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Forsmark site investigation

Seismic refraction survey 2004

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Abstract

This report presents the results of a seismic refraction survey performed in September 2004 in the Forsmark area by IMPAKT GEOFYSIK AB. The intention of the investigation was to correlate the existence of lineaments, indicated by magnetic airborne surveys, with the mapped propagation velocity of compressional energy in the bedrock material. Further, interpreted overburden thickness would provide information aiming to locate sites suitable for trench digging in order to display the bedrock surface.

Twelve profiles, with at total length of 7.3 km were measured. Preliminary results have been presented and delivered as part of the fieldwork reports.

The results indicate a thin overburden with a maximum thickness not exceeding 10 m and with an arithmetic median value of 2.85 m. The measured velocity distribution in the soil material varies between 350 m/s and 1,900 m/s, ranging from dry sandy moraine up to water-saturated moraine. In the bedrock material the mapped velocities indicate a homogenous igneous rock material (5,000–5,700 m/s) with rather few exceptions of low velocity anomalies.

Sammanfattning

På uppdrag av SKB Platsundersökning Forsmark utfördes under september 2004 en refraktionsseismisk undersökning i kandidatområdet. Undersökningen syftade till att genom bestämning av kompressionsvåghastigheten i bergmaterialet verifiera indikerade lineament från bl.a. flygmagnetiska mätningar. Dessutom skulle de tolkade jorddjupen ge information inför dikesgrävning. Totalt mättes 7,3 km uppdelade på 12 mätlinjer.

Resultaten tyder på relativt ringa jorddjup ej överstigande 10 m och med ett aritmetiskt medeldjup på 2,85 m. De uppmätta jordhastigheterna varierar mellan 350 m/s (torr sandig morän) upp till 1 900 m/s (vattenmättad morän). Berghastigheterna är överlag höga och indikerar ett homogent berg (5 000–5 700 m/s) med några få inslag av partier med lägre hastighet.

Contents

1 Introduction

This document reports the results obtained through a seismic refraction survey, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-04-77. The controlling documents for performing this activity are listed in Table 1-1. Both activity plan and method descriptions are SKB's internal controlling documents.

Table 1-1. Controlling documents for the performance of the activity.

Activity	Document	Number	Version
Activity plan	Refraktionsseismik 2004	Ap pf 400-04-77	1.0
Method descriptions	Metodbeskrivning för refraktionsseismik	Skb md 242.001	1.0

The field measurements of the seismic refraction investigation were performed in September 2004. Twelve profiles of totally 7.300 m were measured. The distribution of the profiles is shown in Figure 1-1.

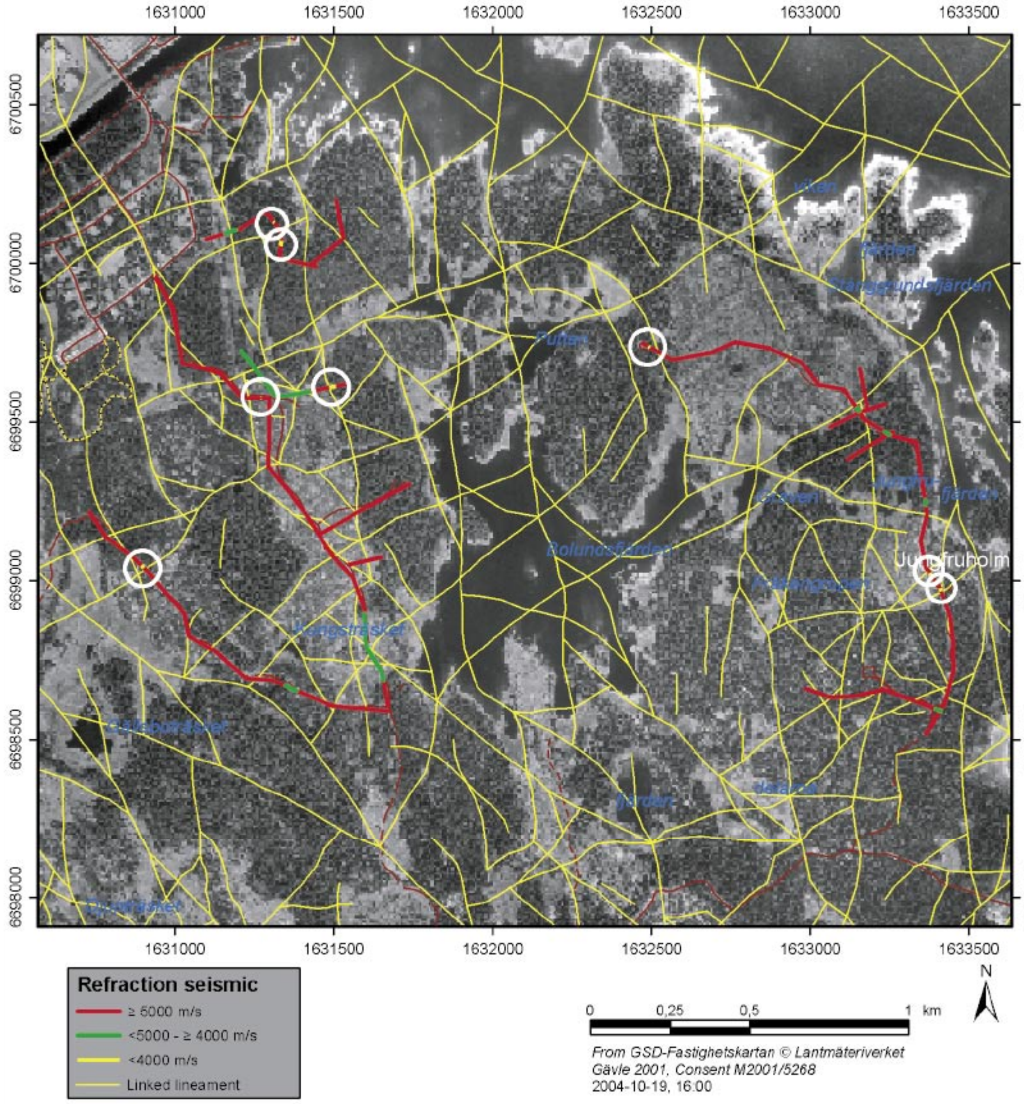


Figure 1-1. *Distribution of seismic refraction profiles. Linked lineaments interpreted from topography, airborne magnetic and electric measurements are also displayed /1/.The circles indicates short segments with low bedrock velocity (< 4,000 m/s), see Appendix 1 for details.*

2 Objective and scope

The purpose of the seismic refraction survey was to obtain information regarding thickness of the overburden in order to optimize the location of trenches, planned to expose the surface of the bedrock for detailed investigation of indicated lineaments. An additional objective was to use the mapped distribution of the bedrock velocities to verify possible correlation with indicated lineaments detected from topography and airborne magnetic and electric surveys. All presented results derived from the seismic data, i.e. velocities of the soil and bedrock, and the calculated depth profiles, have been calculated using only the first arrival of the compressional energy.

3 Equipment

3.1 Description of equipment/interpretation tools

The seismic data was collected and recorded using a 24 channel ABEM Terraloc MK6 seismograph, equipped with 18–bit +3-bit IFP A/D converters (Figure 3-1).

The data is stored primarily in an internal hard disk in SEG-2-format. The signals were registered using vertical 10 Hz geophones connected to specially designed seismic cables. The energy source used consisted of explosives of dynamite type, which where detonated by electric high current/voltage ignition caps.

The collected data was copied onto stationary computers and stored and backed-up on CD-media. A preliminary interpretation using interactive software was performed along with the fieldwork, on a daily basis, thus insuring data quality and helping in planning ahead.

The calibration of the seismic data collecting recording unit (the ABEM Terraloc Mk 6 seismograph) is a matter of testing the performance of the A/D converters. This is done by comparing a known analogue input signal of a suitably wide spectrum to the digital output of the system. Hereby the internal noise and overhearing (crosstalk) can also be monitored. Geophone system impedance can be displayed for each channel using built-in software. The most important parameter in obtaining data of correct quality is the signal/noise ratio, as in all seismic work. This is accomplished during the fieldwork, for example in planting the geophones, placing the shot points, stacking signals and having full control of these parameters during the data collection. This requires a qualified operator, fully trained in seismic interpretation technique.

Figure 3-1. *The seismic equipment (ABEM Terraloc MK6, also shown on inserted picture) mounted on a small field truck.*

4 Execution

4.1 General

The seismic refraction survey was performed in accordance with the method description: “Metodbeskrivning för refraktionsseismik”, SKB MD 242.001 ver 1.0.

