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Oskarshamn site investigation

3D processing of reflection seismic data acquired within and near the array close to KAV04A on Ävrö, 2003

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Abstract

Reflection seismic data were acquired in the fall of 2003 /4/ in the Oskarshamn area, located about 300 km south of Stockholm, Sweden. The Oskarshamn area has been targeted by SKB as a possible storage site for high level radioactive waste. About 3.7 km of high resolution seismic data were acquired along three separate profiles varying in length from 0.8 to 1.9 km. Nominal source and receiver spacing was 10 m with at least 100 active channels when recording data from a dynamite source (15–75 g). All shots were also recorded into a 10×20 channel (200 total) fixed array nearly centred over the KAV04 borehole. In addition, about 100 shots were fired within in the array, providing limited 3D coverage below the array.

Results from the profiles have been presented in an earlier report. The present report focuses on 3D reflection processing of the seismic data acquired within the array and from those portions of the profiles close to the array. It is emphasized that the present data set does not constitute a true 3D data set. The main purpose of the array was to obtain information on the bedrock velocity below the array. For a true 3D survey a more regular geometry and closer station spacing would have been used. In spite of this, it has been possible to produce a clear 3D image of a sub-horizontal reflection at about 230–240 ms. The reflection appears to originate from a folded lens of mafic rock. Further processing may improve the 3D volume image as well as allow more steeply dipping structures to be imaged.

Sammanfattning

Reflektionsseismiska data registrerades hösten 2003 i Oskarshamnsområdet /4/, ca 300 km söder om Stockholm. Oskarshamnsområdet är en ut av platserna SKB har valt för möjlig förvaring av högaktivt kärnavfall. Ca 3,7 km av högupplösande reflektionsseismiska data samlades in längs tre separata profiler med varierande längd från 0,8 till 1,9 km. Nominella käll- och mottagaravstånd var 10 m med minst 100 aktiva kanaler. 15–75 g dynamit användes som källa. Alla skott registrerades också på en fast array (grid med 10×20 kanaler) som var nästan centrerat över kärnborrhålet KAV04A. Ytterligare ca 100 skott sköts inom denna array, vilket gav en begränsad 3D täckning under arrayen.

Resultaten från profilerna har rapporterats tidigare. Denna rapport fokuseras på 3D databehandling av de reflektionsseismiska data som registrerades inom arrayen och närliggande profiler. Det är viktigt att påpeka att detta dataset inte motsvarar en fullskalig 3D seismisk undersökning. Syftet med arrayen var att få information om berggrundshastigheten under arrayen. En fullskalig 3D undersökning skulle ha en mer reguljär geometri och tätare mellan stationerna. Trots detta, har det varit möjligt att få en klar bild av en sub-horisontell reflektion från 230–240 ms. Reflektionen tolkas att härstamma från en veckad mafisk lins. Ytterligare databehandling kan resultera i en bättre bild av 3D volymen, samt ge tydligare bilder av stupande strukturer.

Contents

1 Introduction

This document reports the results gained by the 3D processing of reflection seismic data acquired within and near the array close to KAV04A on Ävrö, 2003, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-03-068 (SKB internal controlling document). In Table 1-1 controlling documents for performing this activity are listed.

Table 1-1. Controlling documents for the performance of the activity (SKB internal controlling document)

Activity plan	Number	Version
Reflektionsseismik vid Ävrö, 2003	AP PS 400-03-068	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för reflektionsseismik	SKB MD 241.004	1.0

Seismic data were acquired in the Oskarshamn area in southeastern Sweden (Figure 1-1) during the month of November in the year 2003 by Uppsala University. Approximately 3.7 km of high-resolution (10 m shot and receiver spacing) reflection seismic data were acquired with the SERCEL 408UL system along 3 different profiles (Figure 1-2) using about 300 shot points. Most of these shots were also recorded on a SERCEL 348 by a stationary array (GSM000010) of 200 channels laid out in a 10×20 channel pattern (Figure 1-2). In addition, about 100 shots were fired within the array (GSM000010) itself and recorded both within the array (GSM000010) and along profile 4 (LSM000198) and the northern part of profile 3 (LSM000197).

