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Oskarshamn site investigation

Evaluation of RAMBØLL reflection seismic surveys on Simpevarpshalvön 2003 using the vibroseismic method

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July 2003

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Summary

RAMBØLL carried out a reflection seismic survey (10 reflection seismic lines) in the Simpevarp area, near Oskarshamn, during the period 23–30 March 2003 using the Pulled Array Seismic method. Shot gathers from the survey show indications of P-wave reflections on some of the lines. However, the stacked sections are of poor quality. They cannot be reliably used to make predictions about sub-surface structures. It is difficult to correlate events from one line to another, suggesting that there are few P-wave reflections in the stacks. A number of the picked events also have apparent velocities which are too slow to be true P-wave reflections. RAMBØLL Line LSM000066 overlaps partly with an explosive source line acquired by Uppsala University (UU) in 1996 on Ävrö. Where the two lines overlap, most of the reflections presented in the UU stack are missing in the RAMBØLL stack. The frequency content of the RAMBØLL stack is also significantly lower than the UU stack. It is possible that an improvement in the RAMBØLL stacks can be made by using different processing parameters than those chosen by RAMBØLL. However, until shown otherwise, it is recommended that future reflection seismic surveys follow the acquisition and processing strategy outlined in SKB report TR-01-31.

Contents

1 Introduction

During the period 23–30 March 2003 RAMBØLL carried out a reflection seismic survey at and around the OKG power plant using the Pulled Array Seismic method. The reflection seismic survey comprised 10 seismic lines (LSM000066–LSM000075) with a total nominal length of 9250 m (Figure 1-1). Processing and interpretation of the data were carried out by RAMBØLL during April and May, 2003. Results from the survey has been presented in a report by RAMBØLL /Vangkilde-Pedersen, 2003/.

The purpose of the present report is to evaluate the results from the RAMBØLL reflection seismic survey based on their report. Reflection seismic data acquired using an explosive source on Ävrö /Juhlin and Palm, 1999/ form the main basis for this evaluation since RAMBØLL Line LSM000066 partly overlaps one of these explosive source profiles. The explosive source data will be referred to as the UU survey in the remainder of this report. Digital data from RAMBØLL's final stacked sections were provided in SEGY format and some of these sections have been replotted in this report to facilitate comparison.

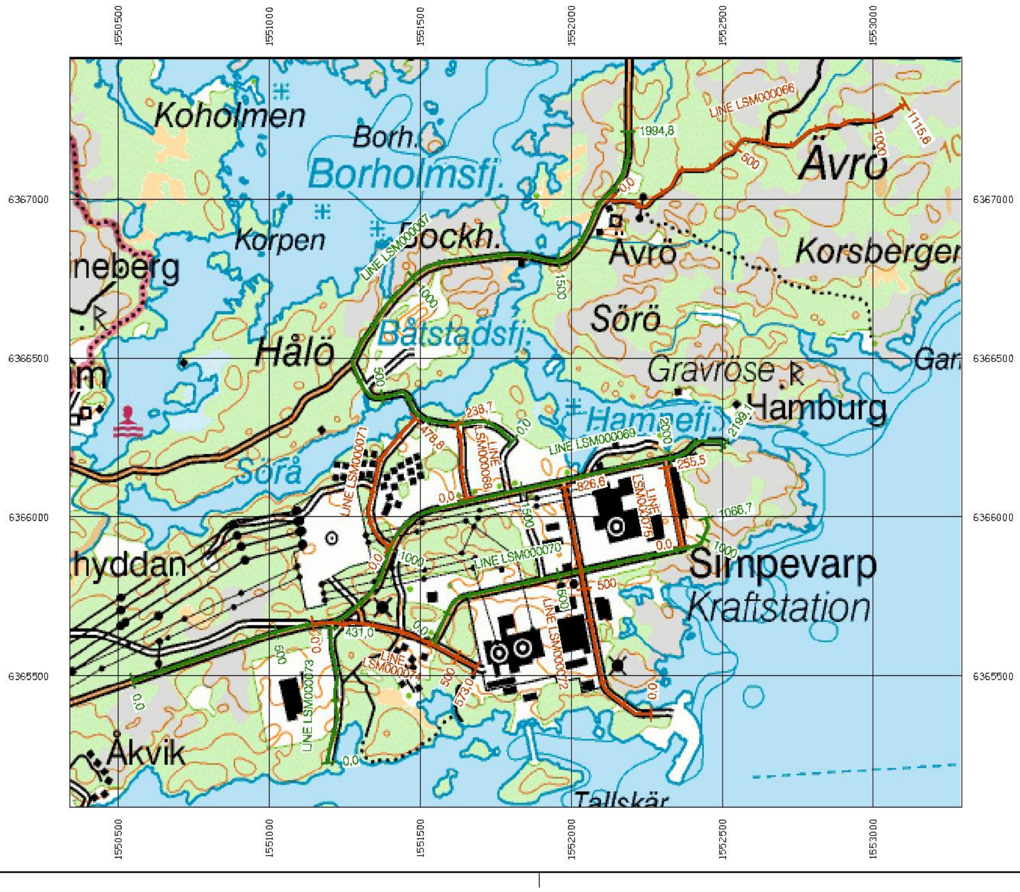


Figure 1-1. Location of the RAMBØLL seismic profiles (red and green lines). The eastern half of LINE LSM000066 coincides with the western part of Line 1 in /Juhlin and Palm, 1999/.

2 Data acquisition

A comparison of the acquisition parameters for the RAMBØLL survey and Line 1 of the UU survey are given in Table 2-1. The UU survey was shot in October 1996. A W-E one (Line 1) with a station spacing of 5 m on average and a N-S one (Line 2) with a station spacing of 10 m on average were acquired /Juhlin and Palm, 1999/.

Table 2-1. Acquisition parameters for the RAMBØLL and UU surveys.

Parameter	RAMBØLL	Line 1 UU
Spread type	End-on, shoot through	End-on, shoot through
Number of channels	93	100
Near offset	5 m	20
Geophone spacing	2.5 m	5 m
Geophone type	14 Hz single	28 Hz single
Source spacing	10 m	5 m
Source	IVI Minivib T7000, 5 sec sweep, 10–350 Hz	Dynamite: 100 grams at 2 m
Nominal fold	47 at 4xCDP binning	50
Recording instrument	Geometrics StrataVisor NZ/2 Geodes	SERCEL 348
Sample rate	0.5 ms	1 ms
Field low cut	Out	Out
Field high cut	250 Hz	250 Hz
Record length	4 seconds	5 seconds

3 Data processing

Standard processing was applied to both the RAMBØLL and UU surveys. The main differences in the processing are mainly in the choice of bandpass filters (Table 3-1) and in that no deconvolution or spectral balancing was applied to the RAMBØLL survey. The bandpass filters applied to the RAMBØLL data were significantly lower than those applied to the UU data. In addition, no refraction statics were applied to the RAMBØLL survey.

In order to facilitate comparison of the RAMBØLL and UU surveys, the RAMBØLL stacks have been replotted using the same plotting parameters as for the UU stack. Replotted stacks have a similar appearance to the original results presented in the RAMBØLL report (Figure 3-1).

Table 3-1. Comparison of the most important processing parameters.