4.2 Preparations

Prior to the start of data acquisition, all function tests were carried out with satisfying results.

4.3 Execution of field work

The twelve investigated profiles were sectioned into straight line segments which were marked in the terrain and cleared to obtain free sight. The placing and marking of the survey lines were performed by the field crew of IMPAKT GEOFYSIK AB and by CALITERRA who also was responsible for the geodetic mapping of the survey.

Geophones were placed along the investigation lines, the number of geophones depending on the length of the straight section. Geophone spacing varied between 2 and 5 m according to terrain obstacles and to the desired resolution in monitoring the vertical velocity distribution. The shot points were established with the intended separation of approximately 25 m in order to give enough resolution in determination of the horisontal velocity distribution of the overburden. The collected data was controlled and stored in specific files for each shot. The normal production rate is 6–10 layout lines per day which gives an amount of 500–1,100 m seismic profile per day. Altogether 436 shots were fired, resulting in 436 data files.

4.4 Data handling/post processing

The collected data is stored in SEG-2 format. Each file represents the information from a specific shot point. The file identifier refers to a unique shot number which is included in the filename. The file consists of a header with information on acquisition date, time, parameters as recording duration, sample rate, number of used channels, and specifies the format for the binary 32 bit data fields where the registered data from each geophone are located.

The data files are transferred to a interpretation computer where the first arrival time of the first arriving compressional energy wave are determined, using an interactive technique providing manual check of each trace.

Geometries of geophones and shot points together with the obtained arrival times are stored in layout-specific files. From these datasets the time elapsed for a compression wave front from each geophone position down to the underlying refractor is calculated. These times are translated into depths by using the velocity information from the shot points within the layout.

4.5 Non-conformities

The survey was conducted in correspondence with the Activity plan and the Method description and no non-conformities that affect the result in negative aspect as been identified. The survey was extended somewhat compared to the Activity Plan.

5 Results

The results of the seismic refraction survey are presented as profiles with information on ground elevation, bedrock elevation, and velocities of the overburden and in the bedrock including low velocity anomalies.

The results were calculated strictly from the results from the seismic measurements, no correlation from drillings or other information has been used in the interpretation work

The main part of the surveyed area shows a very thin soil layer within which no actual layers are detectable or even present. In areas with a thicker overburden, it might be possible to detect intermediate refractor boundaries. The impression, however, is that it is very difficult to connect velocity horizons in the overburden material and that the relatively high variations in velocities is due to rather small-scale irregularities caused by different grades of compression, water- and clay content, occurrence of boulders etc.

The velocities of the overburden indicate a moraine material varying in compactness, constitution and presence of boulders.

These high variations in the velocities in the soil material in combination with a thin overburden and relatively large geophone separations (5 m), implies that it might be hard to detect the presence of a high velocity layer underlying the topsoil. The presence of such an undetectable layer would give an erroneous contribution to the calculated depths that in the worst case could give a considerably deeper bedrock surface.

For most parts of the profiles (more than 95%) the calculated velocities of the bedrock are high, indicating a homogeneous material of igneous type. The few displayed exceptions of intervals with low velocity (2,900–4,200 m/s) are probably caused by fracture zones or indicating occurrence of weathered bedrock material. Results from each profile are presented in Appendix 1.

5.1 Presentation of data and results

All collected raw data was delivered to SKB after the termination of the field activities. All results has been reported as drawing files (.dwg) and in database showing coordinates and velocities (.xls). Output data has been prepared and stored according to SICADA format, see Table 5-1.

Table 5-1. Output data files and format.

Object	File name	No of files	Data Format
Raw data	008020.sg2–008455.sg2	456	SEG-2
Drawing	Forsmark_refrseis041.dwg	1	dwg
Database	Forsmark_refrseis041.xls	1	xls
SICADA	EG-170_Forsmark_refrseis041	1	xls
SICADA	GP-320_Forsmark_refrseis041	1	xls

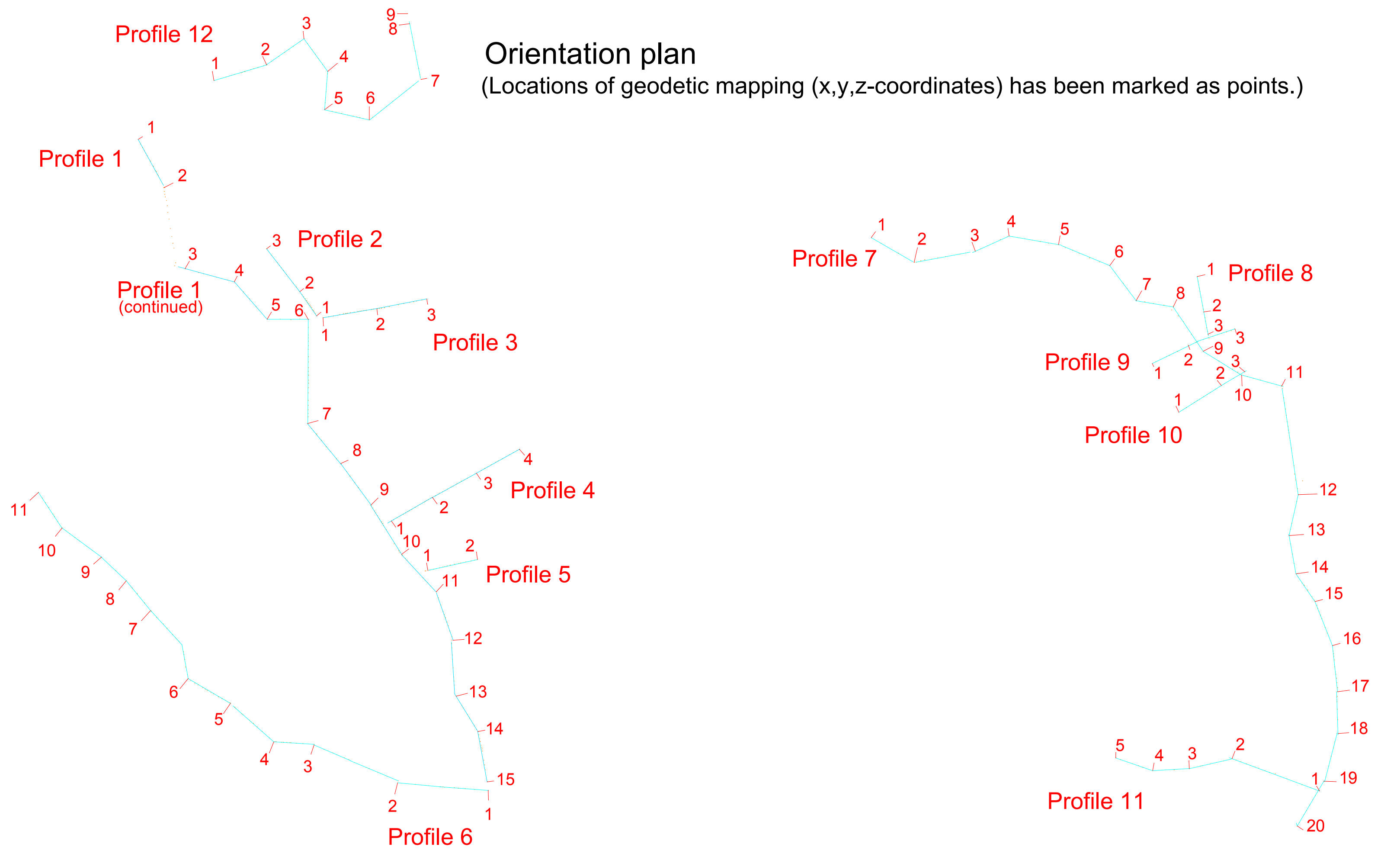
6 References

/1/ **Isaksson H, Thunehed H, Keisu M, 2004.** Interpretation of airborne geophysics and integration with topography. SKB P-04-29.

Presentation of the seismic sections

Forsmark Seismic Refraction Profiles1 - 12

Orientation plan
(Locations of geodetic mapping (x,y,z-coordinates) has been marked as points.)



