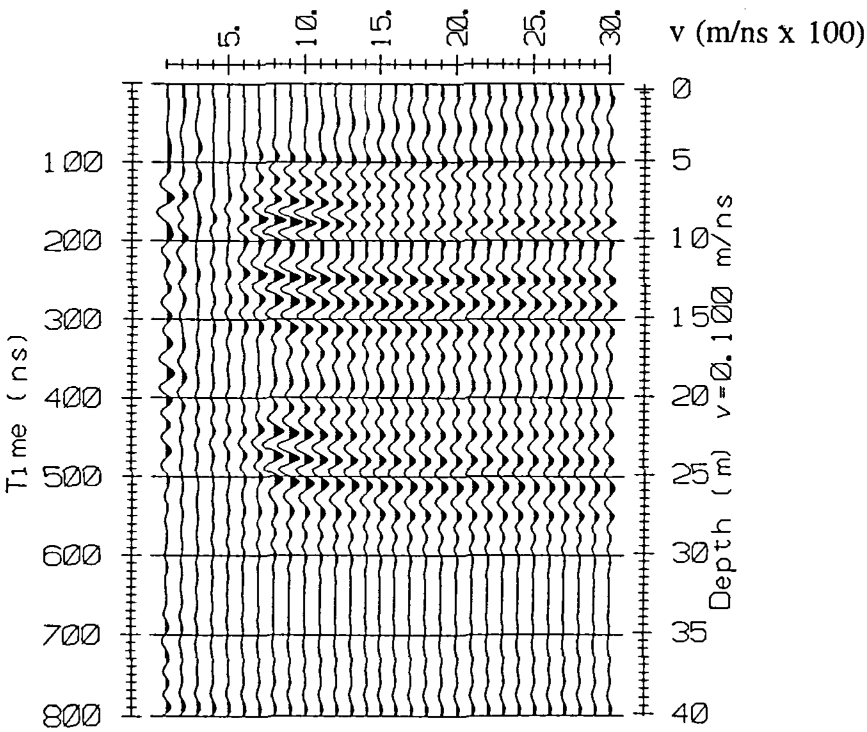

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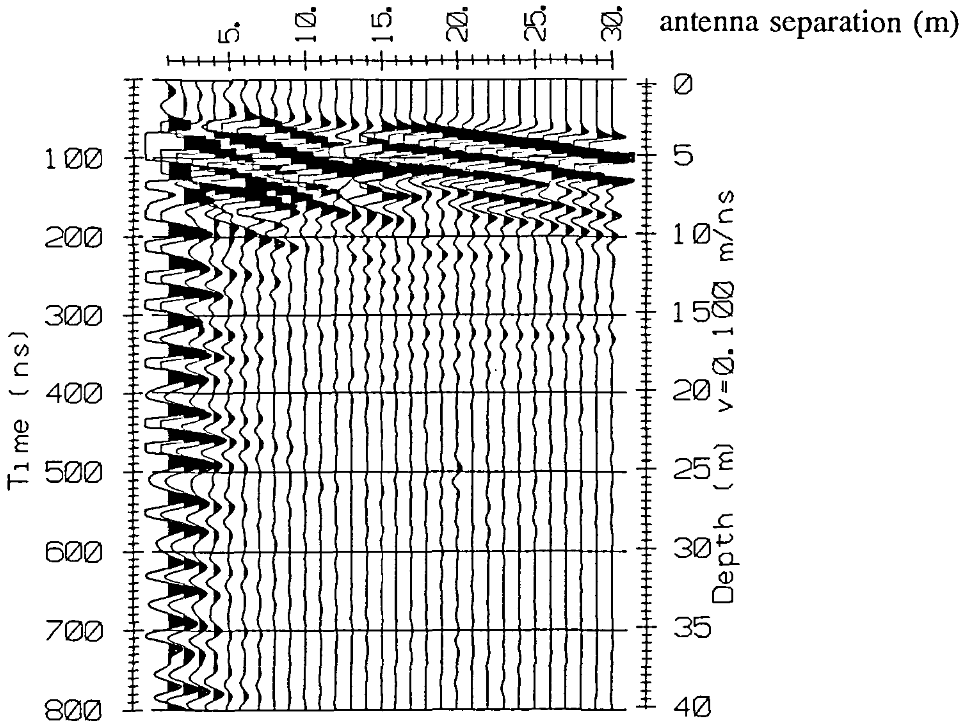

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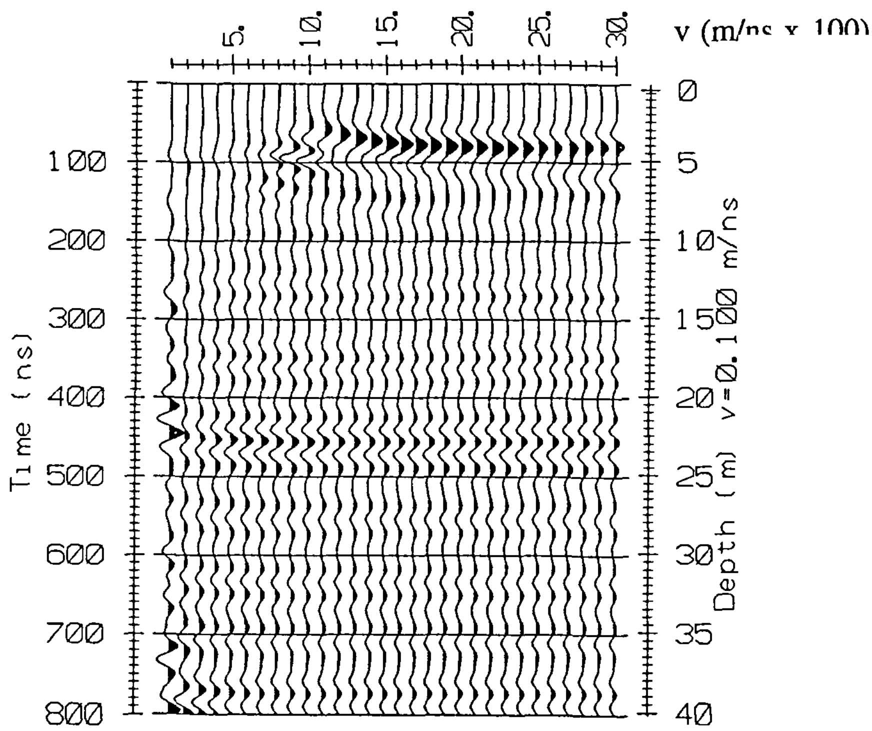