Parameter	RAMBØLL	Line 1 UU
Refraction statics	Not Applied	Quality controlled refraction statics
Deconvolution	Not Applied	Surface consistent spiking deconvolution Design gate 0 m: 200–500 ms, 500 m: 350–600 ms Operator 60 ms White noise added 0.1%
Pre-stack Bandpass filter	50-75-250-350 Hz	0-100-300-450 Hz 0–100 ms 60-90-270-400 Hz 50–500 ms 50-80-240-320 Hz 400–700 ms 40-70-210-300 Hz 600–2000 ms
Automatic Gain Control (AGC) window	100 ms	50 ms
Dip Moveout (DMO)	Not Applied	Common offset F-K DMO velocity 0 ms – 5600 m/s, 200–5850, 500–6000
Post-stack Bandpass filter	30-50-150-250 Hz	Same as pre-stack filter
F-X Deconvolution	Not Applied	50-250 Hz 5 traces x 4 samples

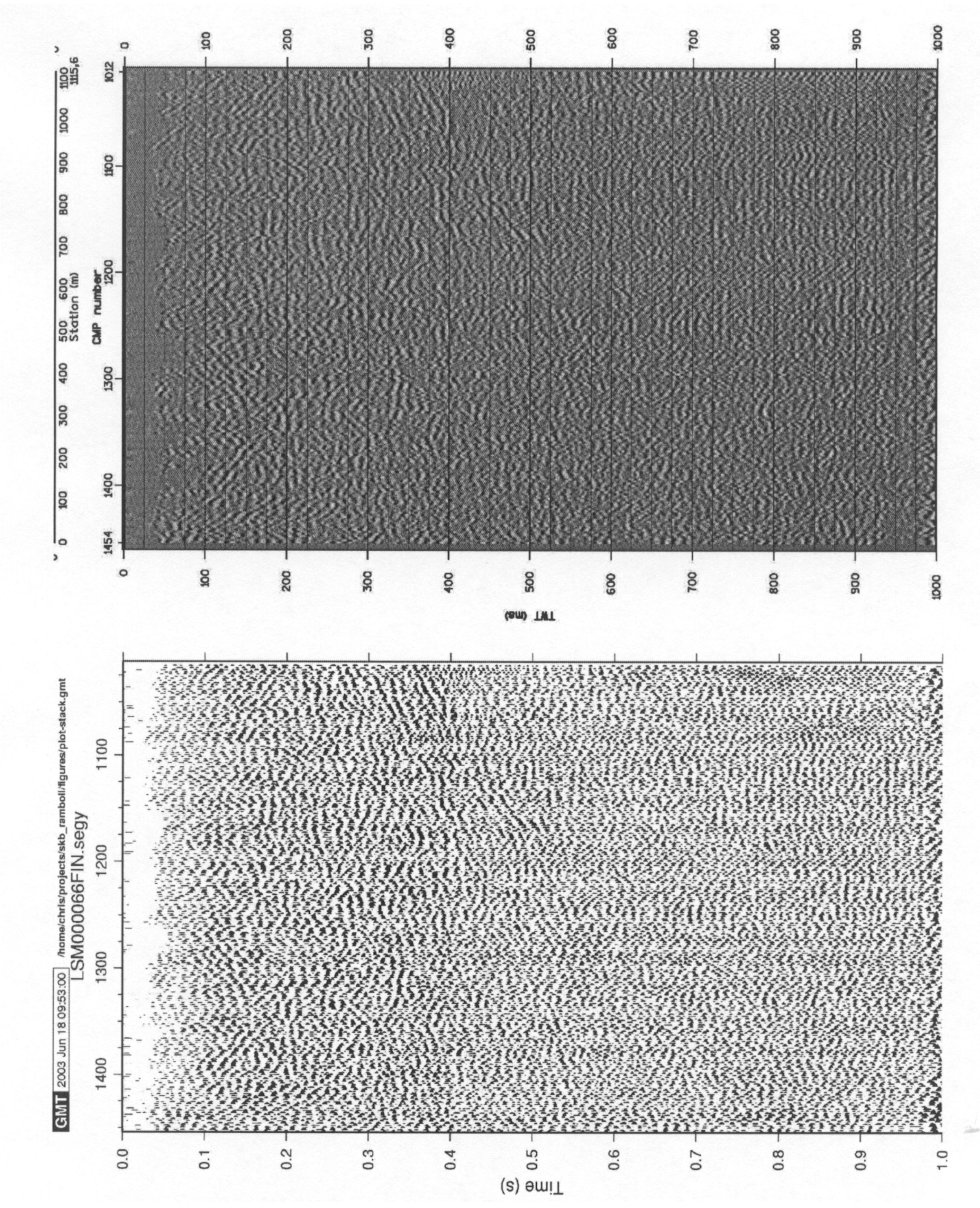


***Figure 3-1**. Top: RAMBØLL display of Line LSM000066 as presented in their report. Bottom: Line LSM000066 replotted using a variable area display.*

4 Comparison between RAMBØLL and Uppsala University on Ävrö

Since the eastern half of RAMBØLL Line LSM000066 (Figure 1-1) approximately coincides with the western half of the explosive source Line 1 acquired by Uppsala University (UU) in 1996 /Juhlin and Palm, 1999/ it is possible to directly compare the two seismic methods here (Figures 4-1 and 4-2). There is a large difference in the seismic images. On the UU stack there are numerous clear reflections down to 1 s, while on the RAMBØLL stack there are only two events which are probable P-wave reflections. These are the steeply dipping events east of CDP 1100 at about 0.4 s. There are also some signs of sub-horizontal reflections at about 0.2 s on the RAMBØLL stack. The UU stack has a much greater frequency bandwidth than the RAMBØLL stack. Note also the absence of information from almost the entire upper 0.1 s in the RAMBØLL stack and the absence of any reflections from below 0.5 s.

The lack of high frequency signal in the RAMBØLL stack is even more apparent when the stacks are transformed to the frequency domain (Figure 4-3). The UU stack contains useful signal up to about 250 Hz in the upper 0.5 s, whereas the RAMBØLL stack has a sharp peak at about 70 Hz in this time interval. Below 0.5 s the UU stack has useful frequencies up to about 220 Hz. The RAMBØLL stack is dominated by 100 Hz signals below 0.5 s, probably originating from electrical or mechanical noise in the area.

In summary, The UU stack is far superior to the RAMBØLL stack where the two data sets overlap on Ävrö. Whether this is due to the acquisition method or to the processing remains to be determined.