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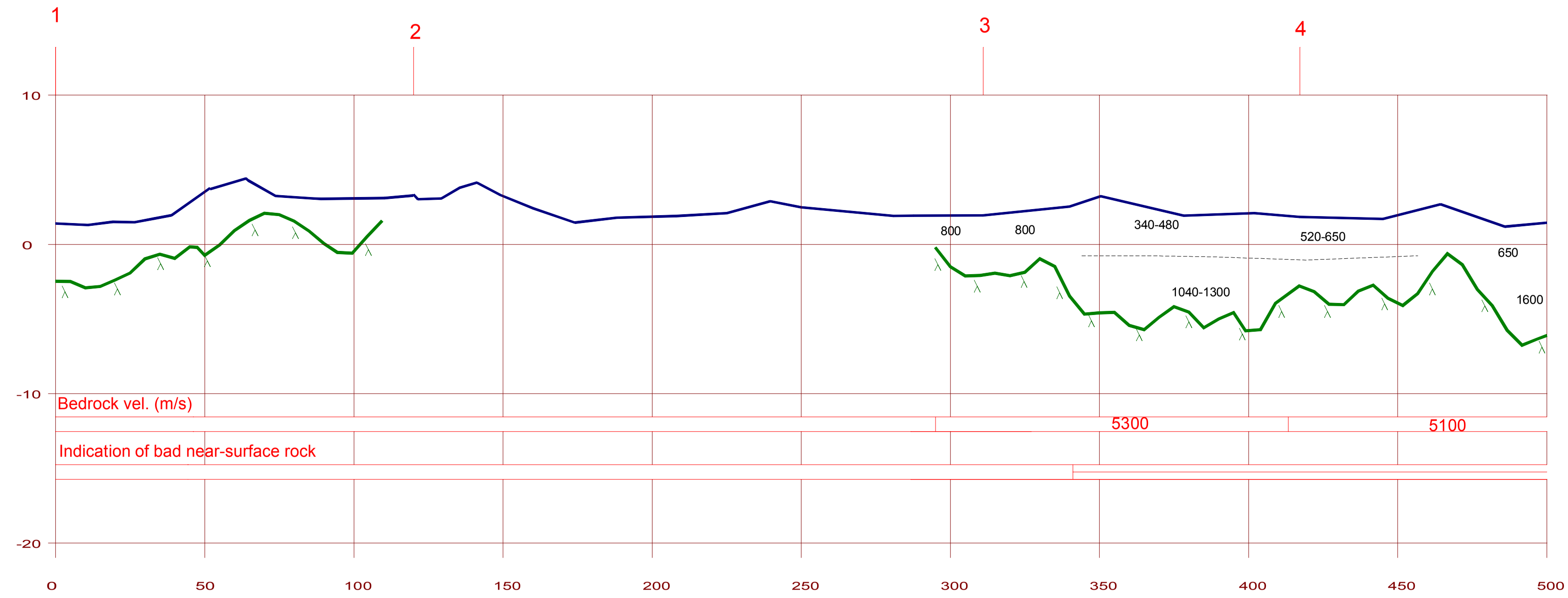

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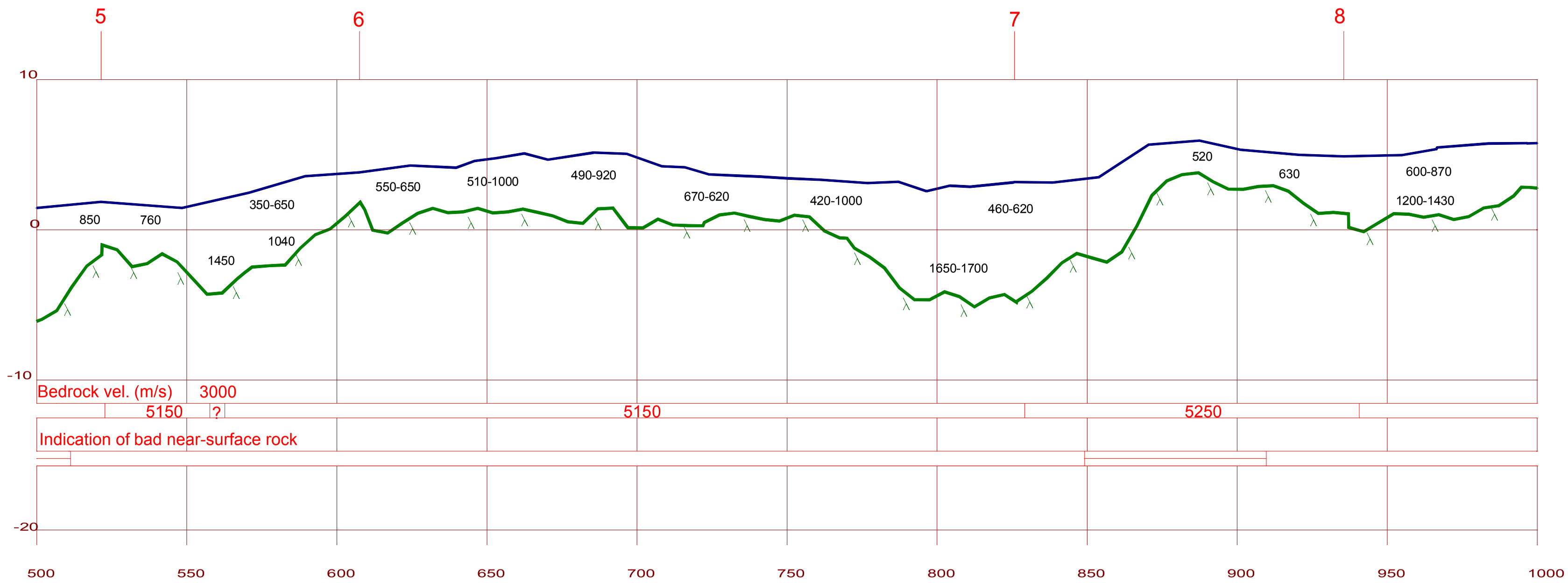