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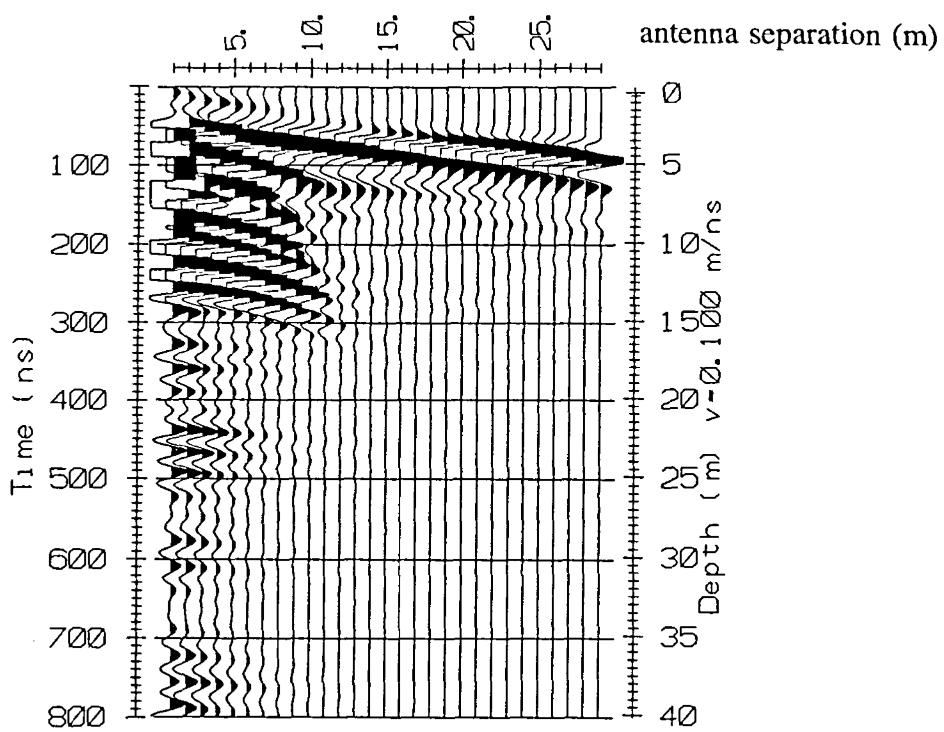

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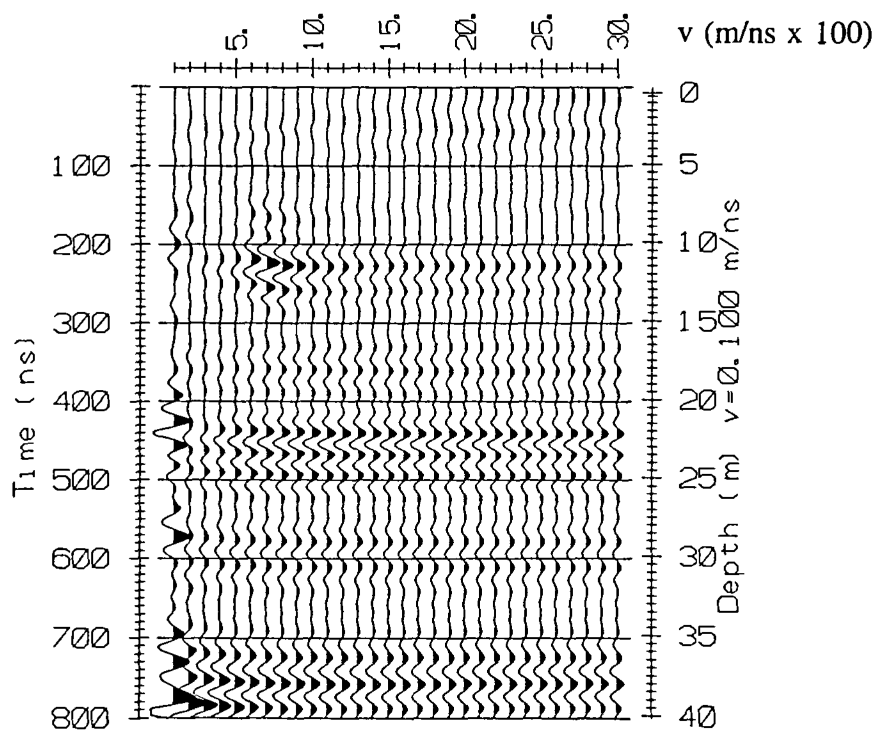

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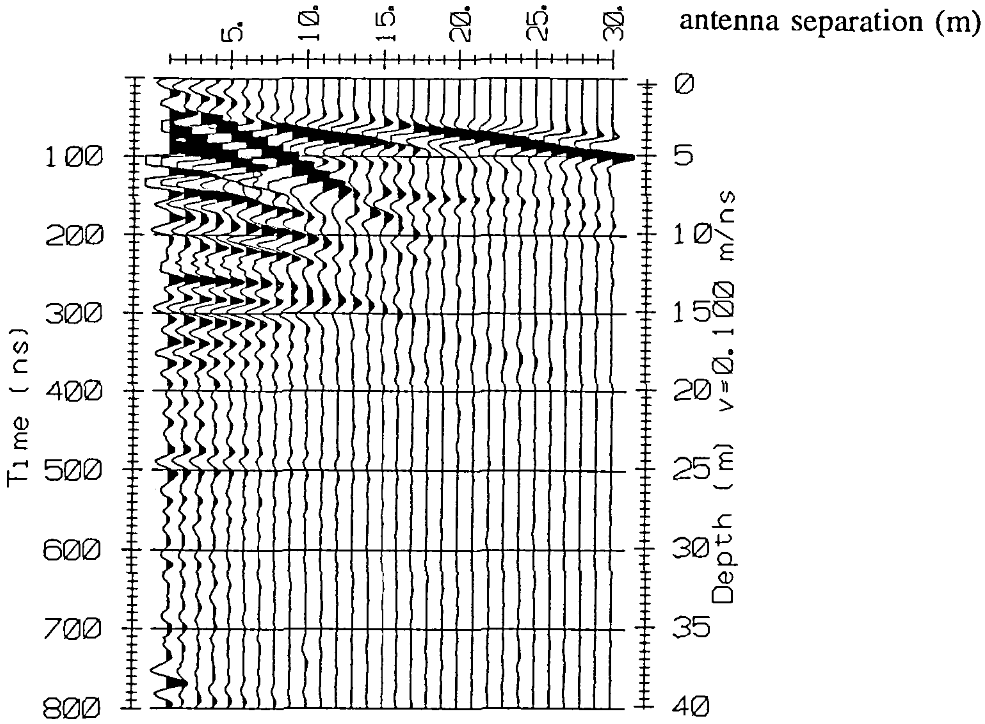

