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Forsmark site investigation

Seismic refraction survey 2005–2006

Björn Toresson, IMPAKT GEOFYSIK AB

August 2006

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

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Abstract

This report presents the results of a seismic refraction survey performed in the Forsmark area by IMPAKT GEOFYSIK AB during the period May 2005 to March 2006. The intention of the investigation was to cover the area with unbiased distributed seismic survey lines in order to map the propagation velocity of compressional energy (P-wave velocity) in the bedrock material, and by this establish a quantitative analysis of the presence of fracture zones or other low-velocity anomalies in the area.

31 profiles, with at total length of 23,200 m were measured. The measurements were performed according to the activity plan AP PF 400-05-034 and the method description SKB MD 242.001 ver 1.0 with the following exceptions: the geophone separation varied between 2 and 5 m depending upon the terrain.

The results indicate a thin overburden with a maximum thickness not exceeding 20 m and with an arithmetic median value of 3.13 m. The measured velocity distribution in the soil material varies between 330 m/s and 2,500 m/s, ranging from dry friction sandy soil up to very well compressed moraine. In the bedrock material, the mapped velocities indicate a homogenous igneous rock material (5,000–5,700 m/s) with rather few low-velocity anomalies.

Sammanfattning

I denna rapport presenteras resultaten av refraktionsseismiska undersökningar utförde av IMPAKT GEOFYSIK AB under perioden maj 2005 till mars 2006. Undersökningen syftade till att förutsättningslöst täcka mätområdet med refraktionsseismiska profiler för att bestämma kompressionsvåghastigheten (P-vågen) i bergmaterialet, och därmed kartlägga eventuella låghastighetszoner i det undersökta området.

Totalt mättes 23 200 m uppdelade på 31 mätlinjer. Mätningarna har följt aktivitetsplanen AP PF 400-05-034 och metodbeskrivningen SKB MD 242.001 ver 1.0, med följande avvikelser: geofonavstånden har varierat mellan 2 och 5 m utifrån förutsättningar i terrängen etc.

Resultaten tyder på relativt ringa jorddjup ej överstigande 20 m, med mediandjup 3,13 m. De uppmätta jordhastigheterna varierar mellan 330 m/s upp till 2 500 m/s indikerande torr sand till hård packad morän. Berghastigheterna är överlag höga (5 000–5 700 m/s) med ett relativt fåtal inslag av zoner 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 400-05-034. The controlling documents for performing this activity are listed in Table 1-1. Both the activity plan and the method description are SKB's internal controlling documents.

The field measurements were performed in the period May 2005–March 2006. 31 profiles with a total length of 23,200 m were measured. The location of the measured profiles is shown in Figure 1-1. The present work is a continuation of similar measurements reported in /1/.

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

Activity	Document	Number	Version
Activity plan	Refraktionsseismik 2005	AP PF 400-05-034	1.0
Method description	Metodbeskrivning för refraktionsseismik	SKB MD 242.001	1.0

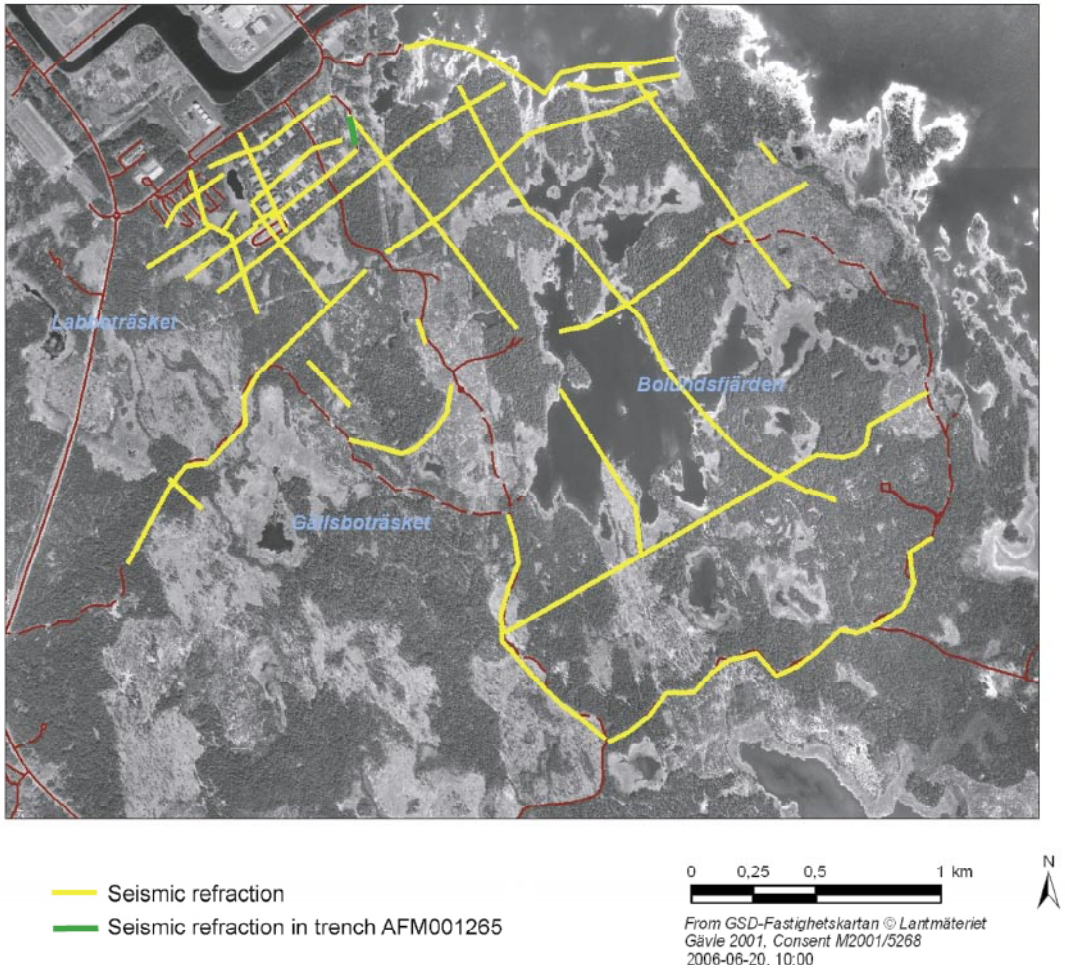


Figure 1-1. *The location of the seismic refraction profiles. The location of the trench AFM001265 in where the detailed survey was made is also marked.*

2 Objective and scope

The purpose of the seismic refraction survey was to establish a picture of the uppermost bedrock properties, based on the calculated velocities of the compressional energy propagation (P-wave velocity). The resulting velocity-grid, covering the target area, can also be used to verify possible correlations with lineaments indicated by other information. Another purpose is to estimate the soil depths along the measured profiles.

All presented results are 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 pulse of the compressional energy and there has been no adjustment or correction of the results based on information from other activities.

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.

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 seismic signal was generated by explosives of dynamite type, which were detonated by electric high-voltage ignition caps.

The collected data was copied onto stationary computers, 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 recording unit (the ABEM 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 relevant 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. This is of practical use in 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 gives an illustration of the fieldwork on an ice-covered lake.

Figure 3-1. *Some of the profiles were measured during the winter on the lakes. The geophones were placed on top of long steel-stakes, pressed into the lake sediments.*

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, SKB internal document.

4.2 Preparations

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

4.3 Execution of field work

The approximate locations of the survey lines were defined by SKB. When placing the lines in the terrain, the profiles were divided into straight sections of varying length, marked and cleared to obtain free sight. Clearing was performed manually in order to cause minimal environmental disturbance.

The geodetic mapping of the profiles was done in direct connection to the execution of fieldwork, using a differential DGPS system with sub-metre precision. An optical levelling instrument was used for the altitude measurements.

The geophones were placed along the survey lines. The number of geophones varied according to the length of the straight sections. The geophone spacing varied between 1 and 5 m, depending upon terrain obstacles and the desired resolution in the velocity estimation.

The shot points were established with an intended separation of approximately 25 m in order to give adequate resolution in determination of the horizontal velocity distribution of the overburden. Explosives were used as seismic energy source at all shot points, except for a few locations in the profiles within the residential area in northwest (LFM000889–LFM000901). At these few locations a sledgehammer was used, in order to avoid damage on buried utilities such as pipes and cables. However, for the offset shots (used for calculating bedrock velocities) explosives were always used.

The collected data was controlled and stored in specific files for each shot.

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 that is included in the filename. The file consists of a header with information on acquisition date, time, measuring parameters (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 an interpretation computer where the time of the first arriving compressional wave is 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

In accordance with the Method Description, explosives were used as seismic energy source at more than 95% of the shot points. In cases where underground cables or pipes were located in the immediate vicinity of the desired shot point, a sledgehammer was used in order to prevent damage from the explosion.

In all other aspects the survey was conducted in correspondence with the Activity plan and the Method Description (except for the varying geophone separation), and no non-conformities were identified.

5 Results

The results of the seismic refraction survey are presented as profiles with information on ground altitude, bedrock elevation, and P-wave velocities of the overburden and P-wave velocities of the bedrock, including low-velocity anomalies. The results were calculated strictly using the output from the seismic measurements, and no correlation from drilling or other information has been used in the interpretation work.

The main volume of the surveyed area indicates a thin soil layer within which no layering is detectable. In areas with a thicker overburden it might be possible to detect intermediate layer boundaries. The analysis shows that it is very difficult to interpret continuous velocity horizons in the overburden material due to the relatively frequent variations in velocities. This behaviour is probably due to rather small-scale irregularities, caused by different grades of compression, varying 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. The variations in the velocities in the soil material in combination with a thin overburden and relatively large geophone separations (typically 5 m), result in a situation where it is hard to detect the presence of a high velocity layer underlying the topsoil. The presence of such an undetected layer would give an erroneous contribution to the calculated depths, which in the worst case could result in a considerably deeper bedrock surface.

The high velocities of the bedrock (typically 5,000–5,700 m/s) indicate a homogeneous material of igneous type. The few exceptions of low-velocity zones (2,300–4,100 m/s) are probably caused by fracture zones or occurrence of weathered bedrock. The exceptions are displayed in the drawings and data files. In some profiles the velocities from long-offset shots as well as from shots close to the geophone layout are presented. The latter are presented above the line. In many cases the velocities from shots close to the geophones are considerably lower than the long-offset shots. This indicates the possible presence of an upper zone of bedrock material with lower velocity than the deeper situated high-velocity rock. Only in cases when there has been enough data to compare the results from closer and more distantly located offset shots, the velocities calculated from the closer shots are presented in the diagrams (Appendix 1).

Along with the specified seismic survey, a direct measurement of the P-wave velocity was carried out on the exposed bedrock surface in the trench AFM001265 (Figure 1-1), parallel to, and approximately 30 m to the East from the profile LFM000894. This measurement was carried out using the same equipment as in the main survey, but with the geophone spacing reduced to one meter. The geophones were placed in predrilled holes 3–5 cm deep and 6–8 mm in diameter. A sledgehammer was used to generate the seismic signal.

The results are displayed in Figure 5-1 and indicate high bedrock velocities with some near-surface irregularities, slightly more expressed in the northern part of the trench. The estimated mean velocity was 5,470 m/s. There is no indication of any low-velocity zones along this profile.

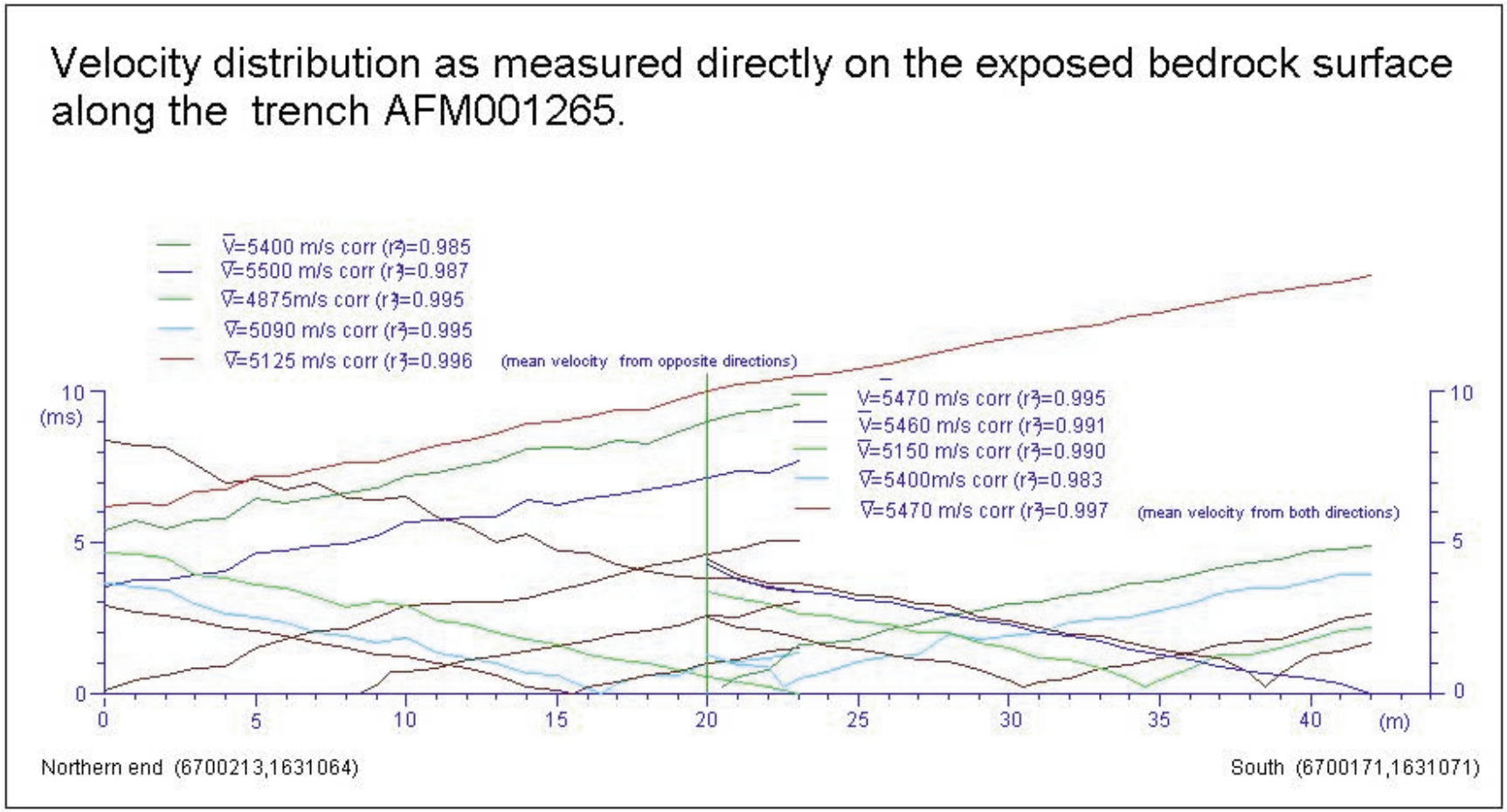


Figure 5-1. *Velocity estimation directly on the exposed bedrock in the trench AFM001265 from (6700171,1631071) to (6700213,1631064).*

5.1 Presentation of data and results

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

Table 5-1. Output data files and format.

Object	File name	No of files	Data Format
Raw data	009302.sg2 – 011719.sg2	1356	SEG-2
Drawing	Forsmarkrefrseis05.dwg	1	dwg
Database	Forsmark_refrseis05.xls	1	xls
SICADA	EG-170_Forsmark_refrseis05	1	xls
SICADA	GP-320_Forsmark_refrseis05	1	xls

The 31 profiles are identified by the SICADA ID-codes:

LFM000889	LFM000915	LFM001013
LFM000890	LFM000916	LFM001014
LFM000891	LFM000917	LFM001015
LFM000892	LFM000918	LFM001016
LFM000893	LFM000919	LFM001017
LFM000894		
LFM000895		
LFM000896		
LFM000897		
LFM000898		
LFM000899		
LFM000900		
LFM000901		
LFM000902		
LFM000903		
LFM000904		
LFM000905		
LFM000906		
LFM000907		
LFM000908		
LFM001018		

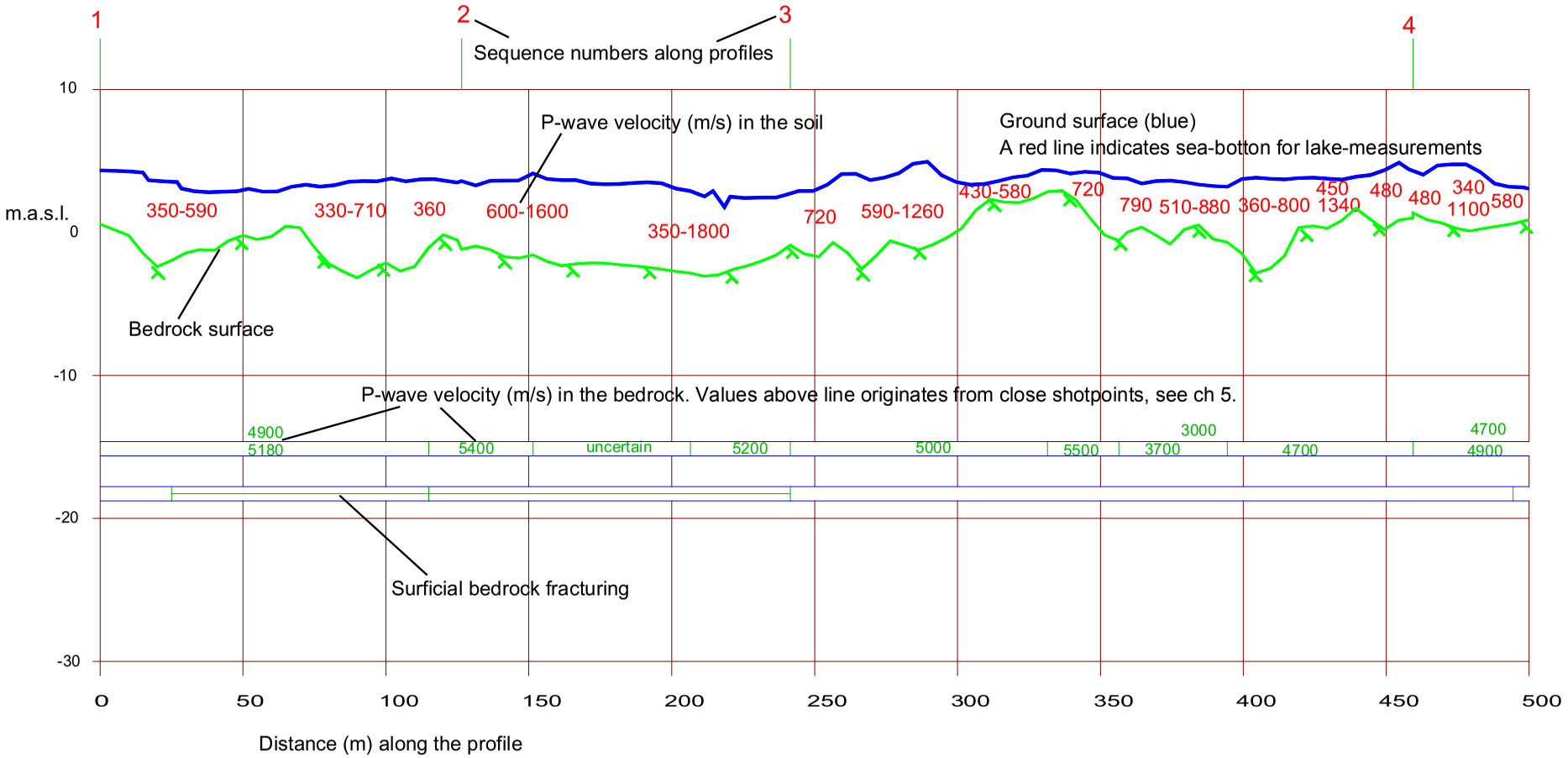
All data are presented in Appendix 1.

6 References

/1/ **Toresson B, 2005.** Seismic refraction survey 2004. SKB P-05-12. Svensk Kärnbränslehantering AB.

Appendix 1

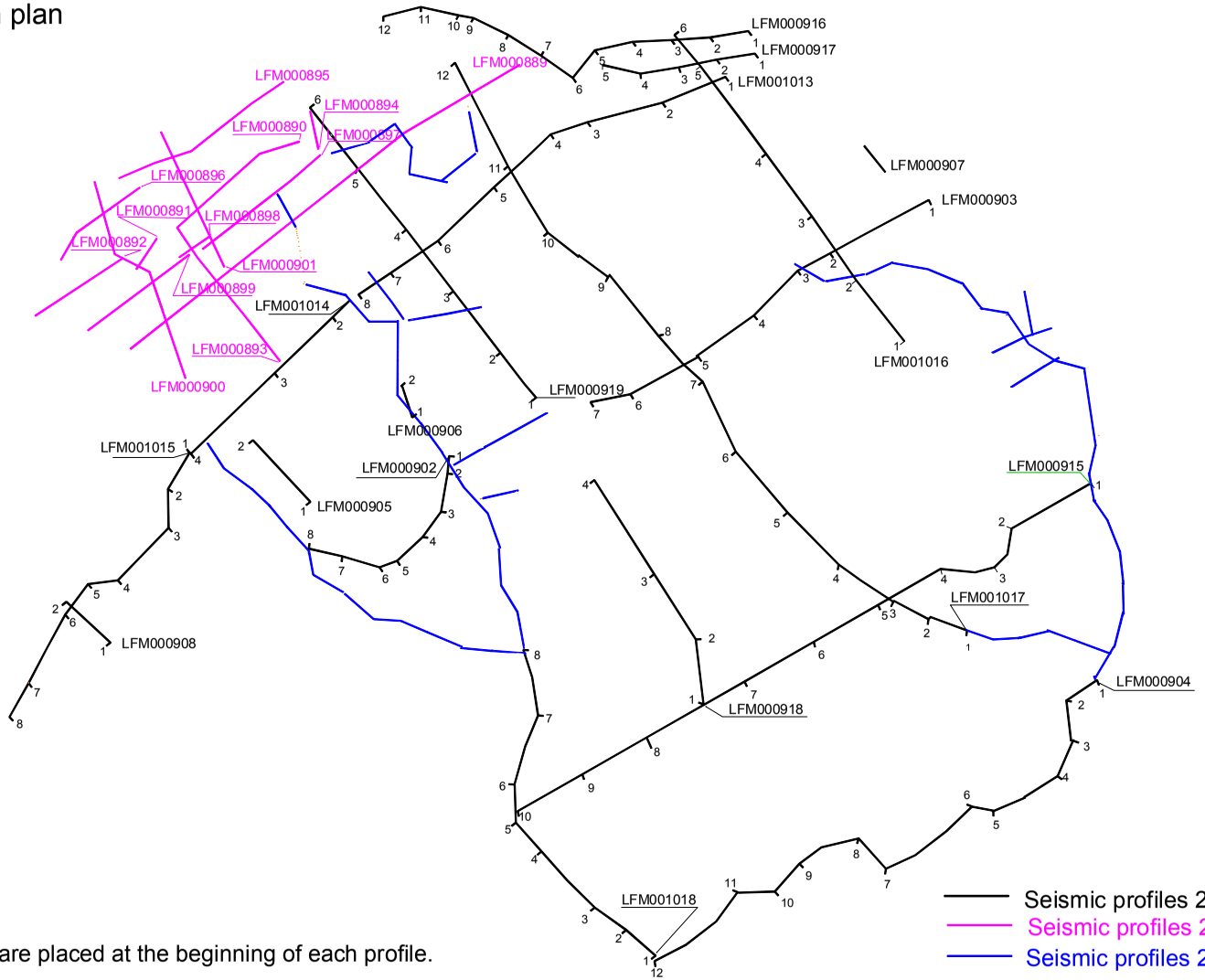
Explanation of components in the following diagrams



