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Geophysical surveying in the Petchenga and Lotta area, Kola peninsula, USSR

NORGES GEOLOGISKE UNDERSØKELSE

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RAPPORT

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Geophysical surveying in the Petchenga and Lotta area, Kola peninsula, USSR

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Sammendrag:

As a part of the cooperation between the Geological Institute, Kola Scientific Center of the USSR Academy of Science and the Geological Survey of Norway, seismic and slingram profiling was carried out in 6 areas on the Kola peninsula.
Aims of these investigations; 1) mapping of soil thicknesses and composition, 2) locating conductive structures in bedrock, 3) studies of P-wave velocity anisotropy.
Interpretation of seismic velocities indicates three layers in the overburden; 1) loosely packed sand, P-wave velocity: 300-700 m/s, 2) loosely packed till, P-wave velocity: 1000-1500 m/s, 3) compact till, P-wave velocity: 1900-2200 m/s. The overburden thickness is in the range 0-30 meters.
Slingram measurements have delineated conductive zones in more detail than previous electrical profiling (MISC). Electrical measurements are more sensitive to structures with low conductivity than slingram measurements.
A correlation between high conductivity and low P-wave velocity in bedrock is indicated. This is probably due to fracturing.
There is an indication of slightly higher P-wave velocity along the bedrock strike direction than across (anisotropy).

Emneord	Refraksjonsseismikk	Lydhastighet
Geofysikk	Elektromagnetisk måling	
	Løsmasse	Fagrapport

CONTENTS

1. INTRODUCTION

As a part of the cooperation between the Geological Institute, Kola Scientific Center of the USSR Academy of Science and the Geological Survey of Norway (NGU), seismic and slingram profiling was performed at different locations on the Kola peninsula. Aims of these investigations;

- mapping of soil thicknesses and composition
- locating conductive structures in bedrock
- mapping of bedrock P-wave velocities across and along the strike directions (anisotropy studies)

The surveys were carried out in the period 27th august to 6th september 1990. Participants from NGU were Oddvar Blokkum and Jan S. Rønning. Participants from the USSR Academy of Science were Dr. A. Zhamaletdinov, A. Tokarev and others. Results from earlier electrical profiling (MISC) were available during the interpretation of seismic and slingram data.

2. GEOPHYSICAL METHODS AND AQUISITION PARAMETERS

2.1 Seismic refraction method

In all profiles the distance between geophones was 10 meters, except at the ends of the spreads (5 meters). The shotpoint interval was 55 meters, with shots placed offend and in the middle of the geophone spreads. To get good bedrock coverage, additional shots were placed at a greater distance from the geophone spreads. The recording unit was a 12-channel ABEM TRIO analog seismograph. The quality of the records was generally very good.

2.2 Slingram method

Slingram measurements were performed using Scintrex SE-88 Genie. This instrument is a horisontal loop EM system working at 4 different frequencies. The measurements are based on simultaneous transmission of two preselected, well separated frequencies. A proportional DC voltage is obtained for each signal, averaged over a selectable time period. The ratio between voltages from the high (signal) and low (reference) frequencies is calculated and displayed in percent. In these surveys the reference frequency was 112.5 Hz and the signal frequencies were 337.5 Hz, 1012.5 Hz and 3037.5 Hz. The distance between transmitter and reciever was 50 meters, and the distance between stations was 25 meters.

2.3 Location of profiles

The surveys were carried out at three locations along the Shuoni-Kuets road (area 1,2 and 3) and at three locations along the Lotta river road (area 4,5 and 6). Table 1 gives information about area location along the roads, area positions referenced to earlier electrical measurements, profile direction versus strike direction and the geophysical methods used for each profile. Locations of profiles within each area are shown in map 91.152-01. The Shuoni-Kuets road is crossing the Petchenga greenstone belt close to the Norwegian border. Surveyed areas along this road are situated in the northern, southern and central part of the greenstone belt. The Lotta river road crosses the southeastern part of the Baltic granulite belt.

3. RESULTS

3.1 Seismic refraction method

Seismic refraction profiling was carried out in 5 different areas. For these areas, there were no topographic maps available to the authors. The terrain surface is nearly flat in all profiles. Map 1 shows the relative positions of the profiles within each area. The refraction records were interpreted using ray-tracing methods. The main objective was to determine bedrock velocities. Interpreted sections are shown in maps 91.152-02, 91.152-03 and 91.152-04.

3.1.1 Area 1, Shuoni-Kuets, northern part

Refraction data from 5 profiles were recorded. The longest profile (P1, 330 m) was located along the 'Shuoni-Kuets' road with position 0 in the profile corresponding to position 4.26 km along the road. The other profiles (P2-5) were placed perpendicular to this profile (see map 91.152-01) and the length of each of these were 110 m. The strike direction of bedrock is nearly parallell with the short profiles.

All sections show at least 3 velocity layers. The upper low velocity layer (velocities range from 350 m/s to 900 m/s) indicates dry, loosely packed material. The layer has a maximum thickness of 4 m. Layer two has velocities from 1000 m/s to 1500 m/s and probably represents dry till. The third layer represents bedrock with velocities from 4800 m/s to 6200 m/s. Bedrock velocities seem to be slightly higher along the strike direction as one would expect. Depth to bedrock is generally 10-15 m, except in profile 3 where there is nearly an outcrop at the end of the profile (position 70-110).

Profile #	*Location*	*Area #*	*Approximate distance along road*	*Central position in electrical profile*	*Profile direction versus strike direction*	*Method*
P1	*Shuoni-Kuets*	*1*	*4 km*	*975*	*across*	*seis.+sling.*
P2	*Shuoni-Kuets*	*1*	*4 km*		*along*	*seis.*
P3	*Shuoni-Kuets*	*1*	*4 km*		*along*	*seis.*
P4	*Shuoni-Kuets*	*1*	*4 km*		*along*	*seis.*
P5	*Shuoni-Kuets*	*1*	*4 km*		*along*	*seis.*
P6	*Shuoni-Kuets*	*2*	*13.5 km*	*100*	*across*	*seis.+sling.*
P7	*Shuoni-Kuets*	*2*	*13.5 km*		*along*	*seis.*
P8	*Shuoni-Kuets*	*3*	*9 km*	*520*	*across*	*seis.+sling.*
P9	*Shuoni-Kuets*	*3*	*9 km*		*along*	*seis.*
P10	*Lotta*	*5*		*5500*	*across*	*seis.+sling.*
P11	*Lotta*	*4*	*118.01 km*	*14000*	*across*	*seis.+sling.*
P12	*Lotta*	*4*	*118.01 km*		*along*	*seis.*
P13	*Lotta*	*6*		*11000*	*across*	*sling.*

TABLE 1: Location and methods overview

3.1.2 Area 2, Shuoni-Kuets, southern part

Refraction data from 2 profiles were recorded (P6 & P7). Profile 6 (220 m) was located across the strike direction along the 'Shuoni-Kuets' road. Position 0 in the profile corresponds approximately to position 13.5 km along the road. Profile 7 was located perpendicular to profile 6 at position -50.