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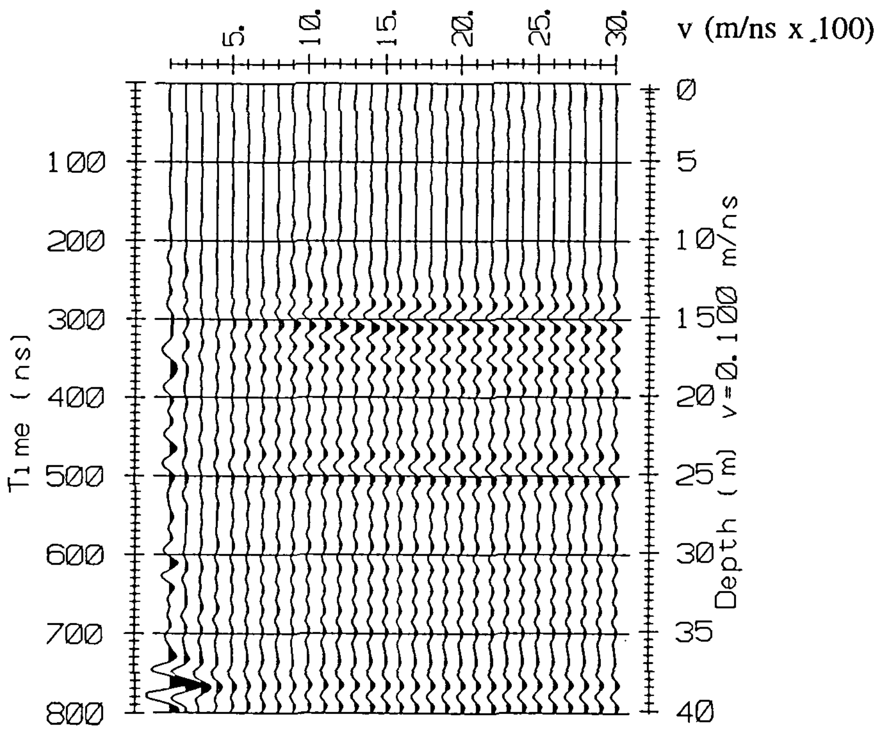

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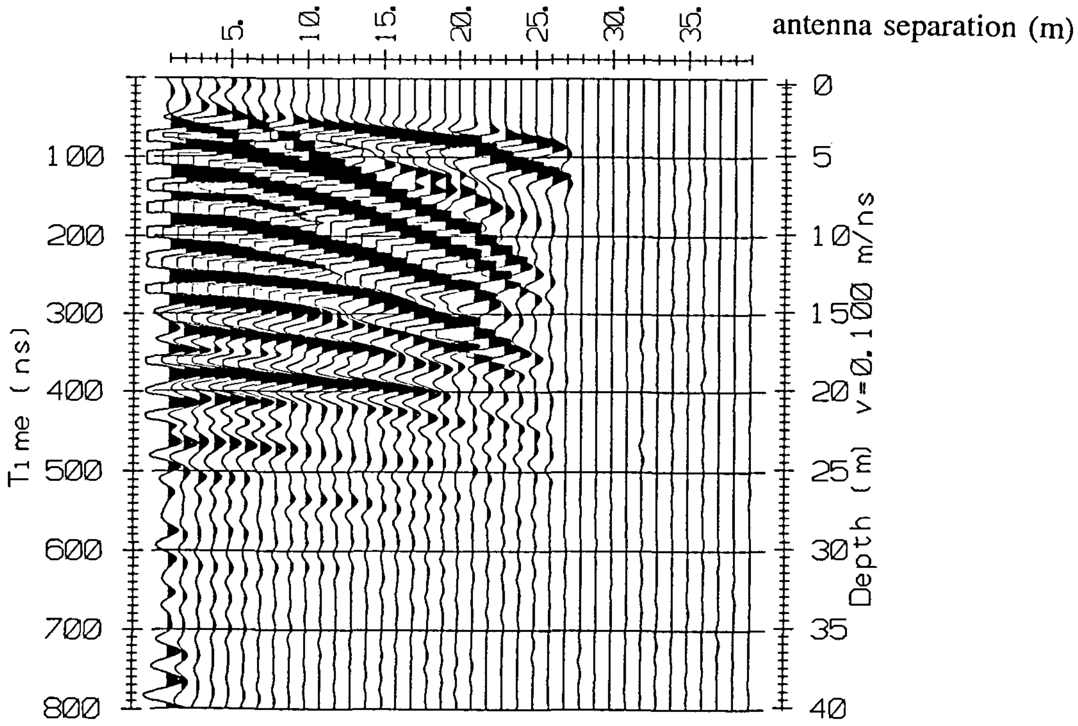