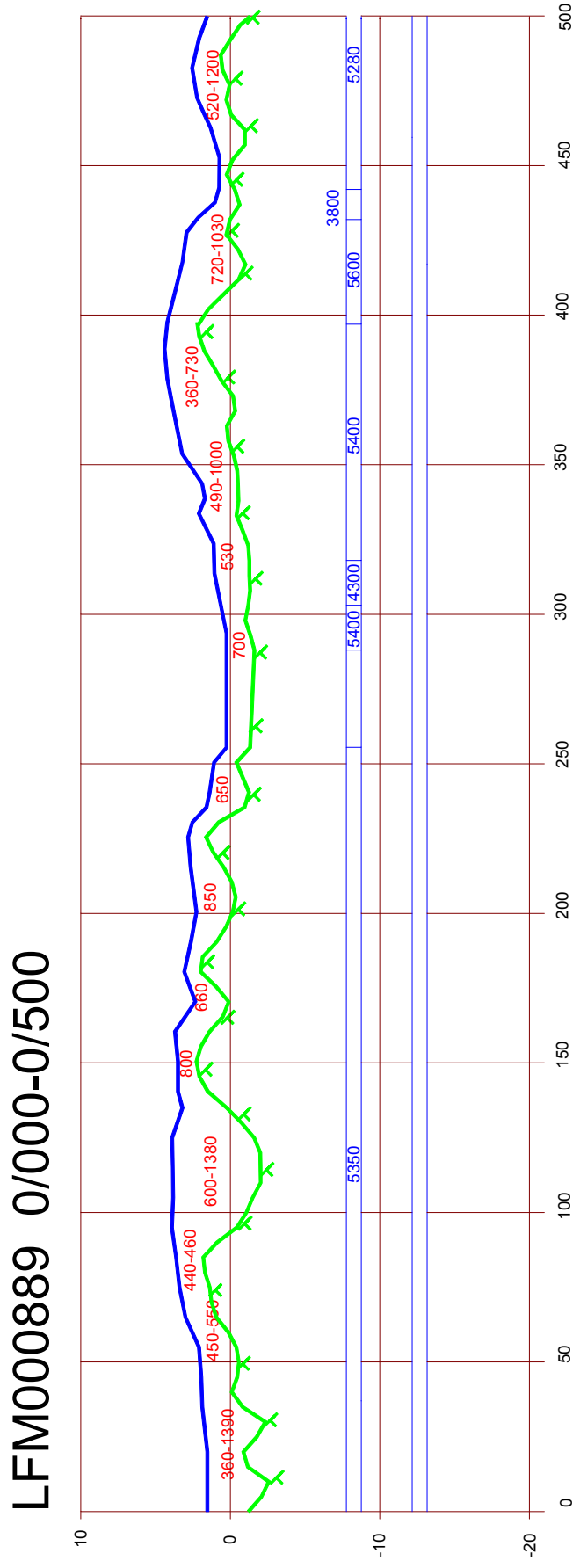
Forsmark Seismic Refraction Profiles

Appendix 1

Orientation plan



The ID-labels are placed at the beginning of each profile.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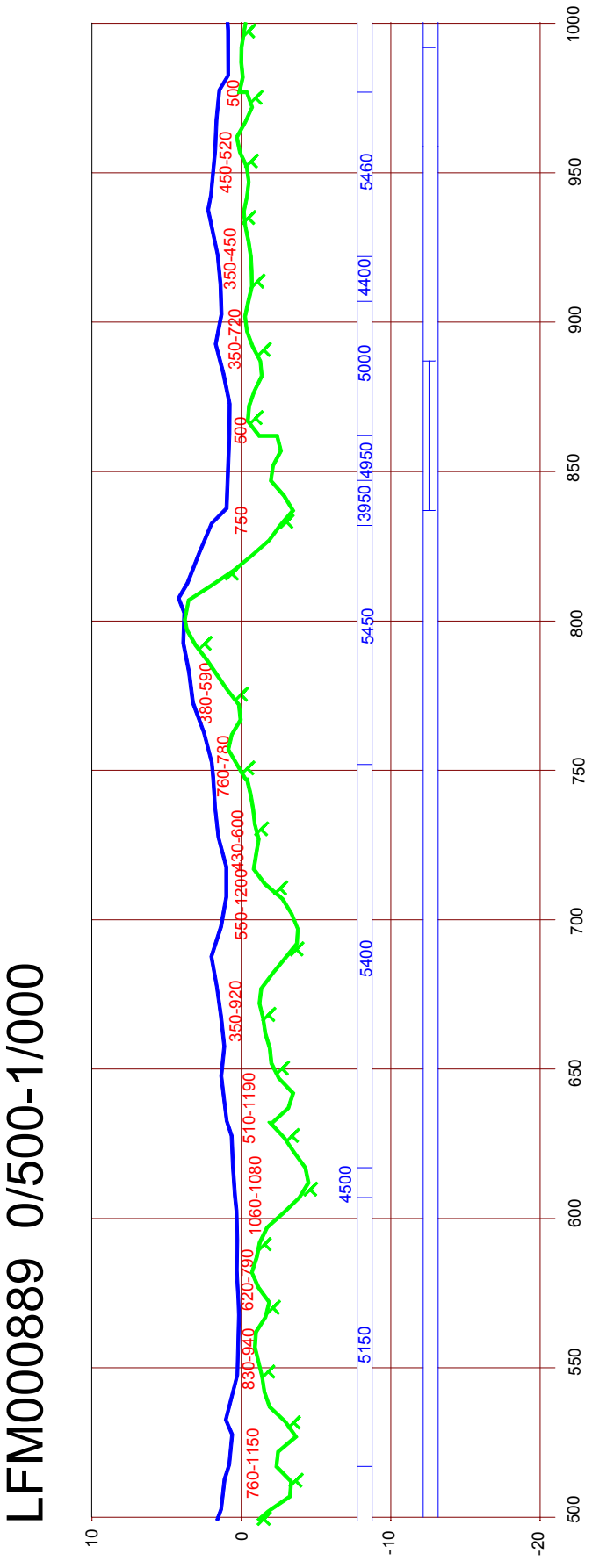
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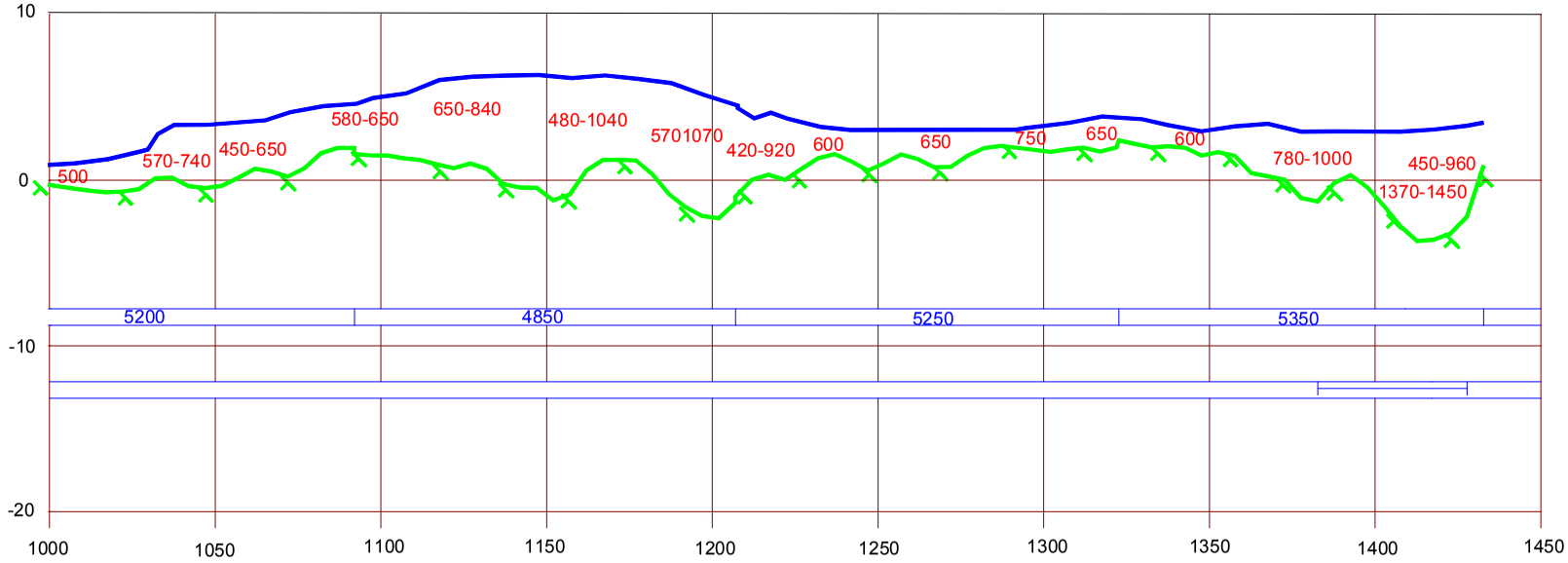

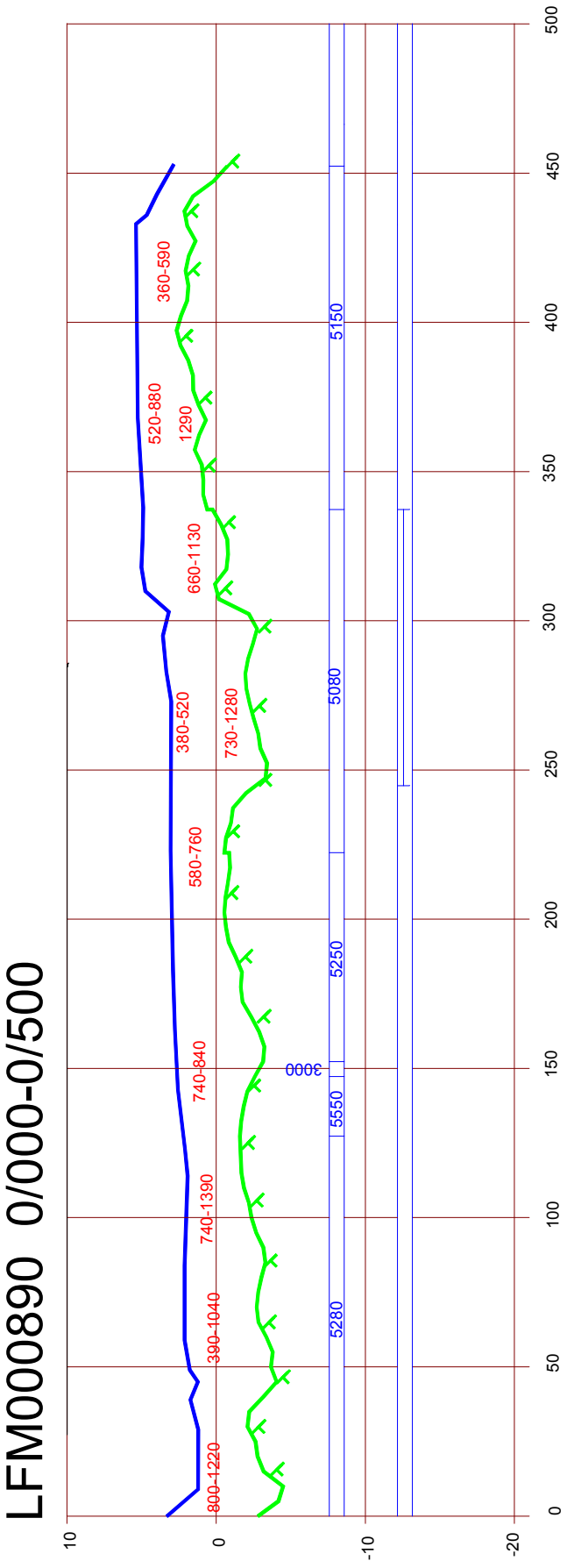
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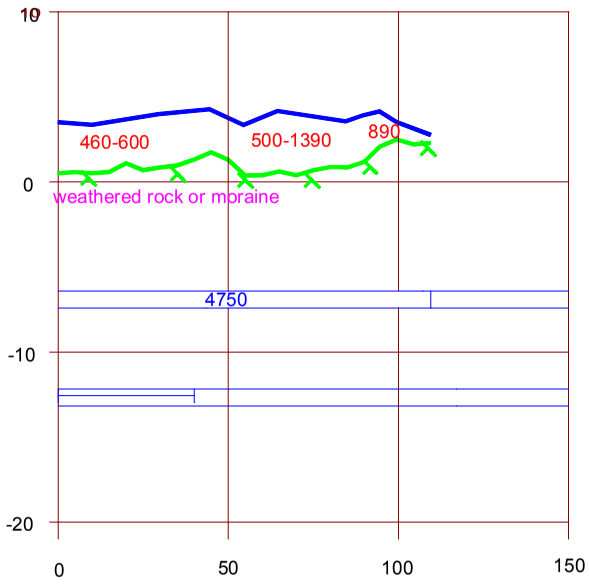

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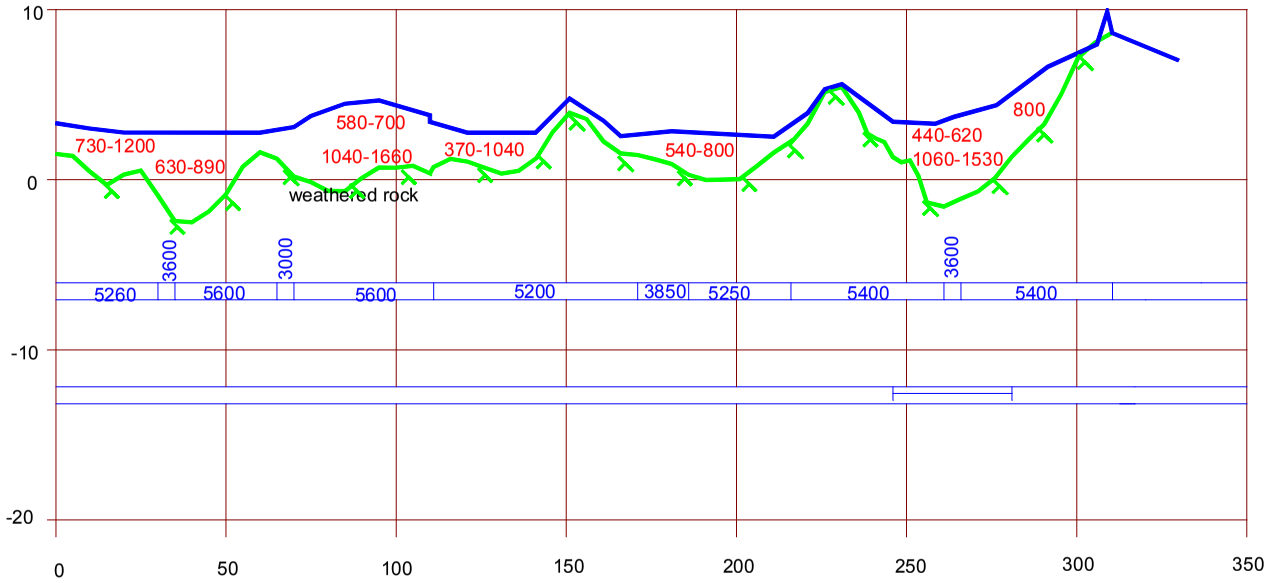

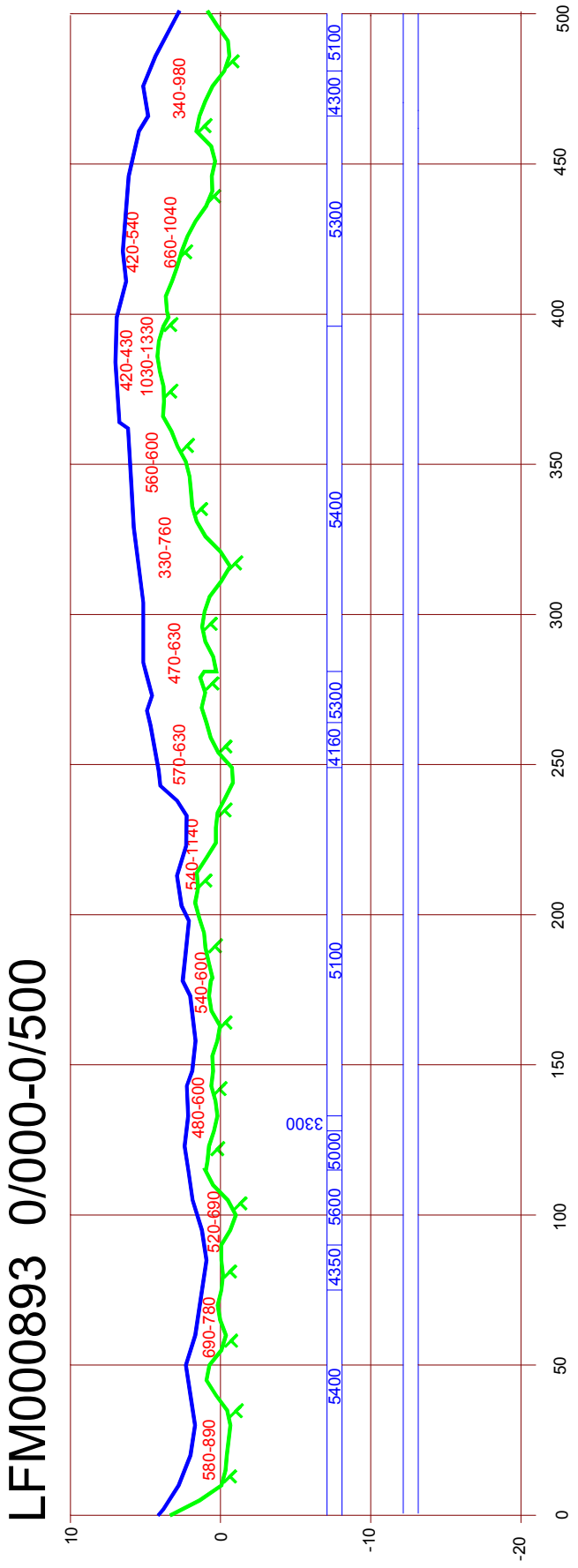
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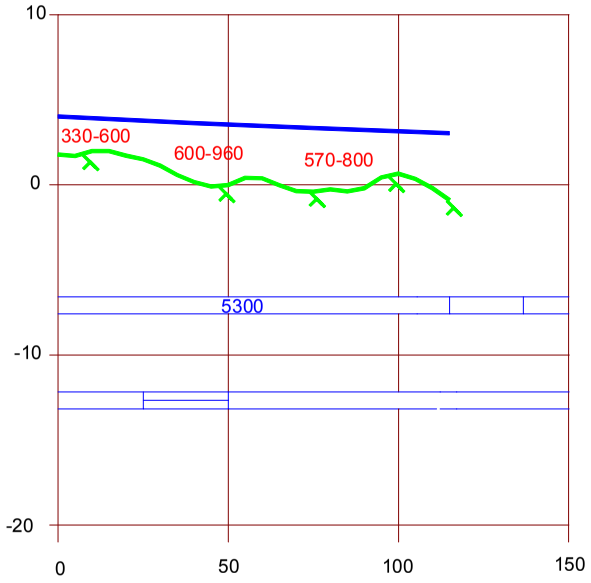

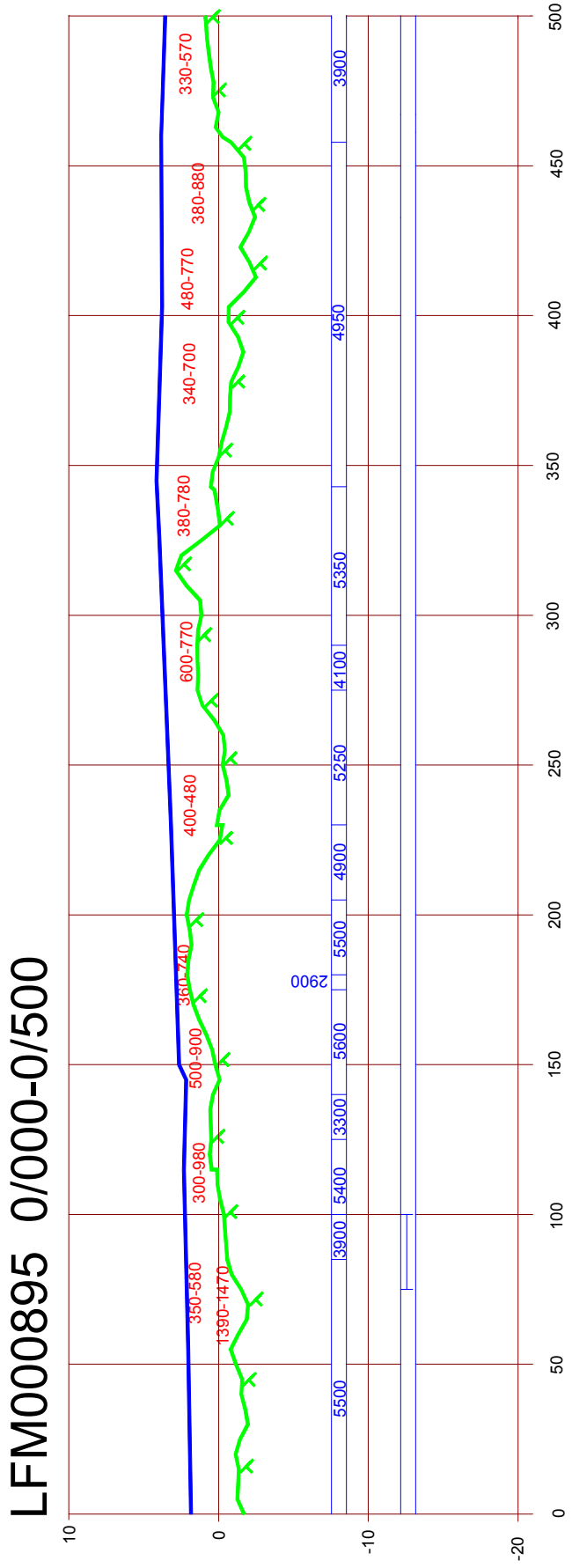
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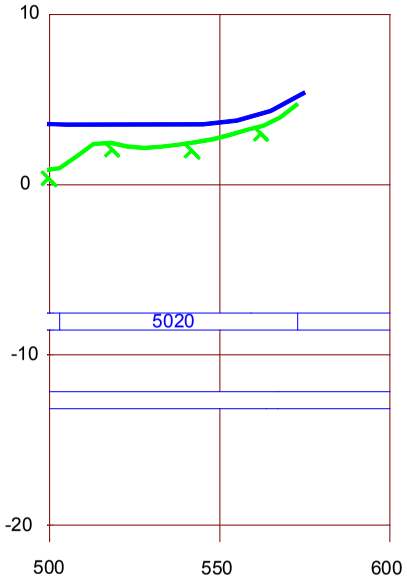

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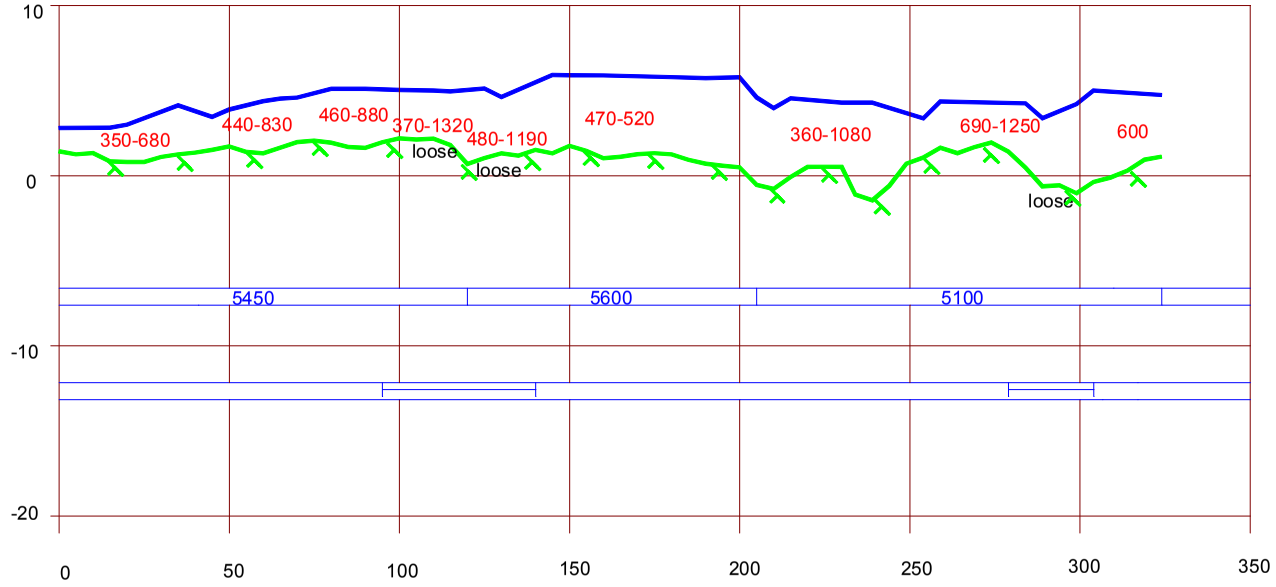

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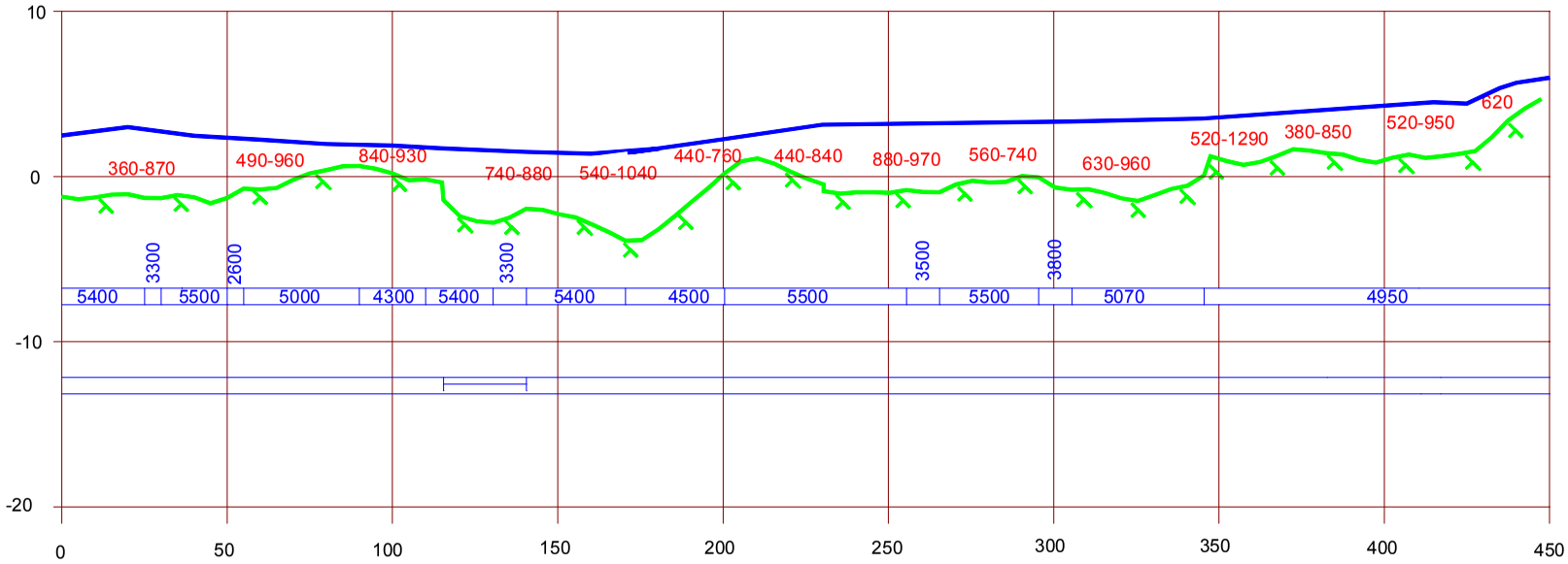