Due to insufficient shotpoint coverage, depth information is available only between position 0 and 110 in profile 6. The section shows 3 velocity layers. The upper layer (420-530 m/s) has a maximum thickness of 3 m and pinches out probably at position 90. The seismic velocity of the second layer is rather poorly determined, but seems to be around 1250 m/s. The layer is not seen directly in the data between position 30 and 80, but could be in a hidden layer zone as shown in map -03. Type of overburden material is interpreted as being the same as in area 1. Depth to bedrock is from 1 to 8 m. Bedrock velocities are available along the entire profile and range from 4200 m/s to 5000 m/s. Lateral variations are distinct and indicate either changes in lithology or fracture zones. Profile 7 was oriented along the strike direction, and the bedrock velocity is 5300 m/s.

3.1.3 Area 3, Shuoni-Kuets, central part

Seismic refraction profiles 8 & 9 (map -03) cover the area of interest. Position 0 in the longest profile (8) is 9 km along the 'Shuoni-Kuets' road. Profile 8 was located across the strike direction. Three velocity layers are recognized in the refraction time sections. The upper layer has a maximum thickness of 4 meters and velocities ranging from 380 m/s to 730 m/s. This layer probably represents dry, loosely packed material. Seismic velocities in the second layer range from 1800-2000 m/s, but are poorly defined in profile 8 from position 100 to 330 and in profile 9. This can cause errors in determination of depths to bedrock. Layer 2 probably represents compact till. In profile 8, depth to bedrock decreases gradually from 18 m at position 10 to 5 m at position 330. A low-velocity zone is indicated between position 0 and 220 (3375-3825 m/s). A high velocity zone between 90 and 130 coincides with a bedrock high. Profile 9 is located along the strike direction in an area of fractured bedrock (3375 m/s in profile 8). Bedrock velocity is 4780 m/s.

3.1.4 Area 4, Lotta, eastern part

Refraction data from 2 profiles were recorded (P11 & P12). Profile 11 (330 m) was located across the strike direction along the 'Lotta' road with position 0 in the profile corresponding to position 13890 in a profile from earlier electrical profiling. Profile 12 was located perpendicular to profile 11 at position 220.

The refraction data indicate a rather complex velocity layering (map -04). The upper layer has velocities spanning from 340 m/s to 500 m/s with thicknesses from 1.5 m to 3.5 m. It represents dry, loosely packed sand. In profile 11, the second layer is indicated between position 55 and 110 and from 165 and throughout the profile. The layer is indicated along the entire profile 12. Velocities range from 1000 m/s to 1350 m/s, and the layer probably represents loosely packed till. Layer 3 can be seen in the refraction data in both profiles, except between position 240 and 330 in profile 11, where it probably 'vanishes' into a hidden layer zone. The velocities are between 1900 m/s and 2170 m/s, and the layer probably represents compact till. Determination of depth to bedrock can be highly erratic, due to hidden layer problems and layers pinching out, but it seems to be in the order of 20-30 m. Low velocity zones in bedrock (probably fracture zones) are indicated in profile 11 between position 50 and 220 (3100-3200 m/s). Elsewhere, the bedrock velocities range from 4200 m/s to 4300 m/s. Bedrock velocities are slightly higher in profile 12 (4300 m/s, along the strike direction) than in profile 11 (4200 m/s).

3.1.5 Area 5, Lotta, western part

Refraction profile 10 (220 m) was located along the 'Lotta' road with position 0 in the profile corresponding to position 5350 in a profile from earlier electrical profiling.

Three layers are seen in the records (map -04). Layer one has a maximum thickness of 2.5 m with velocities ranging from 360 m/s to 510 m/s. The layer probably represents dry, loosely packed sand. Layer two has seismic velocities from 1000 m/s to 1250 m/s and represents dry, loosely packed till. Bedrock velocities are 5340 m/s between position 0 and 110 and 4590 m/s between 110 and 220. Depth to bedrock approximates 10 m between position 80 and 220. The highest bedrock velocities seem to coincide with a bedrock high (3-6 m depth) between position 10 and 80. Lateral change in bedrock velocities can be due to changes in lithology.

3.2 Slingram method

Slingram measurements were performed with one profile in 6 different areas. All profiles were oriented approximately perpendicular to the strike direction. Data are presented in appendices 1-6. The anomalies are grouped as 'strong', 'medium', 'weak' and 'no'. Conductor locations are marked in map -01.

3.2.1 Area 1, Shuoni-Kuets, northern part

Along profile 1 there is a 'medium' anomaly between position 100 and 300. High positive respons, especially for 3037/112 indicates a plate dipping towards decreasing position. This is not in agreement with earlier interpretation of electrical measurements. A 'weak' anomaly can be recognized at position 430.

3.2.2 Area 2, Shuoni-Kuets, southern part

Slingram measurements along profile 6 show two 'medium' anomalies indicating two well separated conductive zones. The dips seem to be near 90 degrees. Both conductors are probably thin; less than or equal to 10 meters. Low values for 3037/112 is caused by reduced transmitted signal at 3037 Hz due to lack of power.

3.2.3 Area 3, Shuoni-Kuets, central part

Profile 8 shows a complicated anomaly pattern, which makes interpretation difficult. Three separate conductors can be recognized. The one located at position 70 is classified as a 'medium' anomaly, and is interpreted as having the shape of a thin plate. The second conductor at position 150 gives a 'strong' anomaly. This conductor seems to have the shape of a thick plate (approximately 50 meters). The third conductor at position 225 gives a 'medium' anomaly. This one also seems to be rather thin, although estimation of thickness of the conductor based on anomaly curve shape is rather ambitious, as anomalies from the other conductors seem to interfere.

3.2.4 Area 4, Lotta, eastern part

Slingram measurements along profile 11 show no anomaly, although earlier electrical profiling indicate a low resistivity zone (in the order of 500 ohmm) between position 14000 and 14150.

3.2.5 Area 5, Lotta, western part

Slingram measurements along profile 10 show a 'weak' anomaly at position 5500 which coincide with a low resistivity zone (in the order of 200 ohmm) from electrical profiling. The thickness of this seems to be approximately 50 meters.

3.2.6 Area 6, Lotta, central part

Slingram measurements along profile 13 shows no anomalies, although electrical profiling indicate a zone with low resistivity (in the order of 400 ohmm) at position 11000.

3.3 P-wave anisotropy studies

Detailed electrical measurements have indicated electrical anisotropy in area 1, Shuoni-Kuets (Zhamaletdinov, personal information). Seismic profiling was carried out across and along the strike direction to see if there was any anisotropy in seismic P-wave velocity as well. Variations in velocity across the strike direction made it difficult to calculate one distinct anisotropy coeffisient. Because of this, table 2 gives maximum and minimum anisotropy values in areas where it was relevant to calculate it.

	P-wave velocity across strike (m/s)		*P-wave velocity along strike (m/s)*		*Anisotropy* v_{along}/v_{across}	
Area	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*
1	*5650*	*4975*	*5870*	*4750*	*1.18*	*0.84*
2	*4960*	*4170*	*5330*	*5330*	*1.27*	*1.07*
3	*6000*	*3375*	*4780*	*4780*	*1.42*	*0.80*
4	*4210*	*3090*	*4300*	*4300*	*1.39*	*1.02*

Table 2: Variations in P-wave velocity along and across bedrock strike direction.

4. DISCUSSION

A discussion of overburden thicknesses and composition was presented in chapter 3.1. Results from interpretation of seismic refraction data are presented in map -02 to -04. Map -01 shows bedrock velocity data and location and extension of conductive zones.