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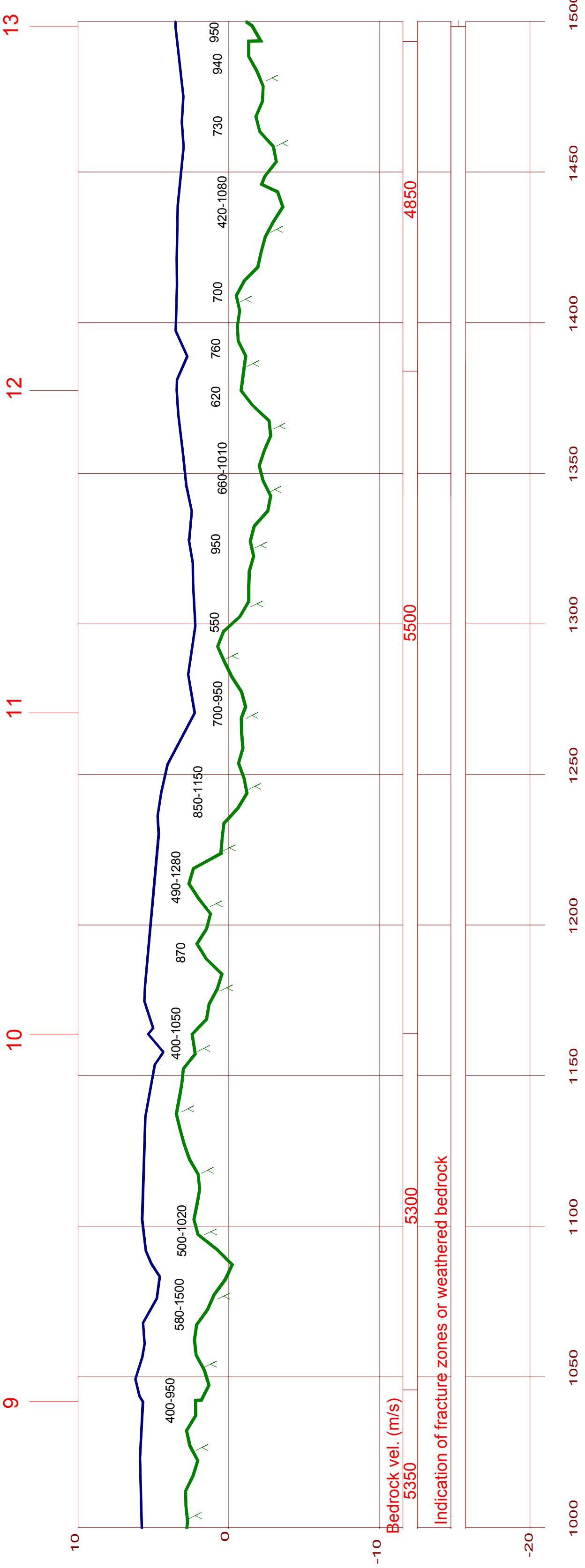
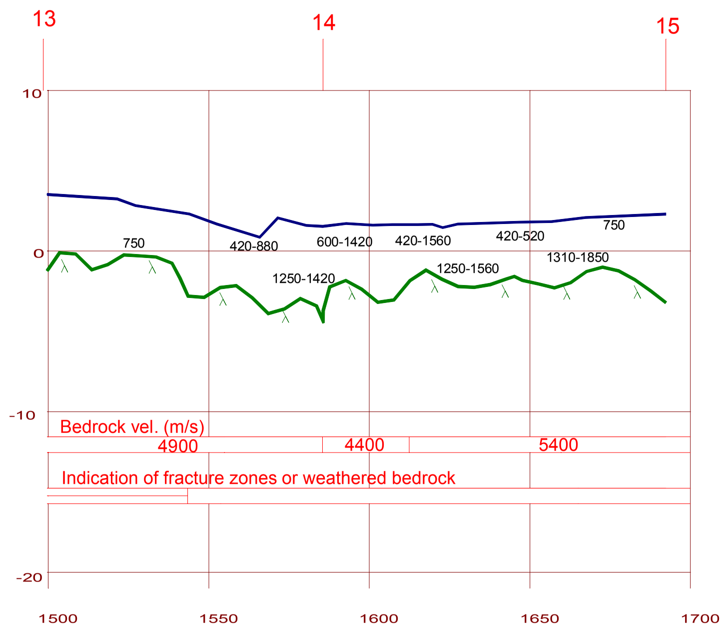
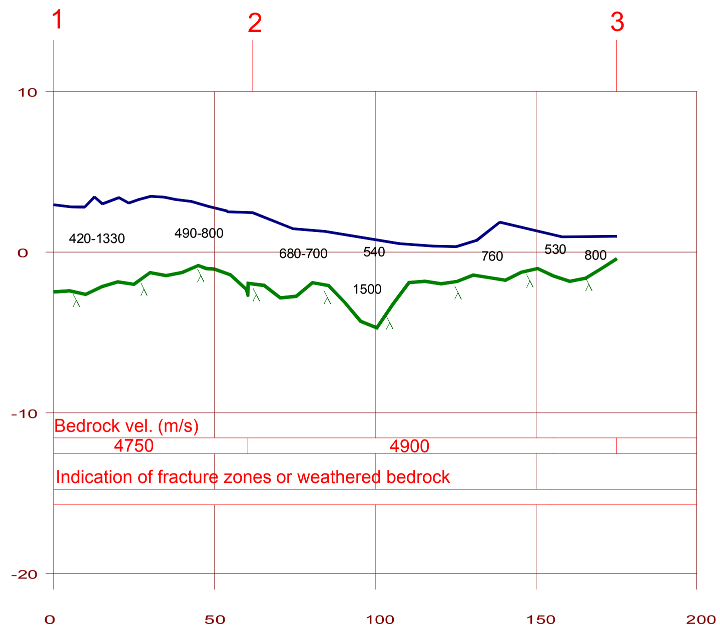