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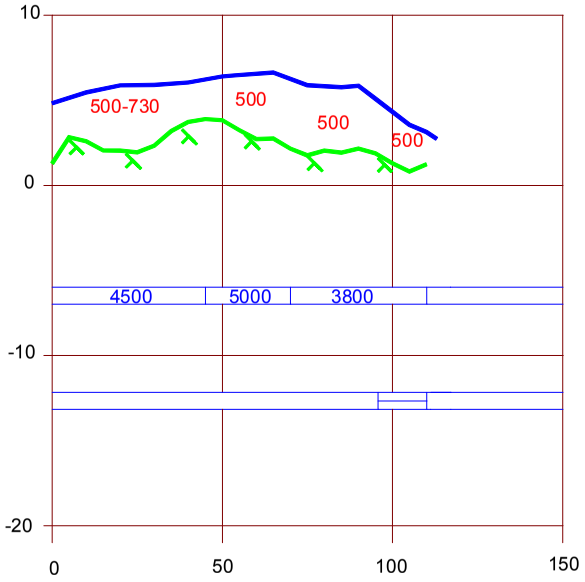

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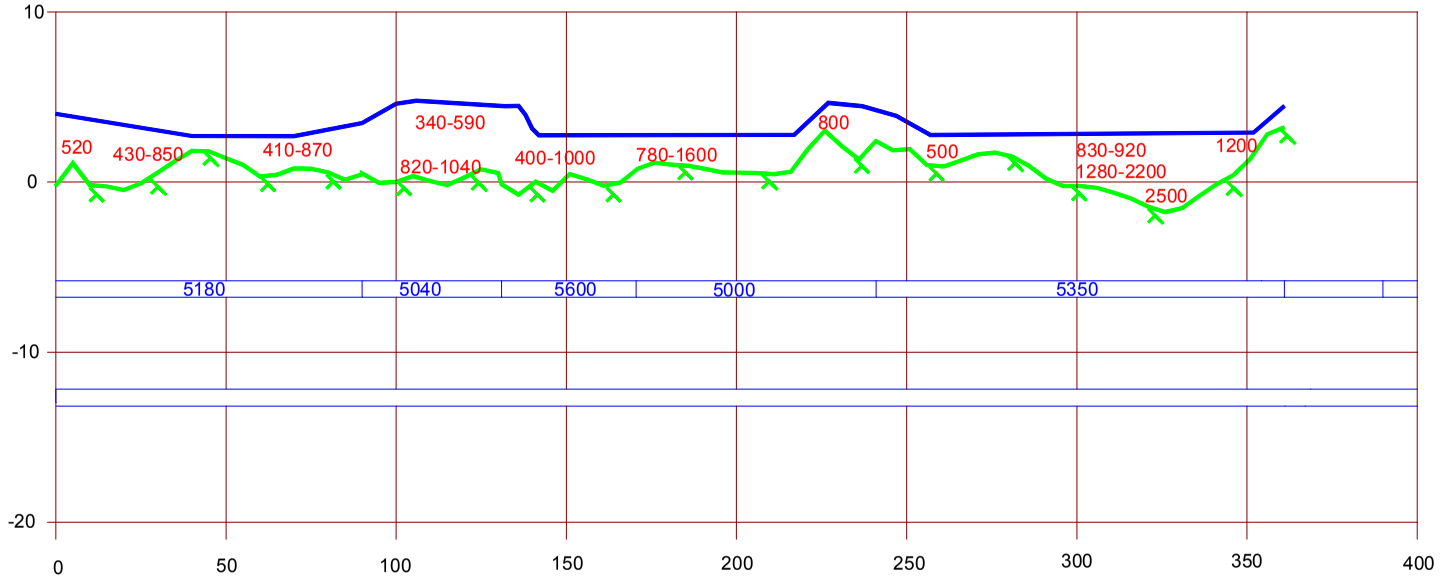

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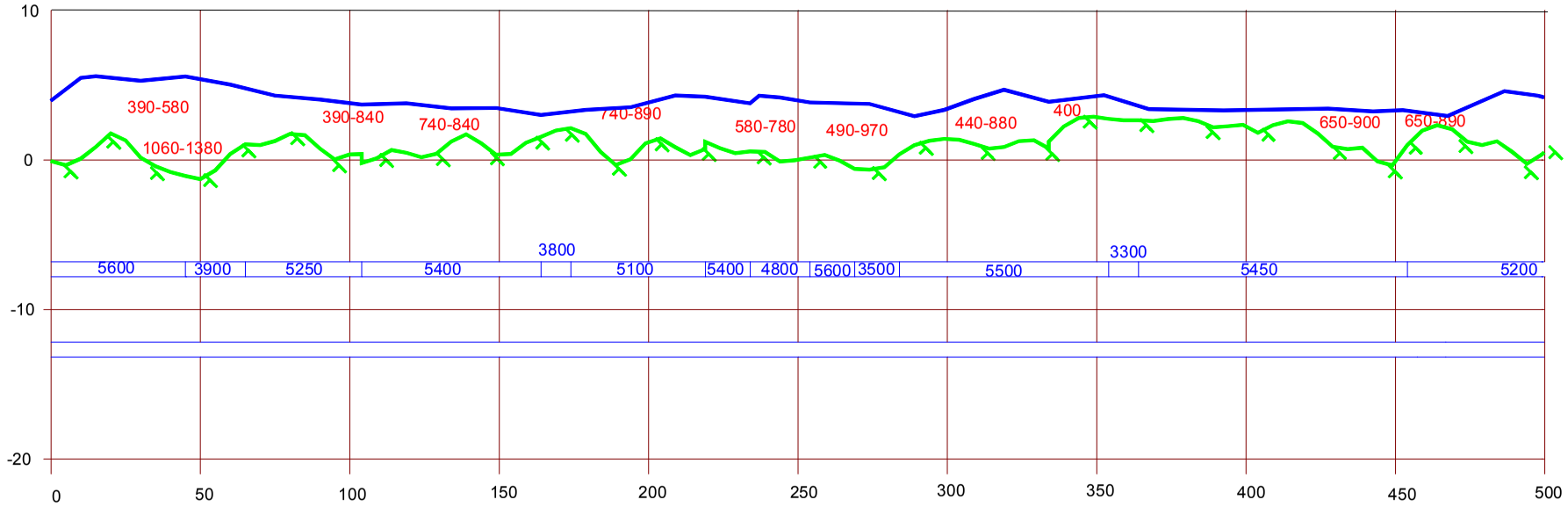

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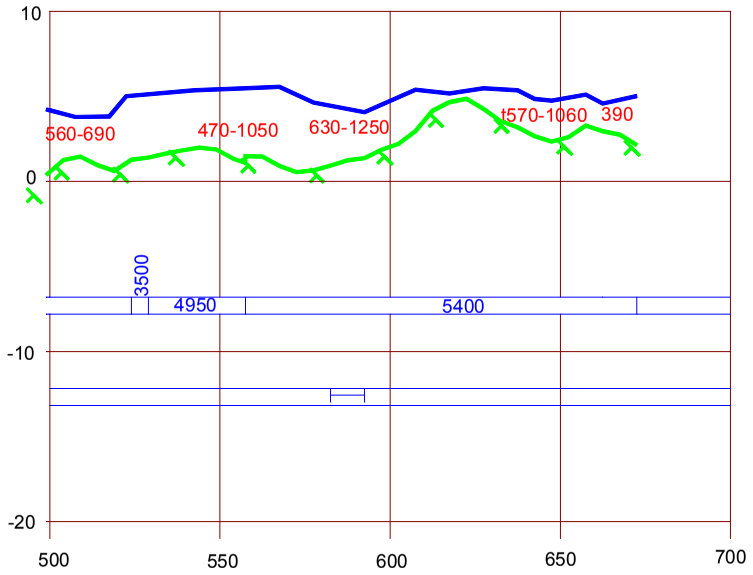

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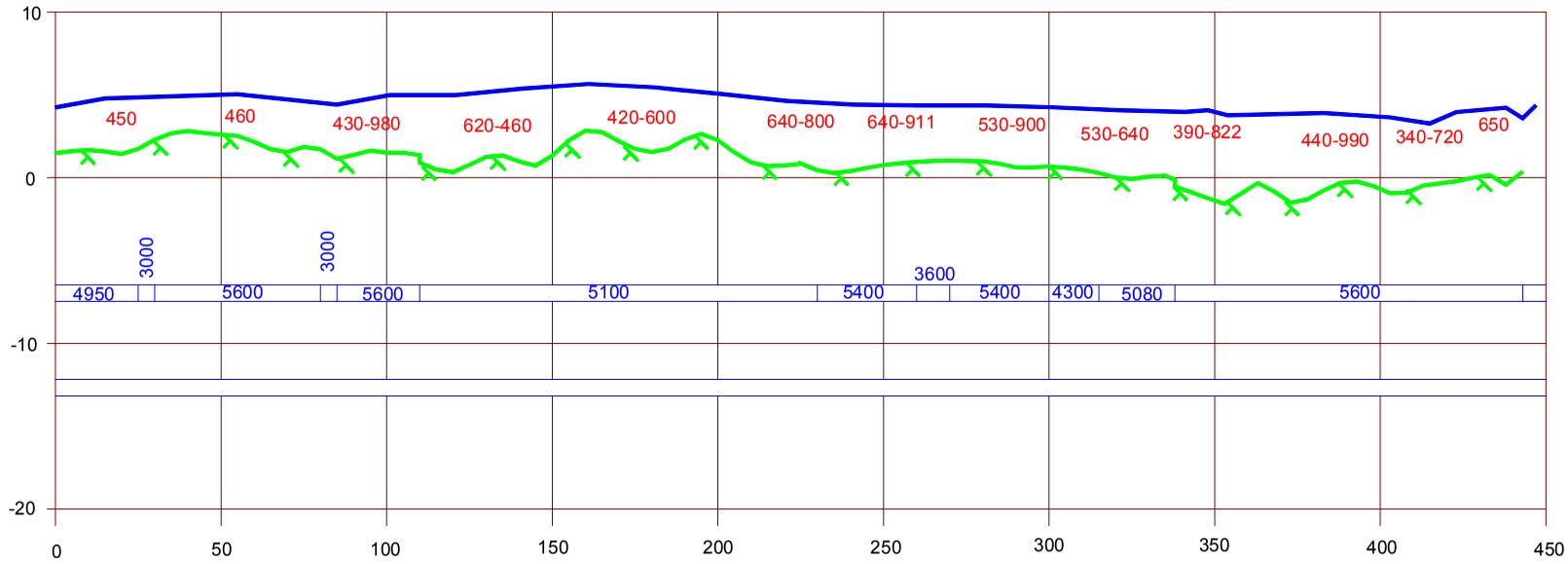

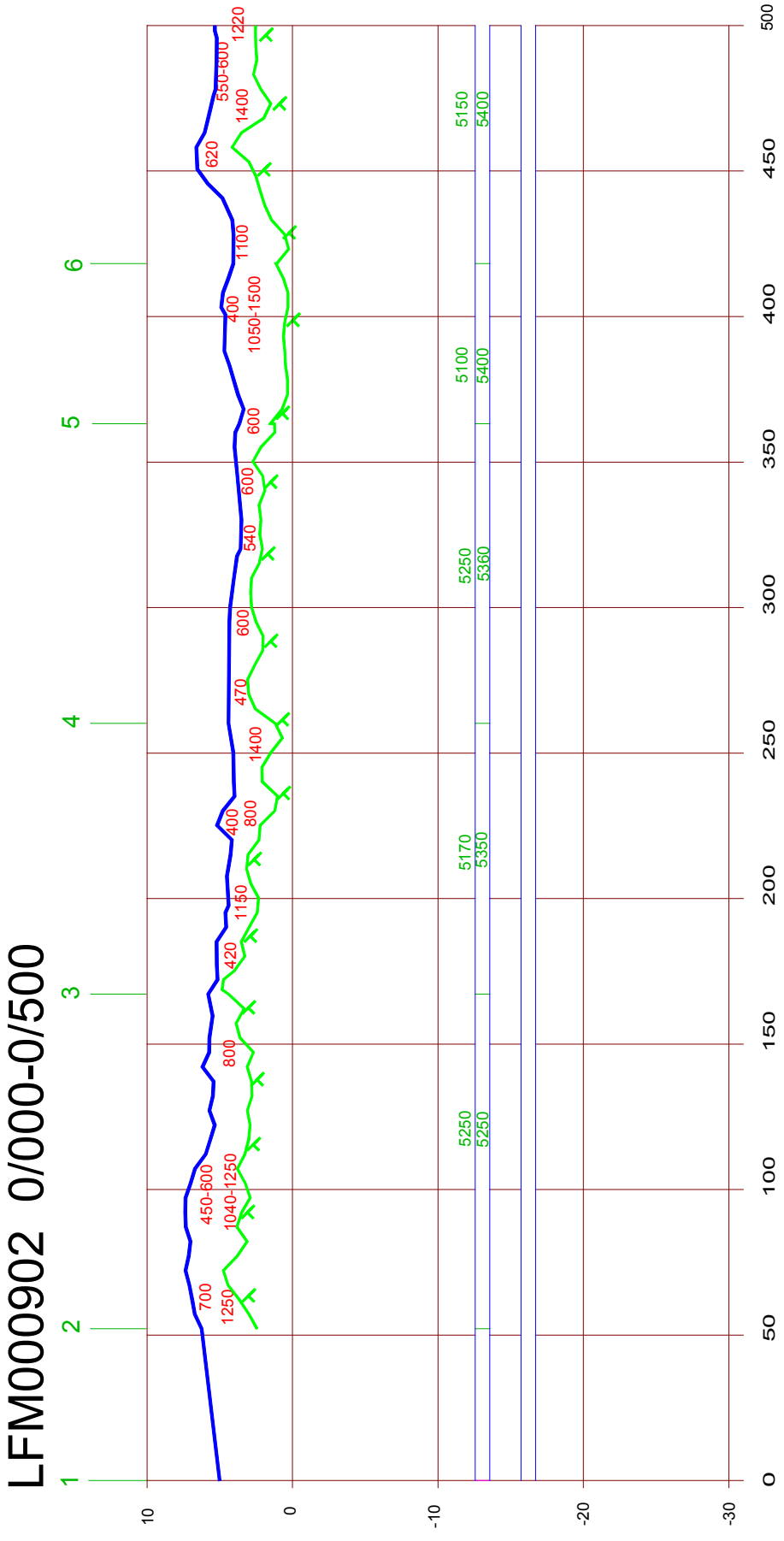
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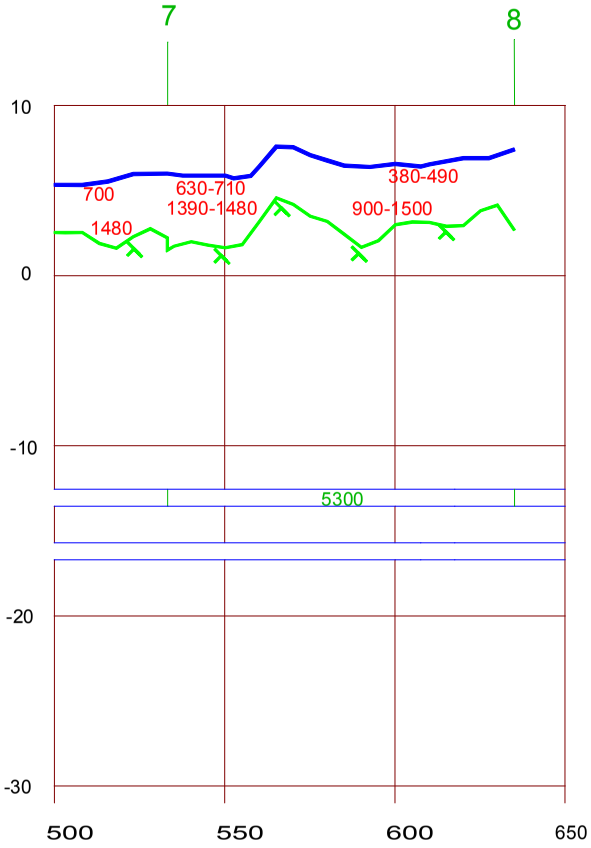

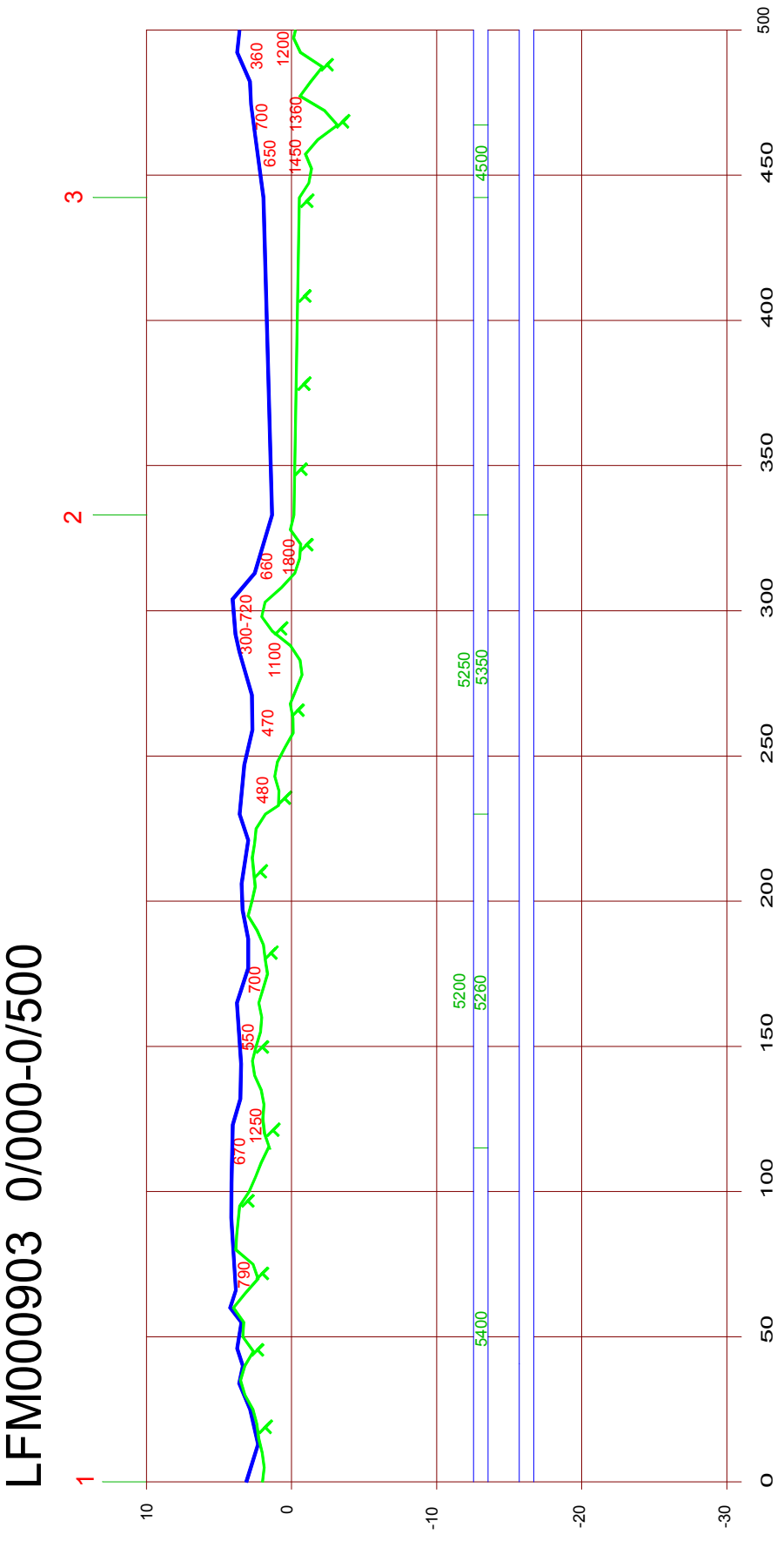
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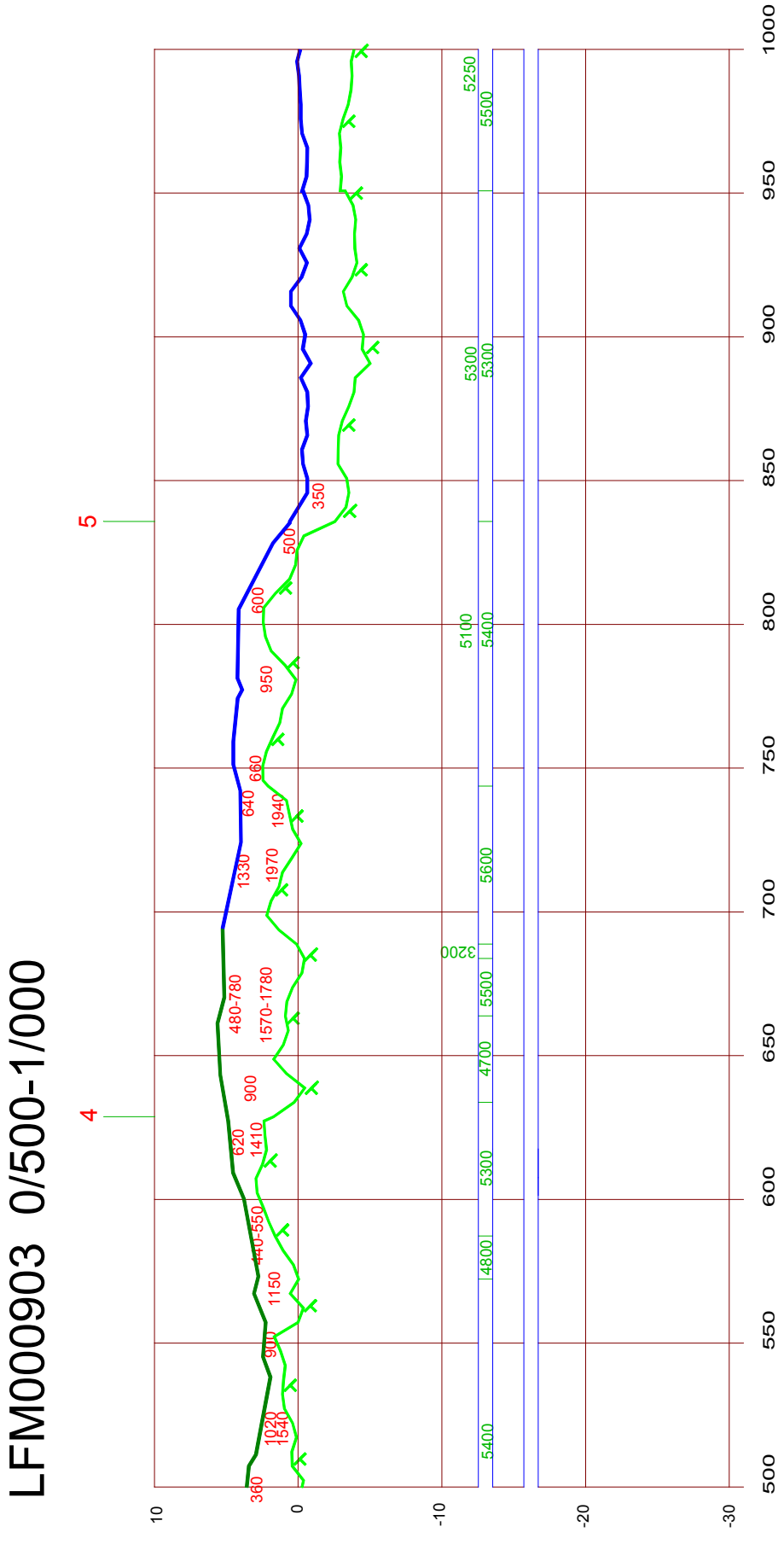
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4
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0
-10
-20
-30
500
550
600
650
700
750
800
850
900
950
1000
360
1020
1540
900
1150
440-550
620
1410
900
480-780
1570-1780
1330
640
660
1940
1970
950
600
500
350
5250
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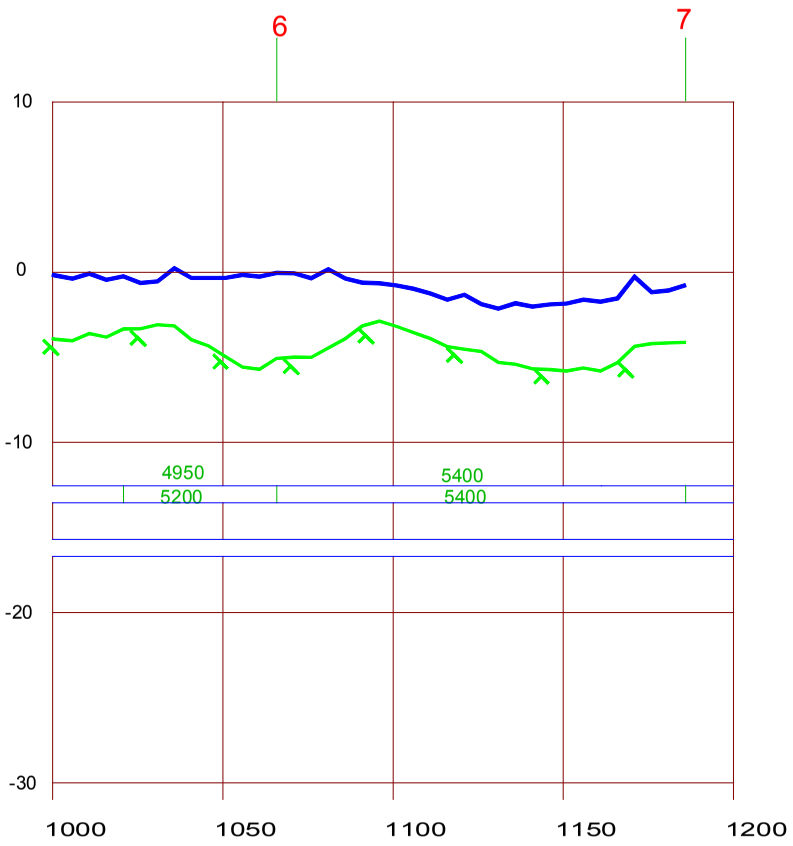
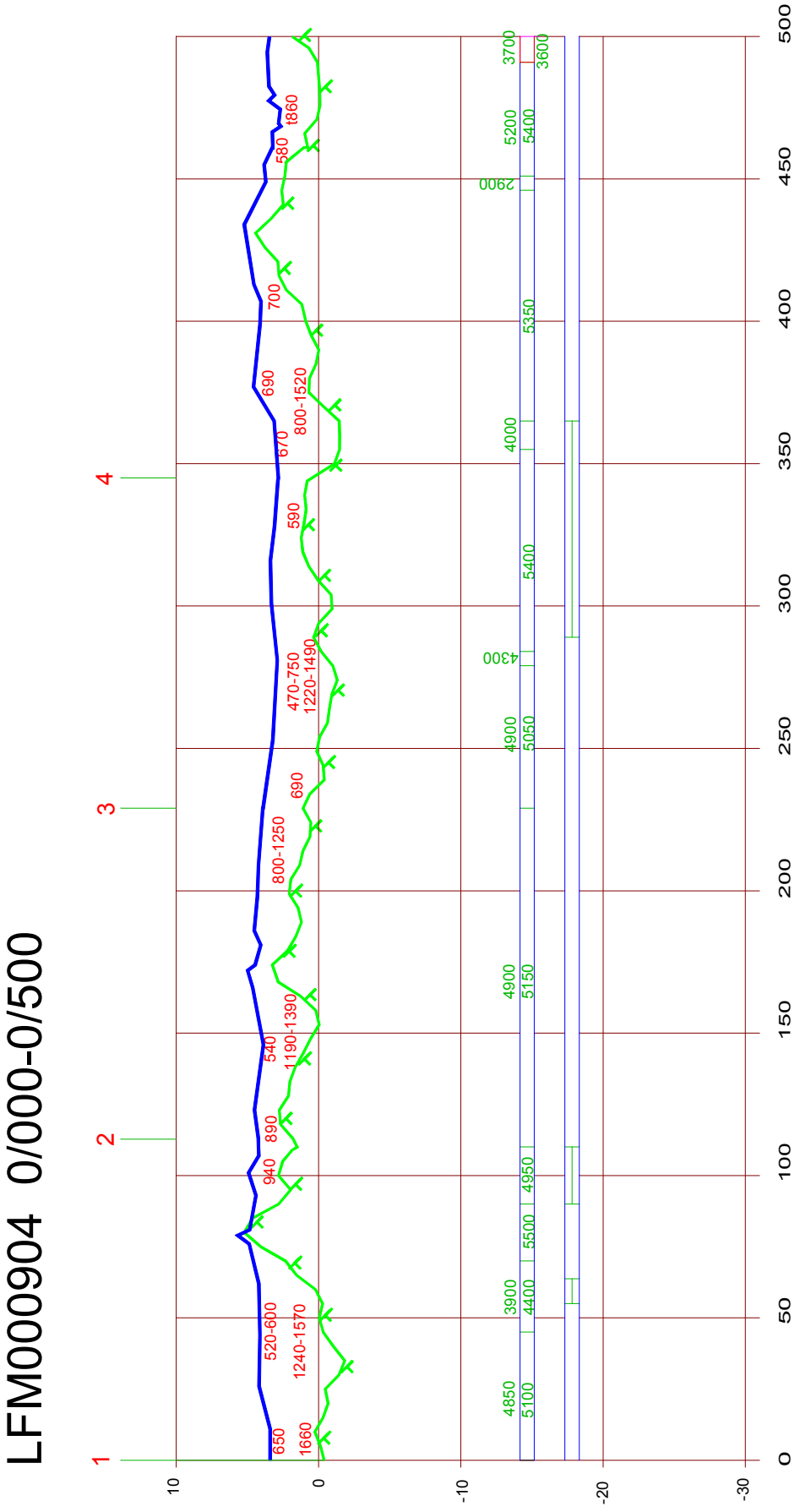
4800
5400