As can be seen in map -01, position of all slingram anomalies coincide with anomalies from electrical profiling, but not vice versa. There are two possible reasons for this. One reason is that the conductors indicated by electrical measurements are too weak (low conductivity) to give anomalies on the slingram profiles (examplified in profile 11, Lotta, eastern part). An other possible reason is that several, thin conductive plates cause shielding effects on the electrical profiles. This gives an impression of one thick, conductive structure. However, it can be seen in profile 6 (area 2, Shuoni-Kuets) and profile 8 (area 3, Shuoni-Kuets) that there are several well separated conductive zones. These two profiles clearly demonstrate how slingram profiling can give information in addition to what can be seen from the electrical profiling (MISC-profiling).

A comparision between electrical anomalies and bedrock velocities shows that conductive material also give low P-wave velocities in the surveyed areas. This is especially good pronounced in profile 8 (area 3, Shuoni-Kuets), but can also be seen in profile 1, profile 10 and profile 11. This might be caused by generally low P-wave velocity in the conductive material, which in the Shuoni-Kuets area is graphitic phylite. In area 4 (profile 11) along the Lotta river road, slingram measurements gave no anomaly, and the resistivity calculated from electrical profiling was about 500 ohmm. This value is in the same order as experienced in Norway on fractured crystalline bedrock (without any electron conducting minerals). Thus, the low seismic velocity (approx. 3100 m/s) and low resistivity (500 ohmm) might be caused by pure fracturing of bedrock.

P-wave velocity anisotropy studies are difficult to conduct in all of the surveyed areas. P-wave velocities vary across bedrock strike direction, indicating either changes in lithology or fracturing. In a few areas, profiles oriented along the strike direction are placed near a velocity interface, but on the 'lower velocity side'. In such cases, one has to be aware of the fact that refractions could come from the 'higher velocity side' of the interface. Nevertheless, P-wave velocities are slightly higher along than across the strike direction, which can be seen in table 2.

5. CONCLUSION

Overburden thicknesses and velocity layering have been mapped using seismic refraction method. Thickness of the overburden varies between 0 and approximately 30 meters. Interpretation of seismic velocities indicates three layers in the overburden;
1) loosely packed sand, P-wave velocity: 300-700 m/s.
2) loosely packed till, P-wave velocity: 1000-1500 m/s.
3) compact till, P-wave velocity: 1900-2200 m/s.
Layer three is not indicated in all profiles, but might be present as a hidden layer.

Slingram measurements have delineated conductive zones in more detail than previous electrical profiling. Electrical measurements are more sensitive to structures with low conductivity than slingram measurements.

A correlation between high conductivity and low P-wave velocity in bedrock is indicated. This might be caused by fracturing.

There is an indication of slightly higher P-wave velocity along the bedrock strike direction than across (anisotropy).