Results from the profiles have been presented in an earlier report /4/. Here, we present results from 3D reflection seismic processing of the array data. The reader should note that the primary purpose of the array was to obtain velocity information on the bedrock below the array, not for acquiring 3D reflection seismic data for imaging sub-surface structure. If the latter had been the main purpose, then the acquisition would have been designed very differently. However, the present data set does allow for limited 3D imaging, primarily below the array close to the borehole KAV04A (GSM000010).

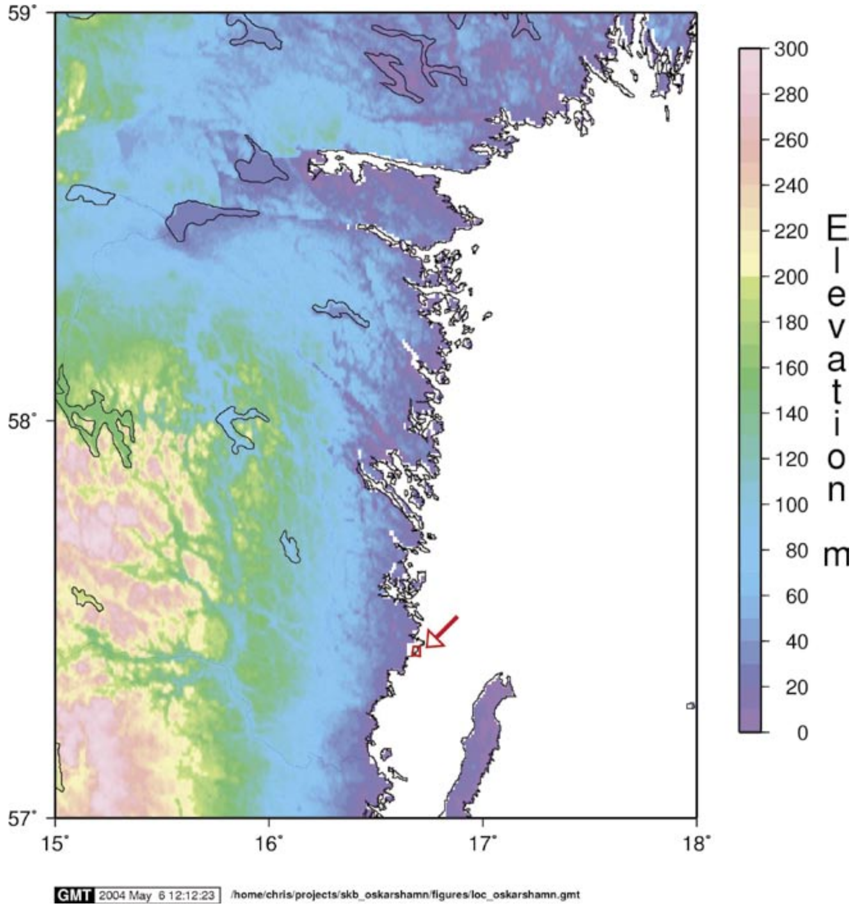

Figure 1-1. *Location of study area (red box marked by arrow).*

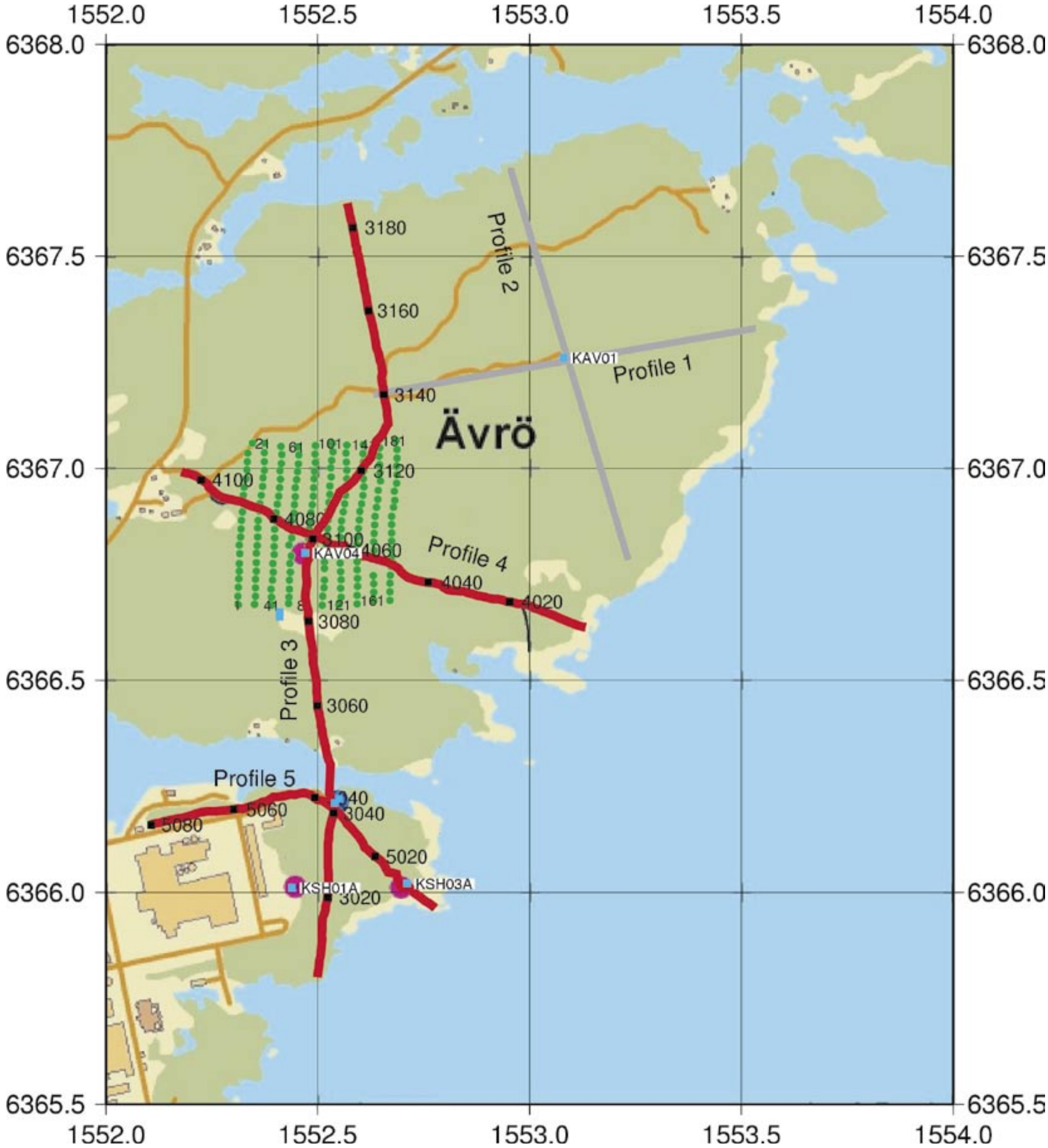

Figure 1-2. Location of the seismic reflection profiles, profile 3, LSM000197, profile 4, LSM000198 and profile 5, LSM000199 (red lines), and the fixed array close to the borehole KAV04A, GSM000010 (green dots). Also shown are the reflection seismic profiles acquired in 1996 (grey lines) which have been reported in /3/ and /1, 2/.

2 Objective and scope

The objectives with the reflection seismic method used here is to imagine the bedrock from the near surface (upper 100 metres) down to depths of several km. Reflectors obtained are due to changes in the elastic properties of the bedrock, i.e. lithological changes or possible fracture zones. Reflecting objects with a width greater than about a metre in thickness and dipping up to 60–70° can be imaged. First arrival picks from the fixed array centered close to the borehole KAV04A (GSM000010) were used to determine the uppermost bedrock velocity below and near the array. Shots fired within the array (GSM000010) will here provide some 3D information on reflectors below the array.

3 Execution

3.1 Data acquisition

The acquisition crew arrived in the field on November 10 and data acquisition began on November 16, 2003 using the acquisition parameters given in Table 3-1. Data acquisition finished on November 26, 2003 followed by 3 days of demobilization and clean-up. During the acquisition period there were 2 days that no data were acquired due to moving of profiles.