LFM000903 1/000-1/200

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2
3
4
650
1660
520-600
1240-1570
540
1190-1390
890
940
800-1250
690
470-750
1220-1490
590
670
690
800-1520
700
580
860
4850
5100
3900
4400
4900
5150
5500
4950
4900
5050
4300
5400
4000
5350
2900
5200
5400
3700
3600
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50
100
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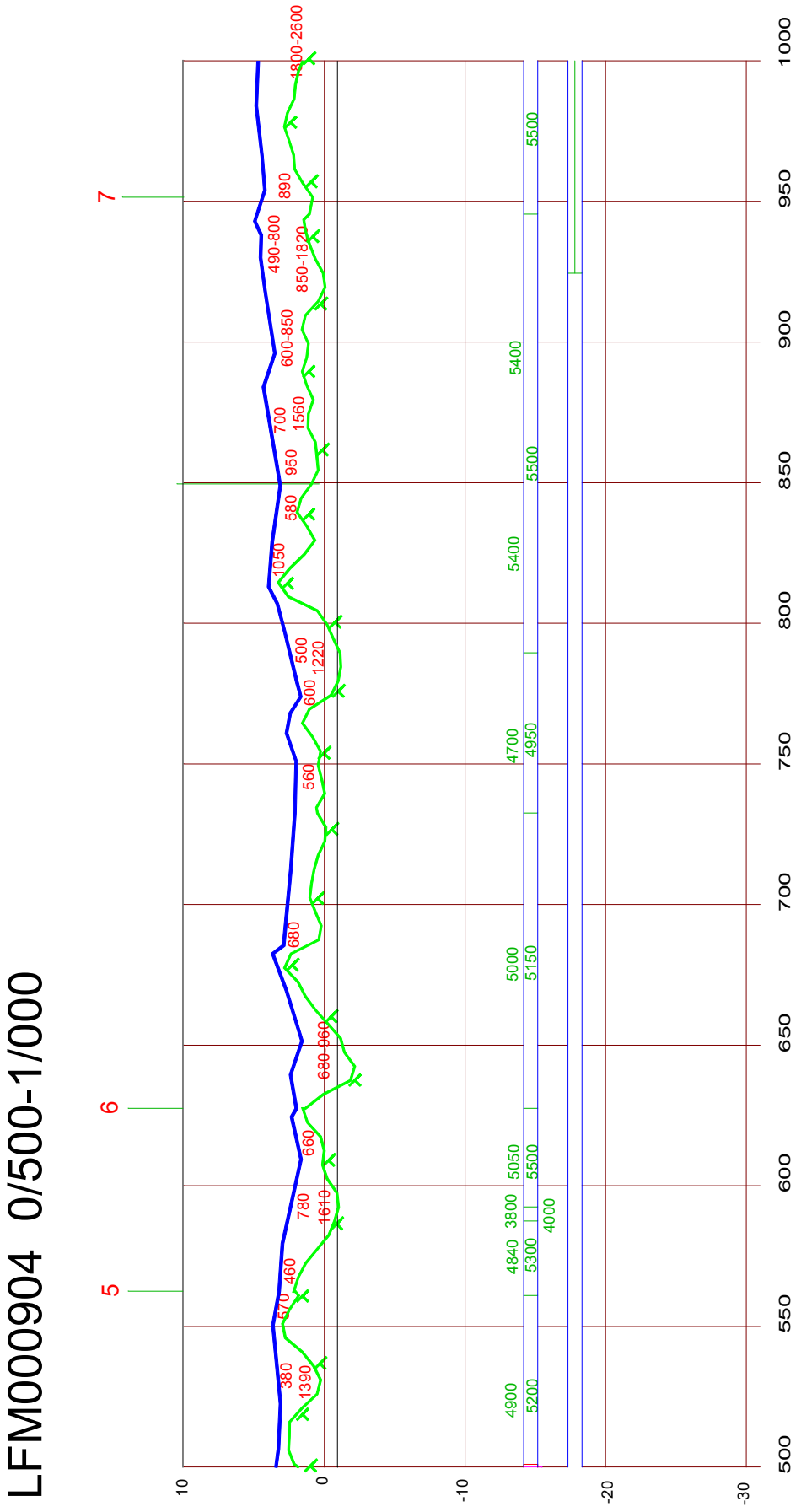
200
250
300
350
400
450
500
10
0
-10
-20
-30


LFM000904 0/500-1/000
7
6
5
1800-2600
890
490-800
850-1820
600-850
700
1560
950
580
1050
500
1220
600
560
680
680-960
660
780
1610
460
570
380
1390
5500
5400
5500
5400
4700
4950
5000
5150
5050
5500
3800
4000
4840
5300
4900
5200
500
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10
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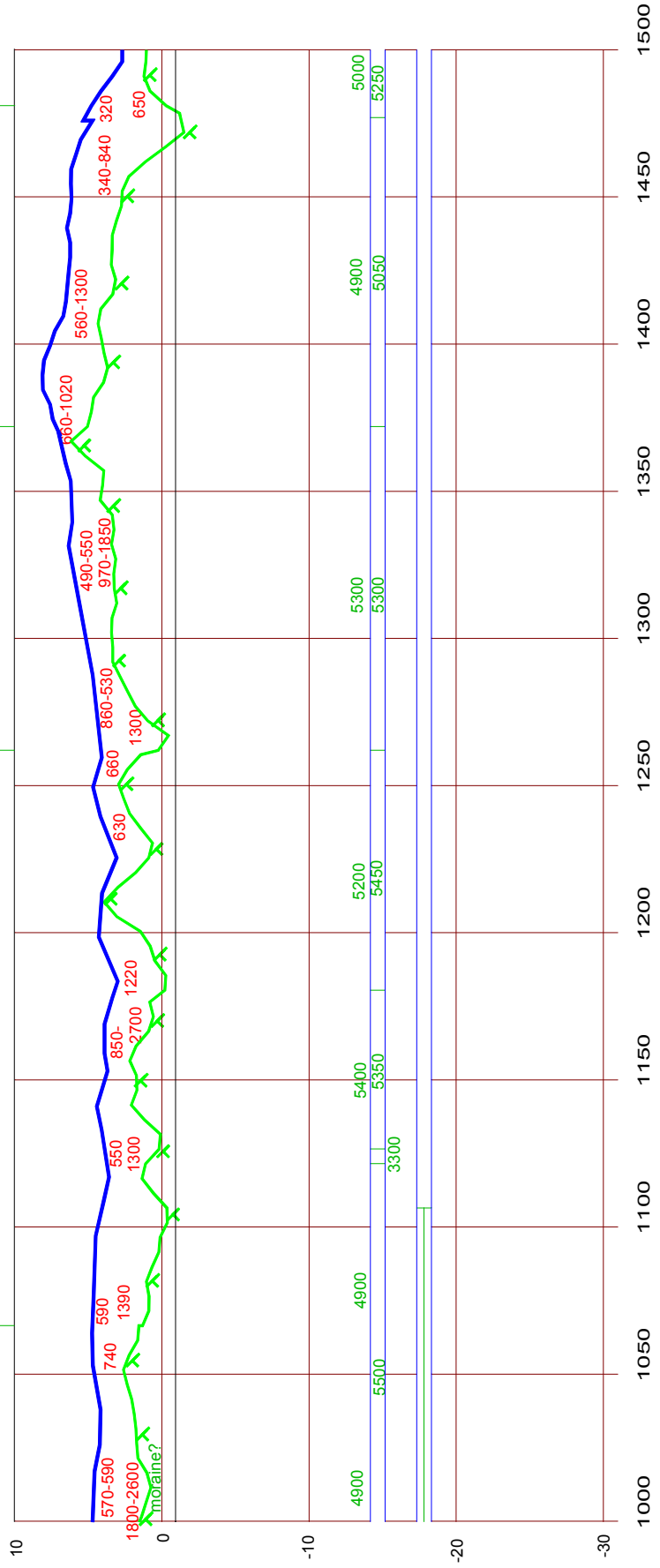
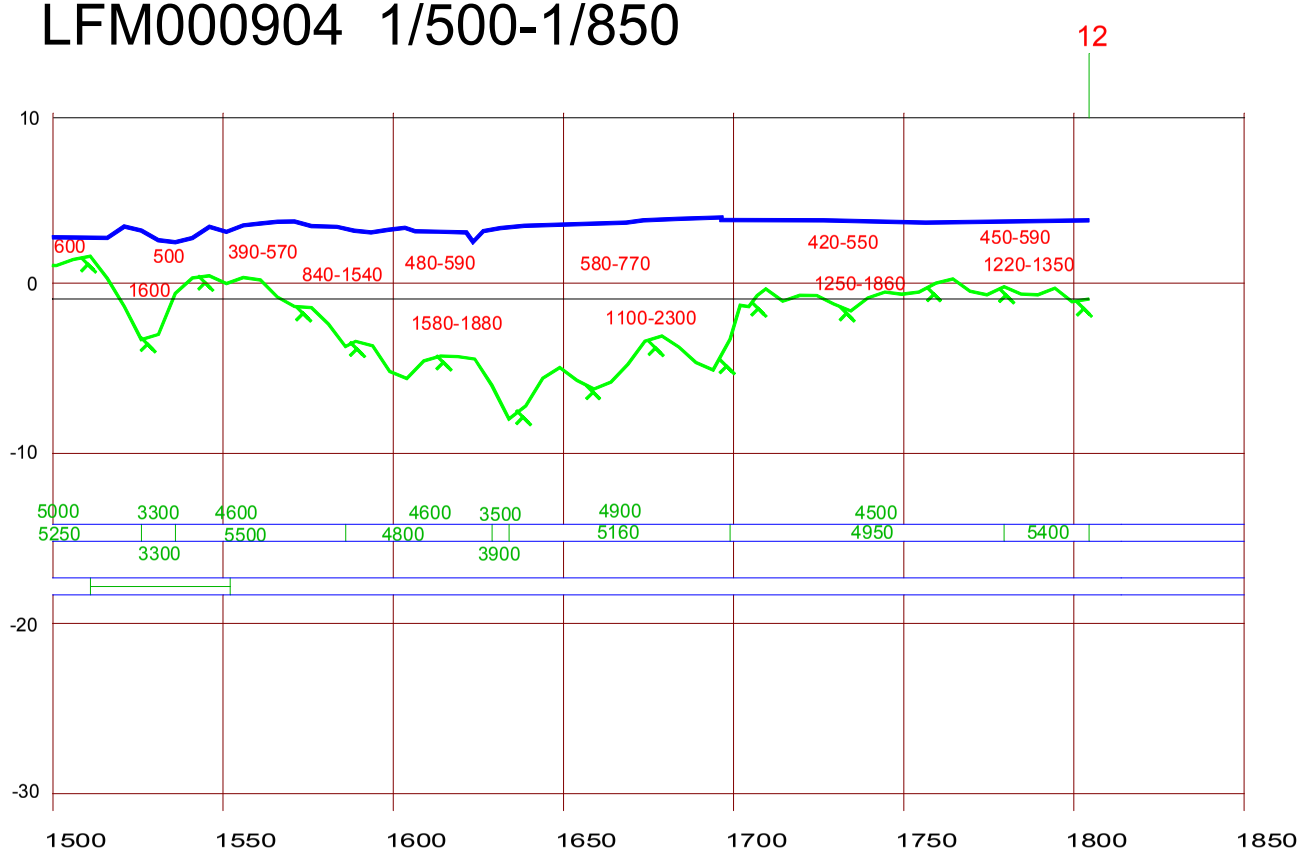
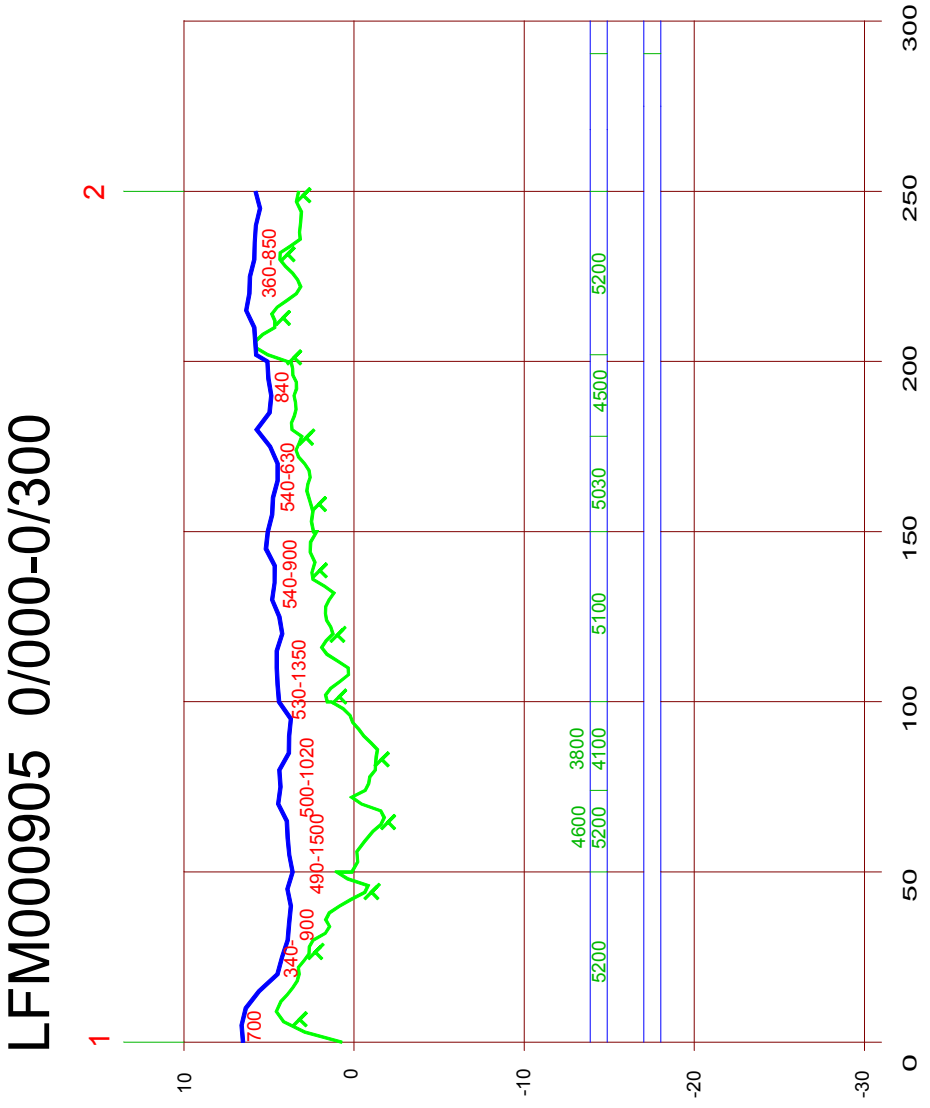
-10
-20
-30

LFM000904 1/000-1/500



LFM000904 1/500-1/850

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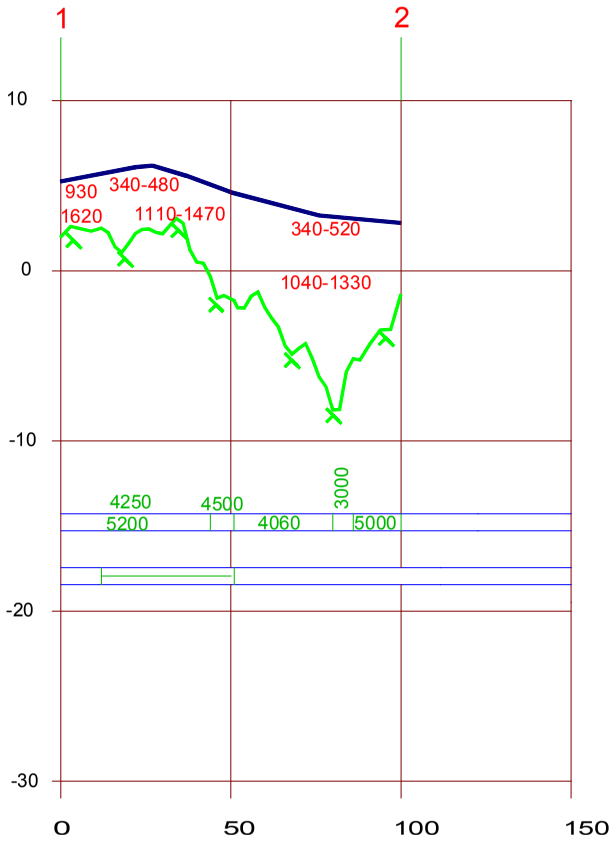
1
2
700
340
900
490-1500
500-1020
530-1350
540-900
540-630
840
360-850
5200
4600
5200
3800
4100
5100
5030
4500
5200
10
0
-10
-20
-30
0
50
100
150
200
250
300

LFM000906 0/000-0/150



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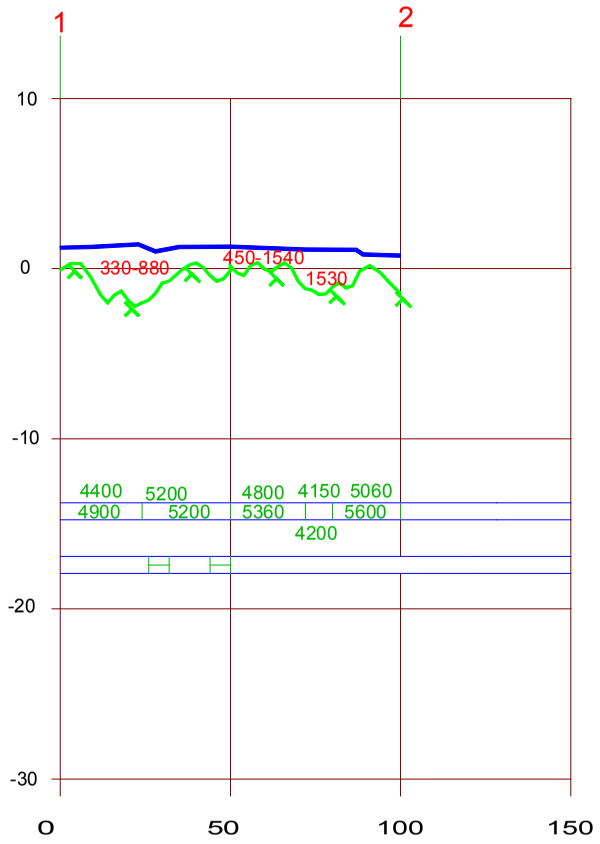
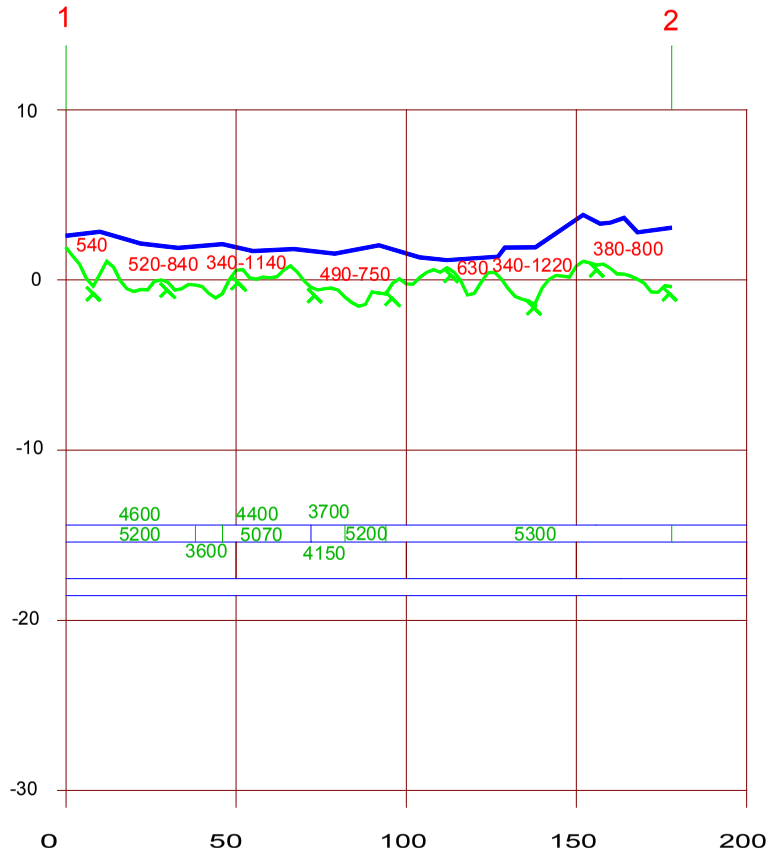
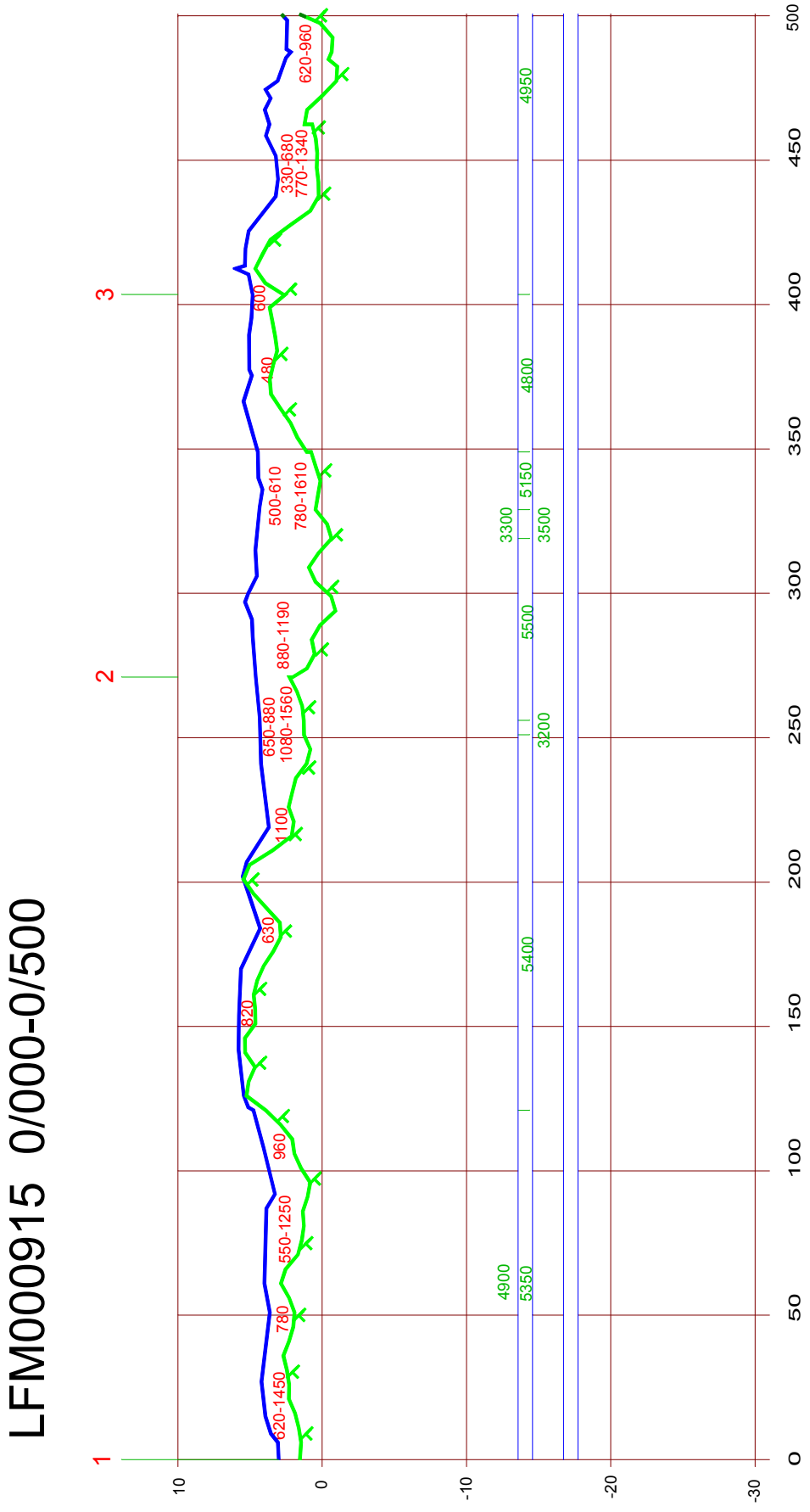