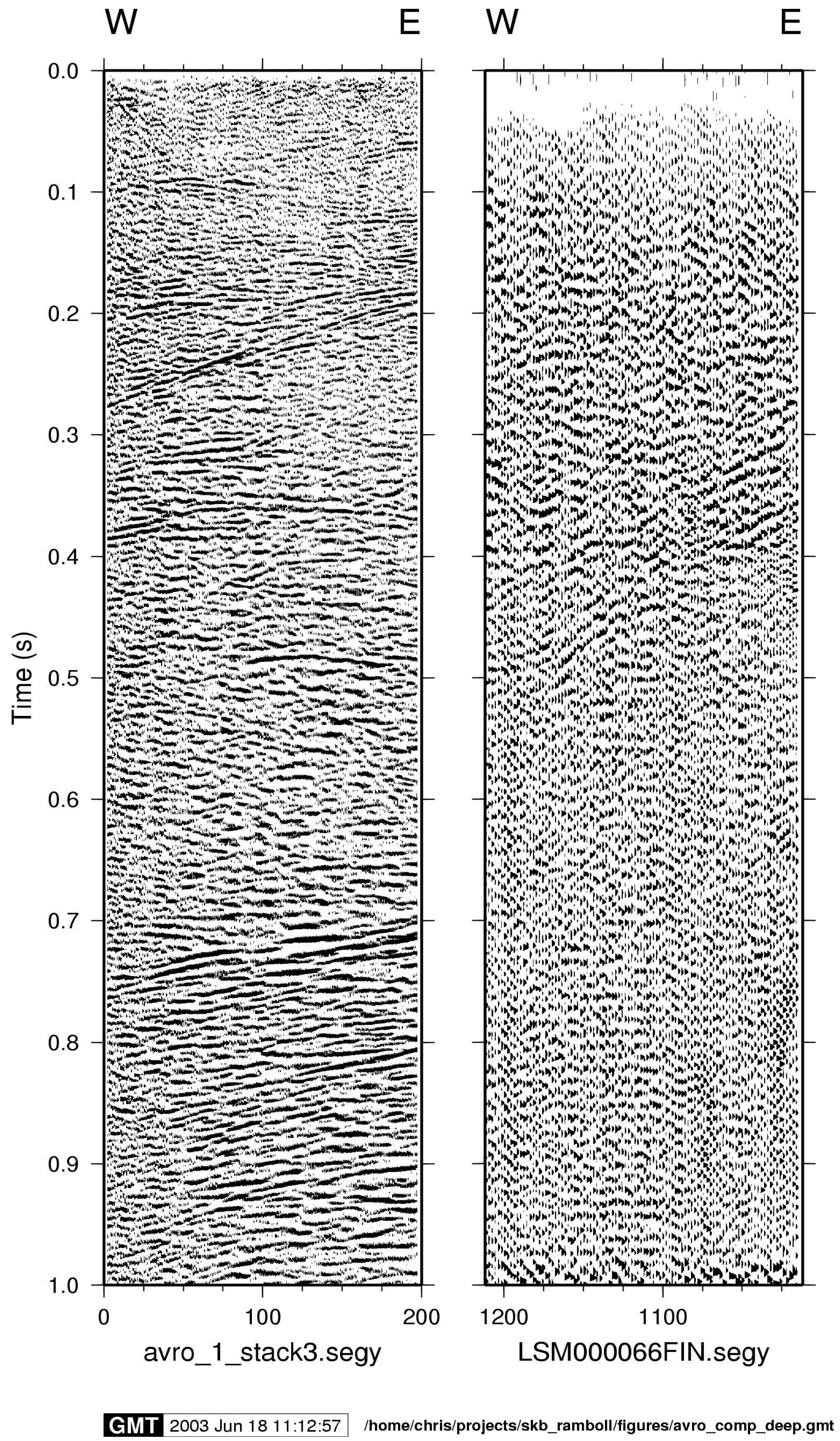


Figure 4-1. *Comparison of stacked sections of the upper 1000 ms between the RAMBØLL and UU surveys where the two lines overlap one another. Left: Western half of Line 1 UU. The UU section has not had DMO applied. Right: Eastern half of RAMBØLL Line LSM000066 replotted. X-axis numbering refers to CDP location.*

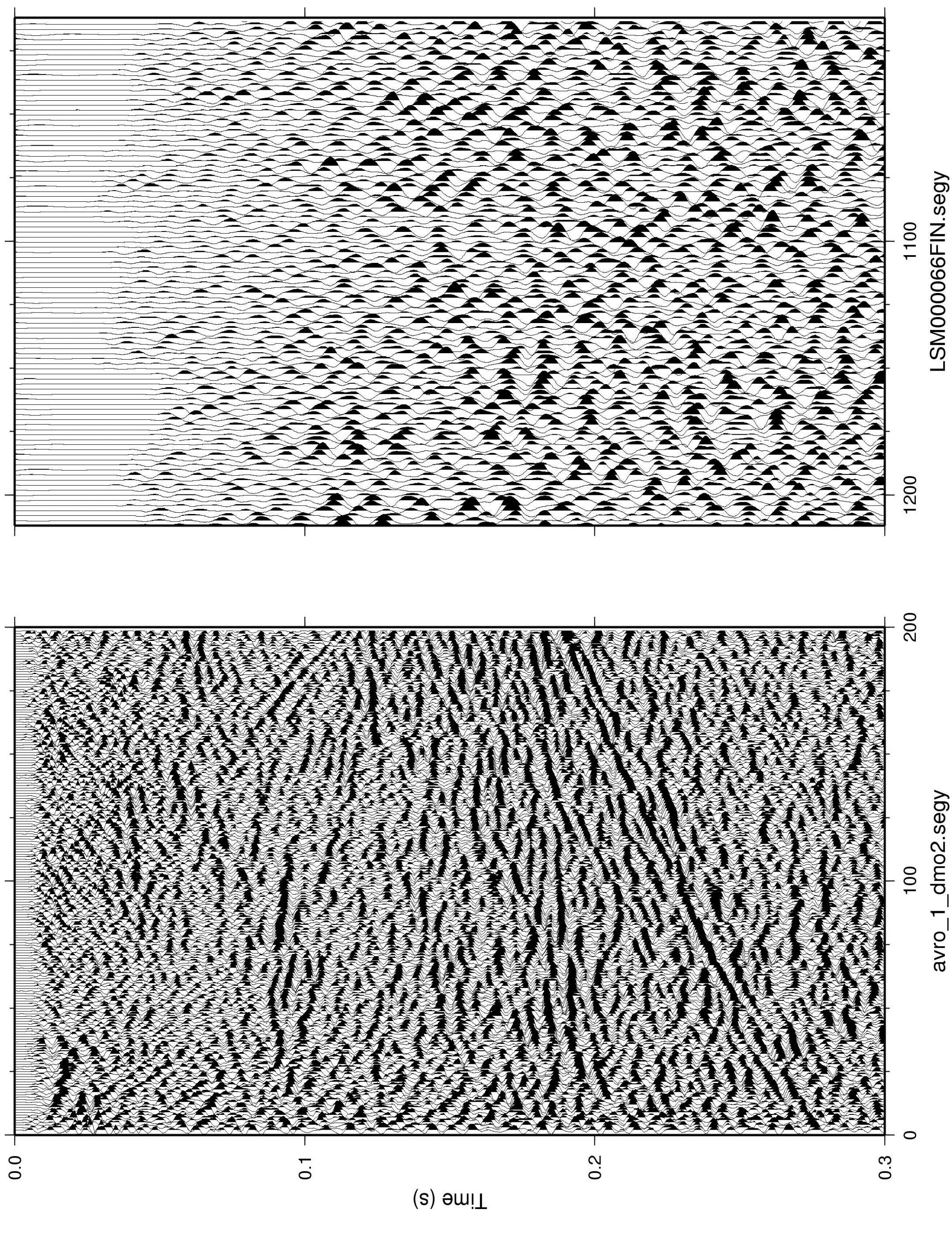


Figure 4-2. *Comparison of stacked sections of the upper 300 ms between the RAMBØLL and UU surveys where the two lines overlap one another. Top: Upper 300 ms of the eastern half of RAMBØLL Line LSM000066 replotted. Bottom: Upper 300 ms of the western half of Line 1 UU. X-axis numbering refers to CDP location.*