Shot points and geophones were located as much as possible on bedrock. Shot holes were drilled at the closest suitable location to a staked point where bedrock was present, but not further from the staked point than 30 cm parallel and 1 m perpendicular to the profile. If no bedrock was found within this area, even after removing 50 cm of soil, the shot hole was drilled at the staked point. In bedrock, 12 mm diameter shot holes were drilled to 90 cm depth with an electric drilling machine powered by a gasoline generator. Charges of 15 g were used in bedrock shot holes. In soil cover, 22 mm diameter shot holes were drilled to 150 cm depth with an air pressure drill. These holes were cased with a plastic casing with an inner diameter of 18 mm. Charges of 75 g were used in these holes. Bedrock shot holes were used on about 50% of the profiles. Geophones were placed in drilled bedrock holes wherever possible, otherwise they were placed directly in the soil cover. All shot holes and geophone locations were surveyed with high precision GPS instruments in combination with a total station. This combination gave a horizontal and vertical precision of better than 10 cm.

Shots were recorded into the array (GSM000010), whenever possible, from all profiles. Since only 100 channels could be recorded at once, the recording pattern was alternated so that the eastern half of the array recorded every second shot and the western half every second shot not recorded on the eastern half. Profile 4 (LSM000198) was acquired first followed directly by the firing of shots within the array (GSM000010). During acquisition of profile 4 (LSM000198) data were also recorded on stations 3046–3174 on profile 3 (LSM000197), whenever possible. Profile 4 (LSM000198) was then picked up and moved to the southern part of profile 3 (LSM000197) and part of profile 5 (LSM000199). Profile 3 (LSM000197) was then shot with data being recorded along the entire profile as well as on stations 5,013–5,051 on profile 5 (LSM000199). Stations north of 3150 on profile 3 (LSM000197) were then moved to profile 5 (LSM000199). Profile 5 (LSM000199) was shot with data being recorded along the entire profile and on stations 3,001–3,150 on profile 3 (LSM000197).

Table 3-1. Acquisition parameters for the reflection and tomographic seismic components.

Parameter	Reflection	Array
Spread type	Shoot through	Fixed array
Number of channels	Minimum 100 Maximum 232	200 with 100 active for recording
Near offset	20 m	20 m
Geophone spacing	10 m	20 m
Line spacing		40 m
Geophone type	28 Hz single	6×10 Hz bunch
Shot spacing	10 m	40 m average
Charge size	15/75 gram	15/75 gram
Nominal charge depth	0.9/1.5 m	0.9/1.5 m
Nominal fold	50	12 in 40×20 m bins
Recording instrument	SERCEL 408	SERCEL 348
Sample rate	0.5 ms	1 ms
Field low cut	Out	Out
Field high cut	500 Hz	250 Hz
Record length	3 seconds	3 seconds
Profile length/shots	3–1,850 m/159	4–1,060 m/100 5–770 m/35 Array– 400×400 m/100

3.2 Data processing

Most of the shots fired within the array (GSM000010), recorded by the array (GSM000010), by stations 3,046–3,174 on profile 3 (LSM000197), and on profile 4 (LSM000198) were included in the processing. In addition, most of the shots fired along profile 4 (LSM000198) and recorded by stations 3,046–3,174 on profile 3 (LSM000197) and parts of the data acquired along the crooked profile 3 (LSM000197) were used for the 3D reflection seismic processing.

Due to the irregular geometry, the midpoint density is very uneven (Figure 3-1). A grid of inlines and crosslines were chosen that cover an area significantly larger than the array itself to allow data acquired along the profiles to be included in the processing. The source-receiver midpoints were binned in 10×10 meter bins. The small number of shots and their uneven distribution lead to a highly varying CDP fold (Figure 3-2). The low fold near the edges of the grid results in poor quality images at these locations. Important processing steps were refraction and residual statics along with deconvolution and filtering. The complete list of processing parameters is given in Table 3-2. DMO (Dip moveout) or migration has not been applied due to the variable acquisition geometry and limited area extent of the grid, respectively. Testing of 3D DMO and migration methods may allow further improvement of the processed results.