LFM000908 0/000-0/200

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1
2
3
620-1450
780
550-1250
960
820
630
1100
650-880
1080-1560
880-1190
500-610
780-1610
600
480
330-680
770-1340
620-960
4900
5350
5400
3300
5150
3500
5500
3200
4800
4950
10
0
-10
-20
-30
0
50
100
150
200
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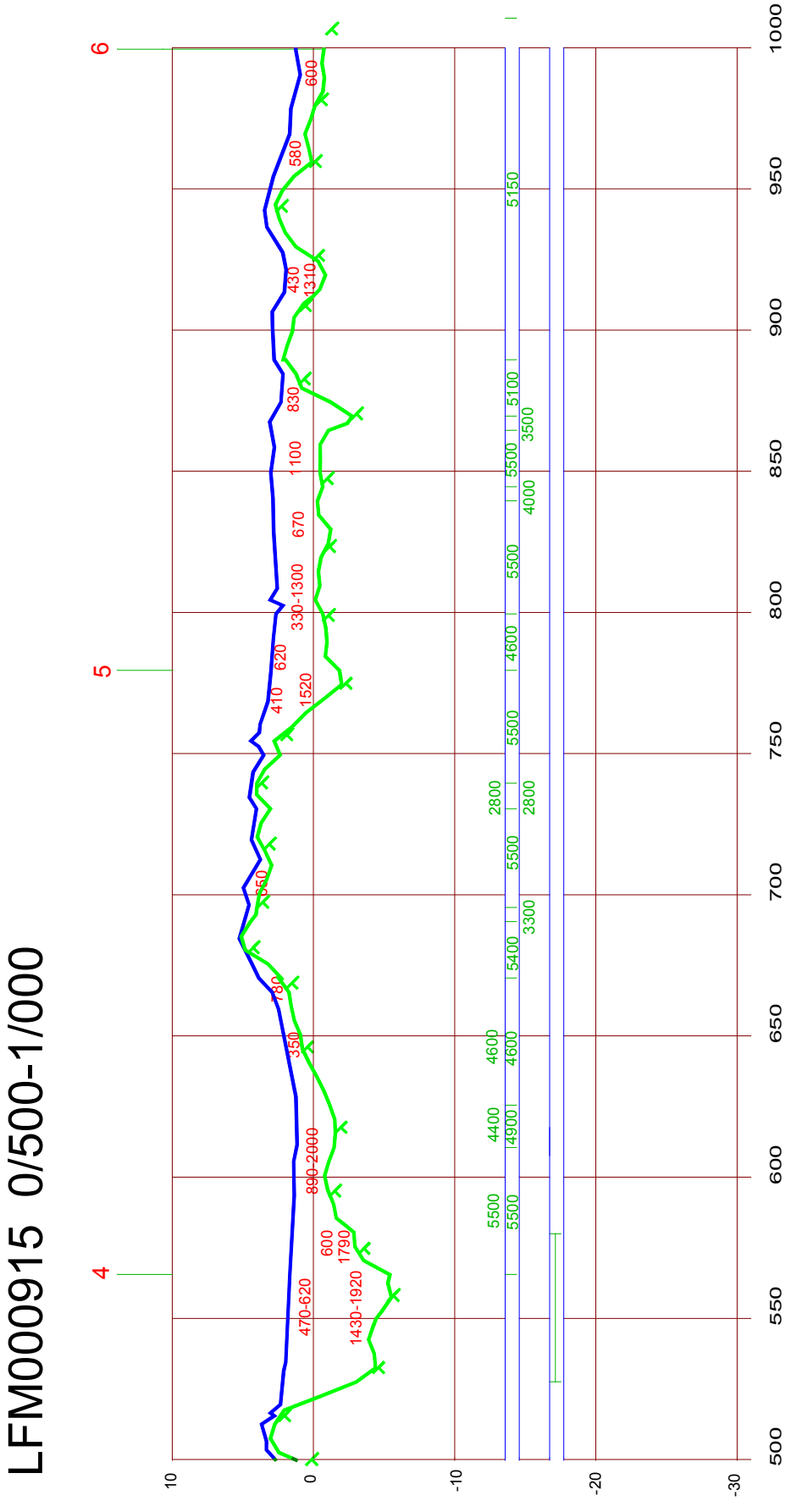
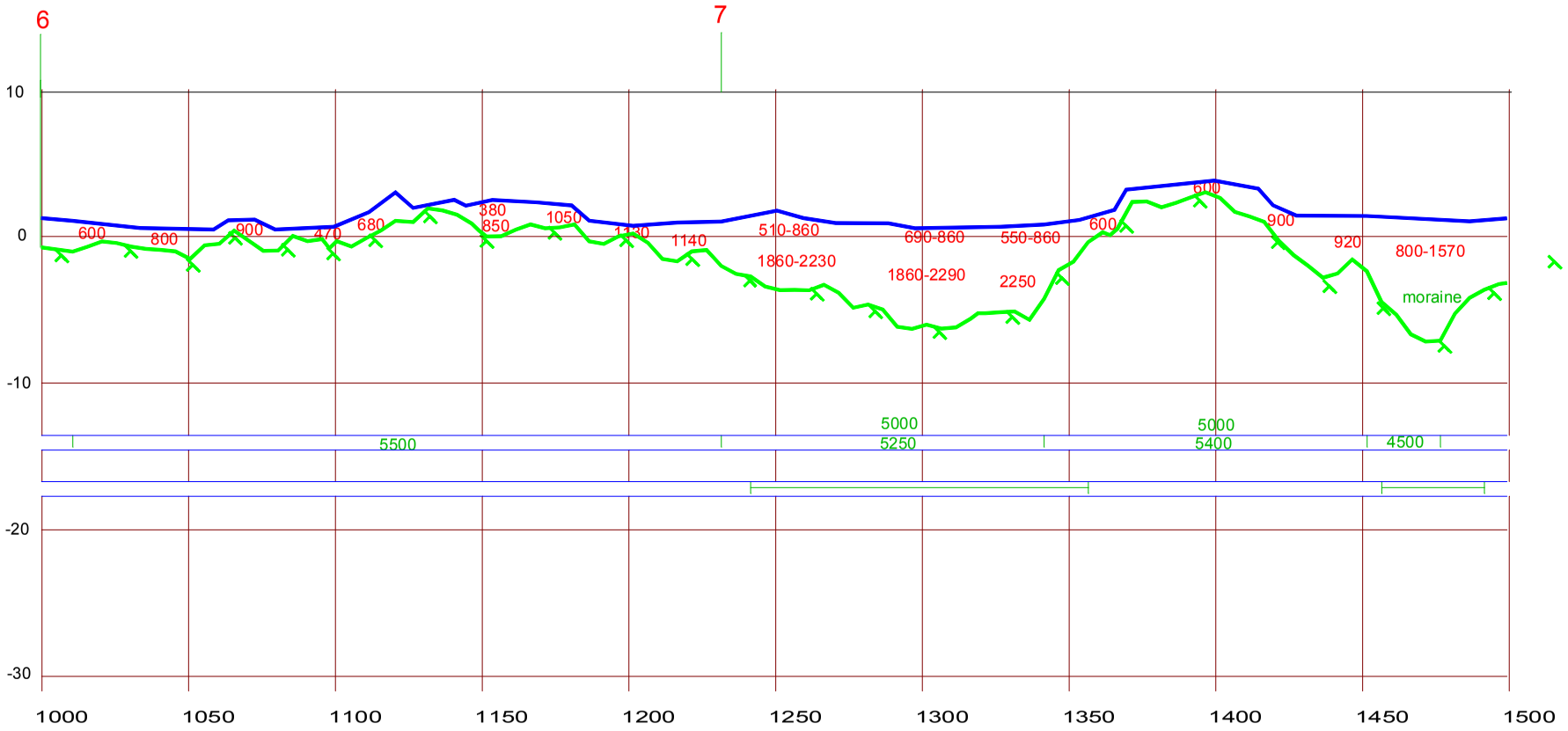
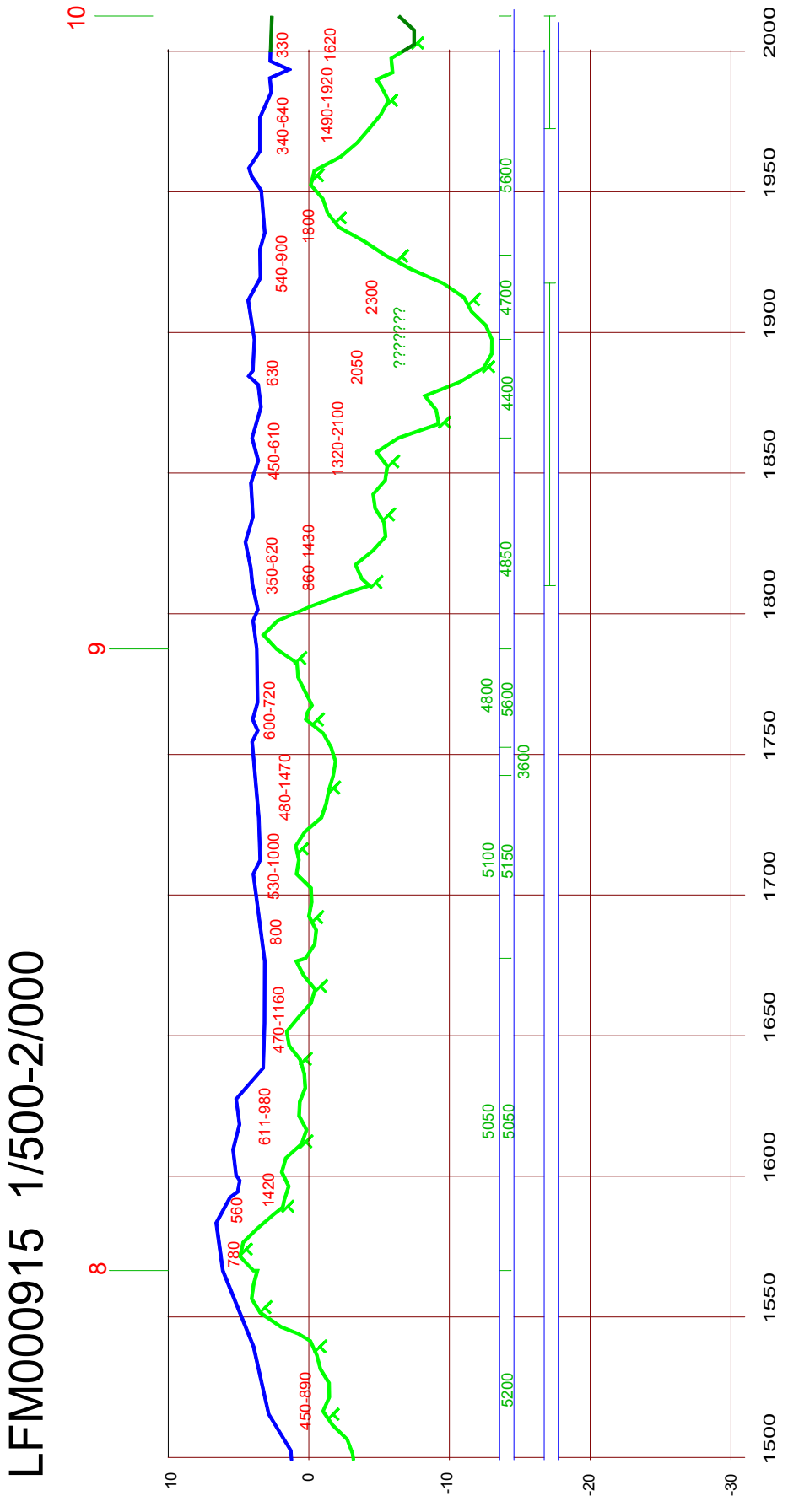
300
350
400
450
500


LFM000915 0/500-1/000
6
5
4
10
0
-10
-20
-30
500
550
600
650
700
750
800
850
900
950
1000
600
580
430
1310
830
100
670
330-1300
620
410
1520
350
780
350
890-2000
600
1790
1430-1920
470-620
5150
5100
3500
5500
4000
5500
4600
5500
2800
2800
5500
5400
3300
4600
4600
4400
4900
5500
5500

LFM000915 1/000-1/500




LFM000915 1/500-2/000
10
9
8
10
0
-10
-20
-30
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000
330
340-640
1490-1920
1620
1800
540-900
2300
????
2050
630
450-610
1320-2100
860-1430
350-620
600-720
480-1470
530-1000
800
470-1160
611-980
1420
560
780
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5600
4700
4400
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4800
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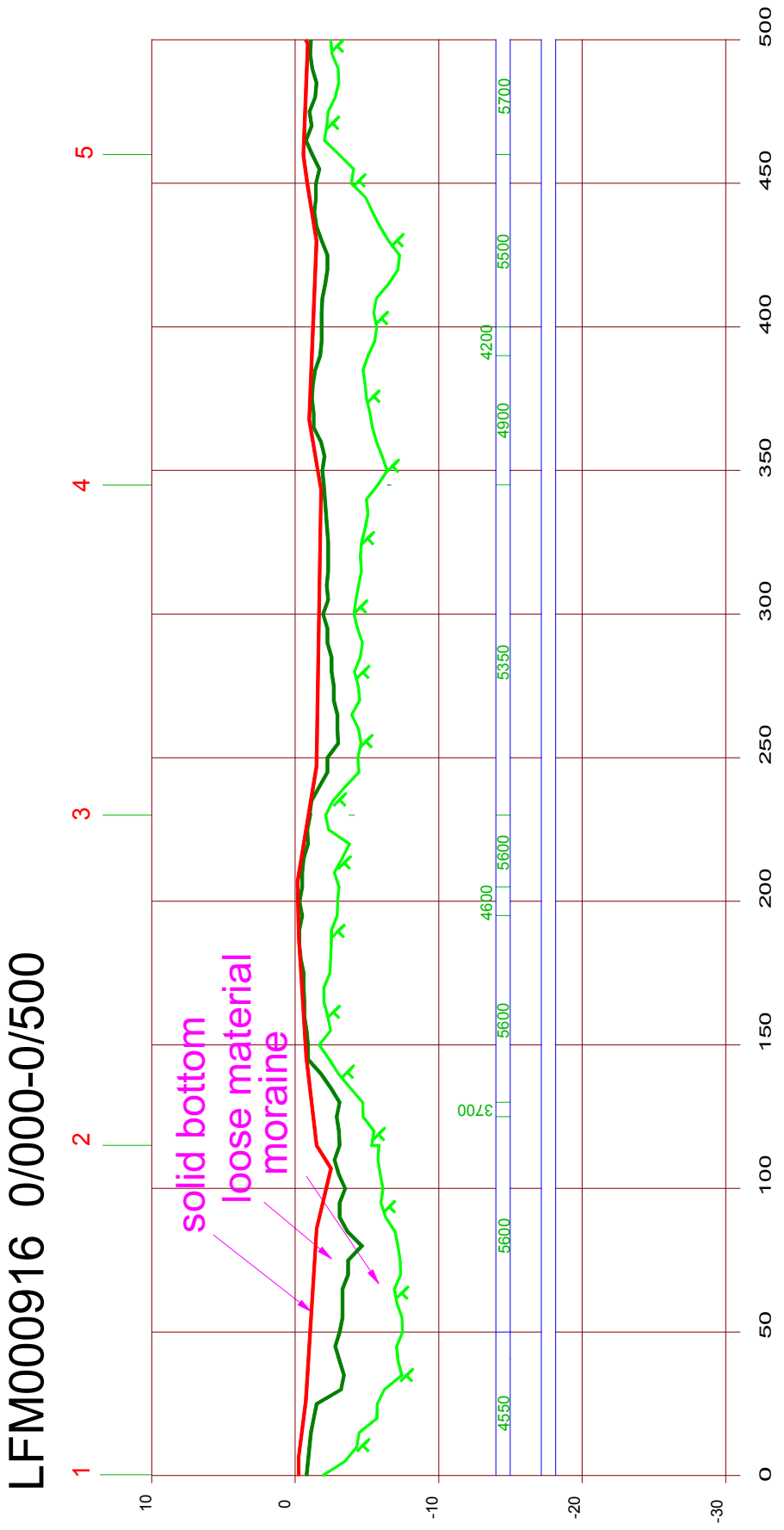
3600
5100
5150
5050
5050
5200


LFM000916 0/000-0/500
solid bottom
loose material
moraine
1
2
3
4
5
10
0
-10
-20
-30
0
50
100
150
200
250
300
350
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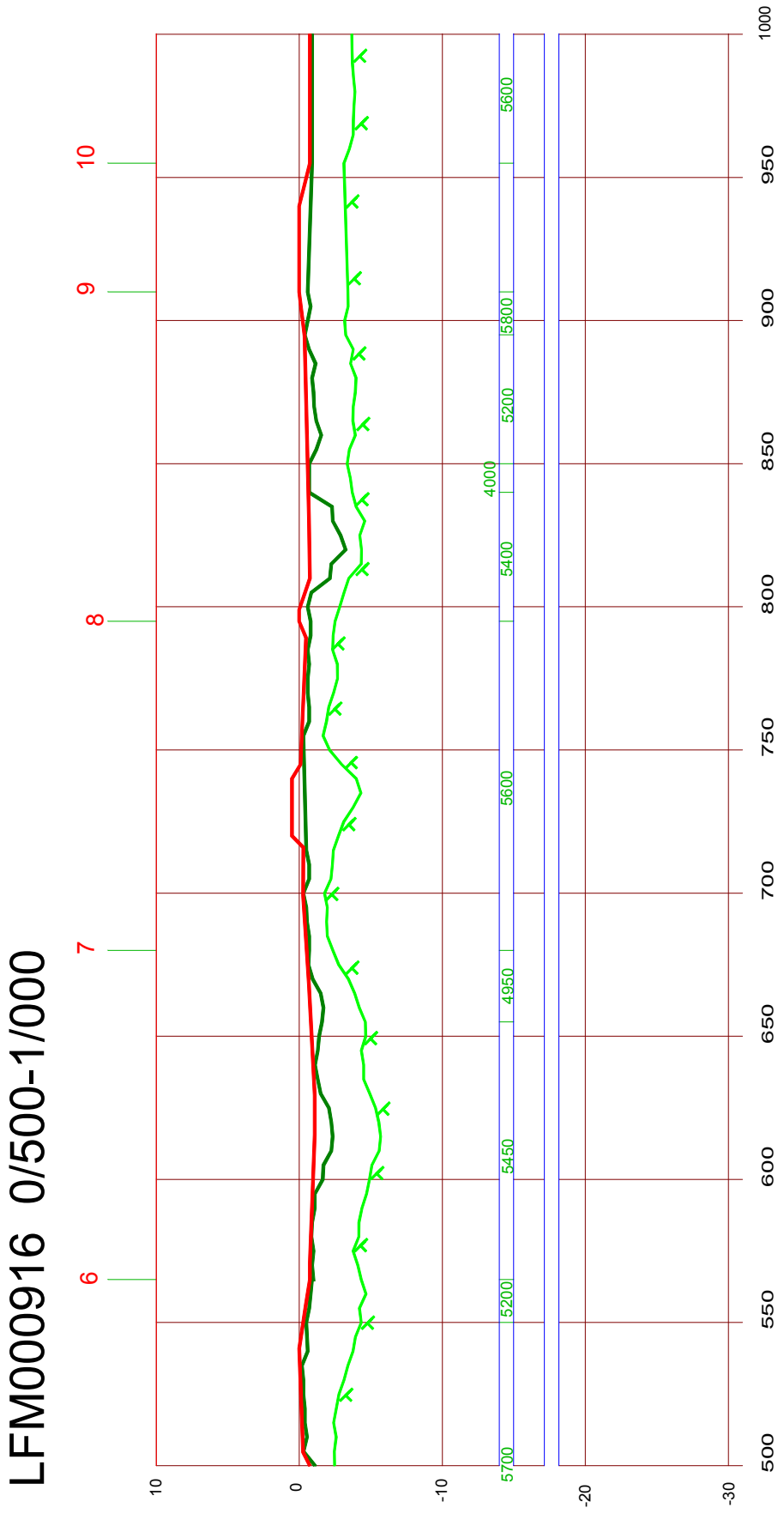
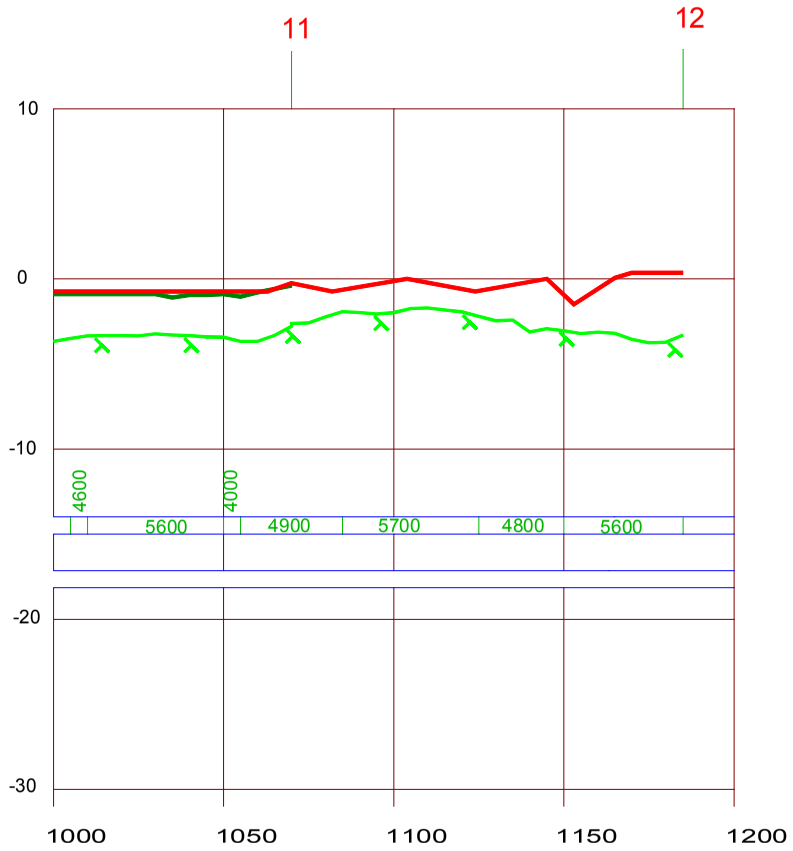
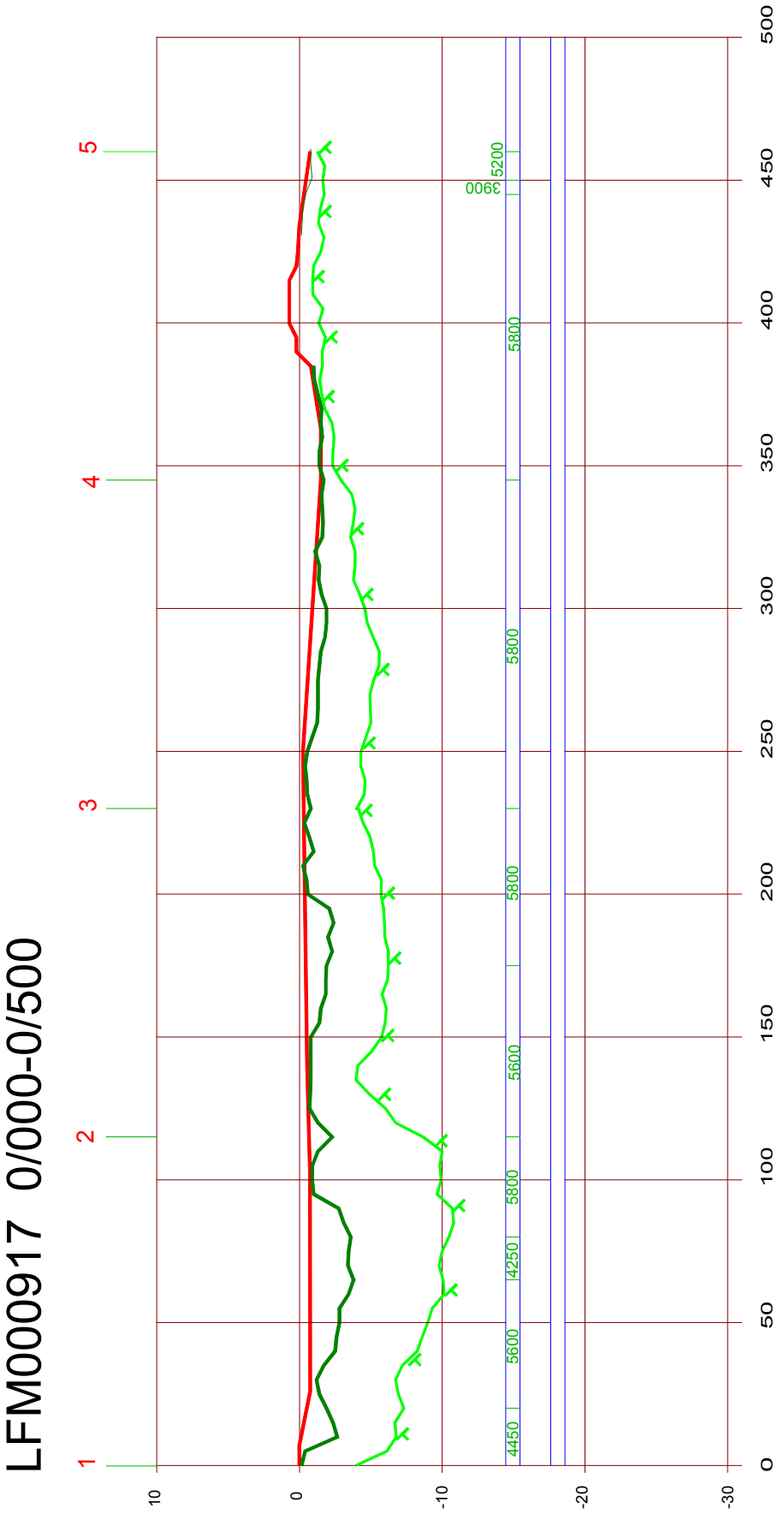
450
500
4550
5600
3700
5600
4600
5600
5350
4900
4200
5500
5700