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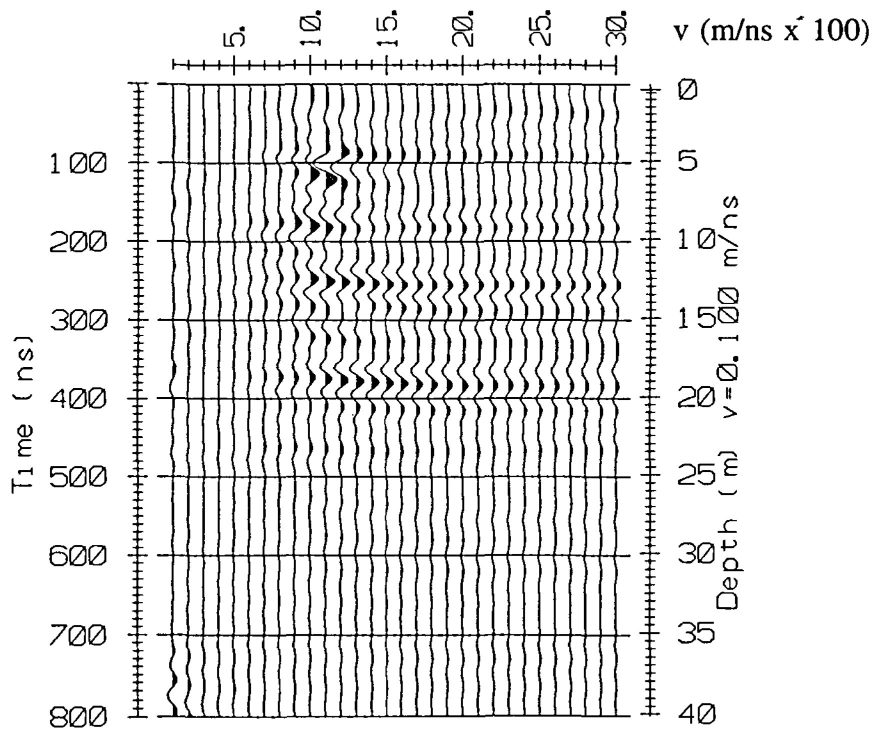