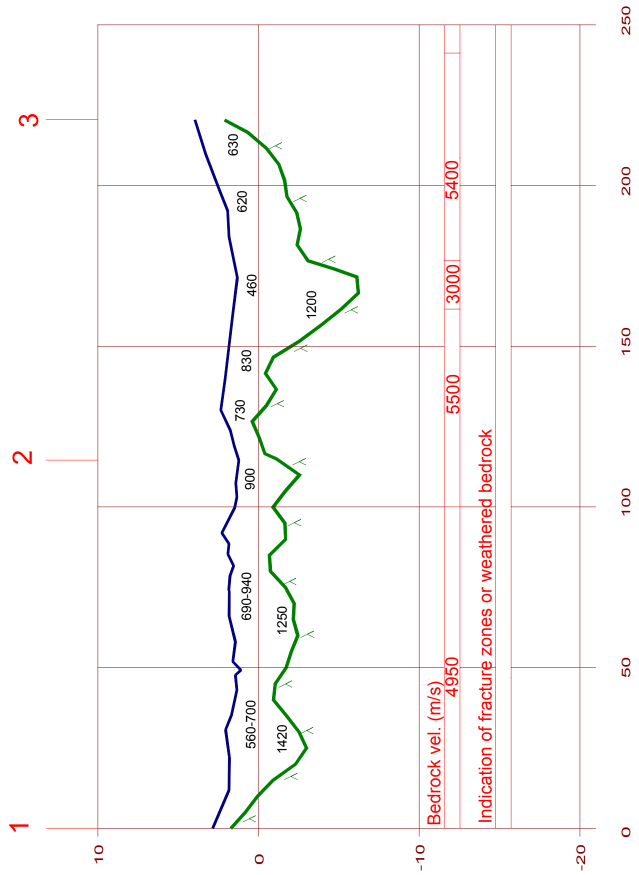
Profile 1 km 1/500-1/700



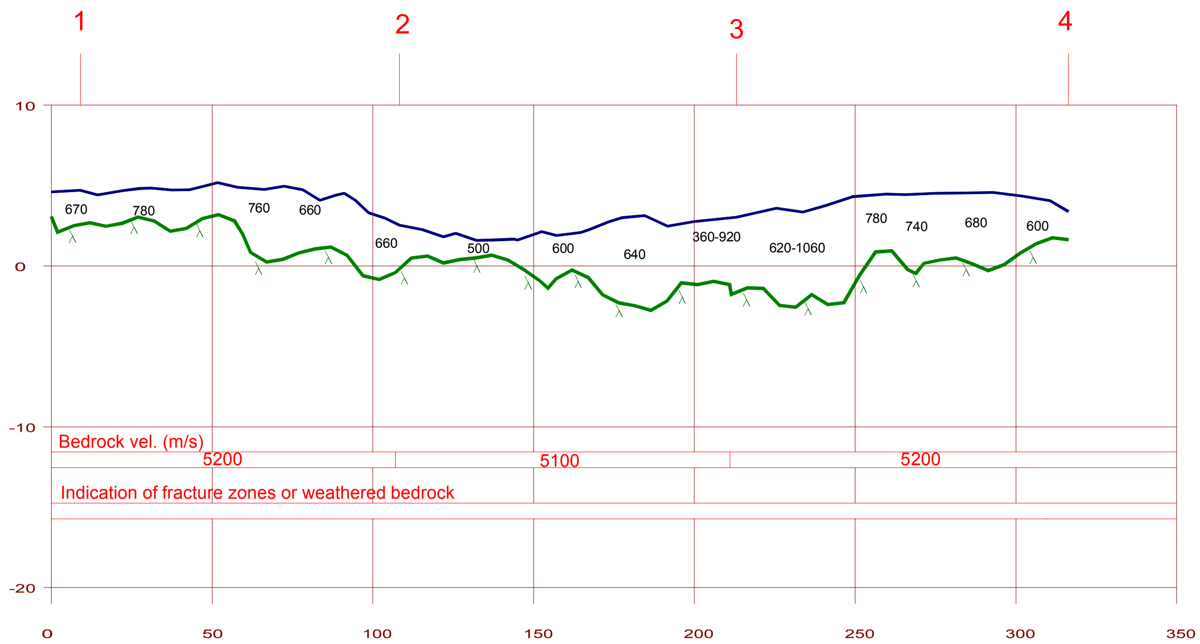
Profile 2 km 0/000-0/200



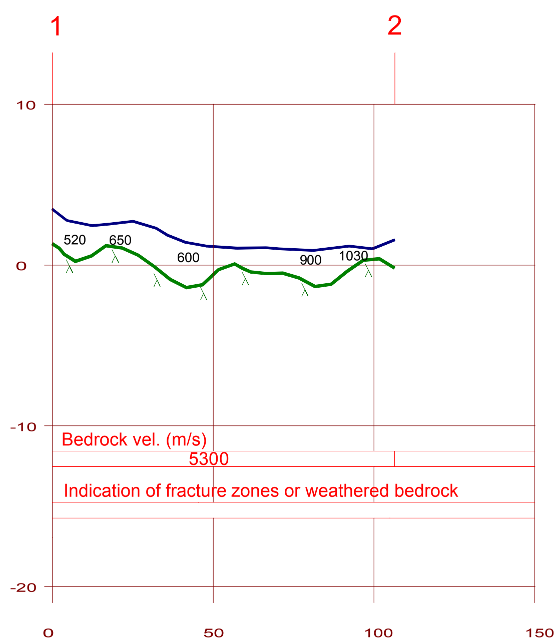
Profile 3 km 0/000-0/250



Profile 4 km 0/000-0/350



Profile 5 km 0/000-0/150



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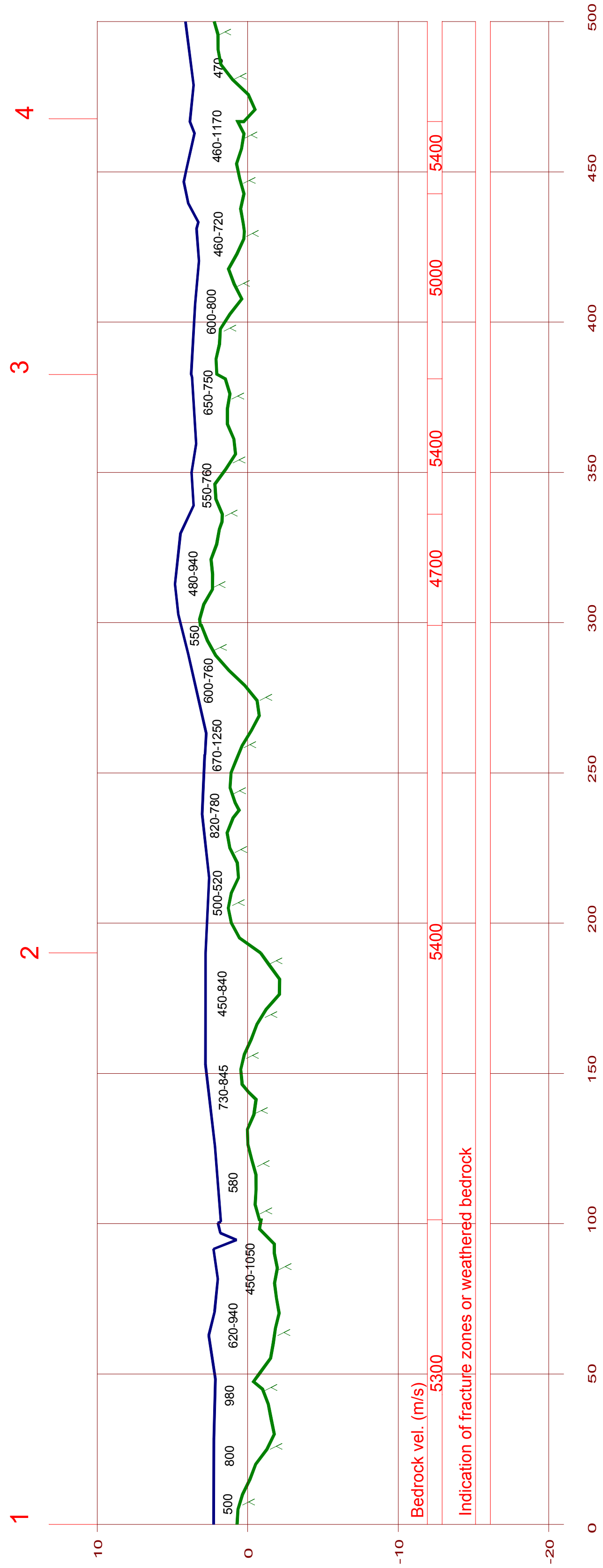

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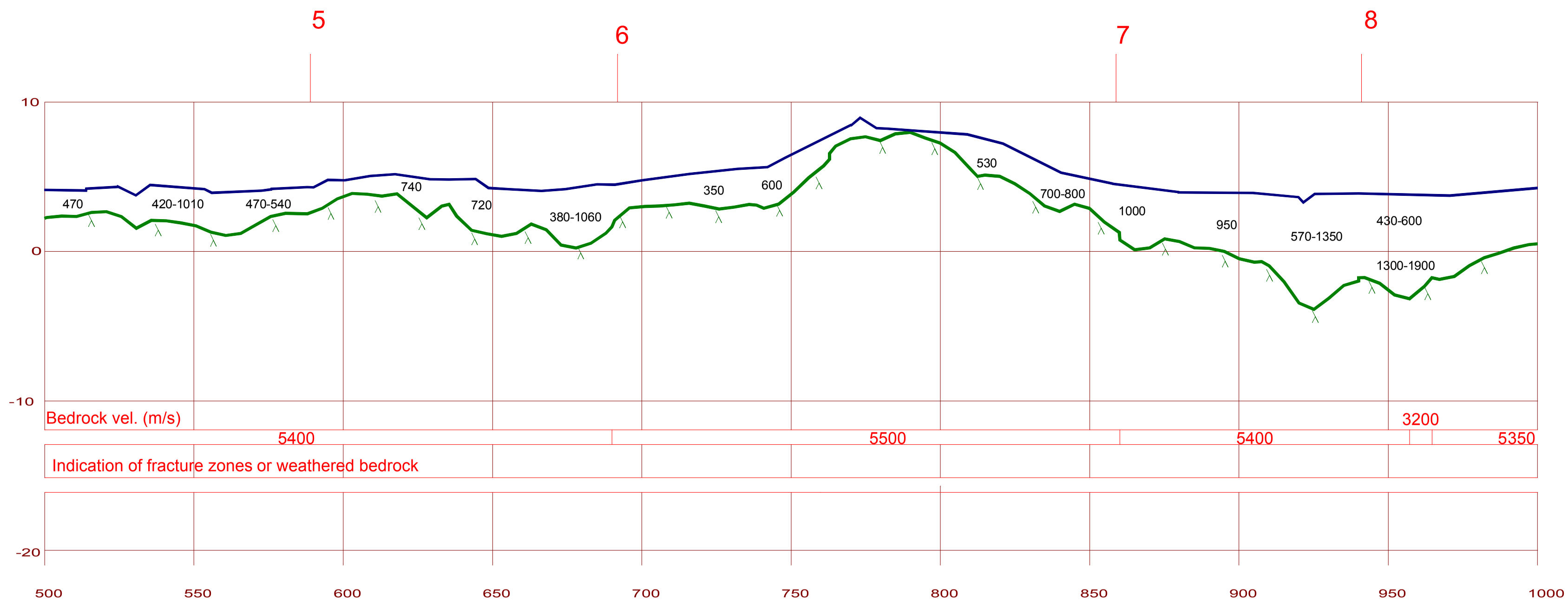

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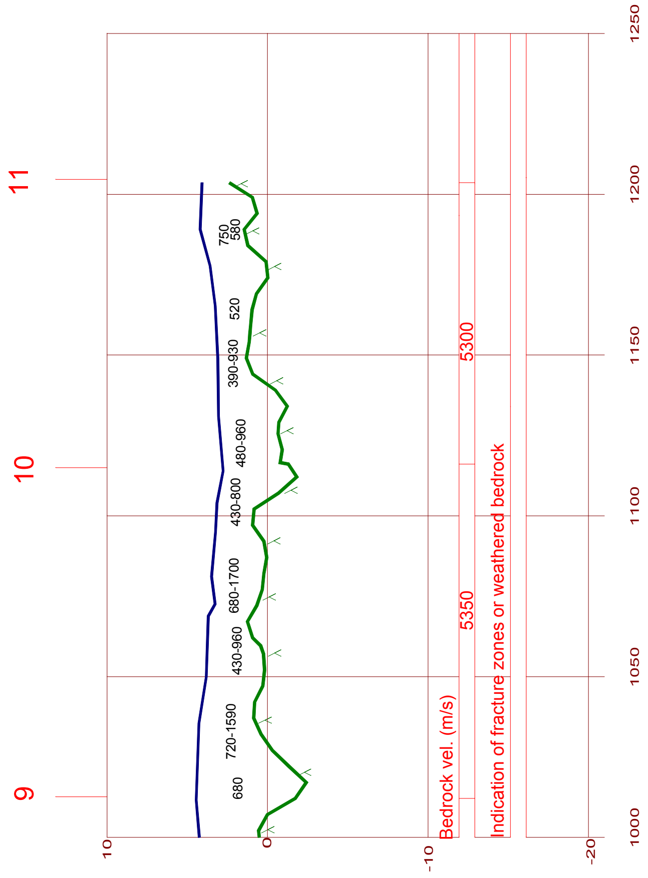