Shot sections show a fairly clear reflection at about 220–240 ms (Figure 3-3) that corresponds to reflection E1 in /4/. This reflection is known to be sub-horizontal and processing has focused on imaging it in 3D. This has probably lead to that more steeply dipping events have been removed in the processing since no DMO was applied.

Table 3-2. Processing parameters used for the 3D seismic processing.

Step	Process
1	Read SEG2 and SEGD data – 2,000 ms
2	Pick first breaks
3	3D Binning 10×10 m, 51×91 bins
4	Desample all data to 1 ms sampling rate
5	Trace edit
6	Scale by t**1.4
7	Air blast attenuation
8	Spike and noise edit
9	Refraction statics
10	Bandpass filter 30-60-400-600
11	Surface consistent spiking deconvolution Design gate: 0 m: 200–500 ms, 500 m: 350–600 ms Operator 60 ms White noise added 1%
12	Bandpass filter 80-110-250-350 Hz 0 m: 0–100 ms, 500 m 0–250 ms 70-100-200-280 Hz 0 m: 50–200 ms, 500 m: 200–350 ms 60-90-180-250 Hz 0 m: 150–500 ms, 500 m: 300–600 ms 50-70-140-200 Hz 0 m: 400–700 ms, 500 m: 550–850 ms 40-60-120-180 Hz 0 m: 800–1,200 ms, 500 m: 950–1,350 ms
13	Trace top mute: 10 + offset/ 5.6 ms
14	Surface consitent amplitude balancing
15	Sort to receiver domain
16	Residual statics – Pass I
17	AGC – Apply and save – 50 ms
18	Velocity filtering – median method Remove 3,300 m/s
19	AGC – Remove
20	Time variant scaling
21	Sort to CDP domain
22	Velocity analyses
23	Residual statics – Pass II
24	NMO (Normal moveout)
25	Stack (mean)
26	Trace equalization 100–500 ms
27	F-xy decon