LFM000916 0/500-1/000
10
9
8
7
6
5600
5800
5200
4000
5400
5600
4950
5450
5200
5700
10
0
-10
-20
-30
500
550
600
650
700
750
800
850
900
950
1000

LFM000916 1/000-1/200




LFM0000917 0/000-0/500
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4
5
10
0
-10
-20
-30
0
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100
150
200
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400
450
500
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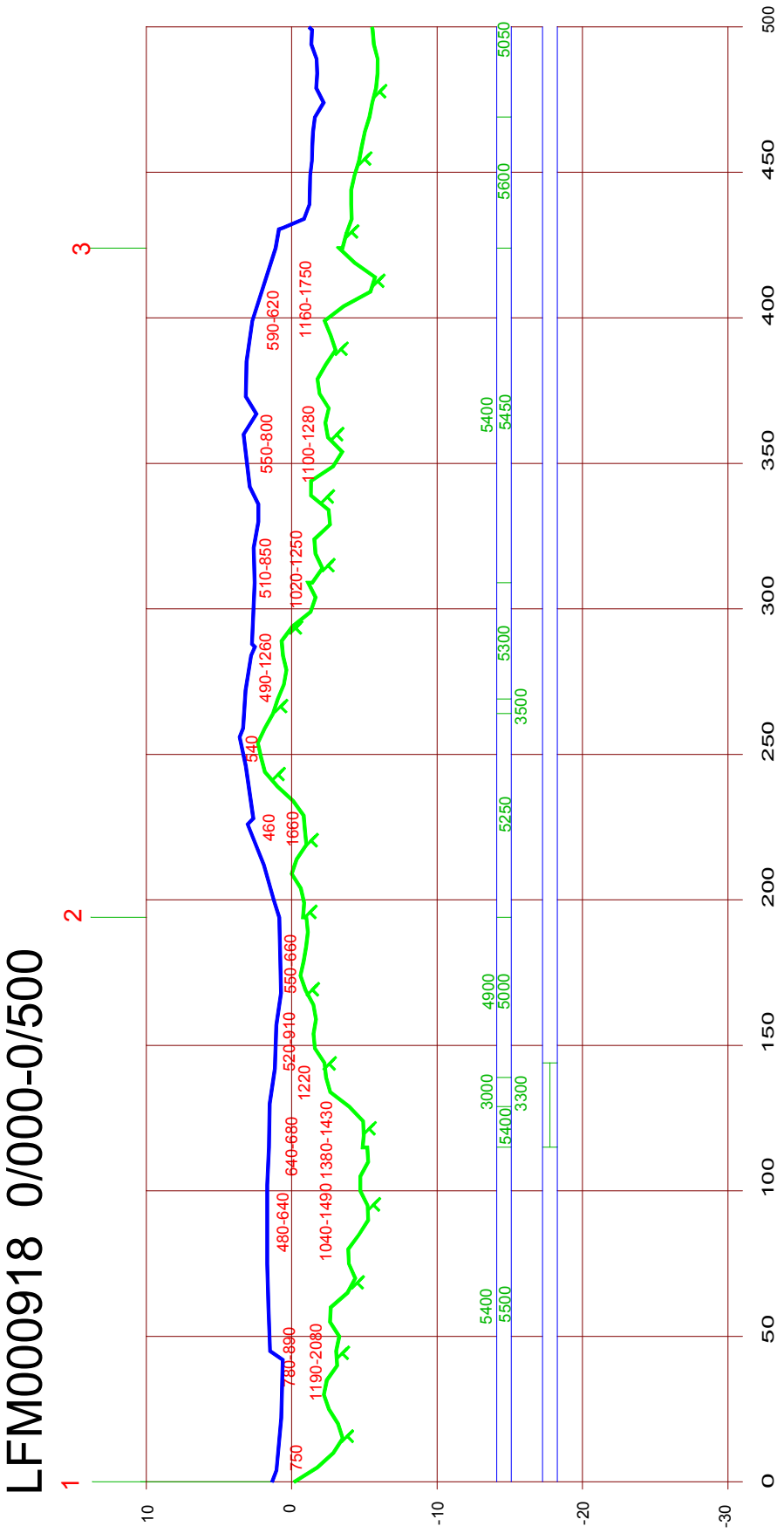
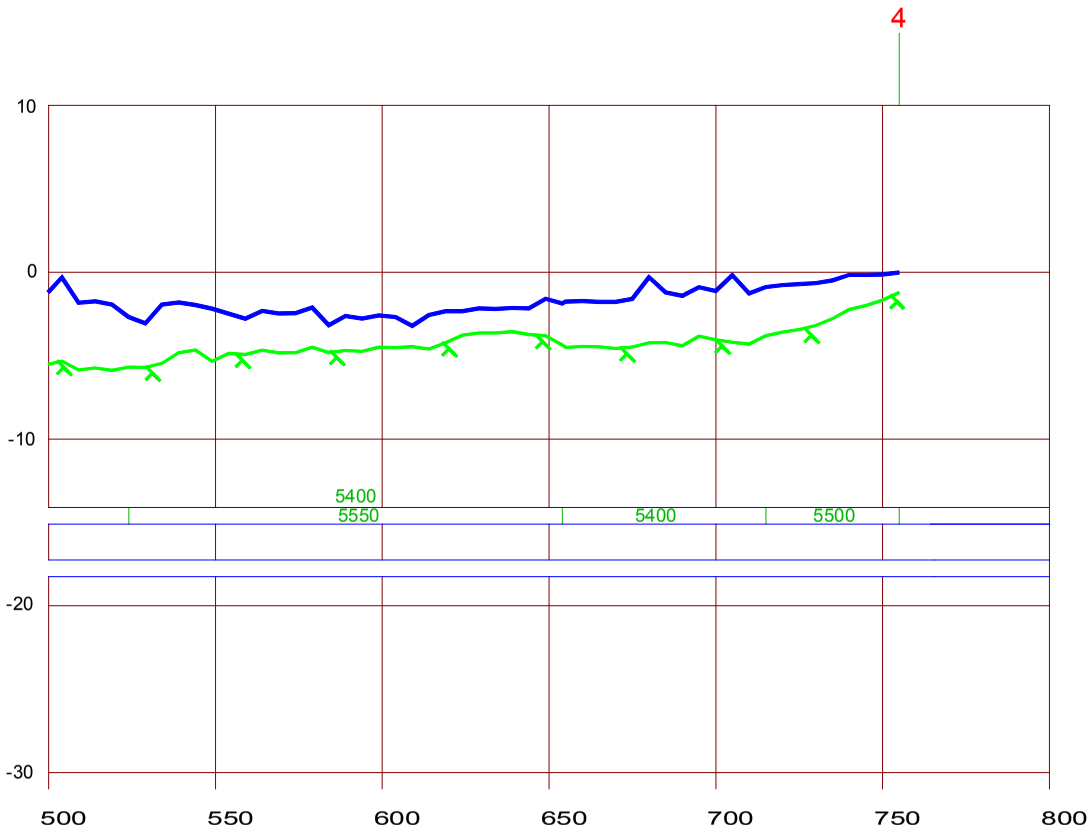
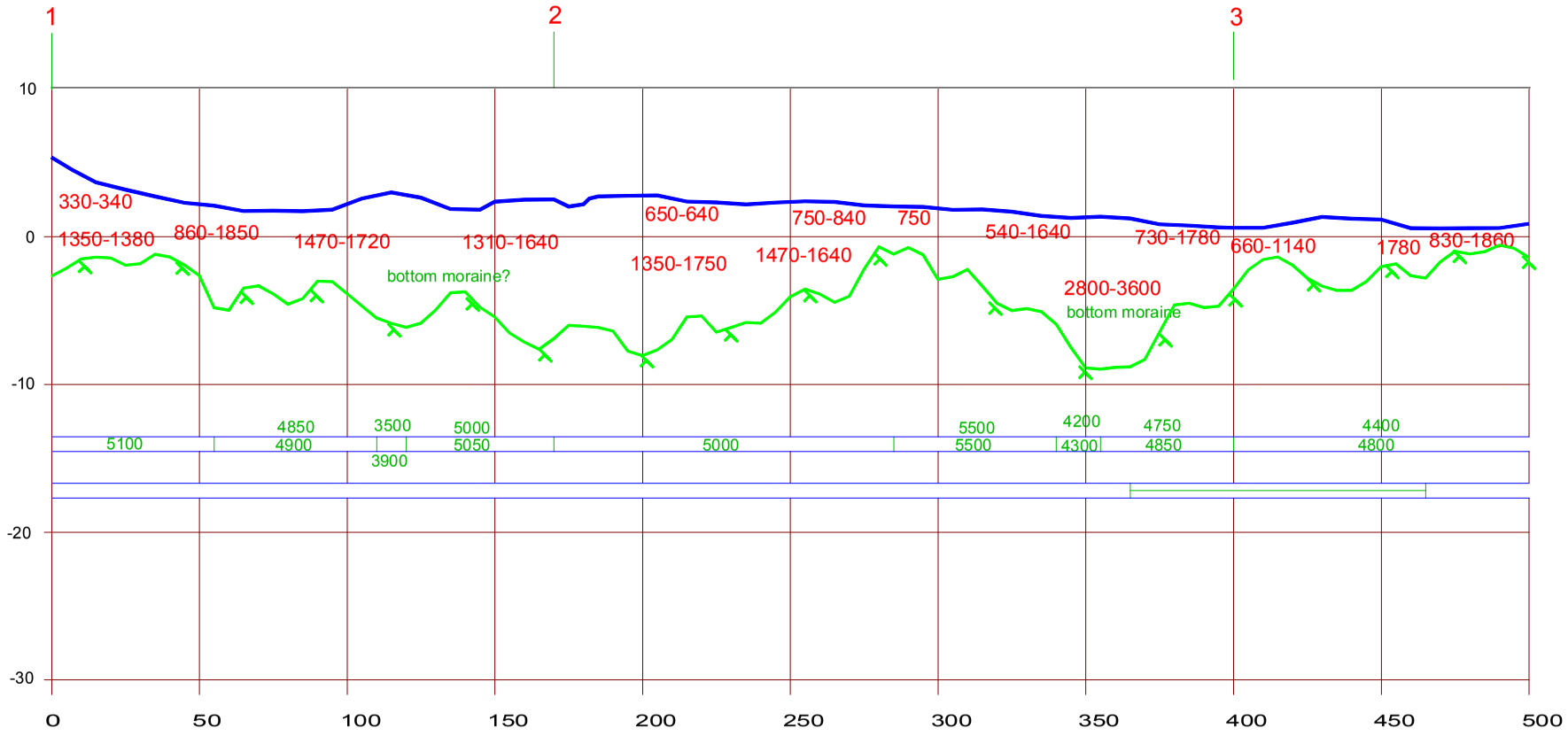
5600
4250
5800
5600
5800
5800
5800
3900
5200

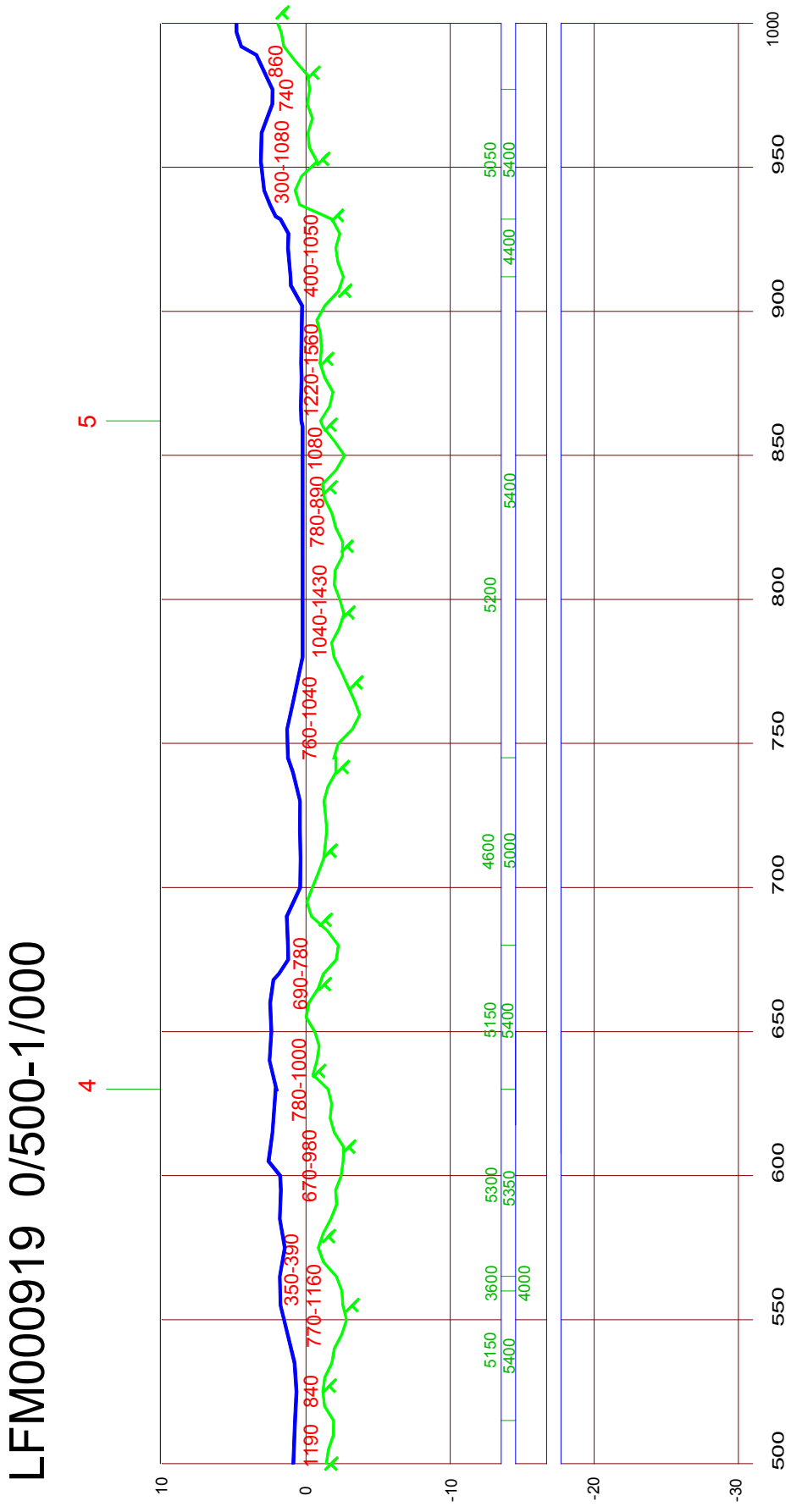

LFM000918 0/000-0/500
1
2
3
750
780-890
1190-2080
480-640
640-680
1040-1490
1380-1430
1220
520-910
660-680
460
1660
540
490-1260
510-850
1020-1250
550-800
1100-1280
590-620
1160-1750
5400
5500
3000
5400
3300
4900
5000
5250
3500
5300
5400
5450
5600
5050
10
0
-10
-20
-30
0
50
100
150
200
250
300
350
400
450
500

LFM000918 0/500-0/800



LFM000919 0/000-0/500




LFM000919 0/500-1/000
4
5
10
0
-10
-20
-30
500
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600
650
700
750
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850
900
950
1000
350-390
770-1160
840
1190
670-980
780-1000
690-780
760-1040
1040-1430
780-890
1080
1220-1560
400-1050
300-1080
740
860
5150
5400
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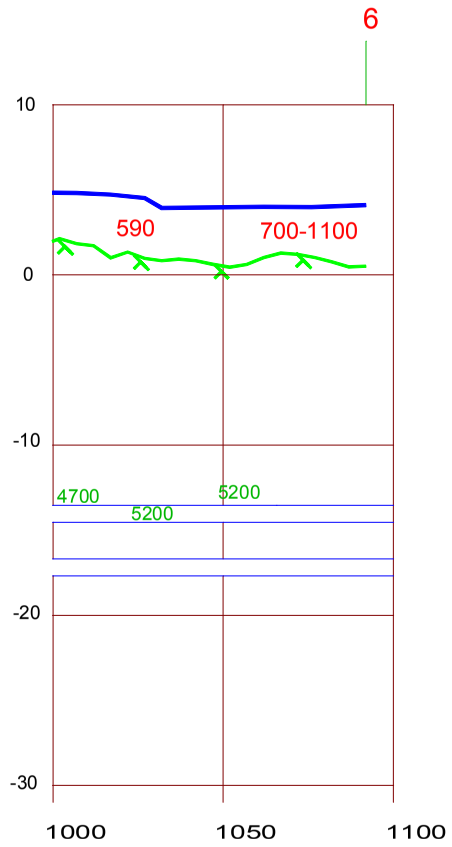
5150
5400
4600
5000
5200
5400
4400
5050
5400

LFM000919 1/000-1/100



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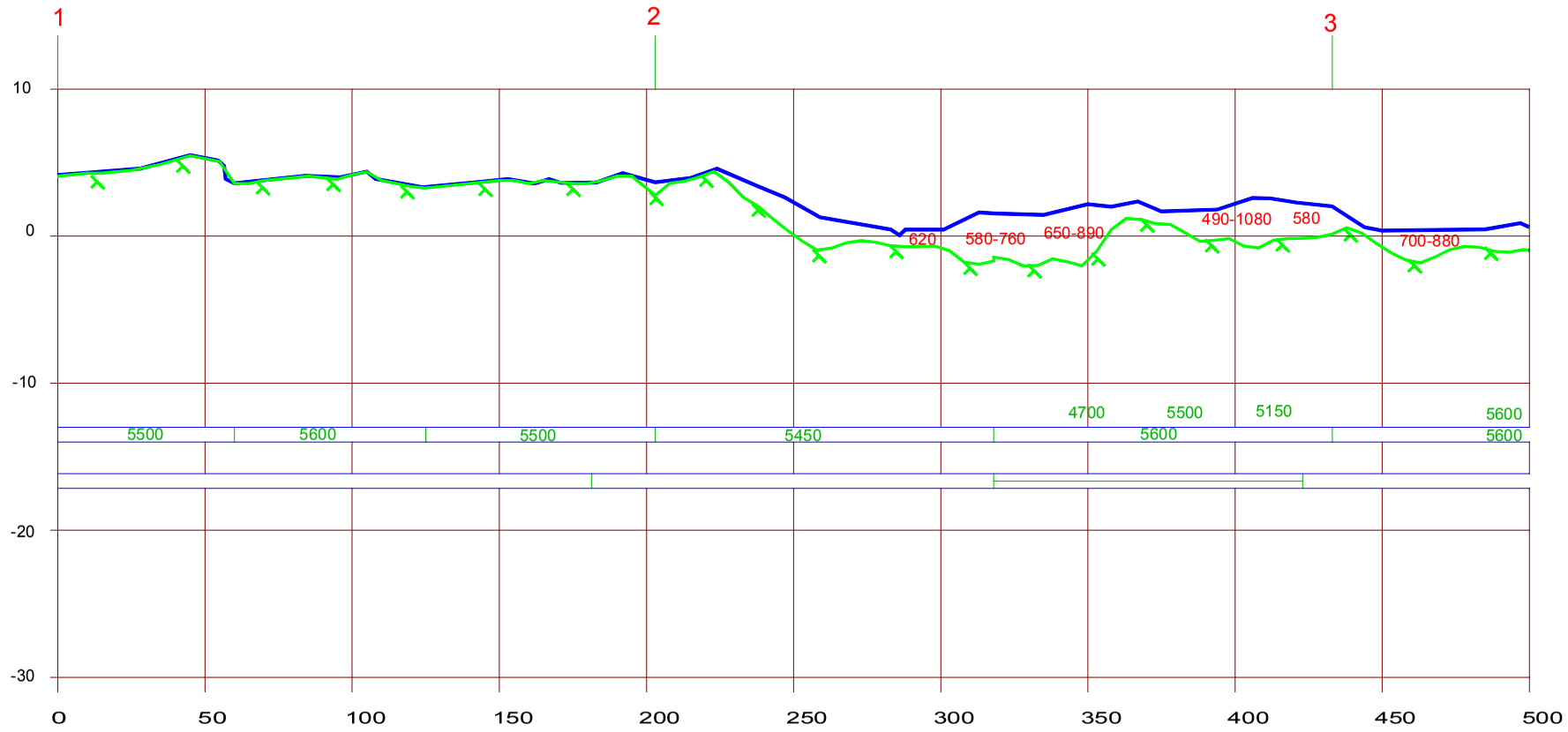