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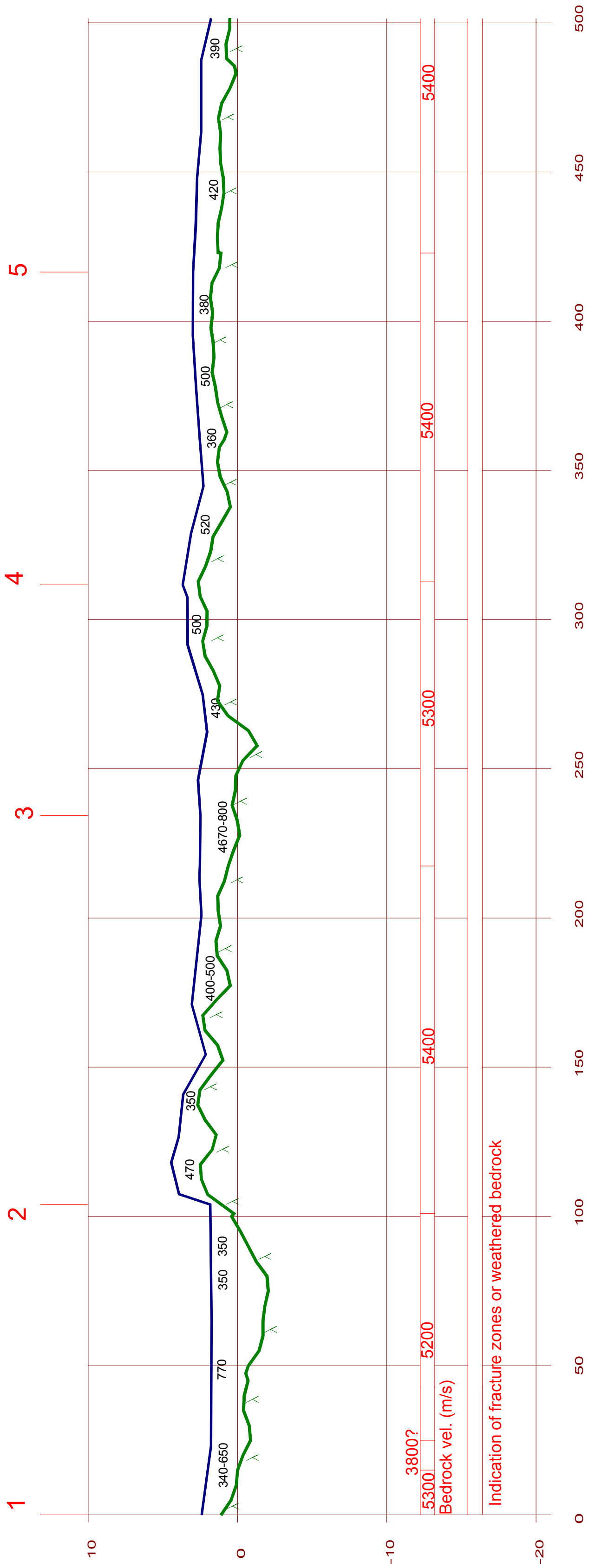

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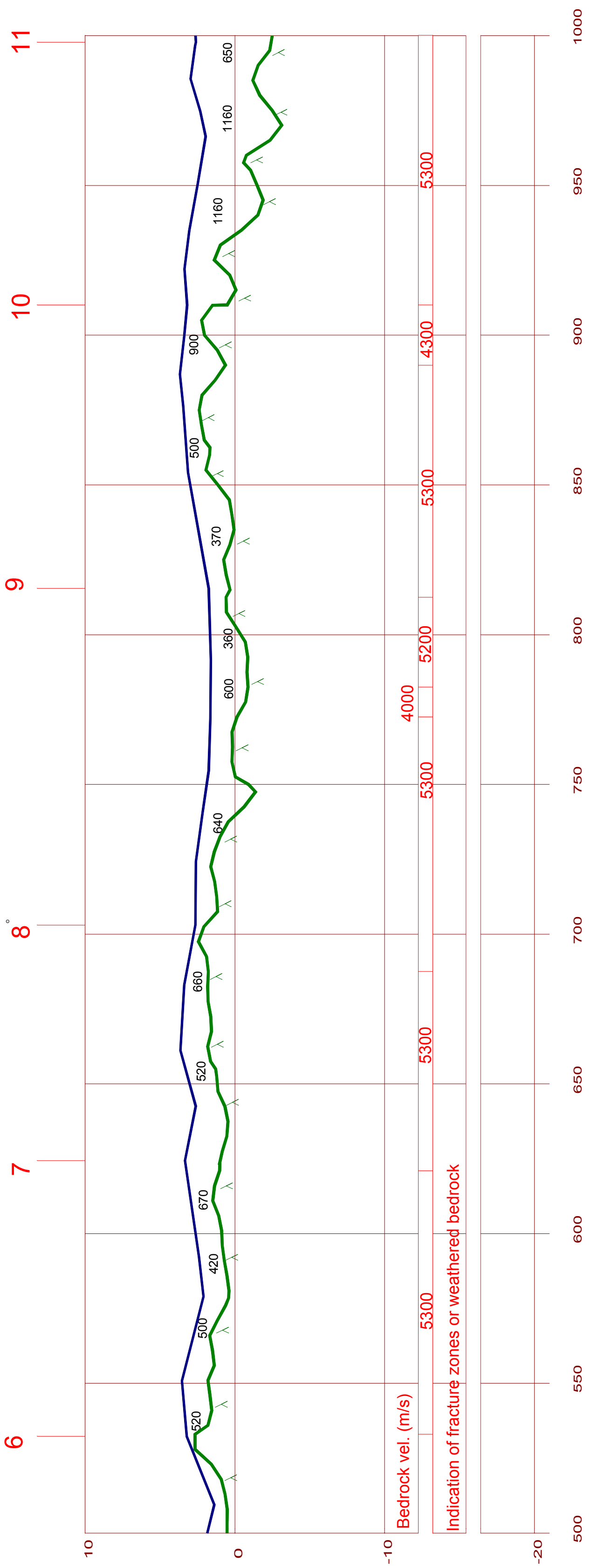