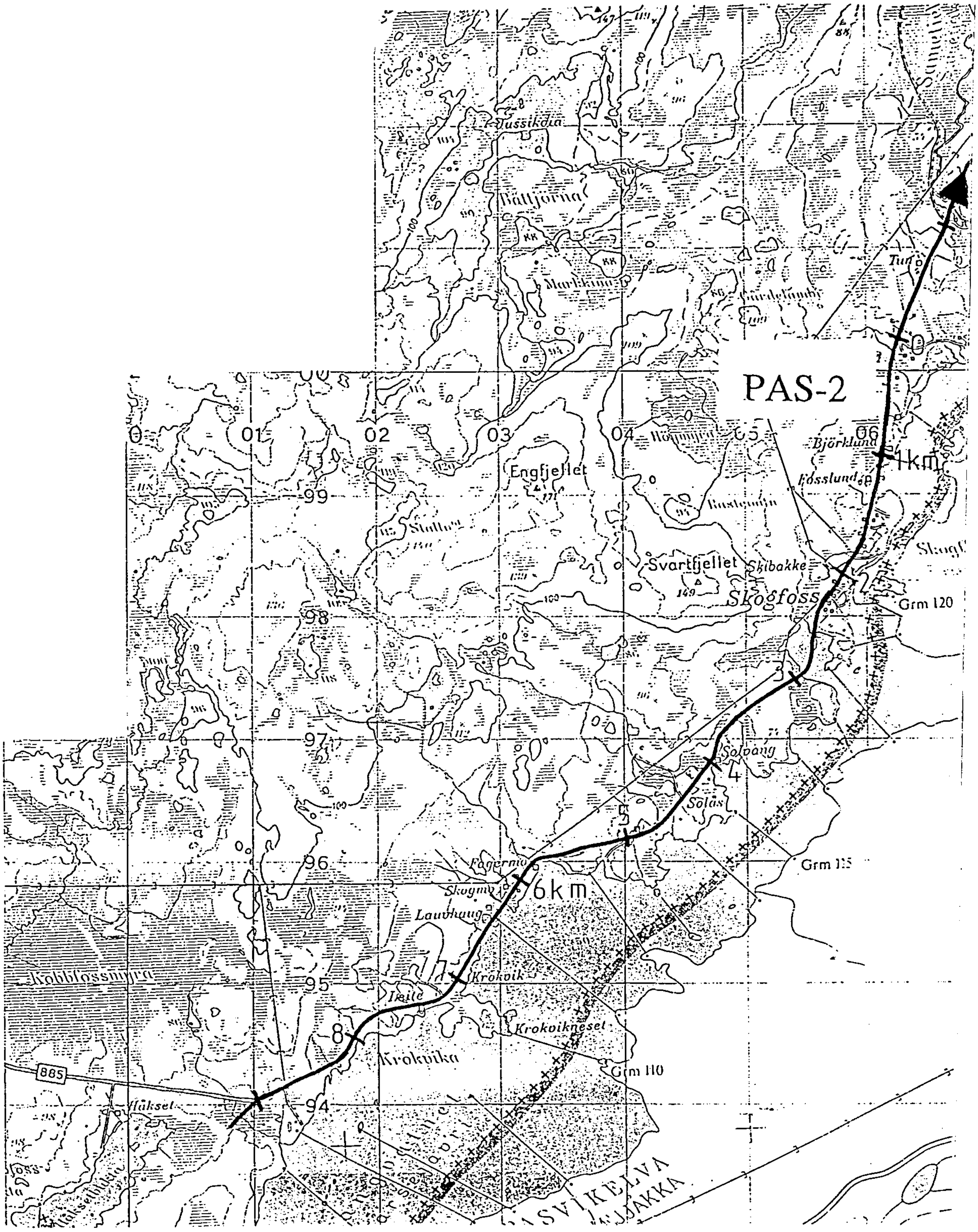

NGU/NAVF/RUSSIAN ACADEMY OF SCIENCE LOCATION MAP PASVIK FINNMARK, NORWAY	SCALE 1:50 000	OPER JSR	June -92
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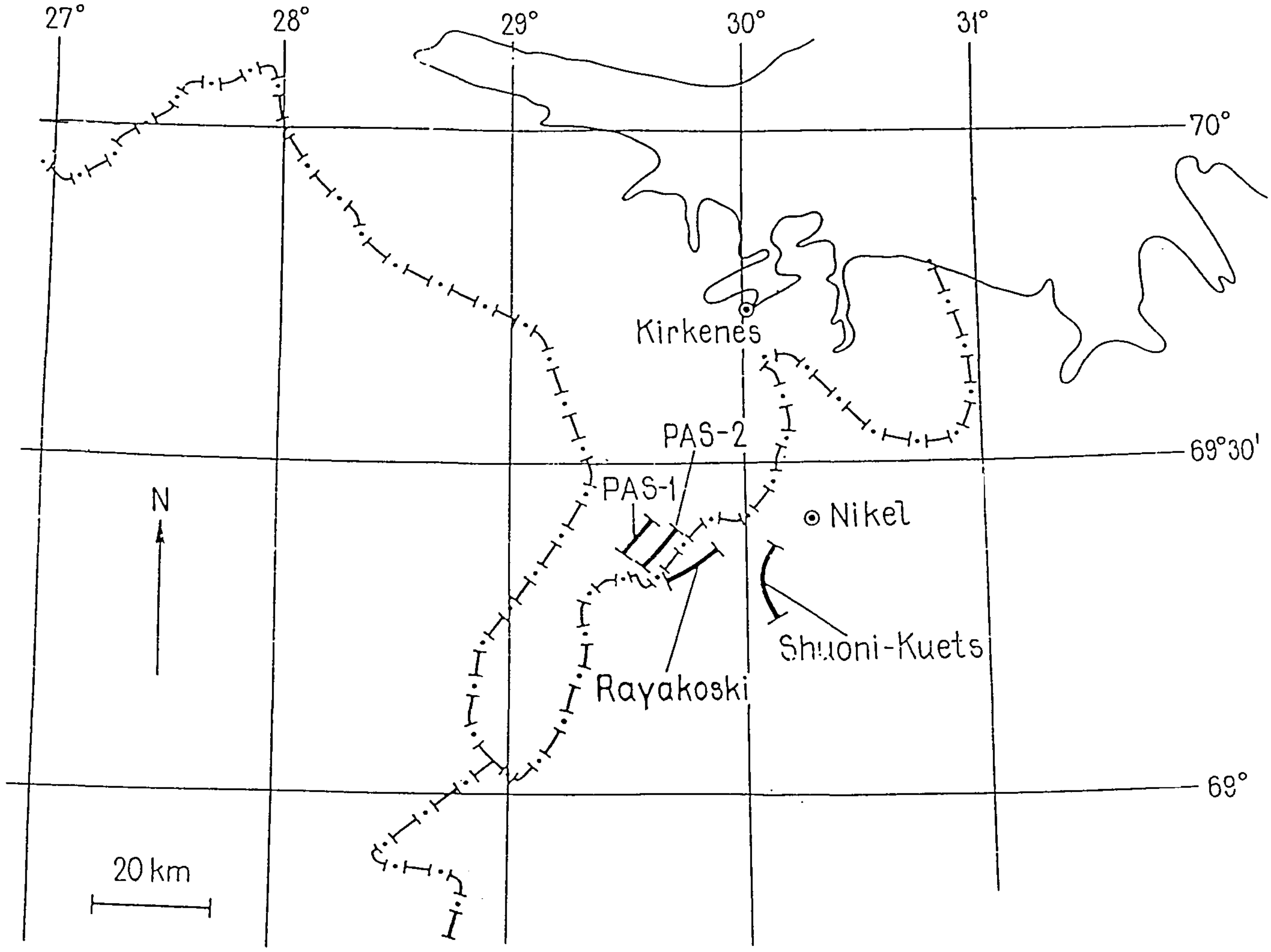

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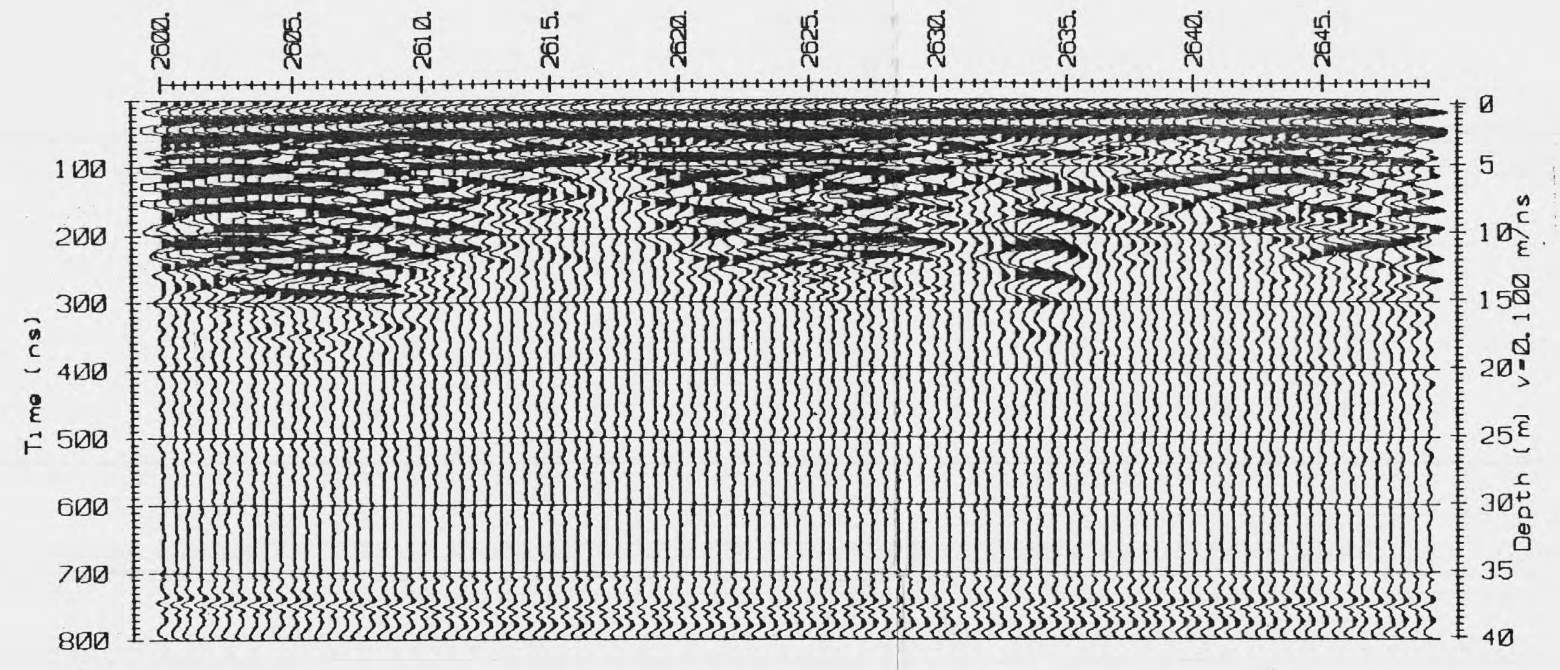