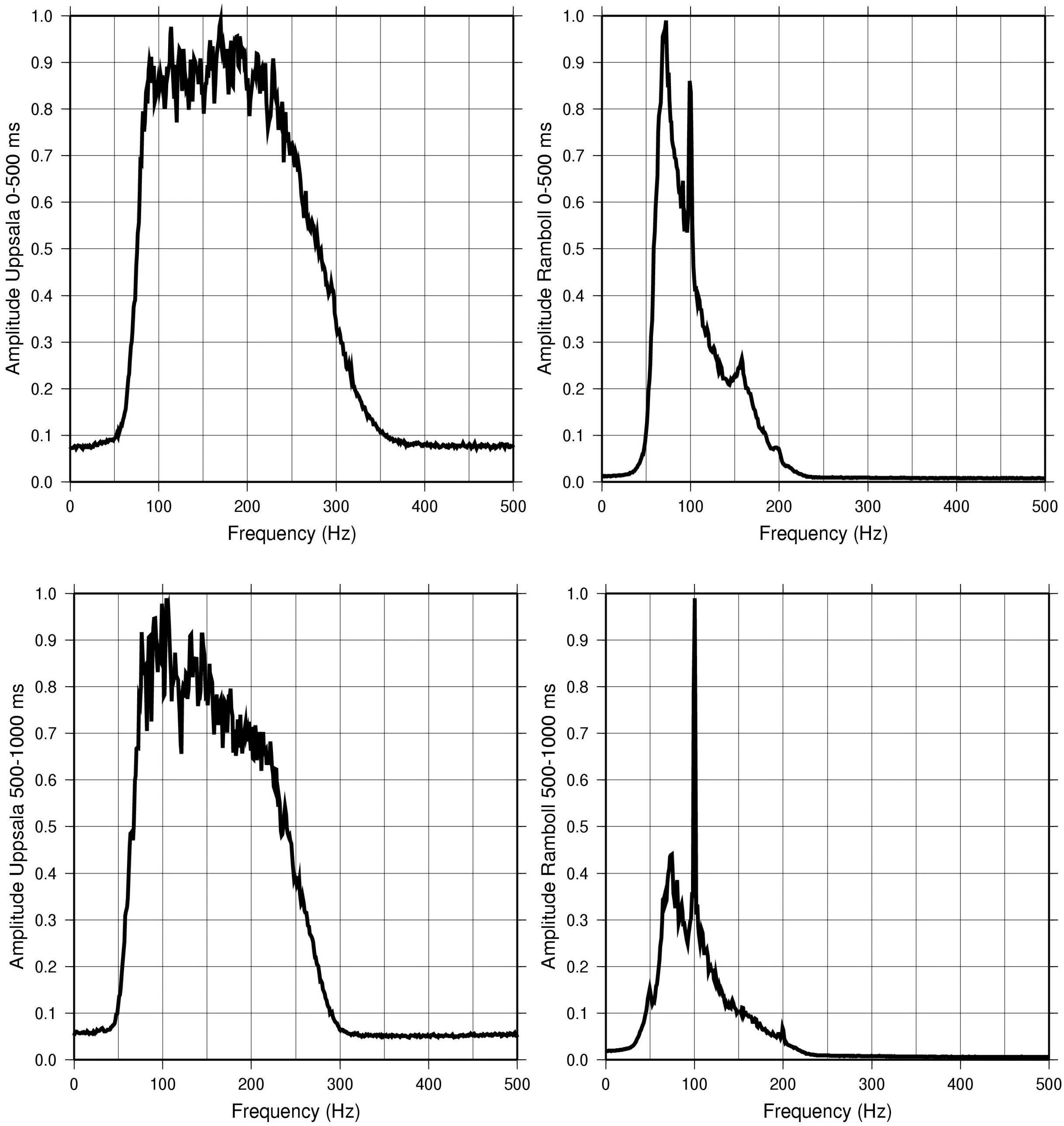


Figure 4-3. *Comparison of the amplitude spectra of the stacked sections between the RAMBØLL and UU surveys. Top: Comparison in the upper 500 ms. Bottom: Comparison in the interval 500–1000 ms. All amplitude spectra have been normalized. Left: Western half of Line 1 UU. Right: Eastern half of RAMBØLL Line LSM000066.*

5 Discussion

5.1 Acquisition

RAMBØLL provided bitmap images of 5 shot gathers from the survey (Figures 5-1 to 5-3) in their report. Digital raw data was not supplied to UU. Therefore, it is not possible to perform a detailed analysis of the shot gathers. It is not stated in the report why these 5 shot gathers were picked out and where they are located along the lines.

There are signs of reflections on the RAMBØLL shot gathers. Possible reflections should have an apparent velocity which is greater than the velocity of the first arrival refracting from the bedrock (about 5.5 km/s). This correspond to a time difference (moveout) of about 40 ms across the 230 m long spread. Any event with an apparent velocity less than this cannot be a P-wave reflection. For example, nearly all of the coherent events in shot gather FFN1622 from Line LSM000070 (Figure 5-3) have velocities less than 5.5 km/s implying that there are probably no P-wave reflections in these data. The events even have a velocity less than the bedrock refracted S-wave velocity implying that they probably represent waves traveling along the surface or reverberations in the near-surface cover. If this shot gather is typical for Line LSM000070 then the stacked section from this line is probably useless. The best candidate for a P-wave reflection in the raw shot gathers is the event at 500 ms (Figure 5-1) on shot gather FFN 1071 from Line LSM000066 (the Avrö line). The apparent velocity is only somewhat greater than 5.5 km/s, implying that it is reflecting off a steeply dipping interface if it is a P-wave reflection. In general, shot gather FFN 1071 is the best quality shot gather of the five bitmaps provided by RAMBØLL.

A direct comparison between raw shot gathers from the UU data and RAMBØLL data cannot be made. However, the bit mapped RAMBØLL shot gather from Ävrö has been scaled to the same size as a plotted raw shot gather from the UU data (Figure 5-4). The main differences between the shot gathers are (i) the stronger first arriving S- waves relative to the first arriving P-waves on the RAMBØLL shot gather, (ii) the stronger air pulse on the RAMBØLL shot gather, and (iii) more low frequency noise on the UU shot gather. The difference between the raw RAMBØLL shot gather and the raw UU shot gather is not as extreme as between the stacks, suggesting that some of the differences in the stacked sections may be due to processing. Note that the UU data were recorded at offsets up to 1000 m and only those offsets corresponding to those recorded by RAMBØLL are shown in Figure 5-4.

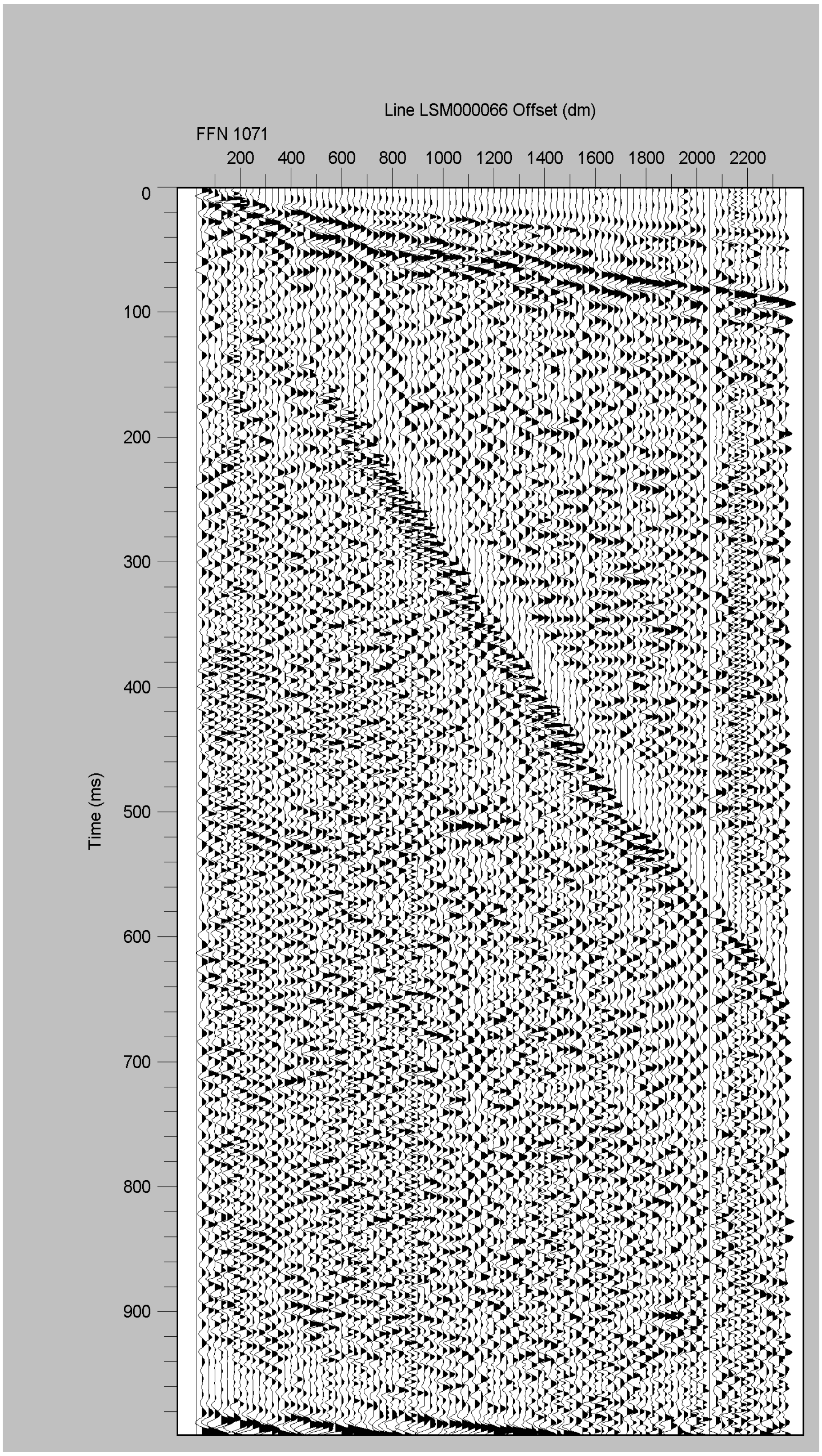
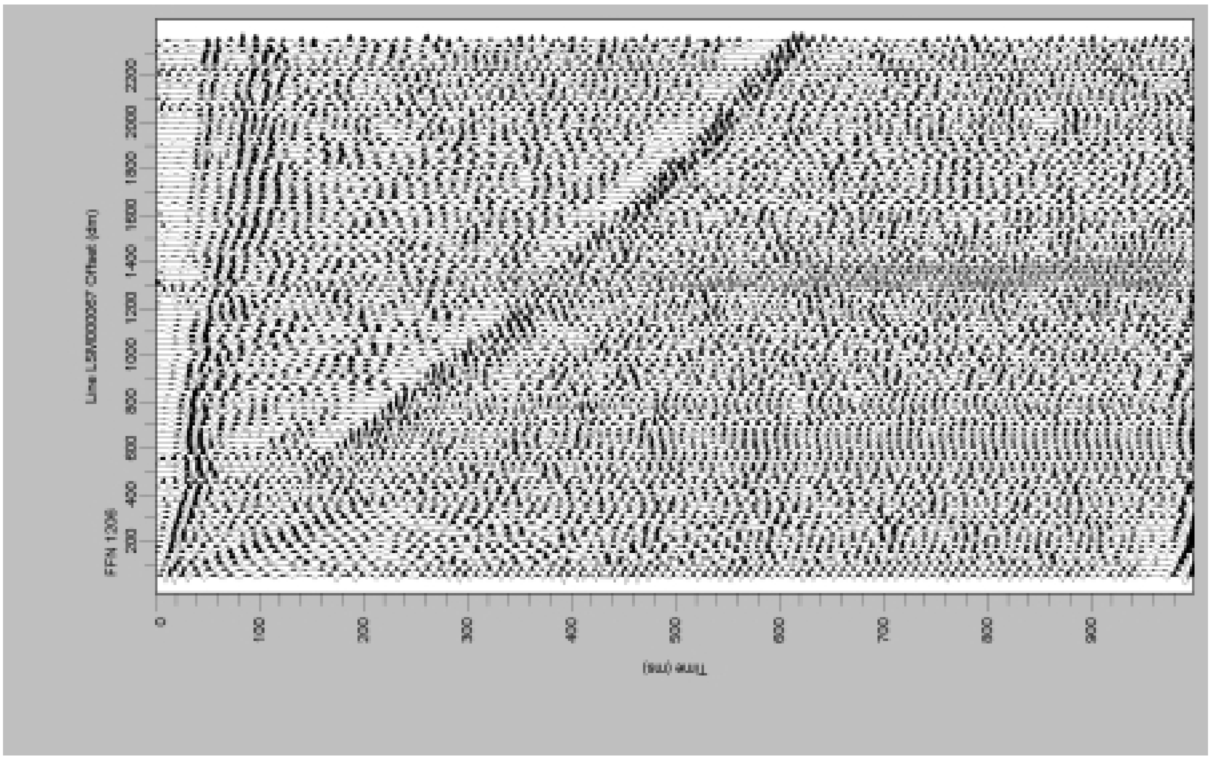