Trondheim, 20/3-1991
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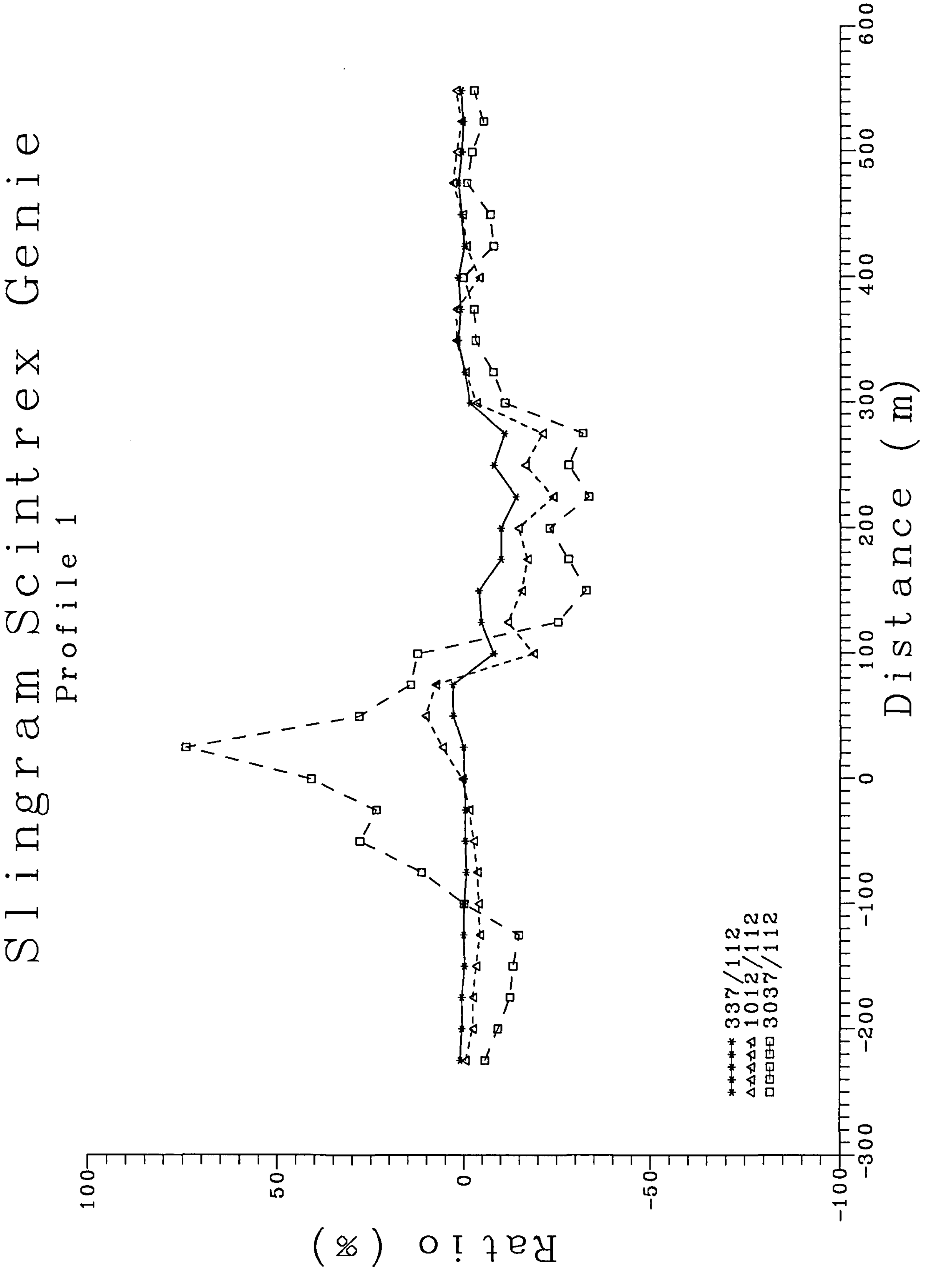
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1012/112
3037/112
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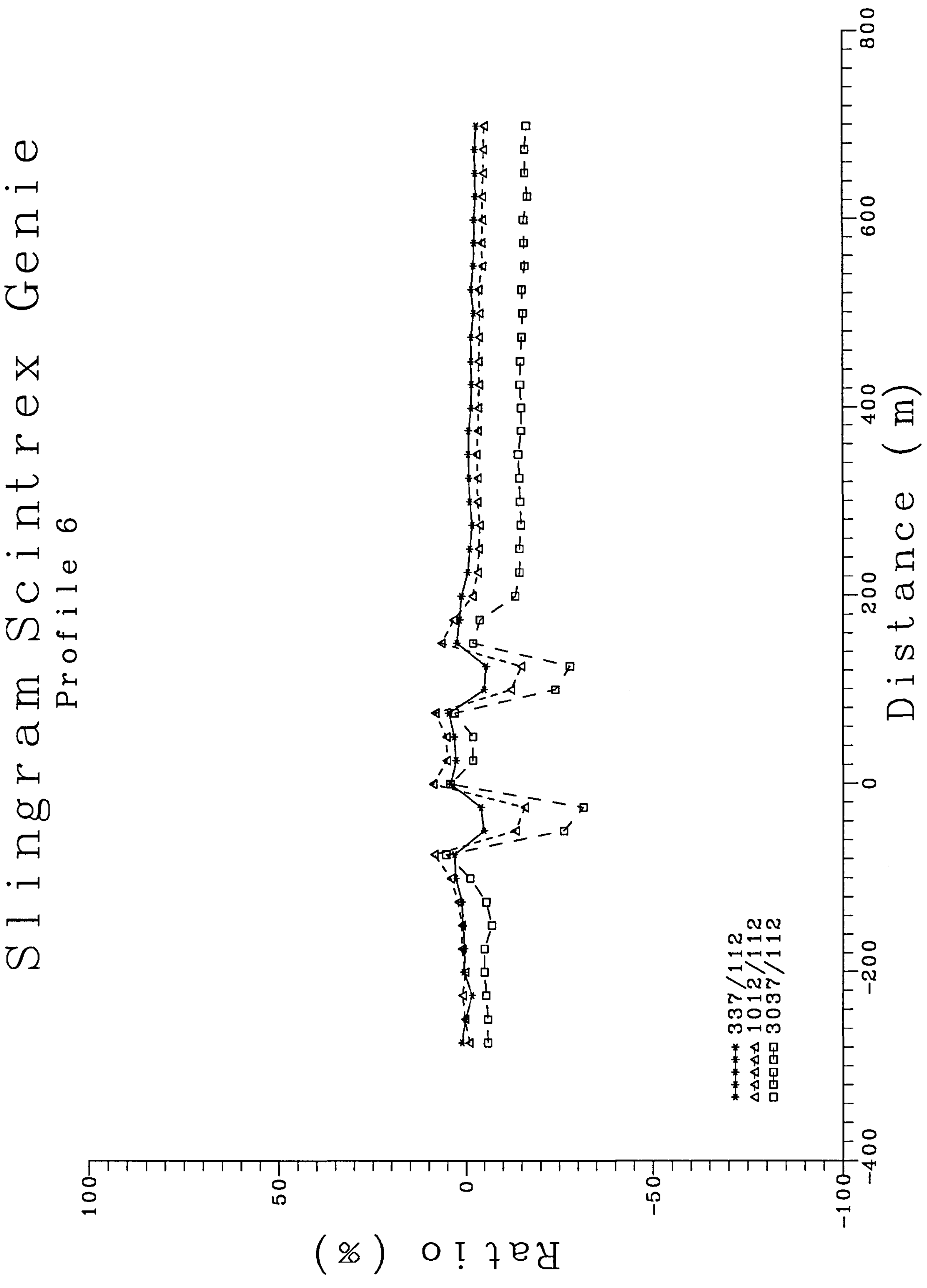
200
300
400
500
600
100
50
0
-50