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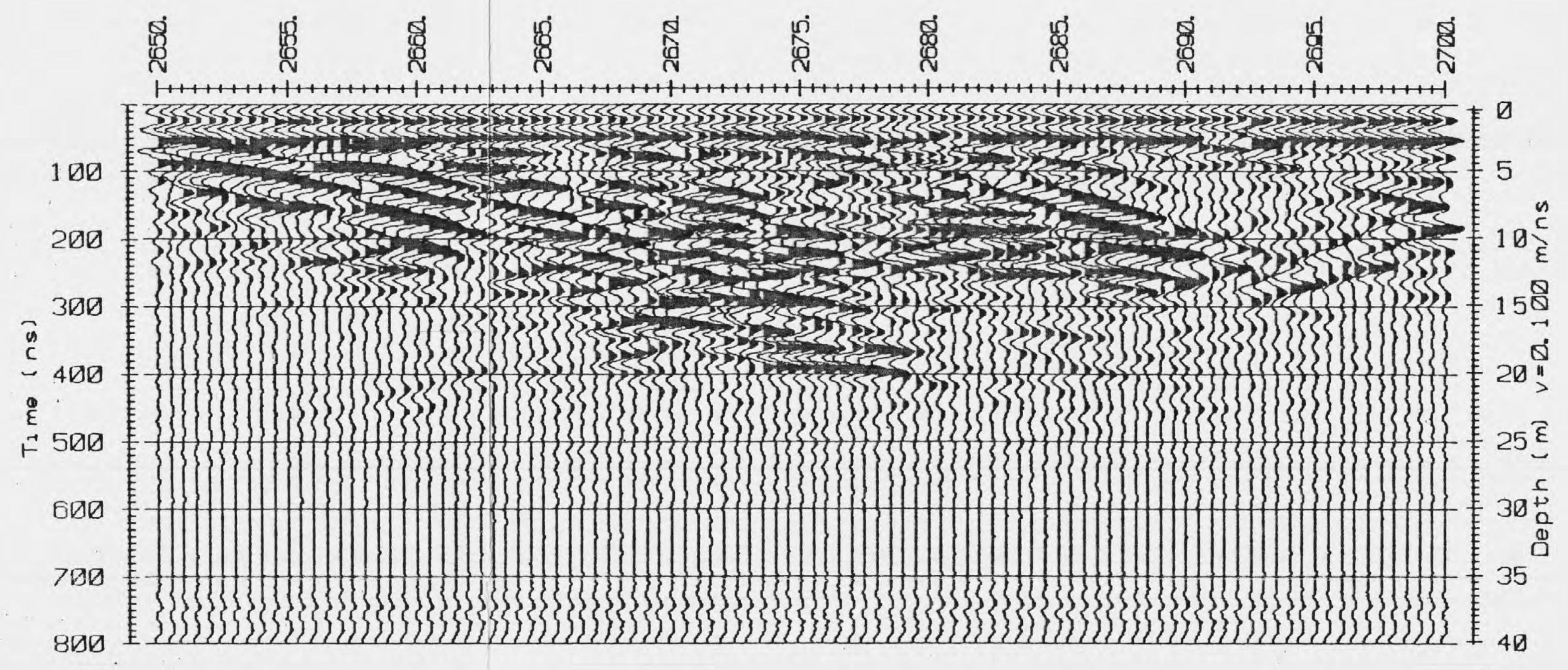
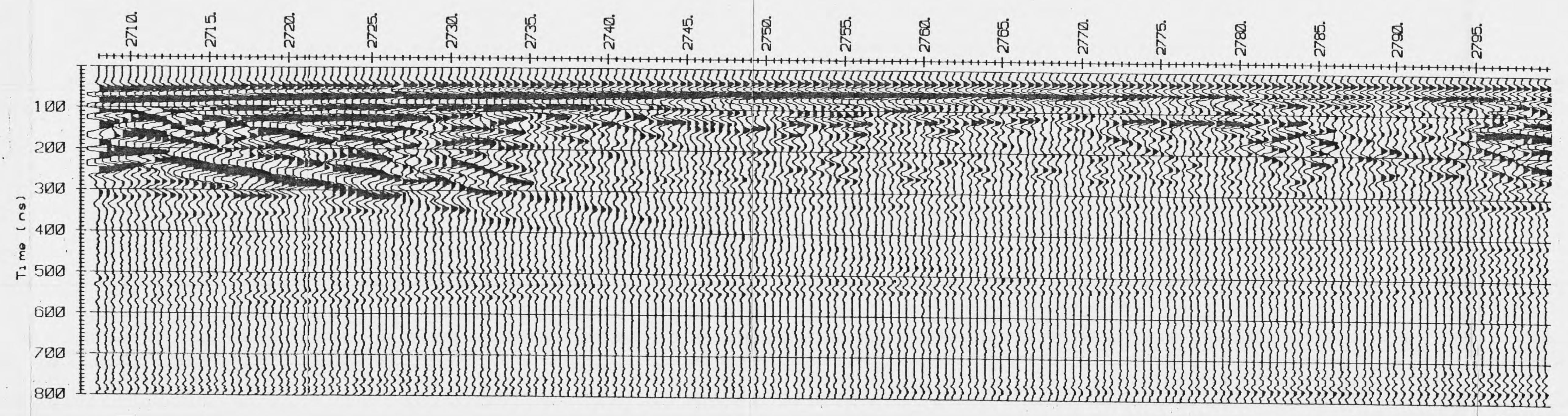