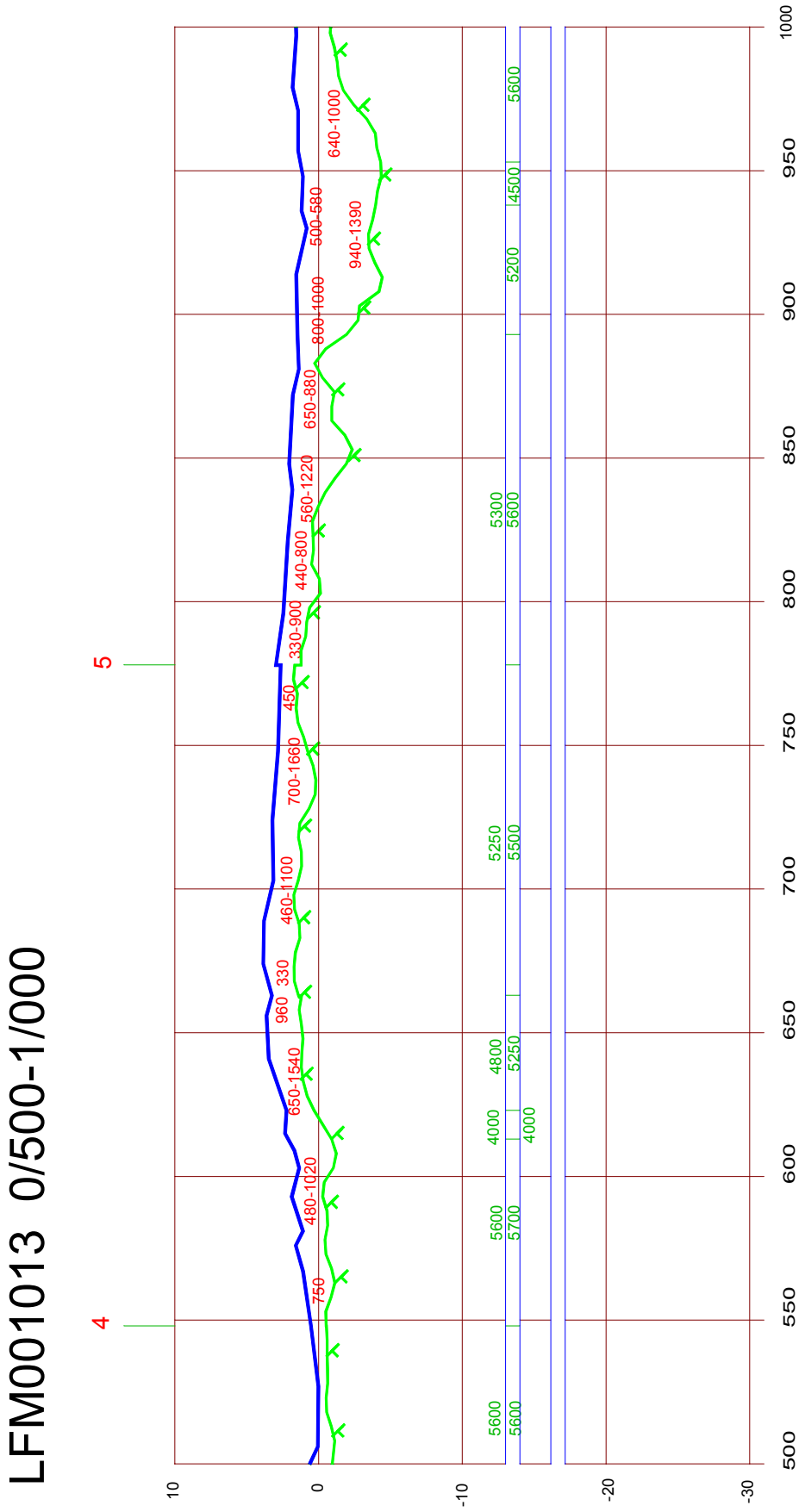
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0
-10
-20
-30
500
550
600
650
700
750
800
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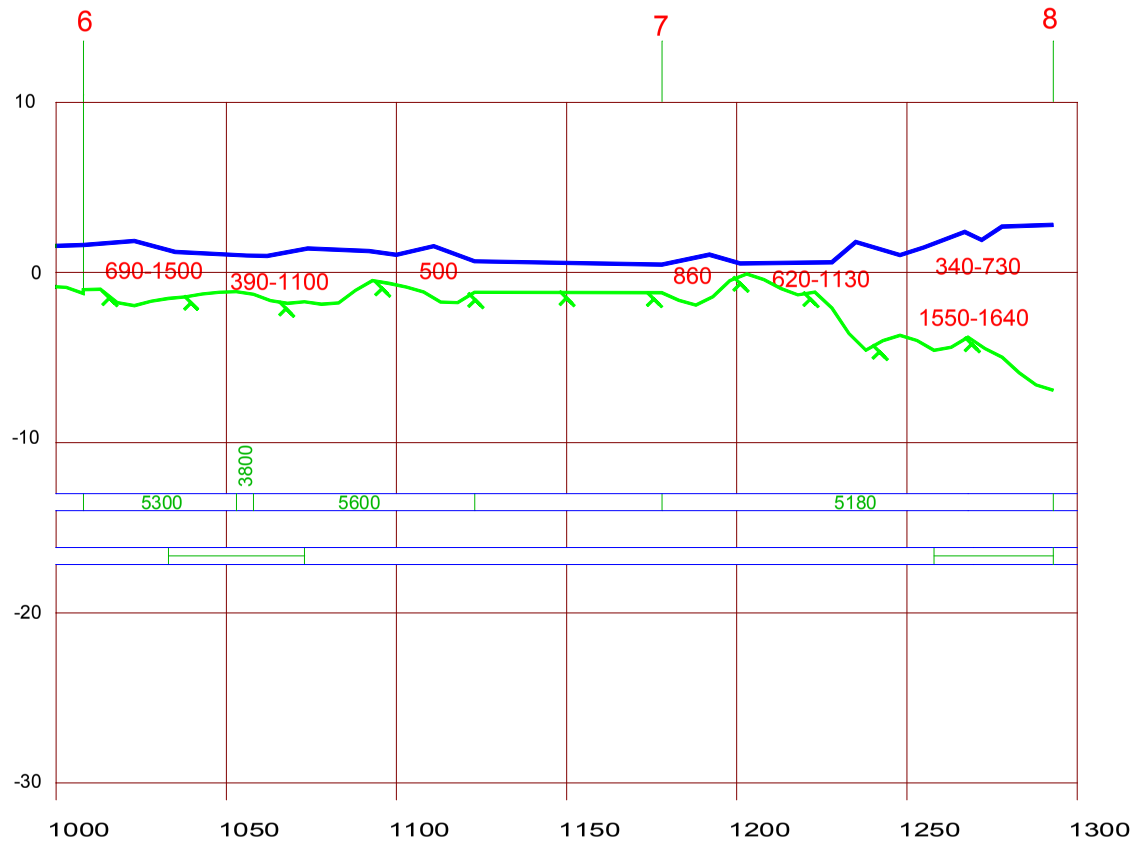
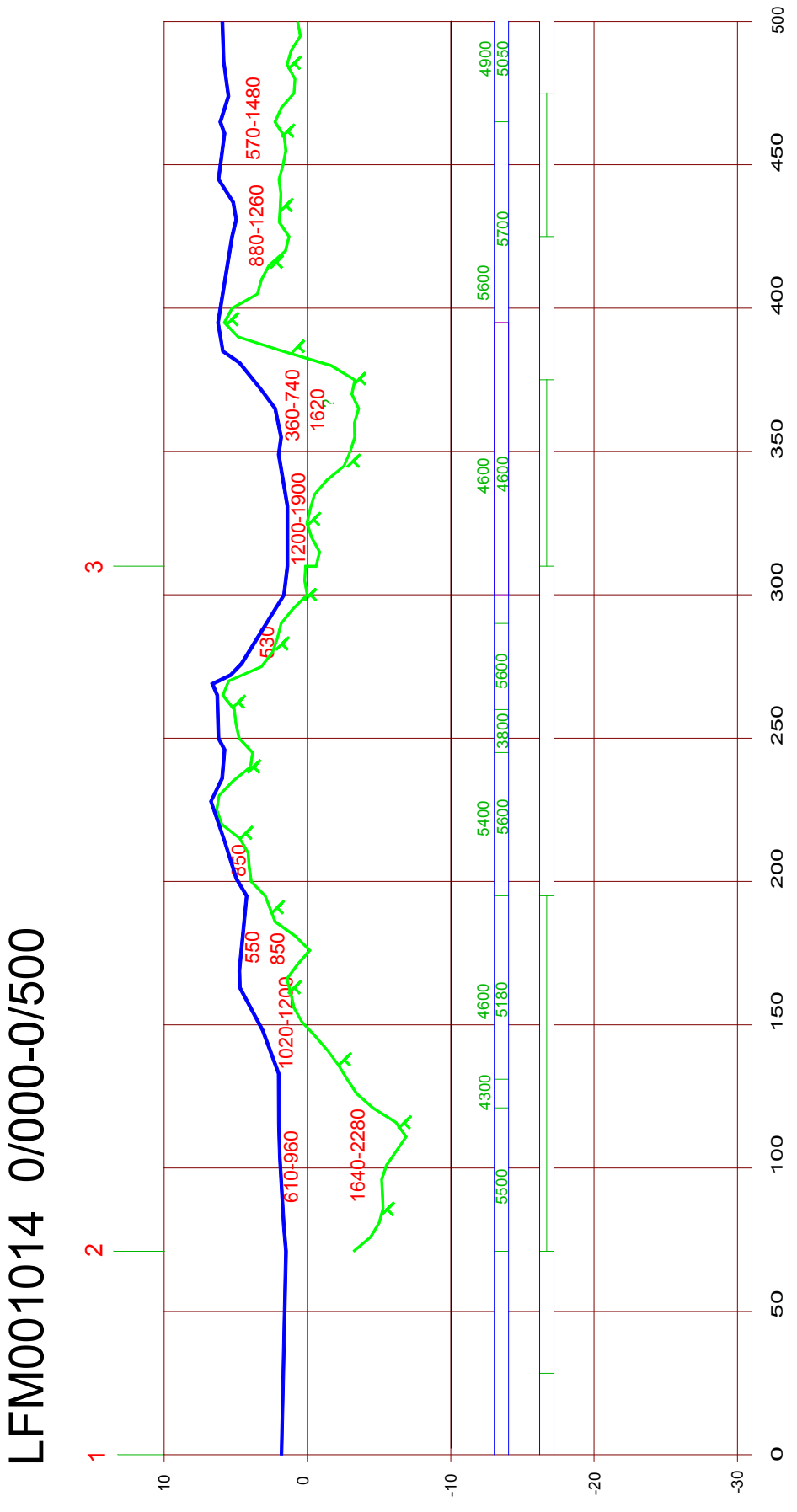
5600
5600
5600
5700
4000
4000
4800
5250
5250
5500
5300
5600
5200
4500
5600
480-1020
650-1540
960 330
460-1100
700-1660
450
330-900
440-800
560-1220
650-880
800-1000
500-580
940-1390
640-1000
750

LFM001013 1/000-1/300

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1
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3
610-960
1020-1200
550
850
850
530
1200-1900
360-740
1620
880-1260
570-1480
1640-2280
4900
5050
5600
5700
4600
4600
5600
3800
5400
5600
4600
5180
4300
5500
10
0
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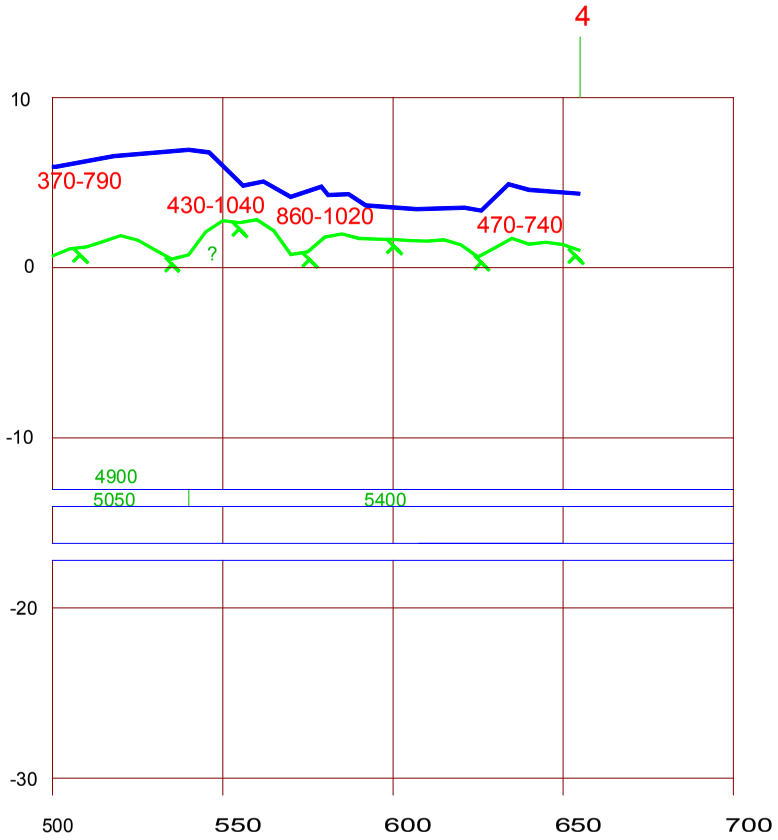
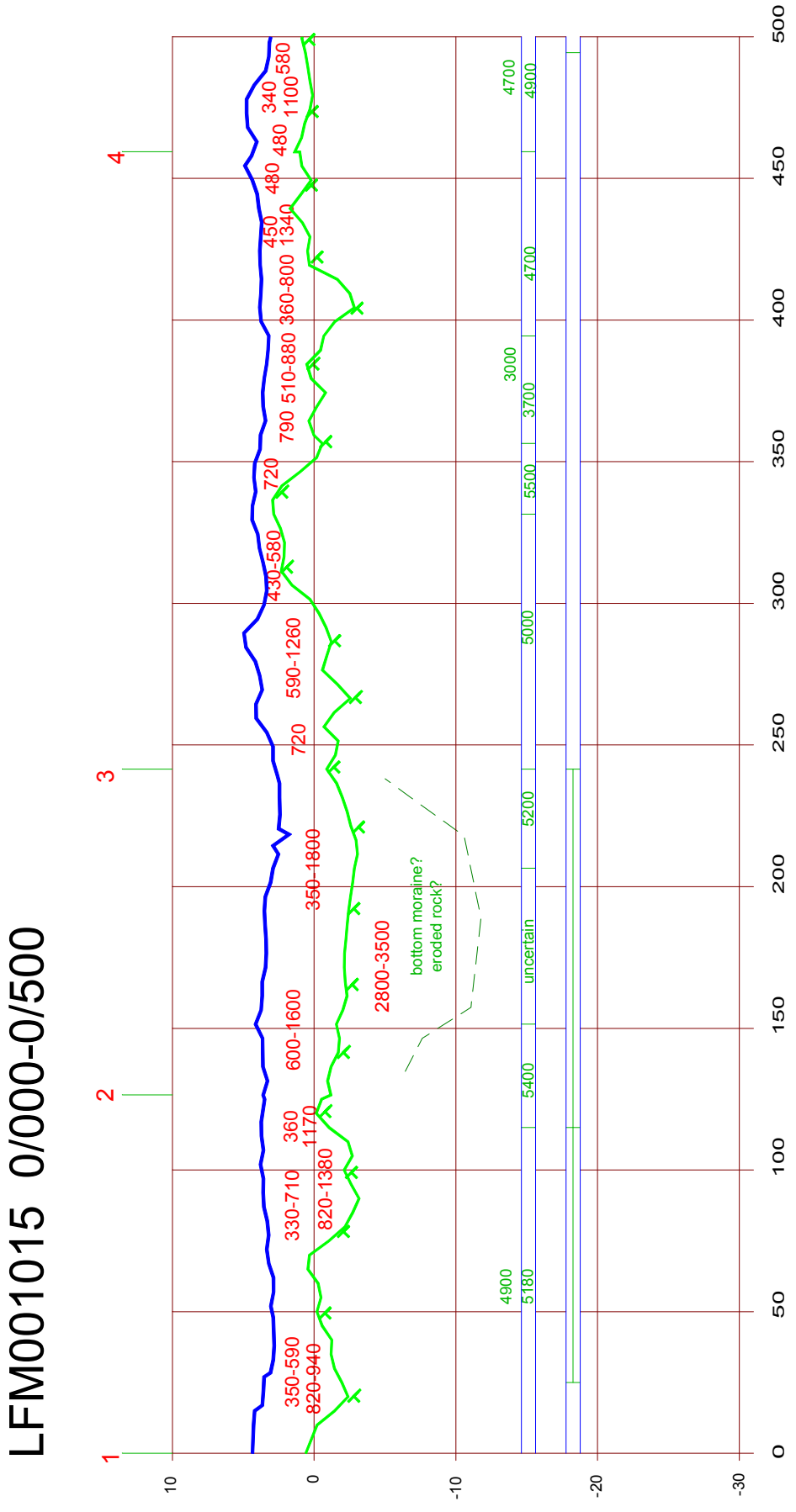
-20
-30
0
50
100
150
200
250
300
350
400
450
500

LFM001014 0/500-0/700

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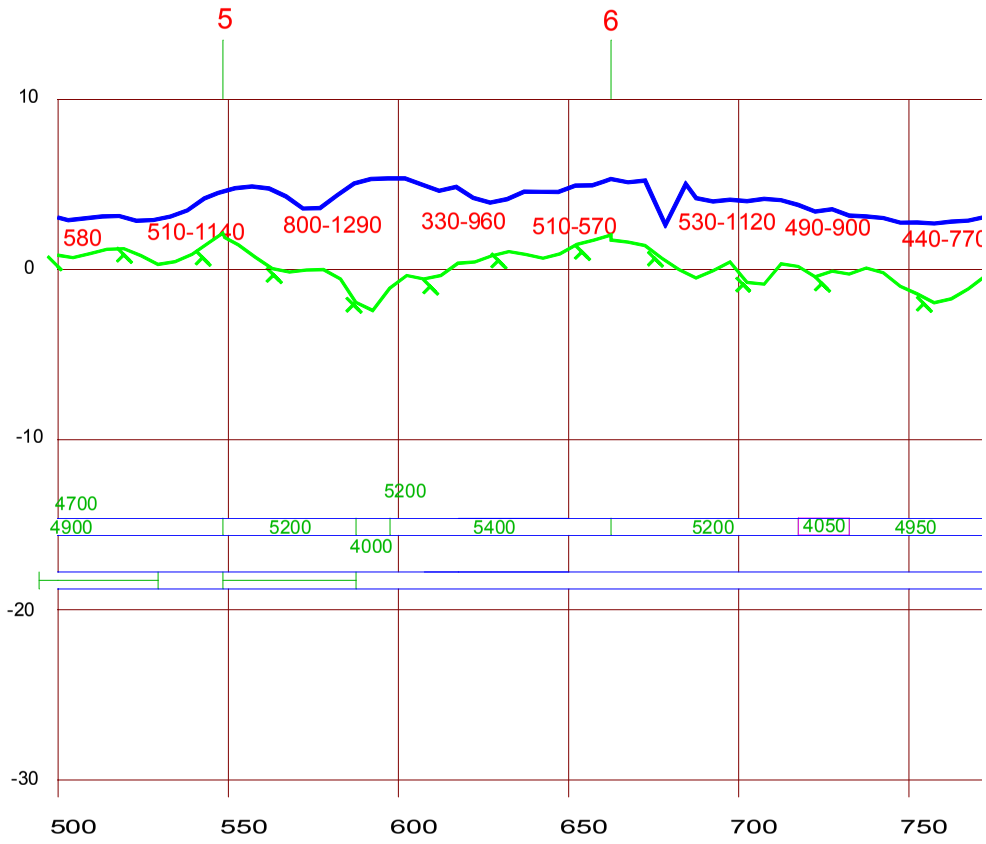
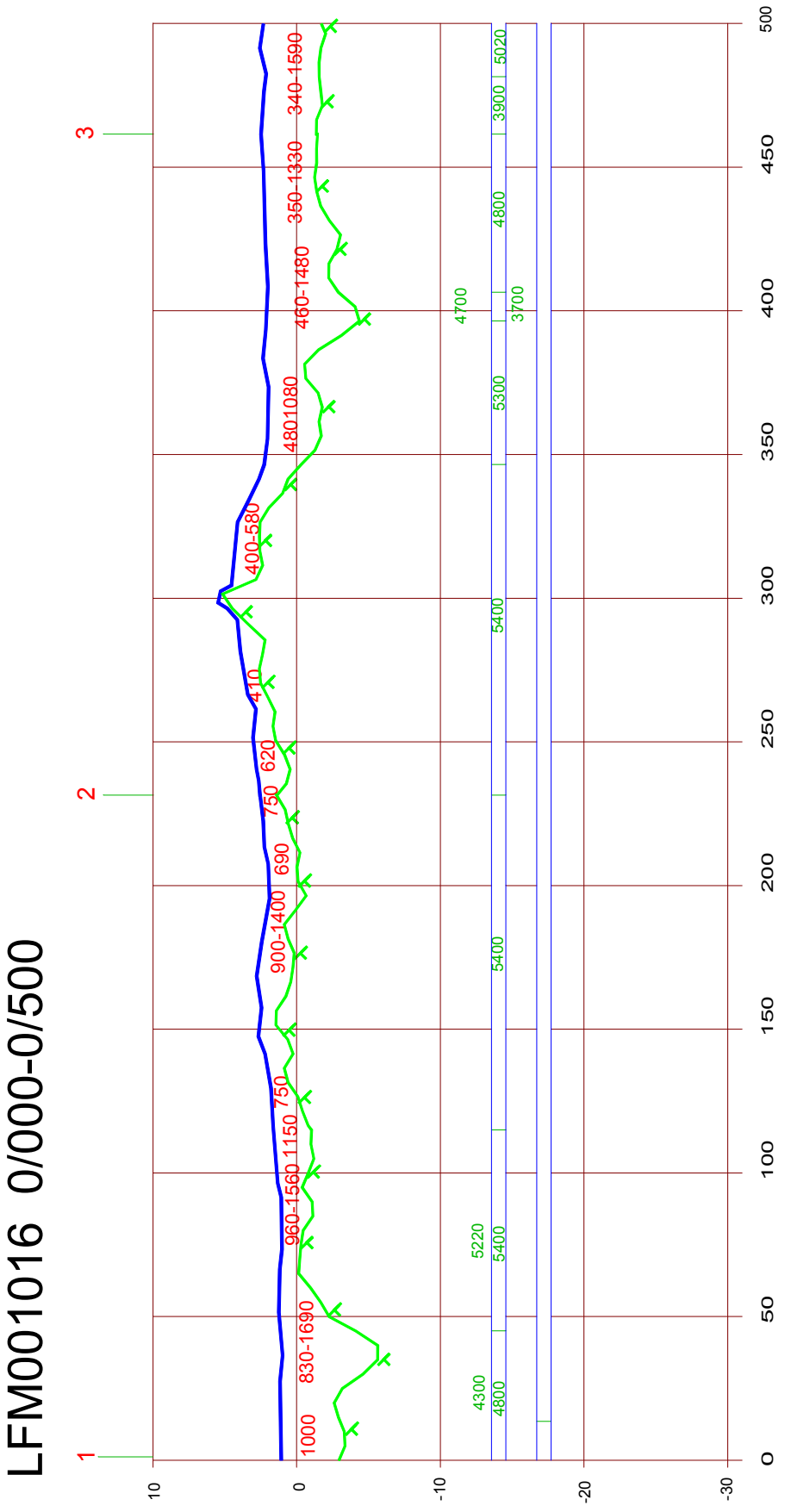
4
0
50
100
150
200
250
300
350
400
450
500
10
0
-10
-20
-30
350-590
820-940
330-710
820-1380
360
1170
600-1600
350-1800
2800-3500
720
590-1260
430-580
720
790 510-880
360-800
450
1340
480
480
340
1100
580
4900
5180
5400
5200
5000
5500
3700
3000
4700
4900
4700
bottom moraine?
eroded rock?
uncertain

LFM001015 0/500-1/050

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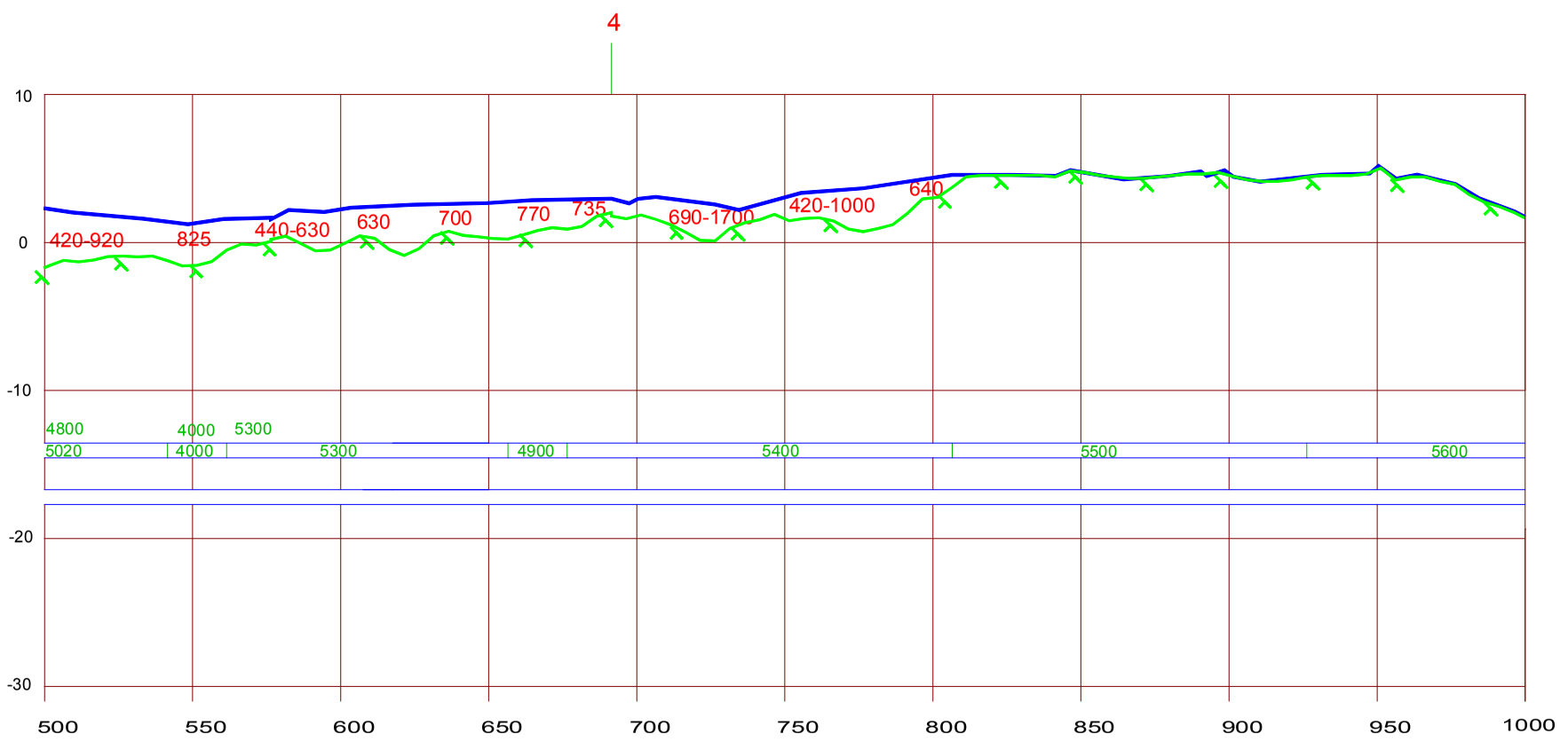
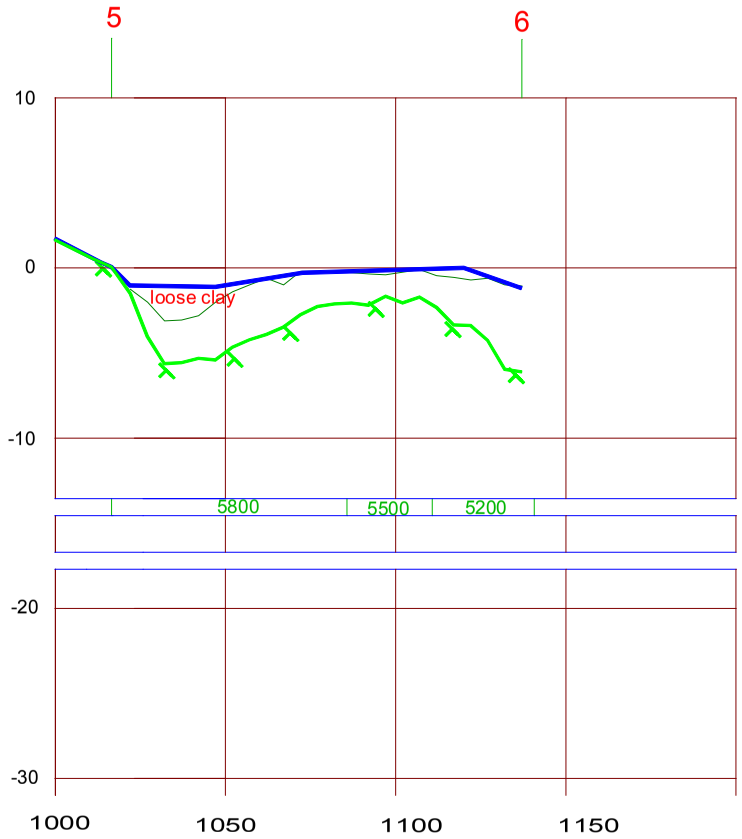
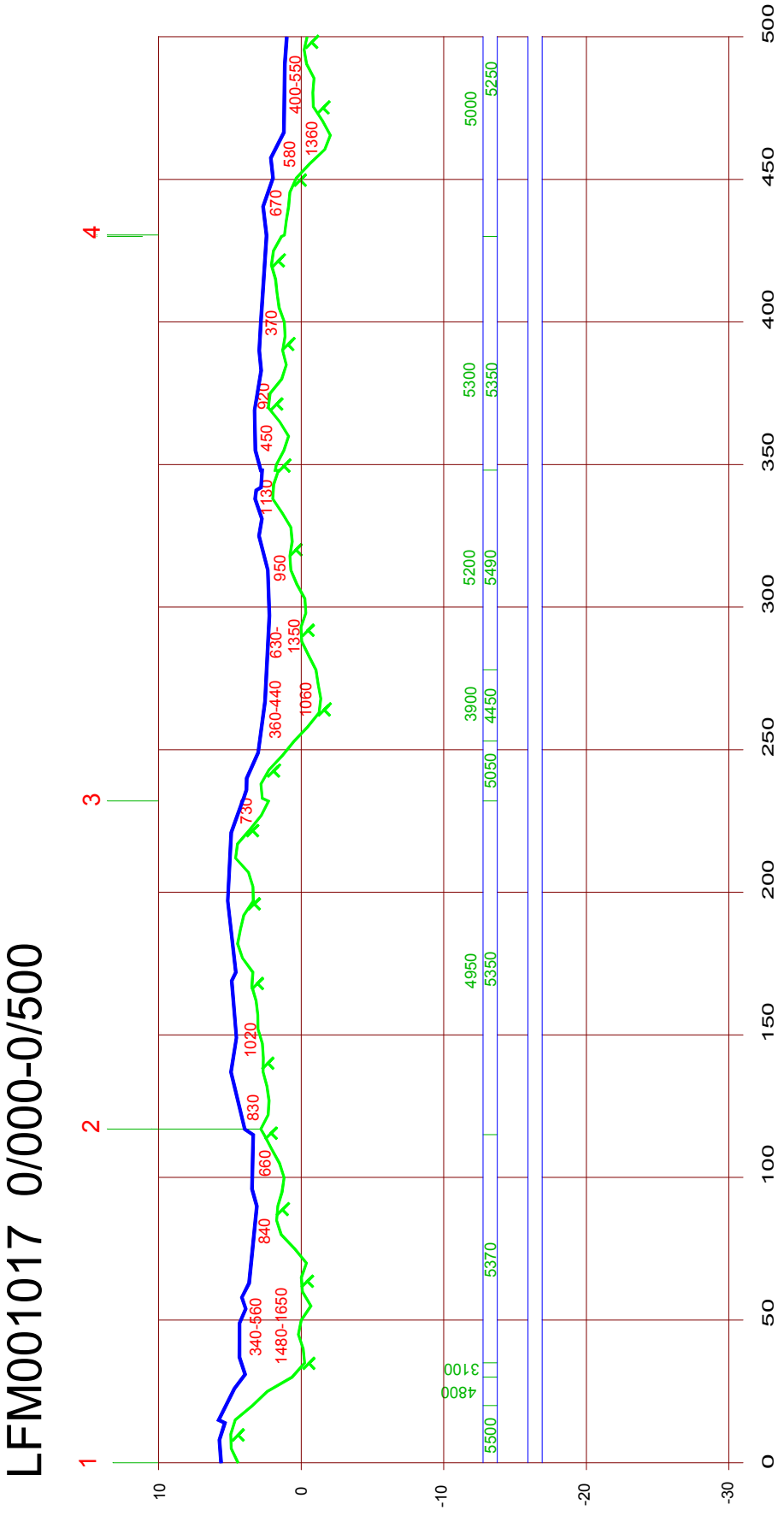
3
10
0
-10
-20
-30
0
50
100
150
200
250
300
350
400
450
500
1000
830-1690
960-1560
1150
750
900-1400
690
750
620
410
400-580
480
1080
460-1480
350-1330
340-1590
4300
4800
5220
5400
5400
4700
5400
5300
4800
3700
3900
5020