-100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200
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600
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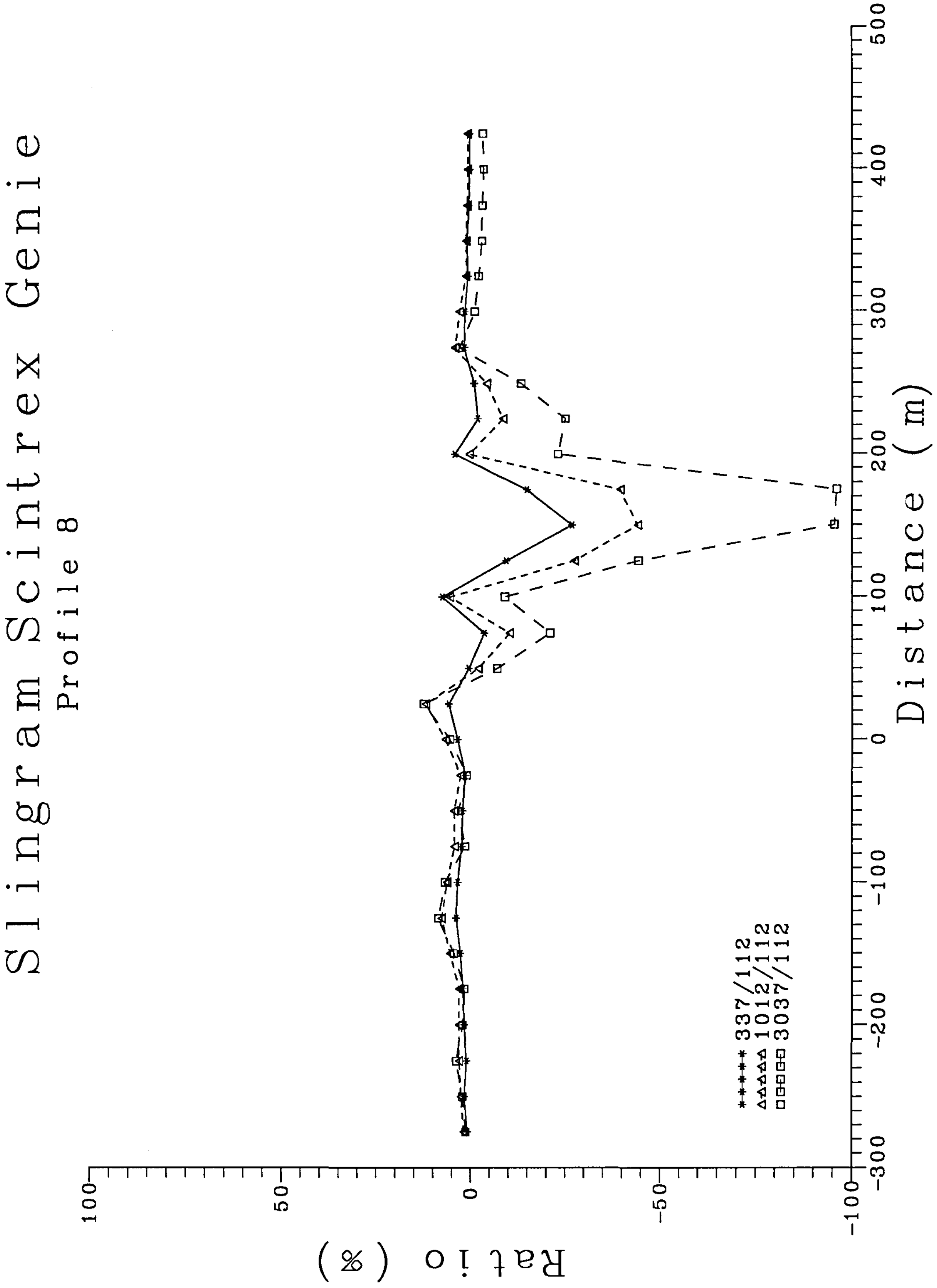
337/112
1012/112
3037/112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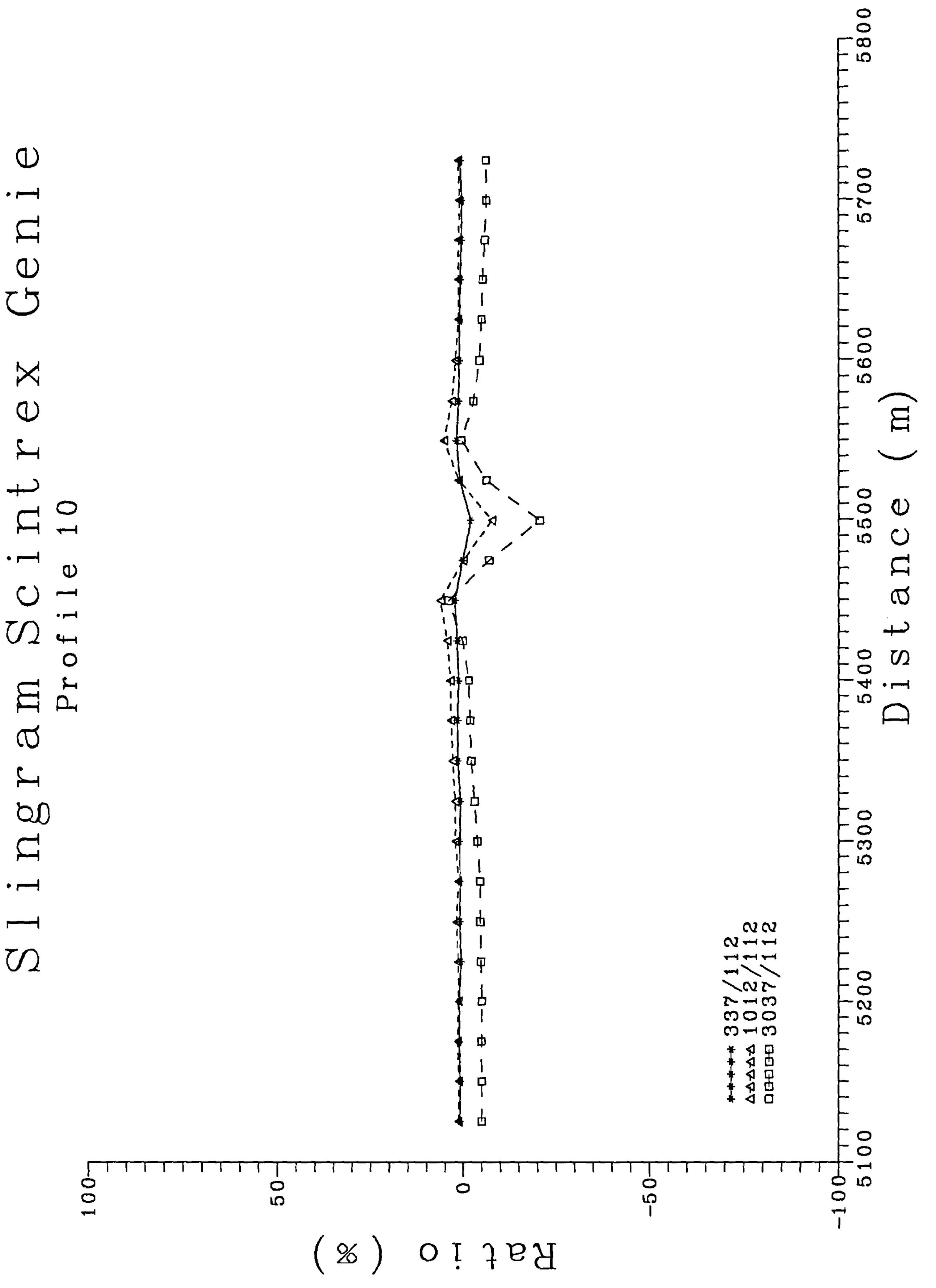
300
400
500
337/112
1012/112