PAS2-C



CMPPAS1

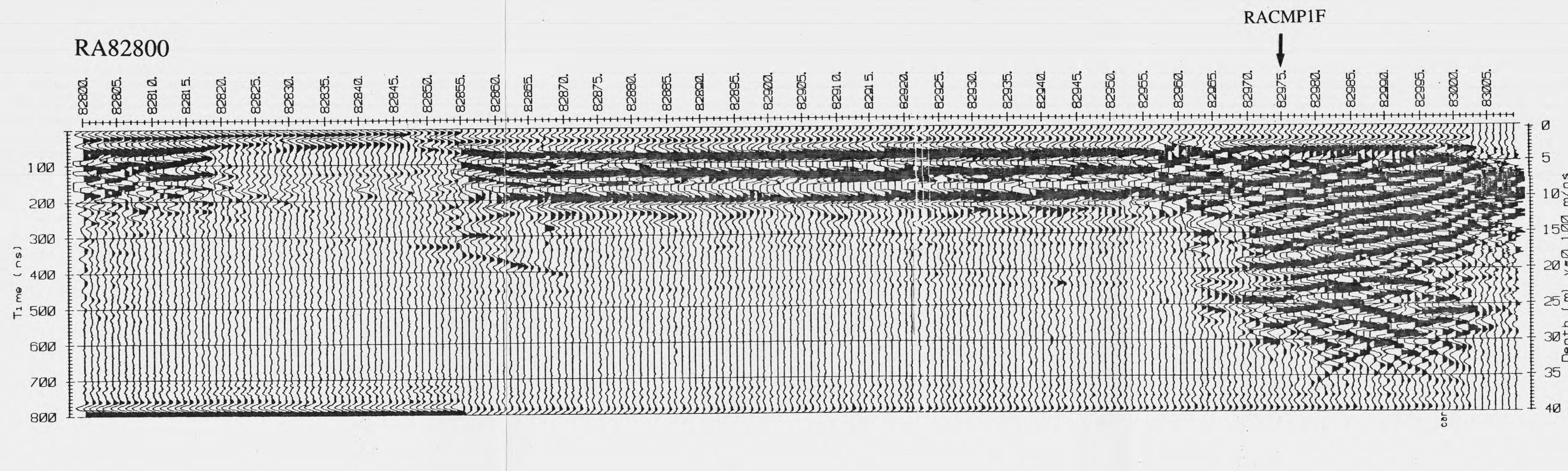
PAS2-C (continued)

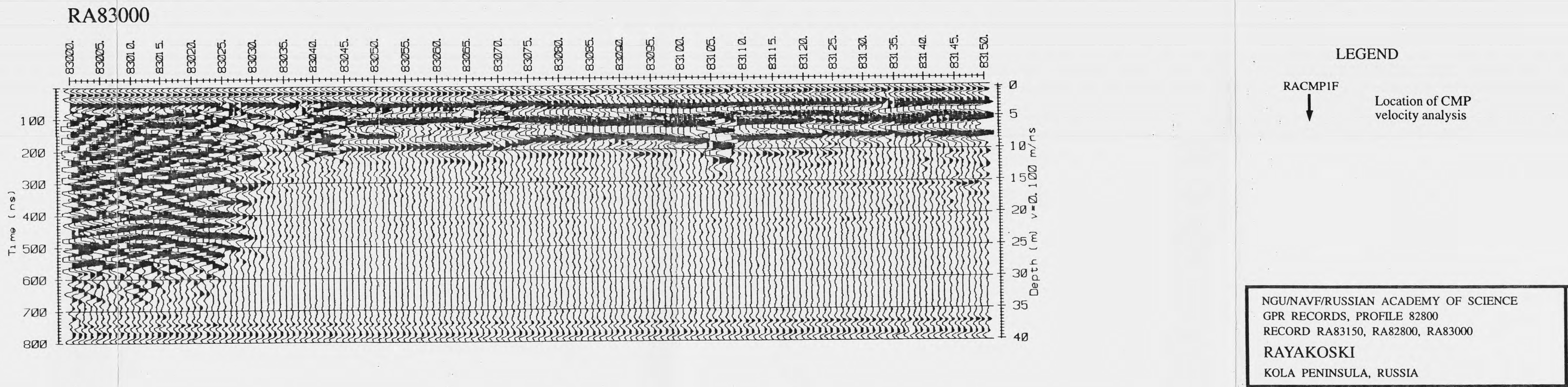
PAS2-CX

LEGEND

CMPPAS1 — Location of CMP velocity analysis

NGU/NAVF/RUSSIAN ACADEMY OF SCIENCE GPR RECORDS, PROFILE PAS2 RECORD PAS2-A, PAS2-B, PAS2-C, PAS2-CX PASVIK FINNMARK, NORWAY	SCALE 1:250	OPER JSR DRAW EM TRAC	June -92 May -93
GEOLOGICAL SURVEY OF NORWAY TRONDHEIM	MAP NO. 93.064-03	MAP 1:50 000 2433 IV	