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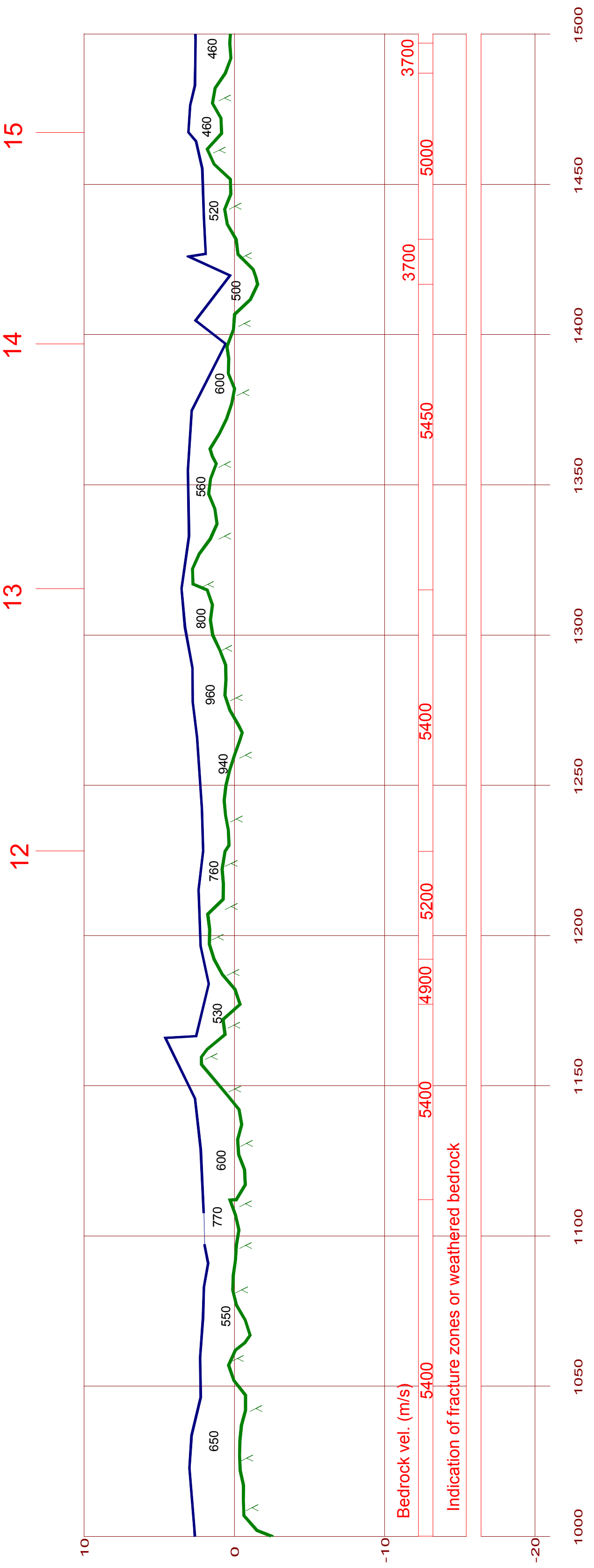
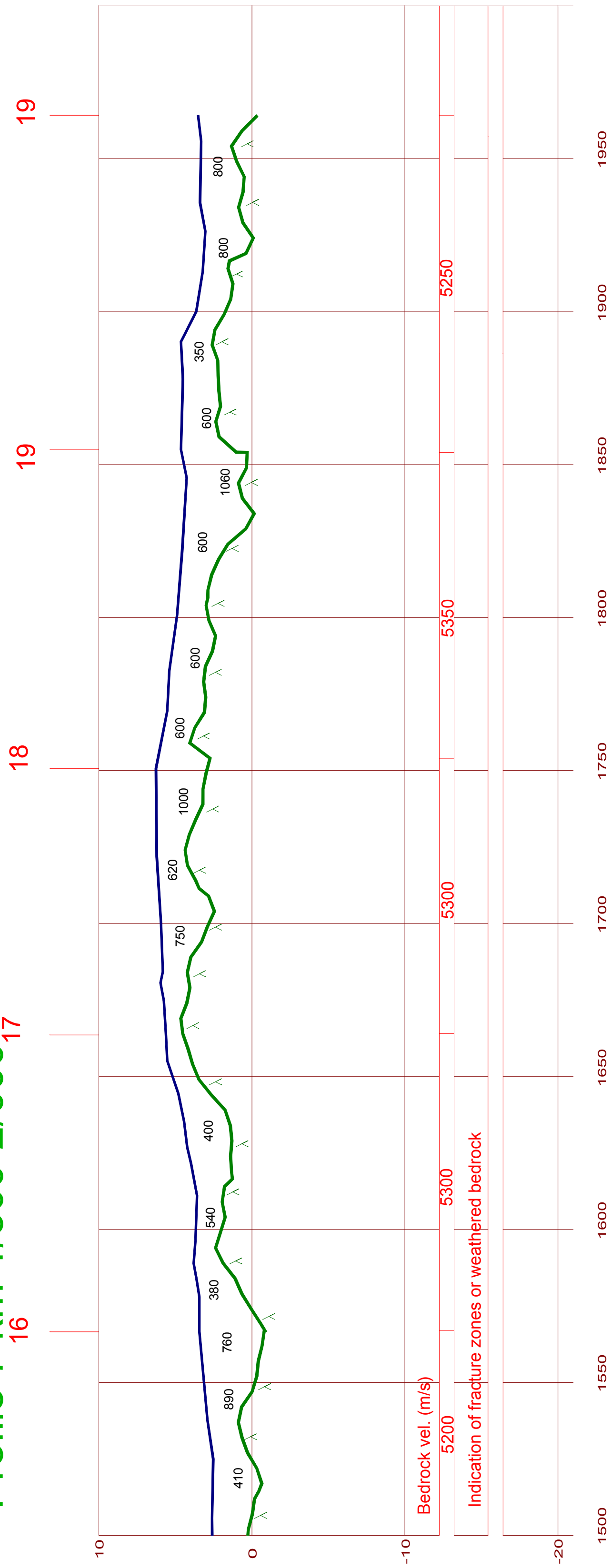
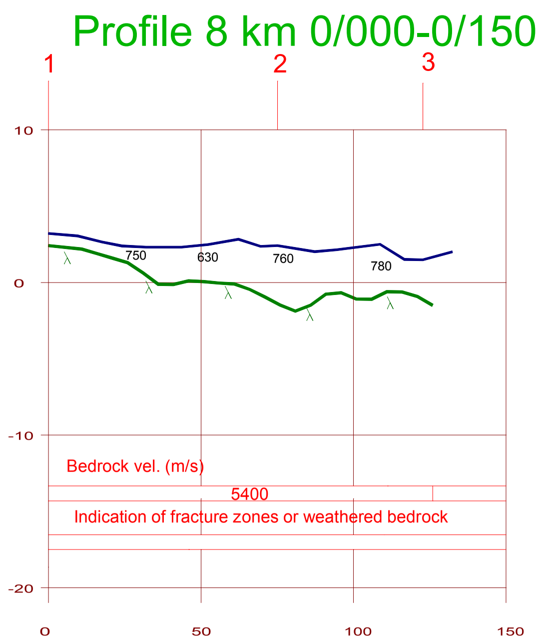
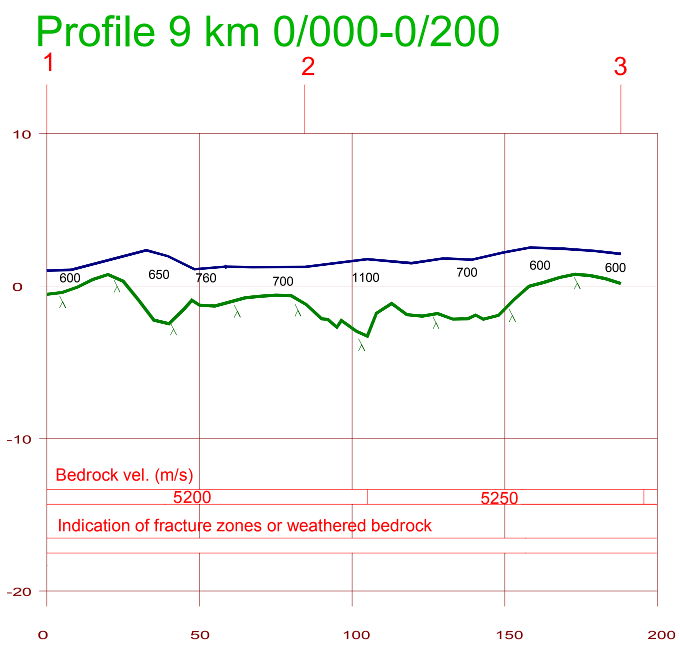
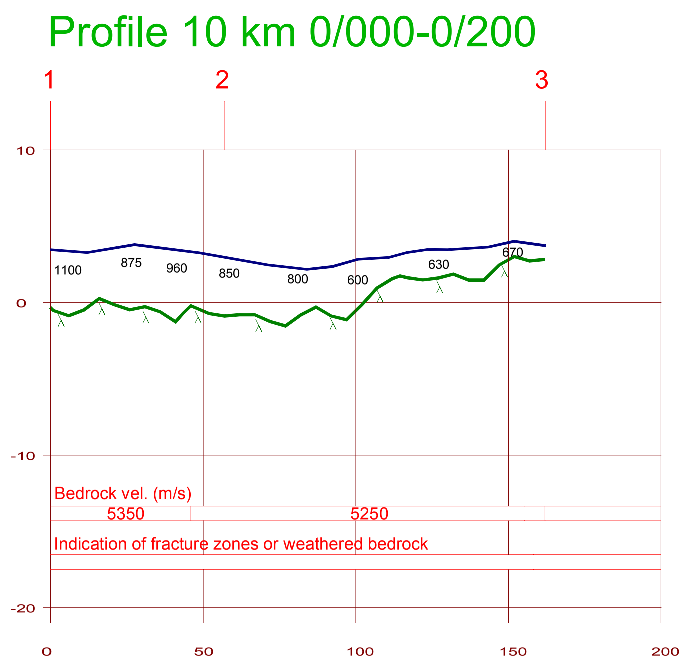