Figure 5-1. *Bitmap images of shot gather FFN 1071 from RAMB ØLL Line LSM000066.*



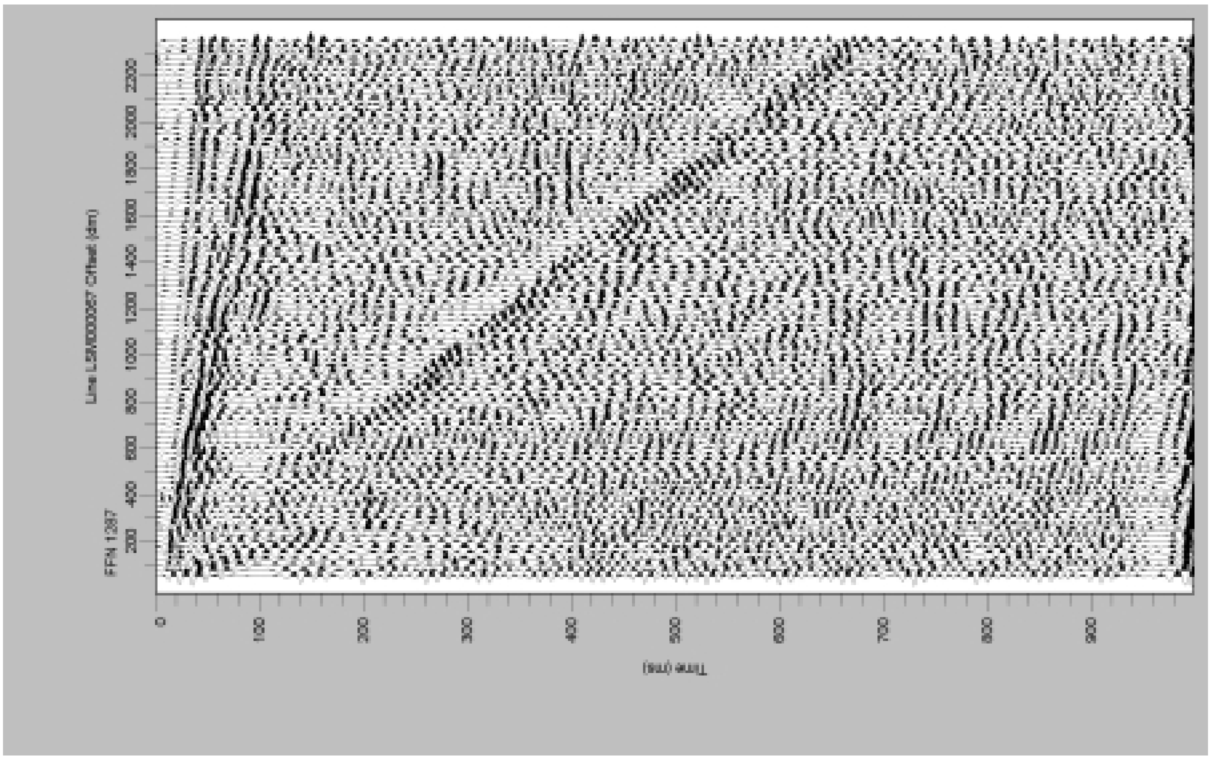
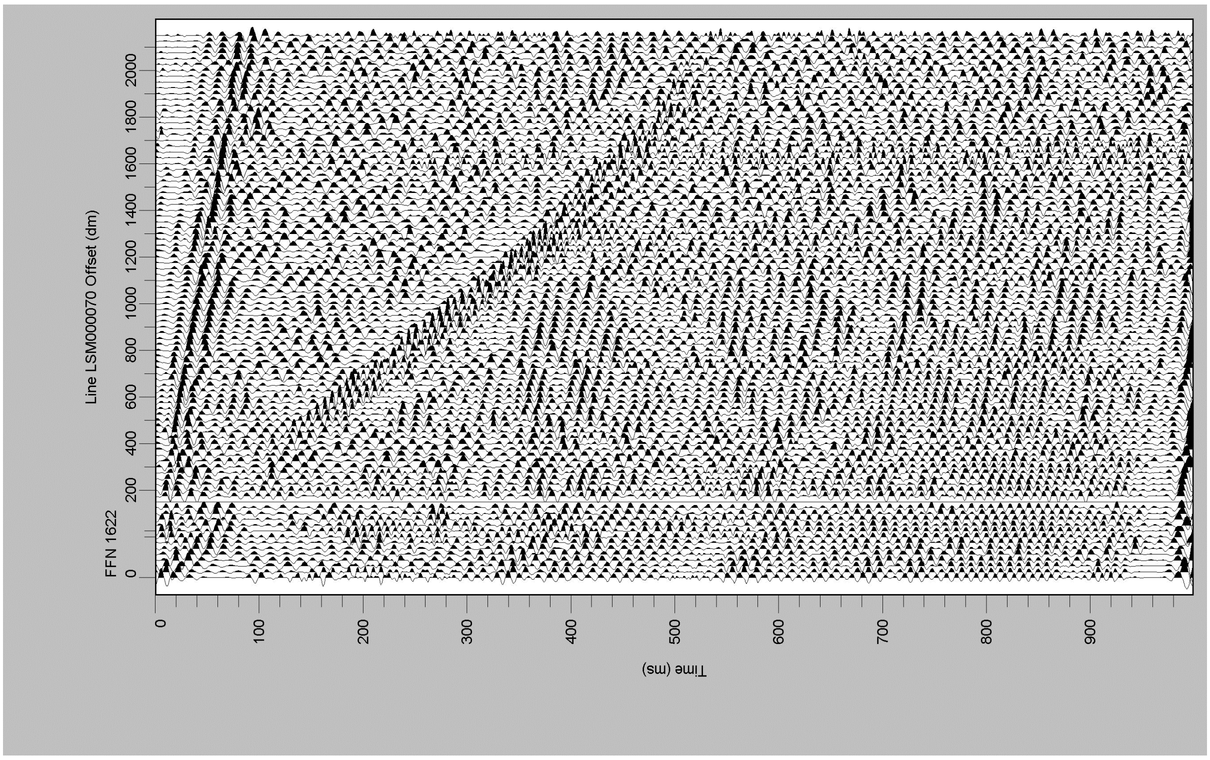