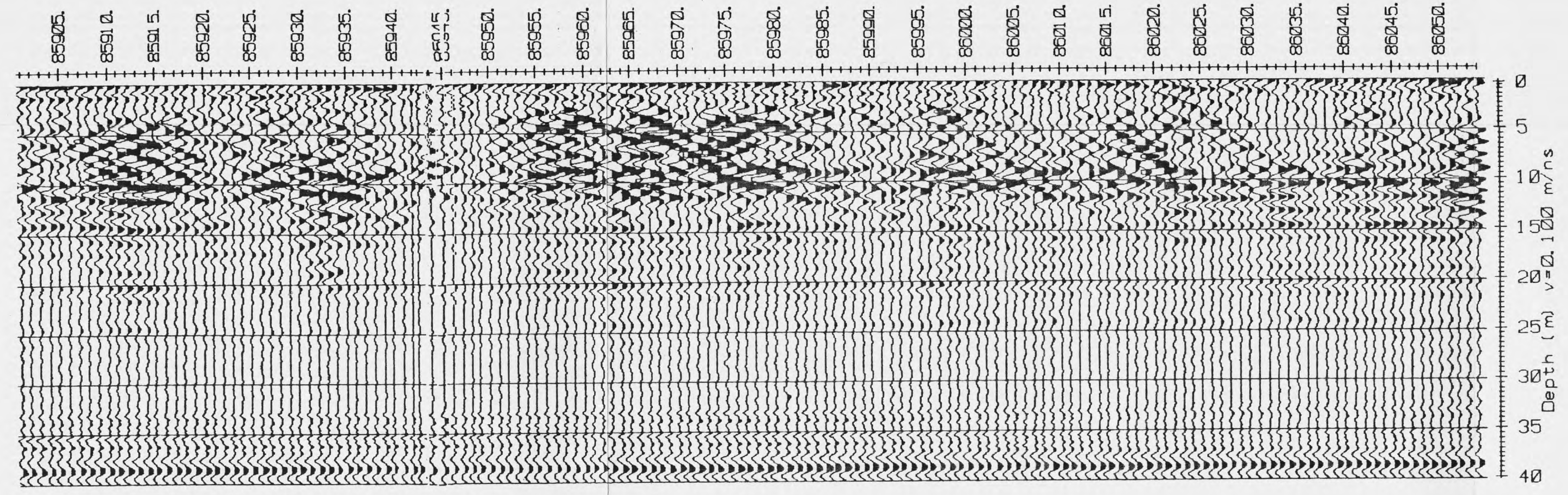
LEGEND

RACMP1F ↓ Location of CMP velocity analysis

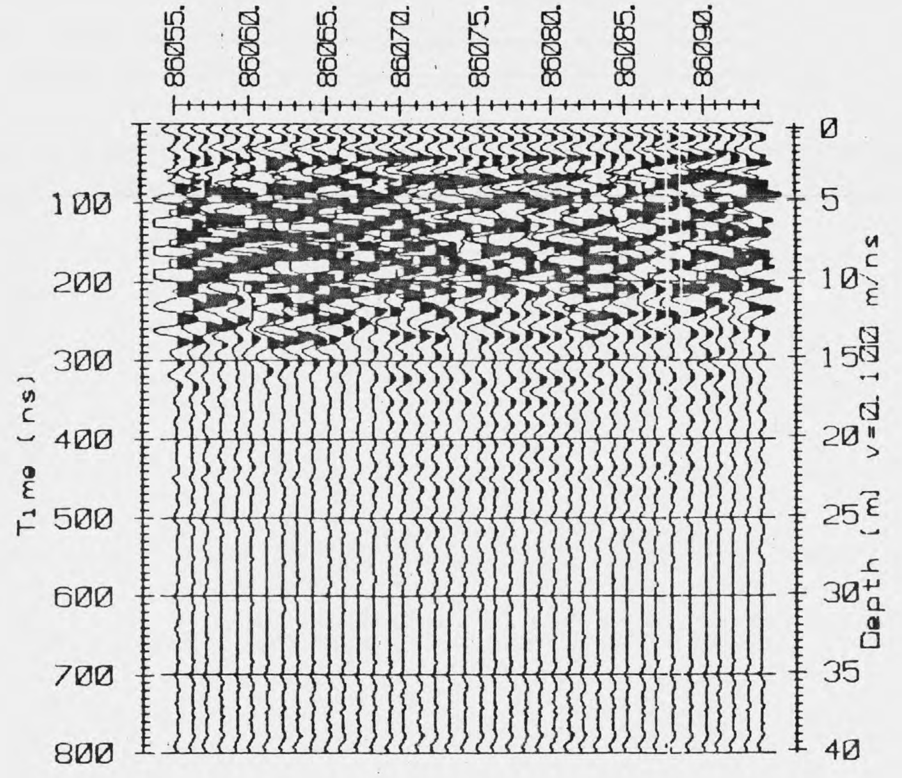
NGU/NAVF/RUSSIAN ACADEMY OF SCIENCE GPR RECORDS, PROFILE 82800 RECORD RA83150, RA82800, RA83000 RAYAKOSKI KOLA PENINSULA, RUSSIA	SCALE 1:890 1:500	OPER JSR DRAW EM TRAC	June -92 May -93
GEOLOGICAL SURVEY OF NORWAY TRONDHEIM	MAP NO. 93.064-04	MAP 1:50 000	

RA85400

RA85400 (continued)



RA86055



NGU/NAVF/RUSSIAN ACADEMY OF SCIENCE GPR RECORDS, PROFILE 85400 RECORD RA85400, RA86055 RAYAKOSKI KOLA PENINSULA, RUSSIA	SCALE 1:500	OPER JSR DRAW EM TRAC	June -92 May -93
GEOLOGICAL SURVEY OF NORWAY TRONDHEIM	MAP NO. 93.064-05	MAP 1:50 000	

NGU/NAVF/RUSSIAN ACADEMY OF SCIENCE
GPR RECORDS, PROFILE 4200
RECORD SK4200, SK4200X, SK-TEST, SK-TESTX

SHUONI-KUETS

KOLA PENINSULA, RUSSIA

GEOLOGICAL SURVEY OF NORWAY
TRONDHEIM

SCALE		
1:500	OPER JSR	June -92
	DRAW EM	May -93
	TRAC	

MAP NO. 93.064-06

MAP 1:50 000

LEGEND

Refraction seismic profile

12 m — Depth to bedrock from refraction seismics

NGU/NAVF/RUSSIAN ACADEMY OF SCIENCE GPR RECORDS, PROFILE 9400 RECORD SK9400 SHUONI-KUETS KOLA PENINSULA, RUSSIA	SCALE 1:500	OPER JSR DRAW EM TRAC	June -92 May -93
GEOLOGICAL SURVEY OF NORWAY TRONDHEIM	MAP NO. 93.064-07	MAP 1:50 000	

SK13000

SK13000 (continued)

NGU/NAVF/RUSSIAN ACADEMY OF SCIENCE GPR RECORDS, PROFILE 13000 RECORD SK13000 SHUONI-KUETS KOLA PENINSULA, RUSSIA	SCALE 1:500	OPER JSR DRAW EM TRAC	June -92 May -93
GEOLOGICAL SURVEY OF NORWAY TRONDHEIM	MAP NO. 93.064-08	MAP 1:50 000	