Profile 7 km 1/500-2/000

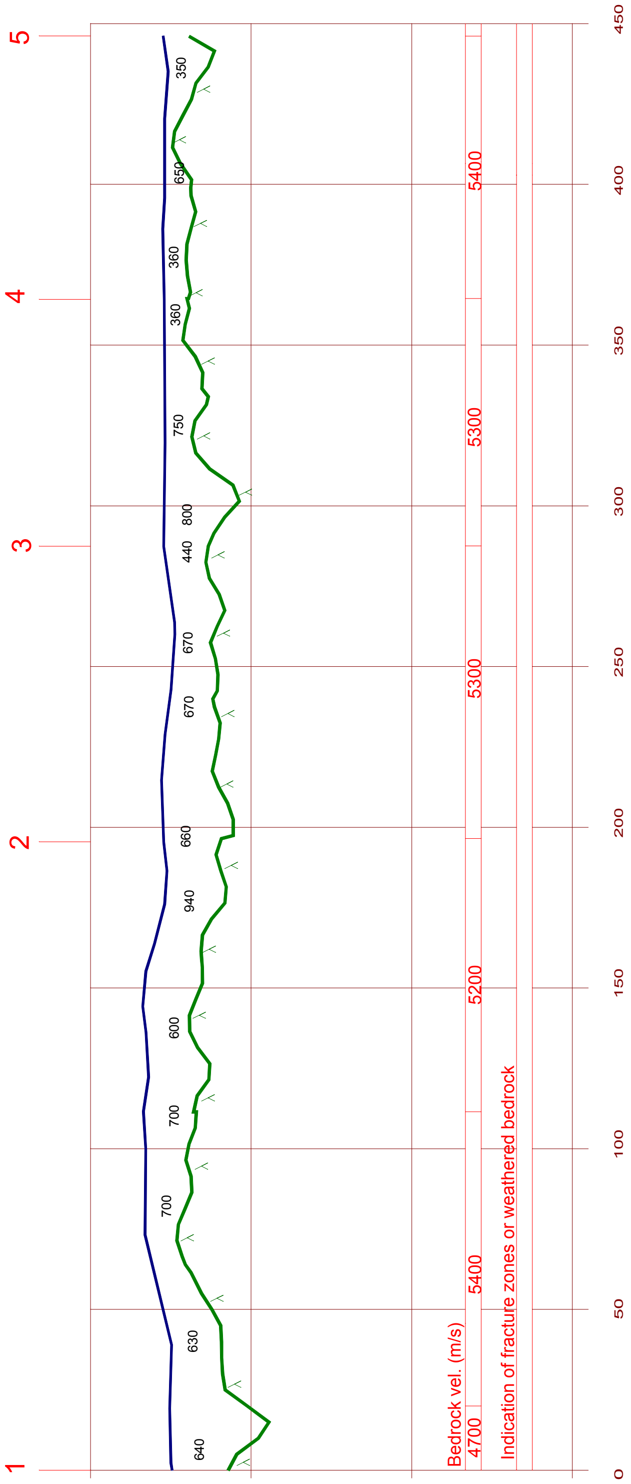



Profile 8 km 0/000-0/150
1
2
3
10
0
-10
-20
0
50
100
150
750
630
760
780
Bedrock vel. (m/s)
5400
Indication of fracture zones or weathered bedrock


Profile 9 km 0/000-0/200
1
2
3
10
0
-10
-20
0
50
100
150
200
600
650
760
700
1100
700
600
600
Bedrock vel. (m/s)
5200
5250
Indication of fracture zones or weathered bedrock


Profile 10 km 0/000-0/200
1
2
3
10
0
-10
-20
0
50
100
150
200
1100
875
960
850
800
600
630
670
Bedrock vel. (m/s)
5350
5250
Indication of fracture zones or weathered bedrock

Profile 11 km 0/000-0/450



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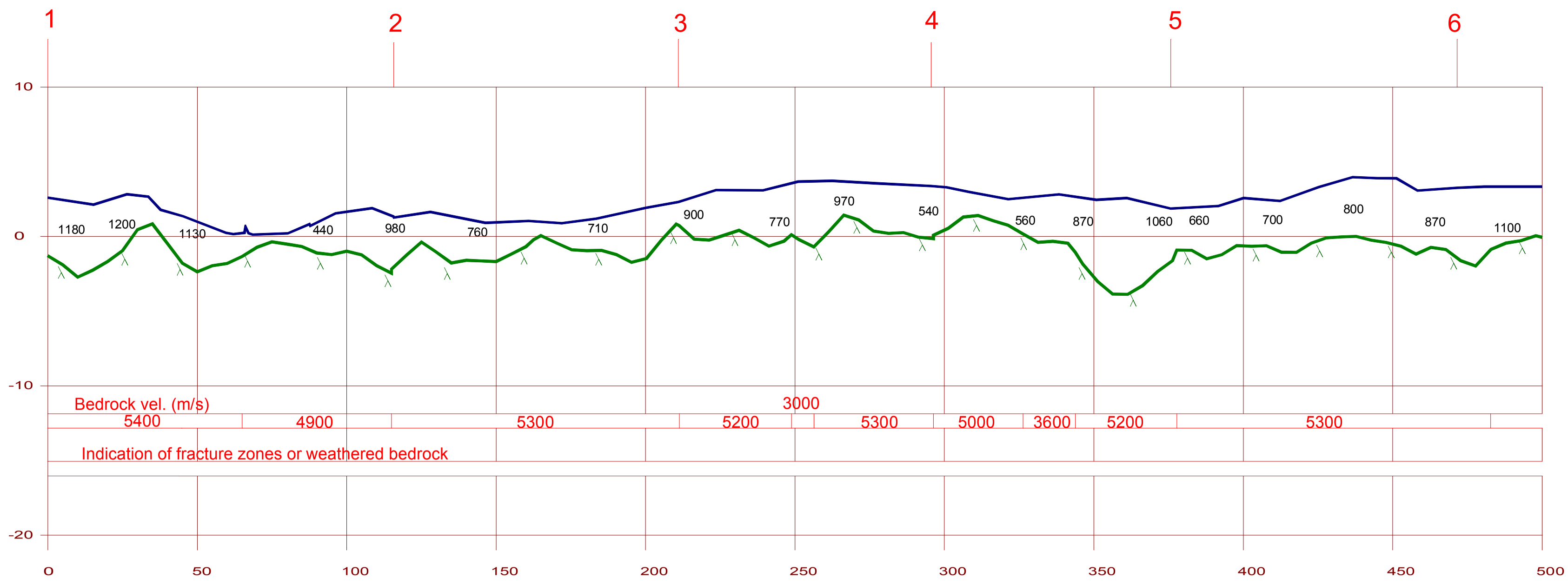

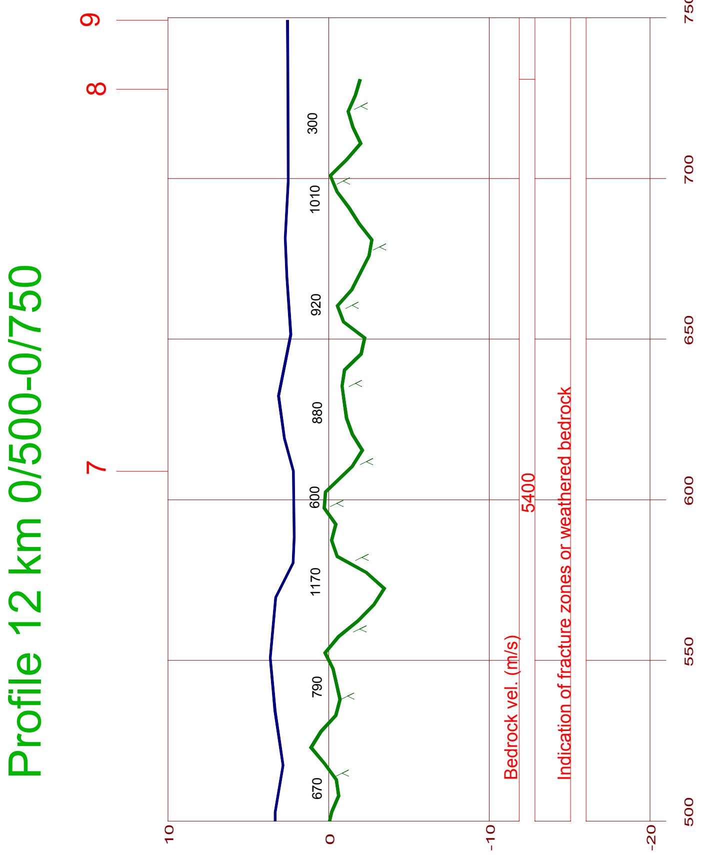
Profile 12 km 0/500-0/750
9
8
7
670
790
1170
600
880
920
1010
300
Bedrock vel. (m/s)
5400
Indication of fracture zones or weathered bedrock
10
0
-10
-20
500
550
600
650
700
750