LFM001016 0/500-1/000



LFM001016 1/000-1/150




LFM001017 0/000-0/500
1
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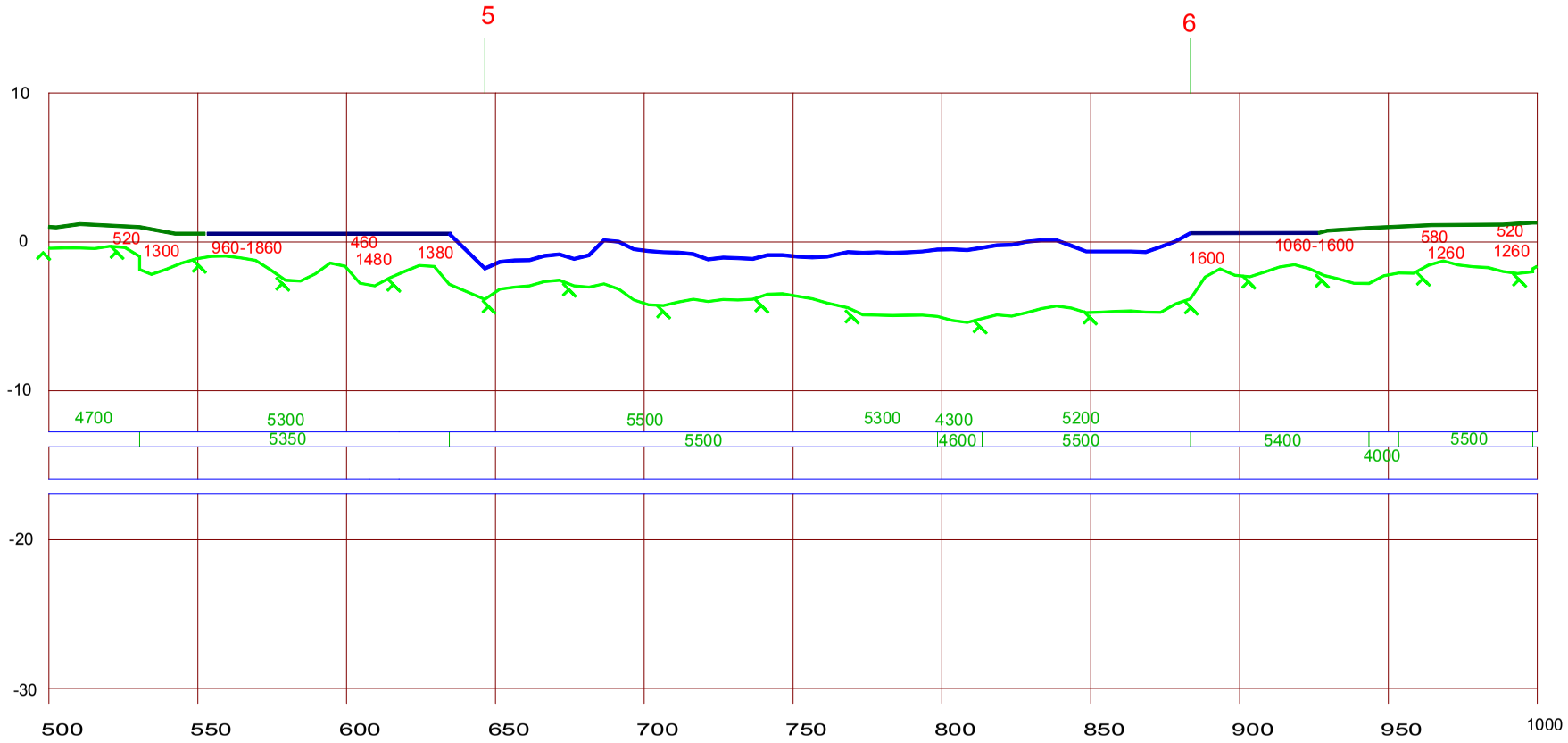
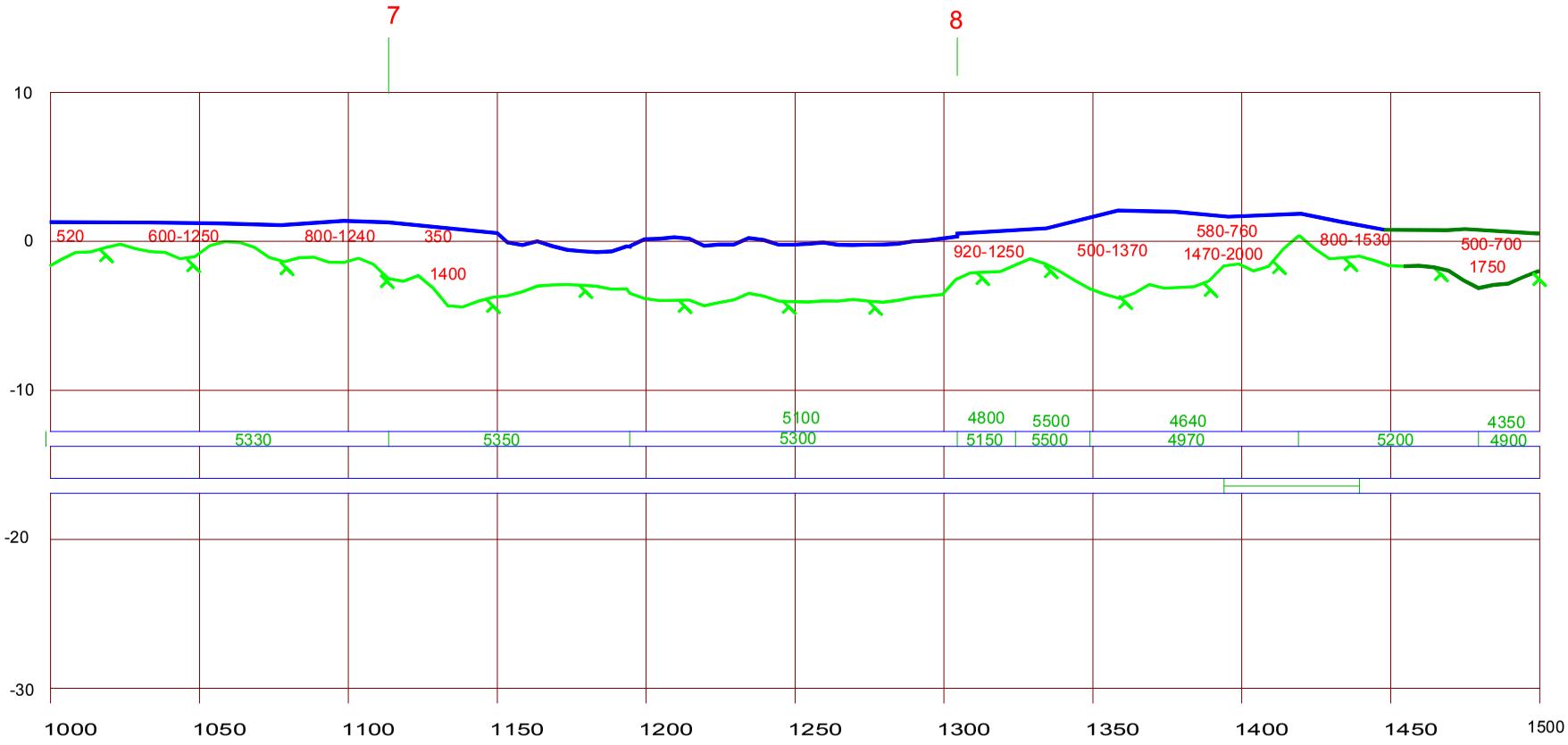
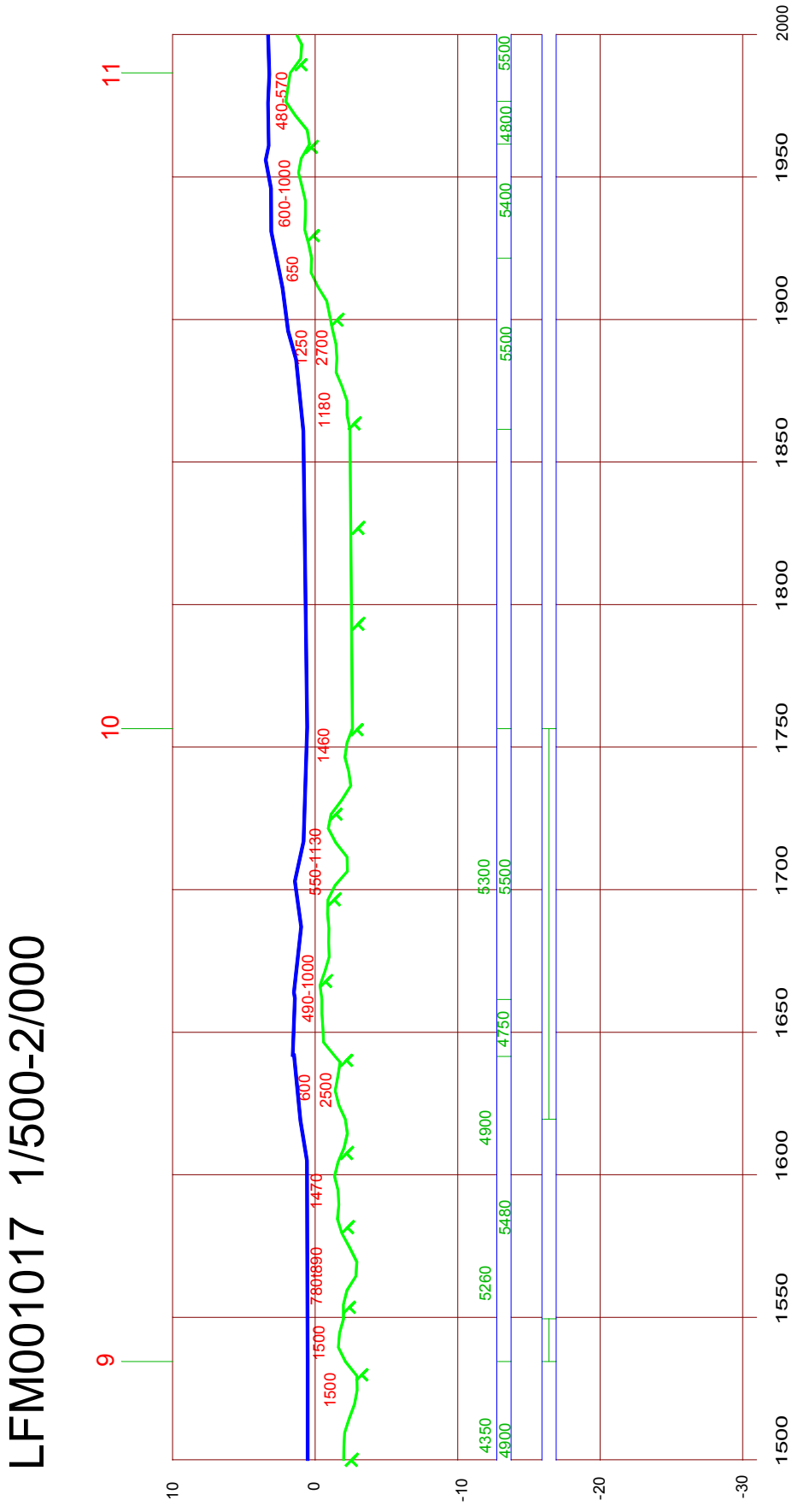
3
4
10
0
-10
-20
-30
0
50
100
150
200
250
300
350
400
450
500
5500
4800
3100
5370
4950
5350
3900
5050
4450
5200
5490
5300
5350
5000
5250
340-560
1480-1650
840
660
830
1020
730
360-440
630-
1350
1060
950
1130
450
920
370
670
580
1360
400-550

LFM001017 0/500-1/000



LFM001017 1/000-1/500

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1550
1600
1650
1700
1750
1800
1850
1900
1950
2000
10
0
-10
-20
-30
480-570
600-1000
650
1250
2700
1180
1460
550-1130
490-1000
600
2500
1470
780/890
1500
1500
4350
4900
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5500
5500
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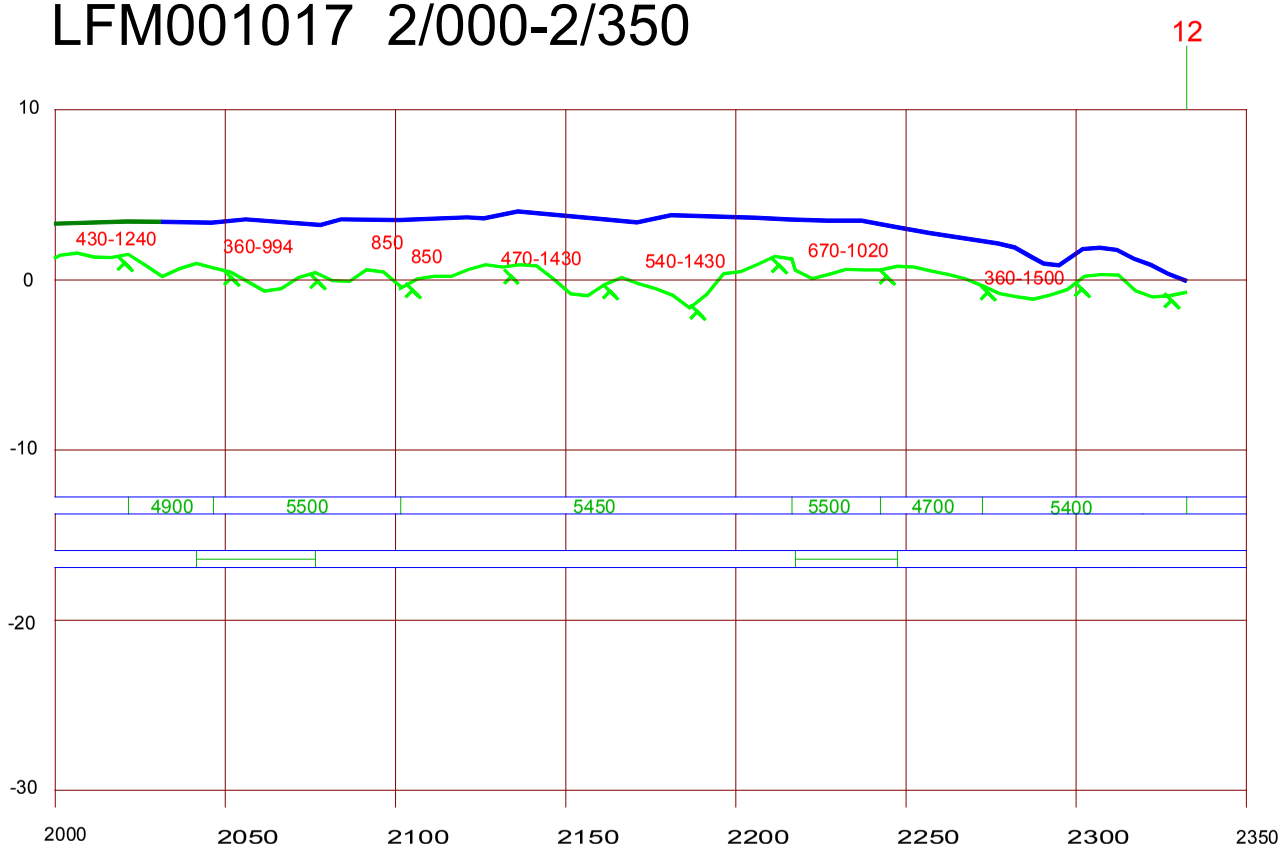

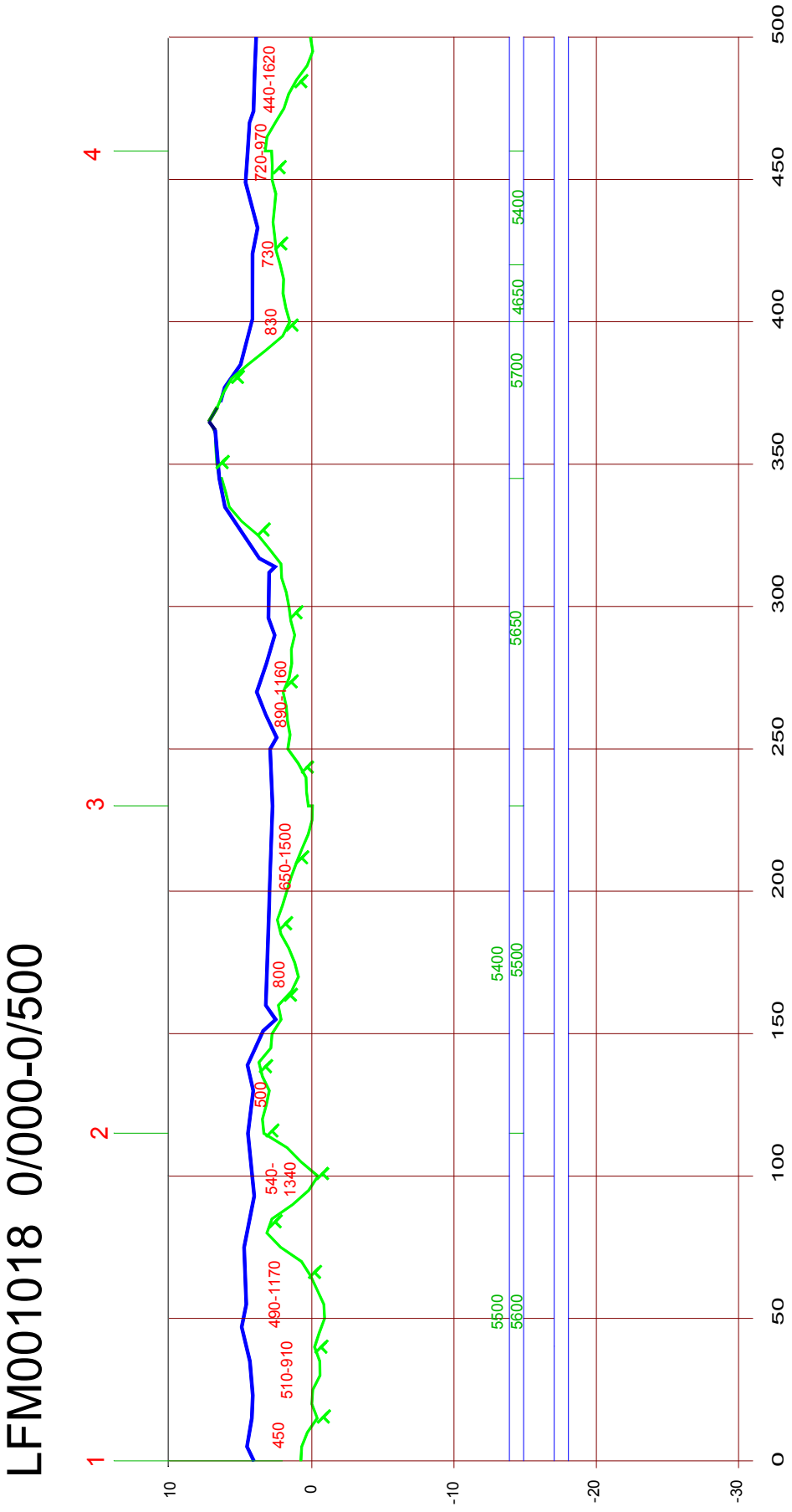
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-20
-30
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510-910
490-1170
540-1340
500
800
650-1500
890-1160
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720-970
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4650

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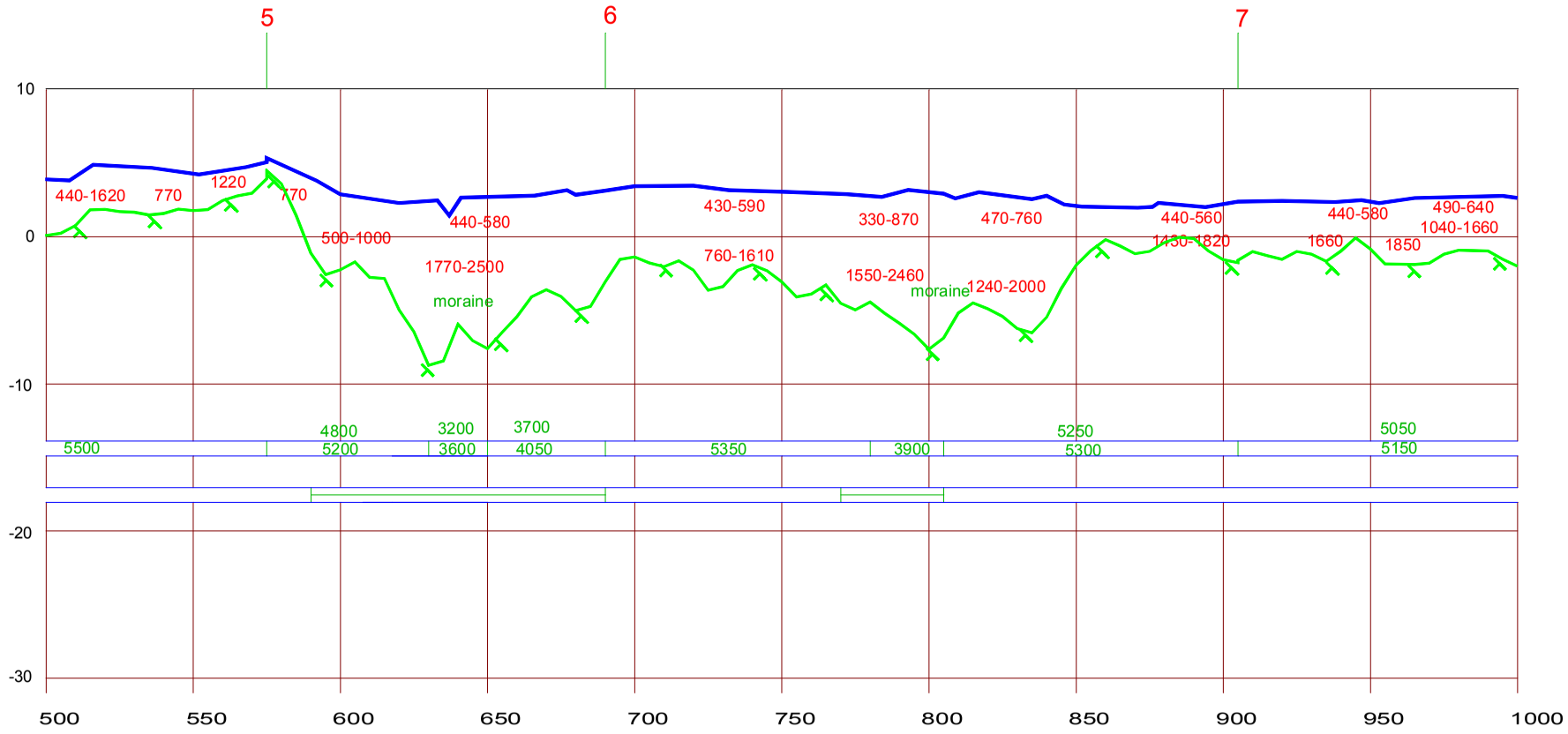

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