3037/112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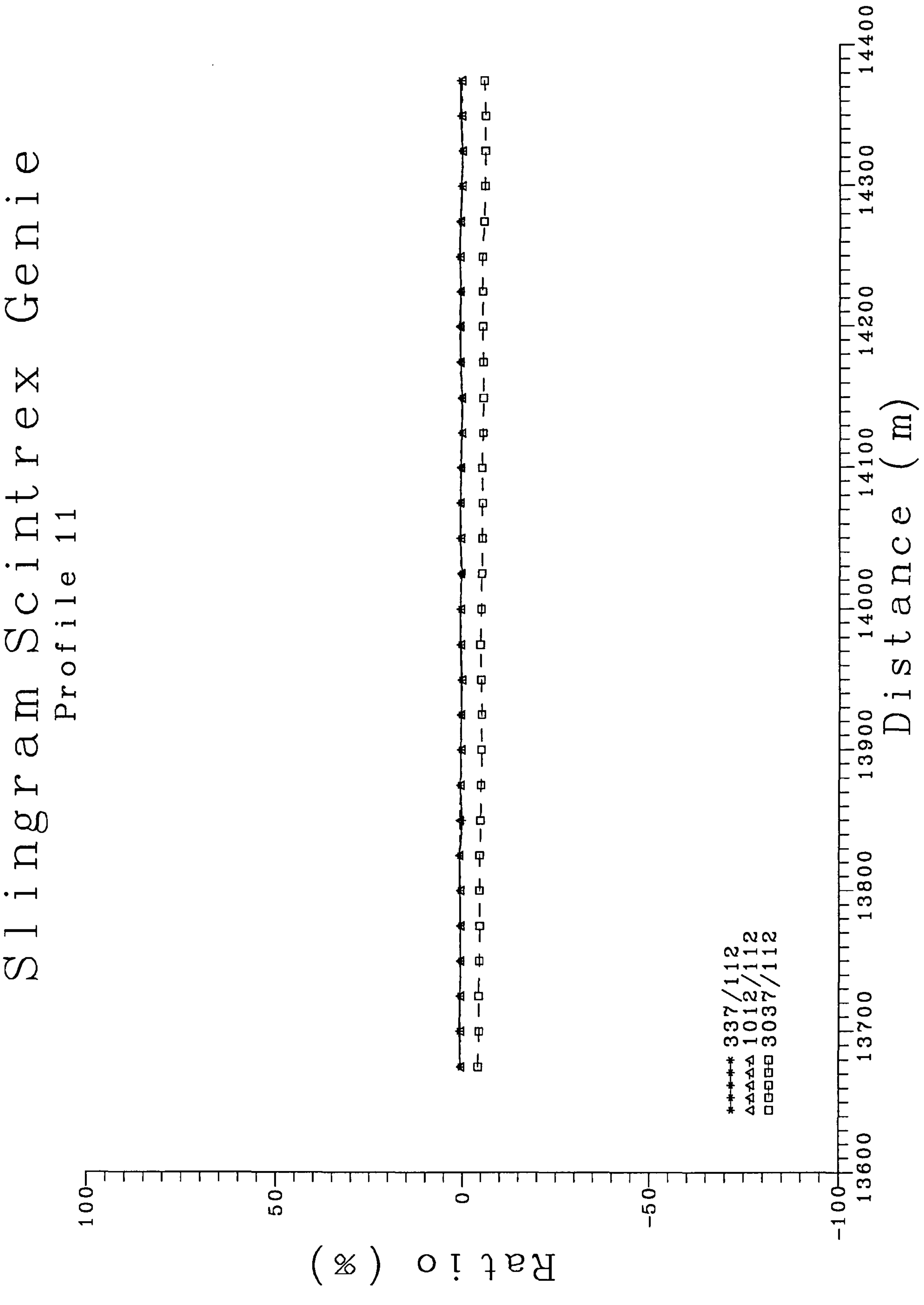
1012/112
3037/112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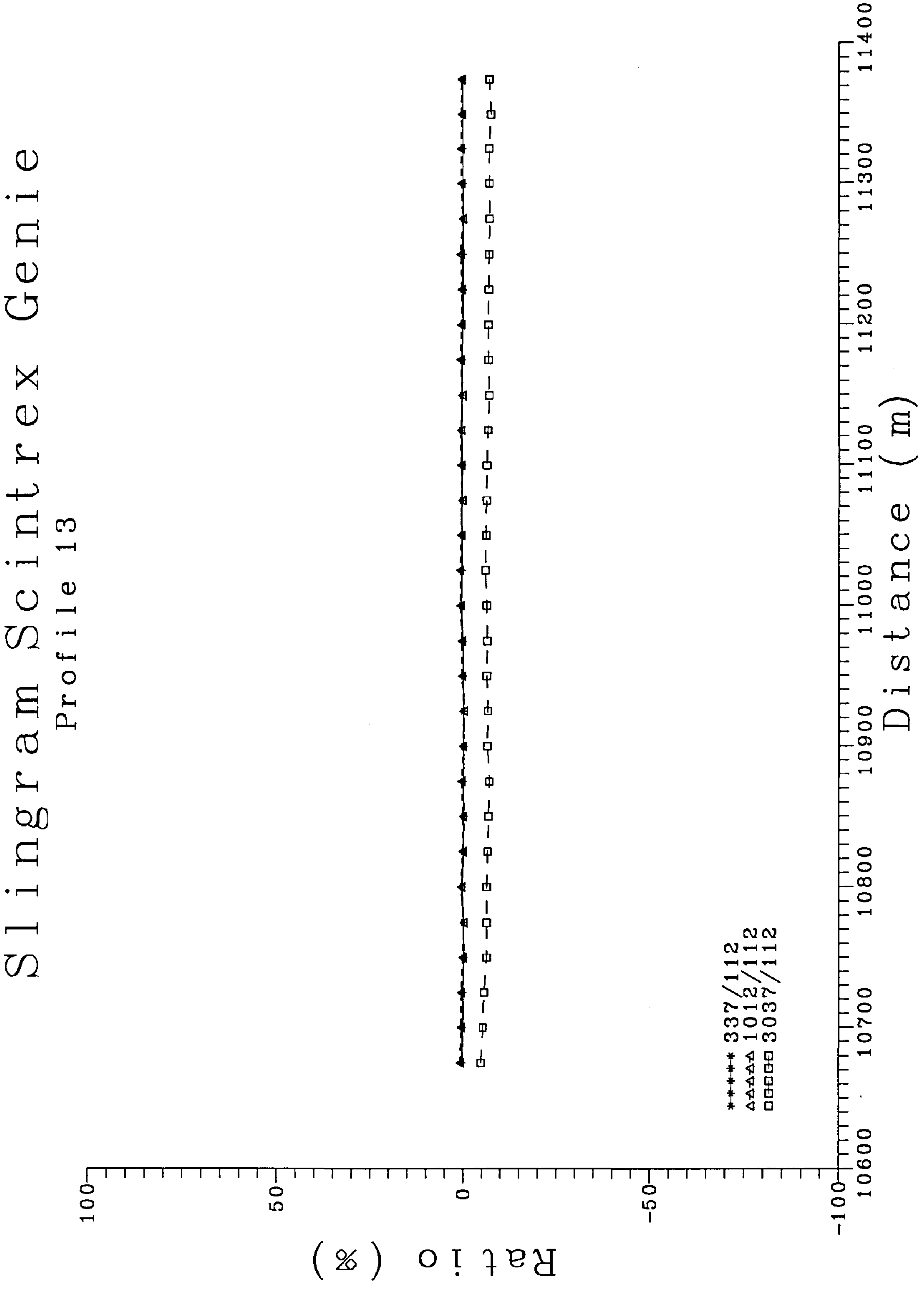
337/112
1012/112
3037/112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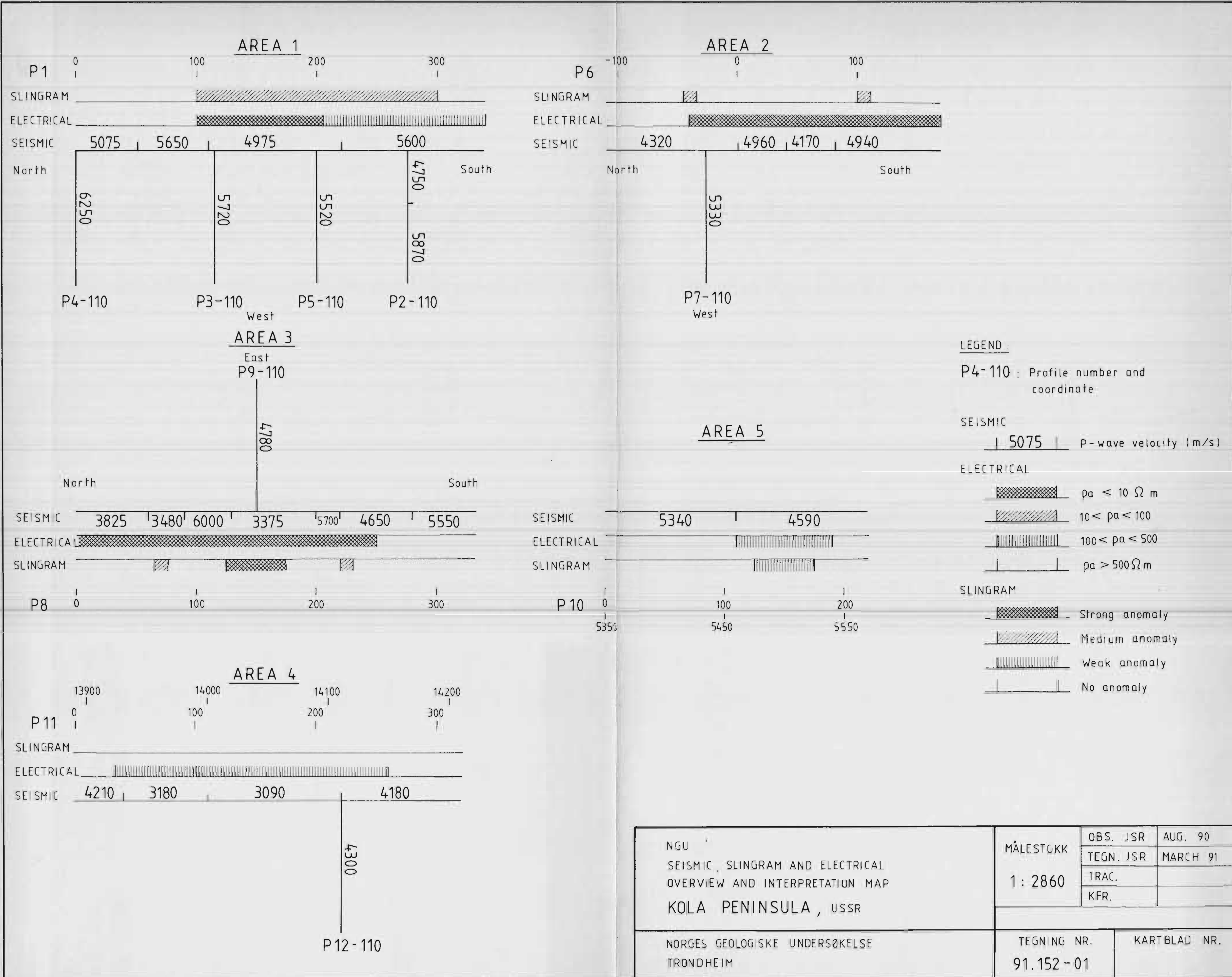
1012/112
3037/112