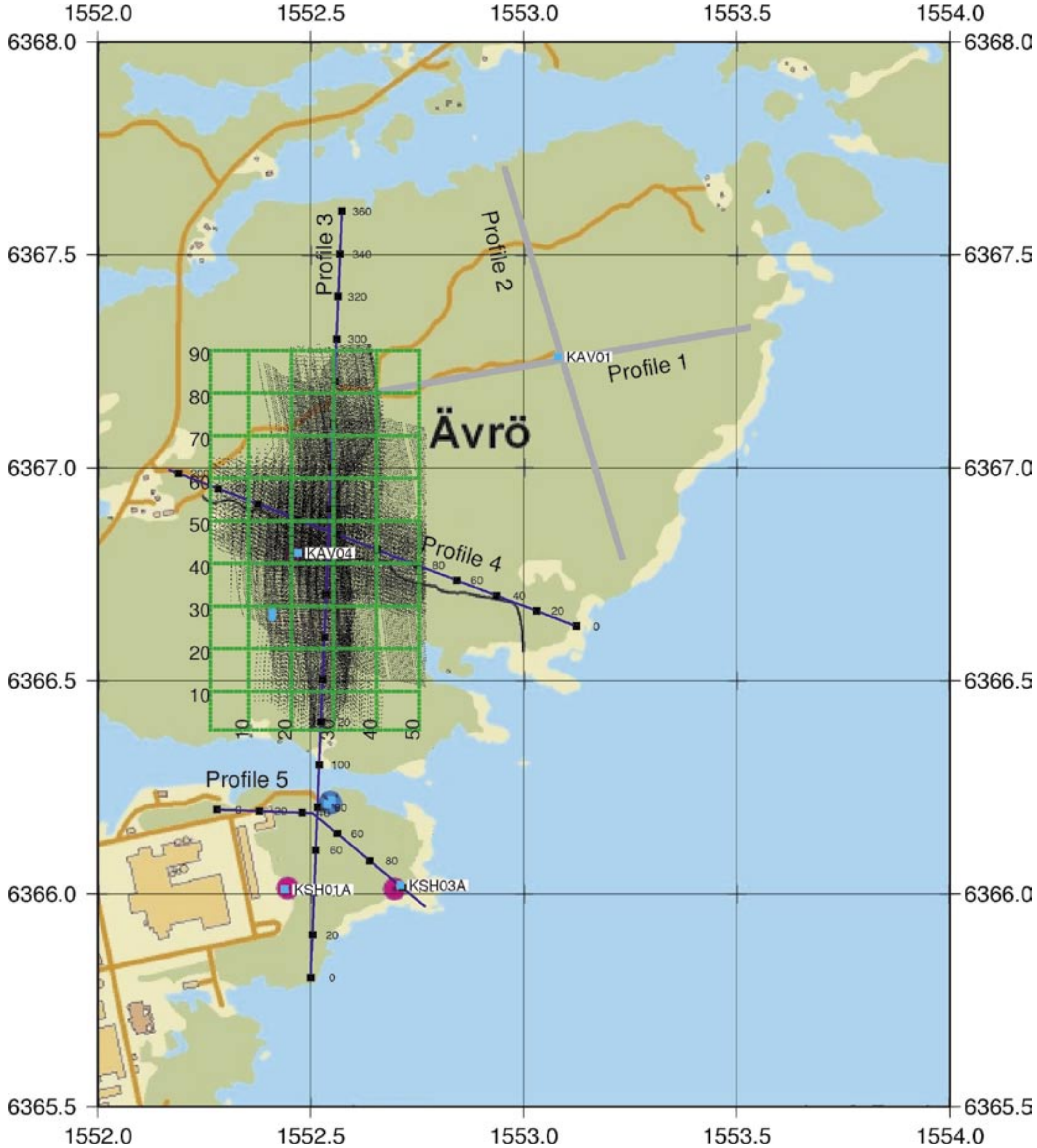

Figure 3-1. Midpoints between shots and receivers (black dots) used in the processing and the inline (N–S) and crossline (W–E) sections that the data have been projected onto and stacked along (green). Every 10th line is shown. CDP line locations along profiles 3 (LSM000197), 4 (LSM00198) and 5 (LSM000199) are also shown.