Figure 5-2. *Bitmap images of shot gathers FFN 1287 (bottom) and FFN 1206 (top) from RAMBØLL Line LSM000067.*



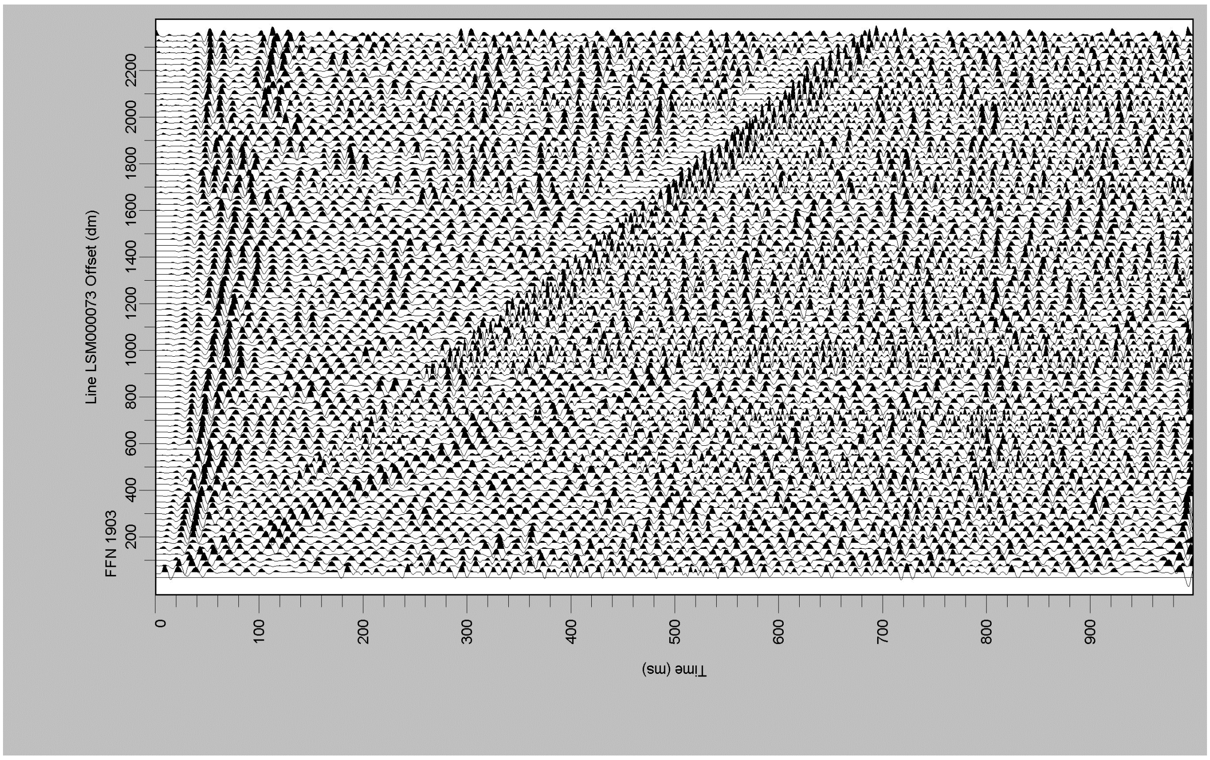


Figure 5-3. *Bitmap images of shot gathers FFN 1903 from RAMBØLL Line LSM000073 (bottom) and FFN1622 from RAMBØLL Line LSM000070 (top).*

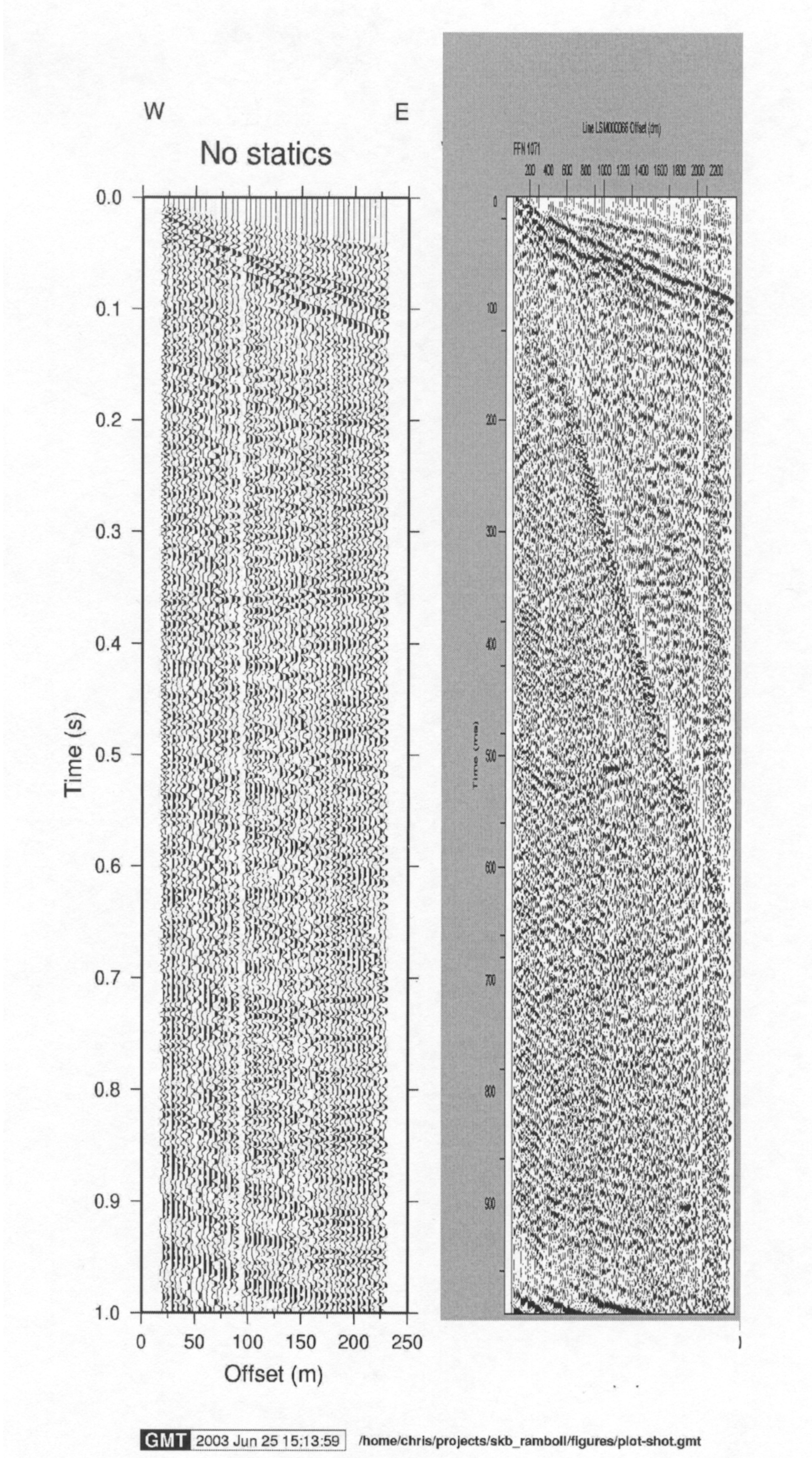


Figure 5-4. *Raw shot gathers from Ävrö, 100 ms AGC applied. Left: Line UU. Right: RAMBØLL.*

5.2 Processing

Since digital raw data from RAMBØLL have not been processed at UU it is difficult to say how much improvement could be made to the stacked sections by a different choice of processing parameters. However, it is worthwhile to note that two known important processing steps /Juhlin, 1995; Wu et al, 1995/, refraction statics and deconvolution/spectral whitening were not carried out in the RAMBØLL processing. The effect of these steps on the raw UU shot gather are shown in Figure 5-5. Refraction statics improves the coherency of both the first arriving P and S waves, as well as the potential reflections. Spectral whitening boosts the high frequency component of the data and balances the spectral content of the traces. The dipping reflection at 350 ms is now very clear in the shot gather (Figure 5-5). It is possible that some improvement could be made to the RAMBØLL sections by reprocessing. Note that the frequency content of the RAMBØLL raw shot gather from Ävrö does not visibly differ significantly from that of the UU shot gather (Figure 5-4).