AREA 1
P1
0
100
200
300
SLINGRAM
ELECTRICAL
SEISMIC
5075
5650
4975
5600
North
South
6250
5720
5520
4750
5870
P4-110
P3-110
P5-110
P2-110
West
AREA 2
P6
-100
0
100
SLINGRAM
ELECTRICAL
SEISMIC
4320
4960
4170
4940
North
South
5330
P7-110
West
AREA 3
East
P9-110
4780
North
South
SEISMIC
3825
3480
6000
3375
5700
4650
5550
ELECTRICAL
SLINGRAM
P8
0
100
200
300
AREA 5
SEISMIC
5340
4590
ELECTRICAL
SLINGRAM
P10
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100
200
5350
5450
5550
AREA 4
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0
100
200
300
P11
SLINGRAM
ELECTRICAL
SEISMIC
4210
3180
3090
4180
4300
P12-110
LEGEND :
P4-110 : Profile number and coordinate
SEISMIC
5075
P-wave velocity (m/s)
ELECTRICAL
ρa < 10 Ω m
10 < ρa < 100
100 < ρa < 500
ρa > 500 Ω m
SLINGRAM
Strong anomaly
Medium anomaly
Weak anomaly
No anomaly
NGU
SEISMIC, SLINGRAM AND ELECTRICAL
OVERVIEW AND INTERPRETATION MAP
KOLA PENINSULA, USSR
MÅLESTOKK
1 : 2860
OBS. JSR
AUG. 90
TEGN. JSR
MARCH 91
TRAC.
KFR.
NORGES GEOLOGISKE UNDERSØKELSE
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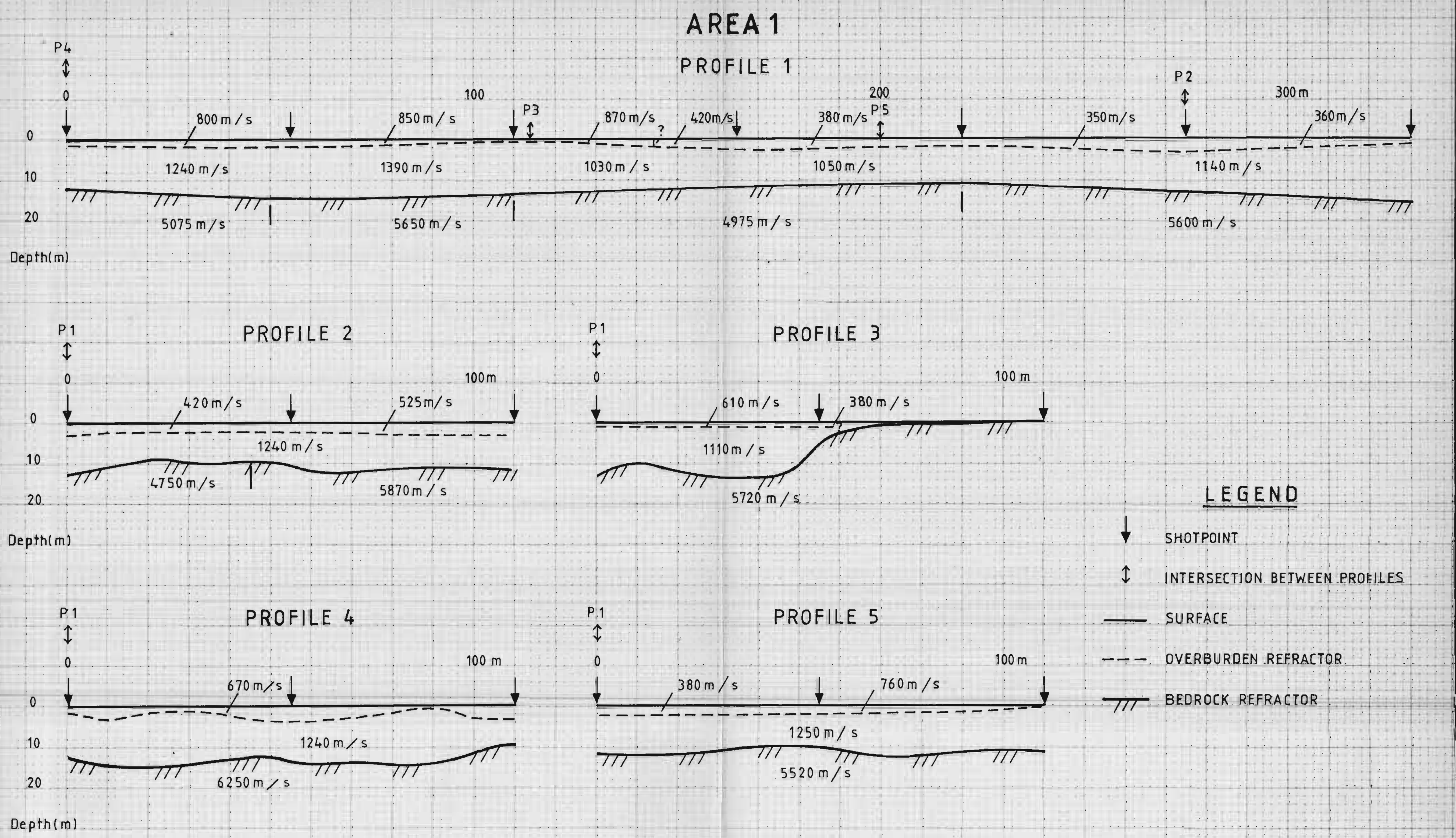
91.152-01
KARTBLAD NR.