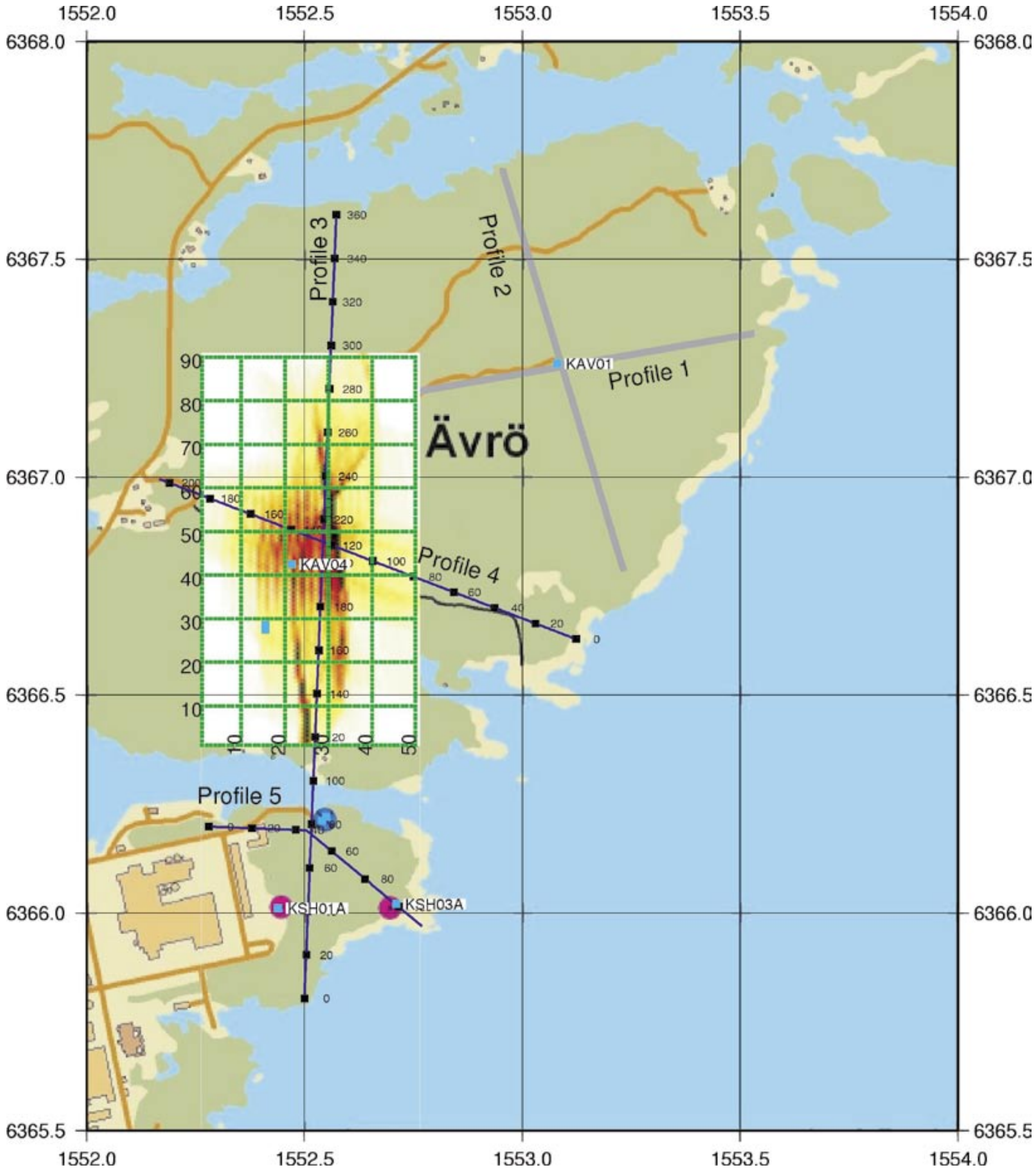

Figure 3-2. *Grid of the fold with the inline (N–S) and crossline (W–E) sections that the data have been projected onto and stacked along (green). Every 10th line is shown. CDP line locations along profiles 3 (LSM000197), 4 (LSM00198) and 5 (LSM000199) are also shown. Fold less than 25 is shown in white.*