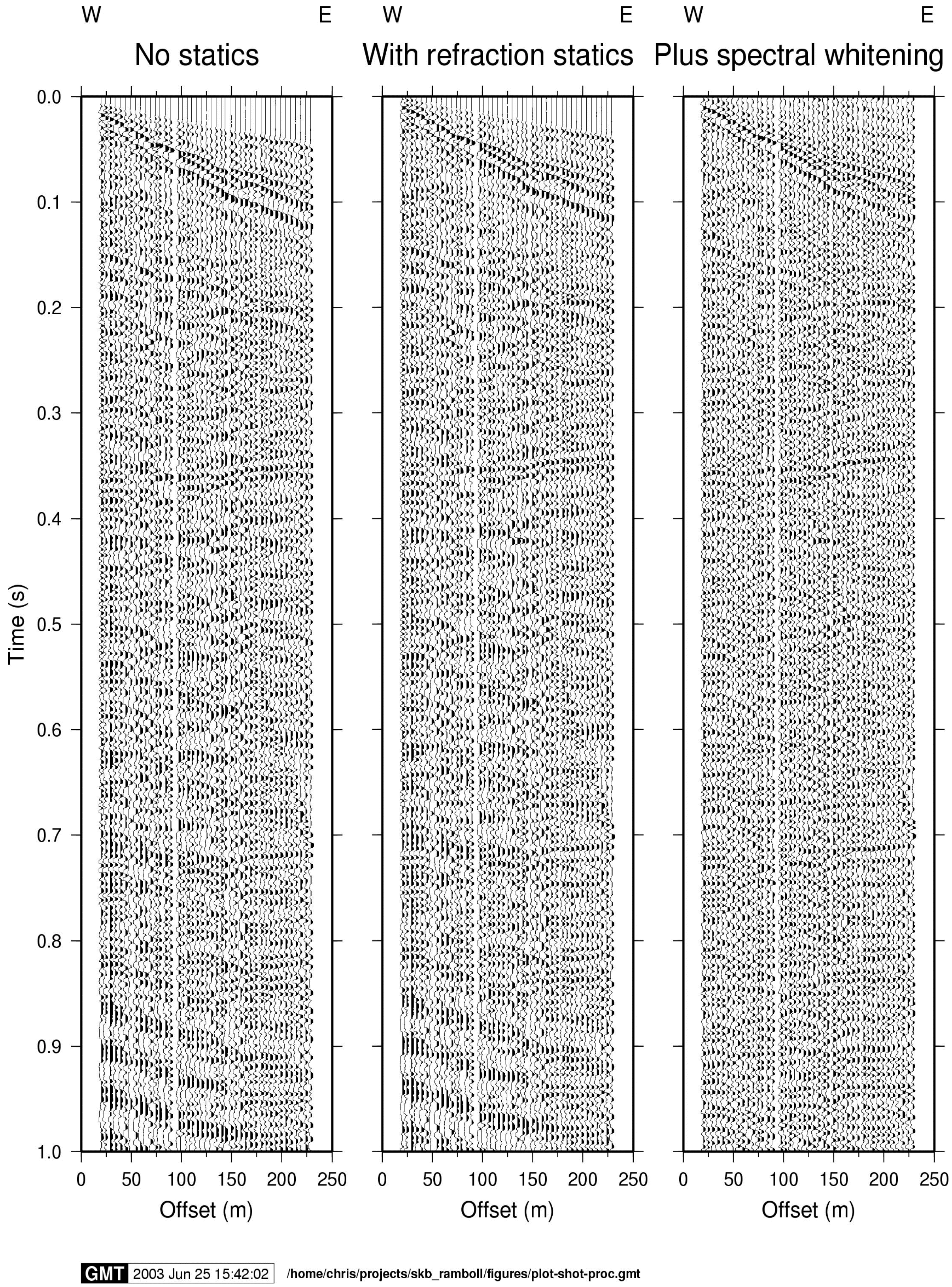


Figure 5-5. *Shot gathers from Line 1 UU acquired near the KAV01 borehole. Panels show raw data, data after refraction statics and data after refraction statics plus spectral whitening. A 100 ms AGC window has been applied prior to plotting.*

5.3 Interpretation

RAMBØLL has identified 76 reflections in their table of seismic interpreted reflectors delivered to SICADA, most of them being on Lines LSM000066, LSM000067 and LSM000069. They state that some of these reflections can be correlated from one line to another, but do not show any examples of such correlation. Stacked sections from parts of RAMBØLL Lines LSM000069, LSM000072 and LSM000070 are plotted in Figure 5-6 so that these parts form a continuous section on the eastern part of the Simpevarp peninsula. The white stripes in Figure 5-6 mark where the section changes direction at intersection points of the lines. Reflections from the sub-surface should be observed across these stripes. The only candidate is the sub-horizontal event at about 0.27 s where Lines LSM000072 and LSM000070 intersect. However, given the poor quality of the stacked sections, not too much significance should be put into this correlation. In general, it is very difficult to correlate any events from one line to another where the lines intersect. In their present state, it is the opinion of the author that the RAMBØLL sections should not be used for predicting sub-surface structures.

Many of the possible reflections identified by RAMBØLL have a high dip. In fact, some of them have a dip which exceeds that which is possible for P-wave reflections. Reflections from a near-vertical boundary striking perpendicular to the profile will have an apparent velocity that is the velocity of the media. The apparent velocity is defined as

$$V = 2\,\frac{\delta X}{\delta T}$$

where δX is the difference in distance along the profile and δT is difference in arrival time along this distance. Any event which has an apparent velocity which is less than the velocity of the media cannot be a P-wave reflection. Events which have an apparent velocity greater than the velocity of the media may or may not be P-wave reflections. The velocity of the media can be considered to be almost constant in crystalline rock and is in the Ävrö area about 5.8–6.0 km/s. Interpreted reflectors from Line LSM000066 have been plotted on top of the stacked section (Figure 5-7). Event number 3 has an apparent velocity of 4.23 km/s and cannot be a P-wave reflection. Events from other lines with apparent velocities less than 5.8 km/s are numbers 20, 61, 63 and 69. There are also a number of events in the table delivered to SICADA with apparent velocities just above 6.0 km/s that may be regarded with suspicion.