NGU
SEISMIC REFRACTION PROFILES
PETCHENGA, AREA 1
KOLA PENINSULA, USSR

NORGES GEOLOGISKE UNDERSØKELSE
TRONDHEIM

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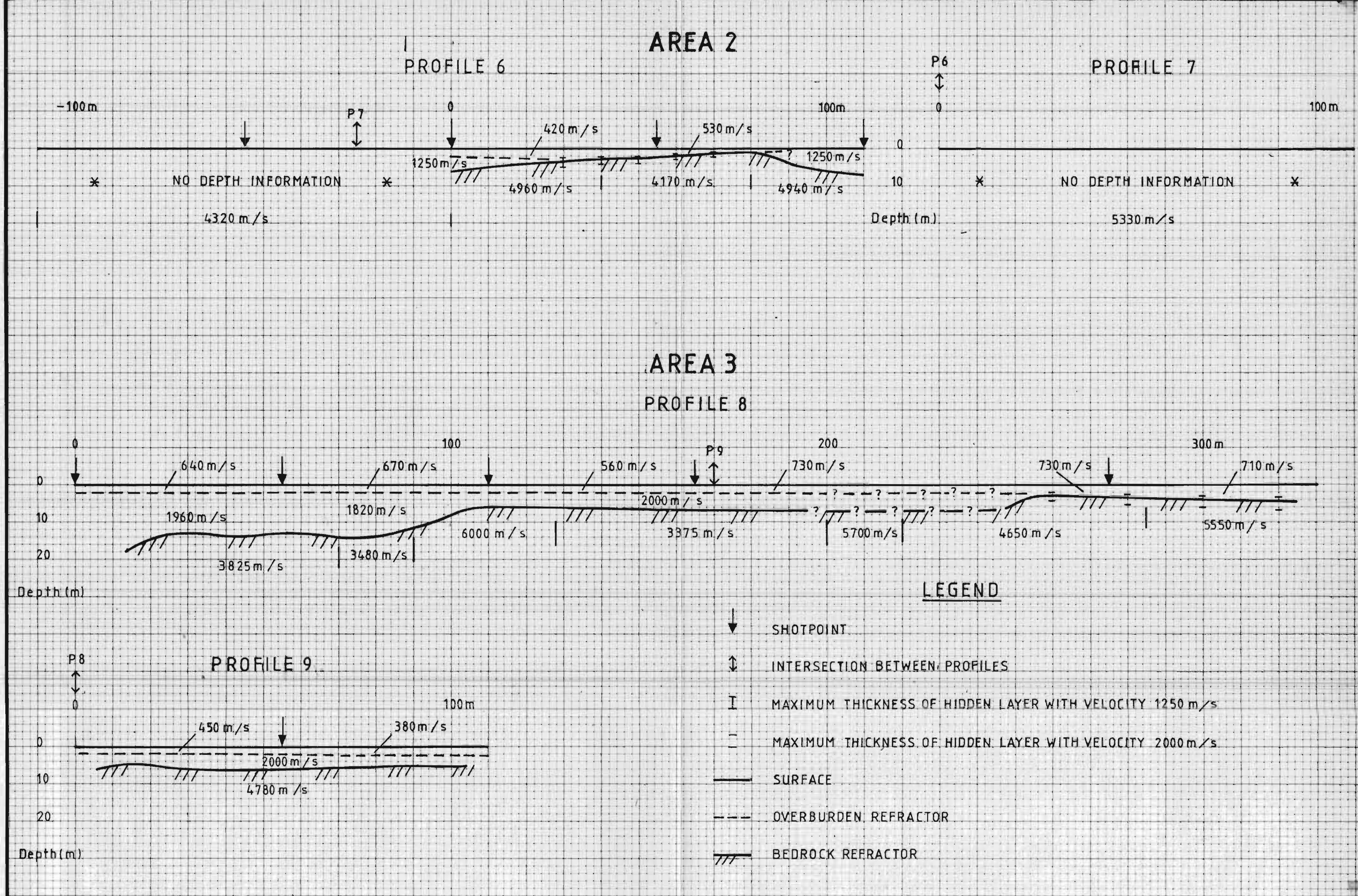
TEGNING NR. 91.152-02

KARTBLAD NR.



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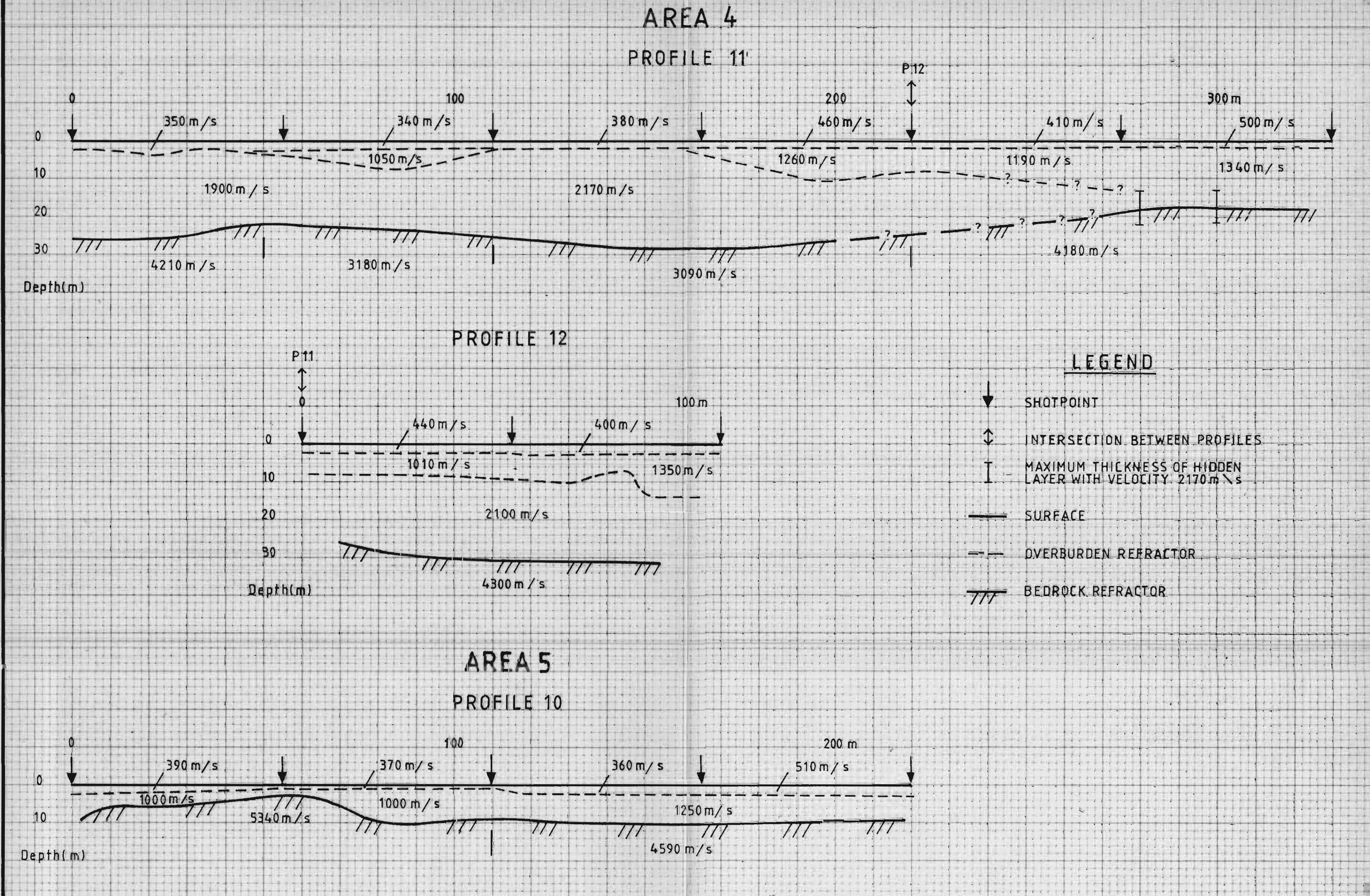

NGU
SEISMIC REFRACTION PROFILES
PETCHENGA, AREA 4&5
KOLA PENINSULA, USSR

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TRONDHEIM

TEGNING NR. 91.152-04
KARTBLAD NR.