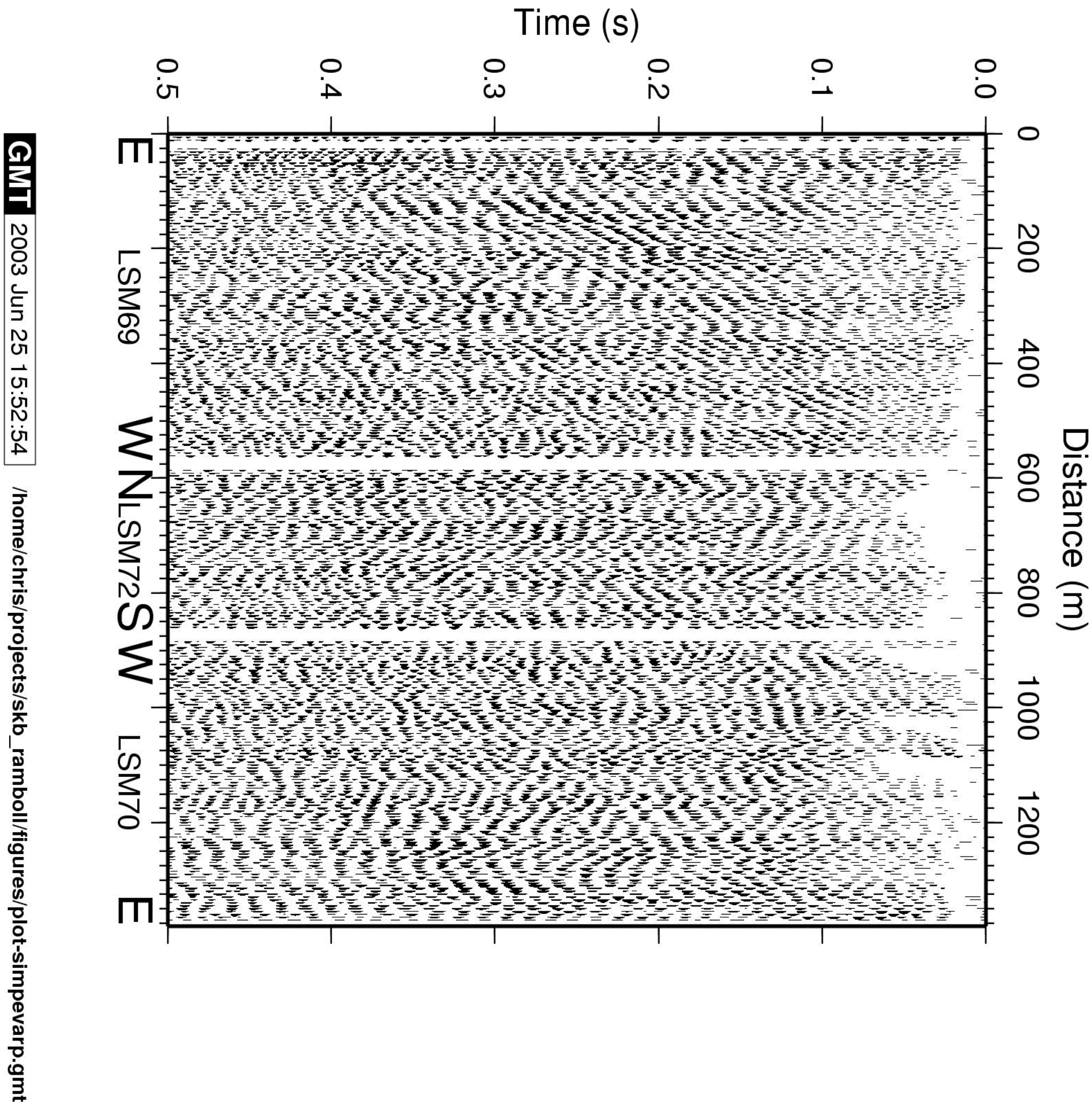


Figure 5-6. *Stacked sections from parts of RAMBØLL Lines LSM000069, LSM000072 and LSM000070. The data have been plotted so that stacks intersect where the white stripes are located.*

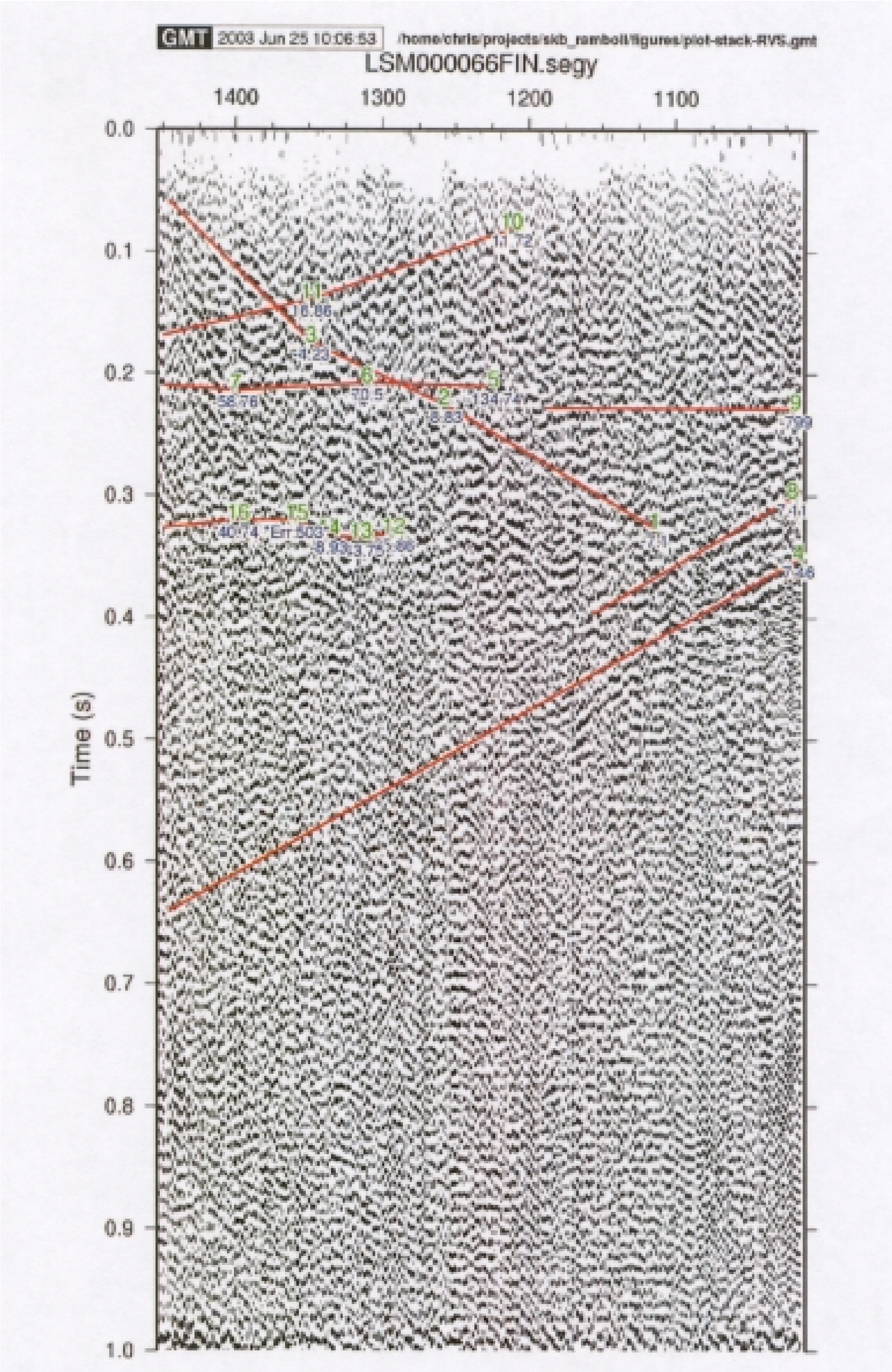


Figure 5-7. Stacked section from RAMBØLL Line LSM000066 with RVS identified reflections plotted on top. Green numbers at the end of the reflections are the event number and the corresponding blue number is the apparent velocity of the event.

6 Recommendations

Given that the apparent frequency content of the shot gathers from the RAMBØLL surveys is higher than that in the stacked sections there is a possibility that the RAMBØLL sections can be improved by reprocessing. Reprocessing of UU Line 1 using only those offsets that correspond to the RAMBØLL survey would also provide a fairer image to compare the RAMBØLL stack to. This would help clarify if the poor results from the RAMBØLL survey are due to the acquisition or to the processing.

The RAMBØLL acquisition method is attractive since it is faster and less expensive than using explosive sources. A reason for using the Vibroseismic method was that explosives was restricted to be used at parts of the Simpevarp peninsula. It is possible that the source may be adequate, but that the geophone array does not give sufficient coupling in the conditions present at Simpevarp. A comparison of the mechanical SIST /Park et al, 1996/ source and an explosive source in the Laxemar KLX01 borehole show that similar, but lower frequency, signals are obtained downhole with the SIST source /Juhlin et al, 2002a/. Studies have shown that geophone coupling is an important component in obtaining high quality seismic sections /Bergman et al, 2001; Juhlin et al, 2001/. Testing of mechanical sources as an alternative to explosives for high resolution reflection seismic profiling on crystalline rock is still relevant. However, any such test should be done under controlled conditions. Acquisition and processing of reflection seismic data as outlined by /Juhlin et al, 2001/ is still the most suitable method for obtaining high quality seismic images of the upper 1 km of the crystalline bedrock. The method has been tested thoroughly /Juhlin et al, 2001/ and used successfully in larger scale surveys /Bergman et al, 2002; Juhlin et al, 2002b/. It is recommended that these guidelines be followed until other methods have been shown to work.

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