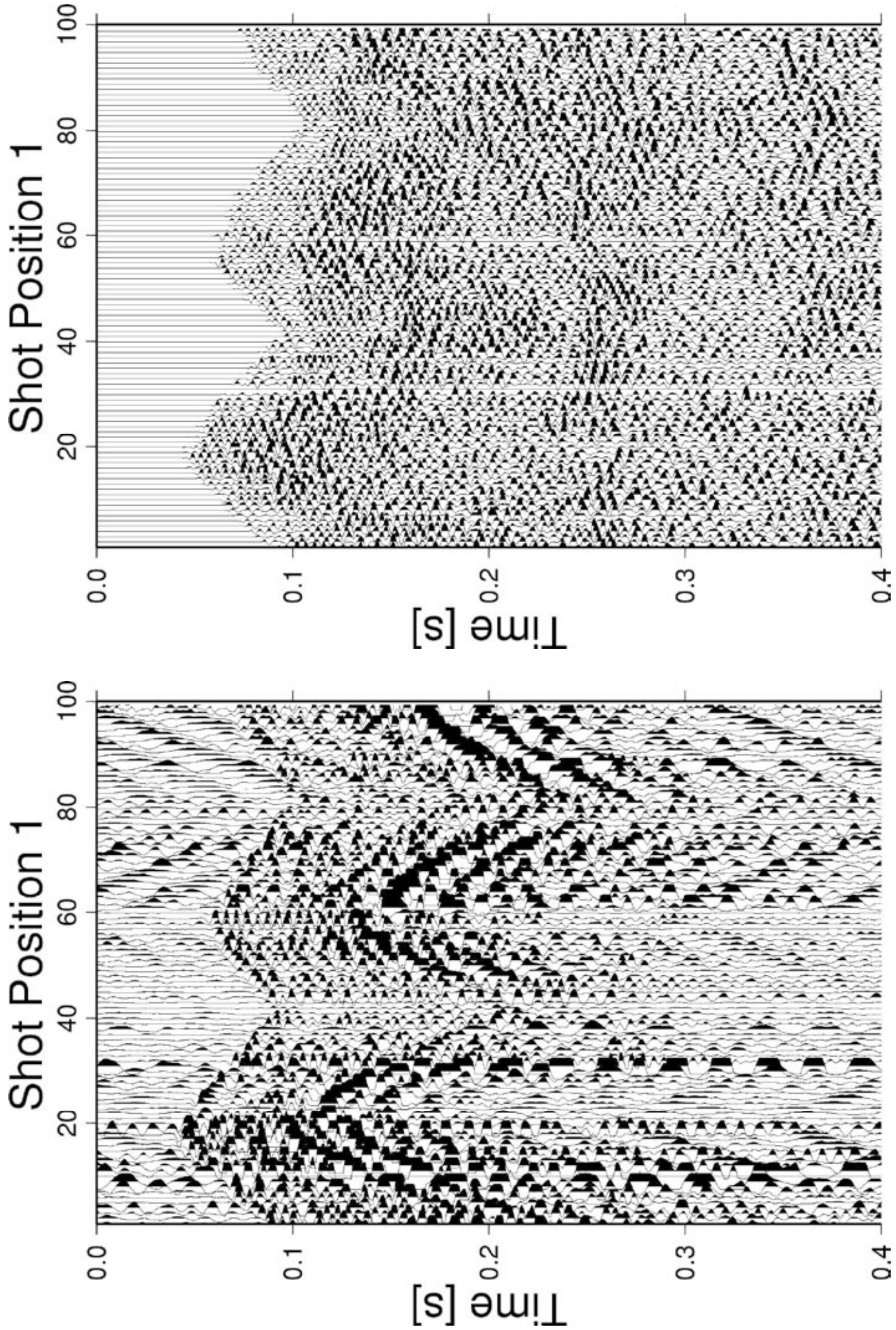

Figure 3-3. *Example of a shot gather from the array (GSM000010) showing raw data (bottom) and after processing (top).*

4 Results

4.1 Data delivery for input into RVS

Raw data from the measurements were delivered directly after the termination of the field activities. The delivered data have been inserted in the database (SICADA) of SKB. The SICADA reference to the present activity is field note no 201. The cooordinates for the reflecting elements which have been picked for input into RVS where delivered separately together with the results reported earlier /4/.

4.2 Stacked sections

Vertical cross sections through the 3D stacked seismic volume are shown in Figures 4-1 to 4-4 down to 0.5 seconds. In these figures the data have been processed to step 27 in Table 3-2. There are 51 inline sections (N–S with 0 in south) and 91 crossline sections (W–E with 0 in west), however, only 4 inline and 6 crossline sections are shown.

4.3 Time slices

It is also useful to present time slices for displaying the lateral extent of reflections. Figure 4-5 shows 6 time slices from 220 ms to 245 ms that focus on the reflection E1. The reflection is most clear at 230, 235 and 240 ms and appears to have a lensoidal form in the horizontal planes. Note that the poorer image of the E1 reflection south of crossline 30 and possibly north of crossline 70 is probably due to the lower fold and not to the reflection being limited to being below the array.

4.4 E1 reflection mapping

Traveltimes to the E1 reflection have been picked on each crossline allowing the surface of the reflection to be mapped in 3D (Figure 4-6). This map gives an idea of the shape of the reflector. Again, the reflection may extend further to the north and south, but is not imaged due to the lower fold.

4.5 Comparison with 2D profiles

Figure 4-7 shows a N–S section containing inline 30 merged with profile 3 (LSM000197). The E1 reflection at about 230 ms can be followed across the section boundary, as can some other reflections. The resolution of the 3D data volume is obviously lower than the 2D profile. Note that the clear dipping B1 reflection is not observed on 2D profile 3 since DMO has not been applied to this section. Figure 4-8 shows a W–E section containing crossline 48 merged with profile 4 (LSM000198).

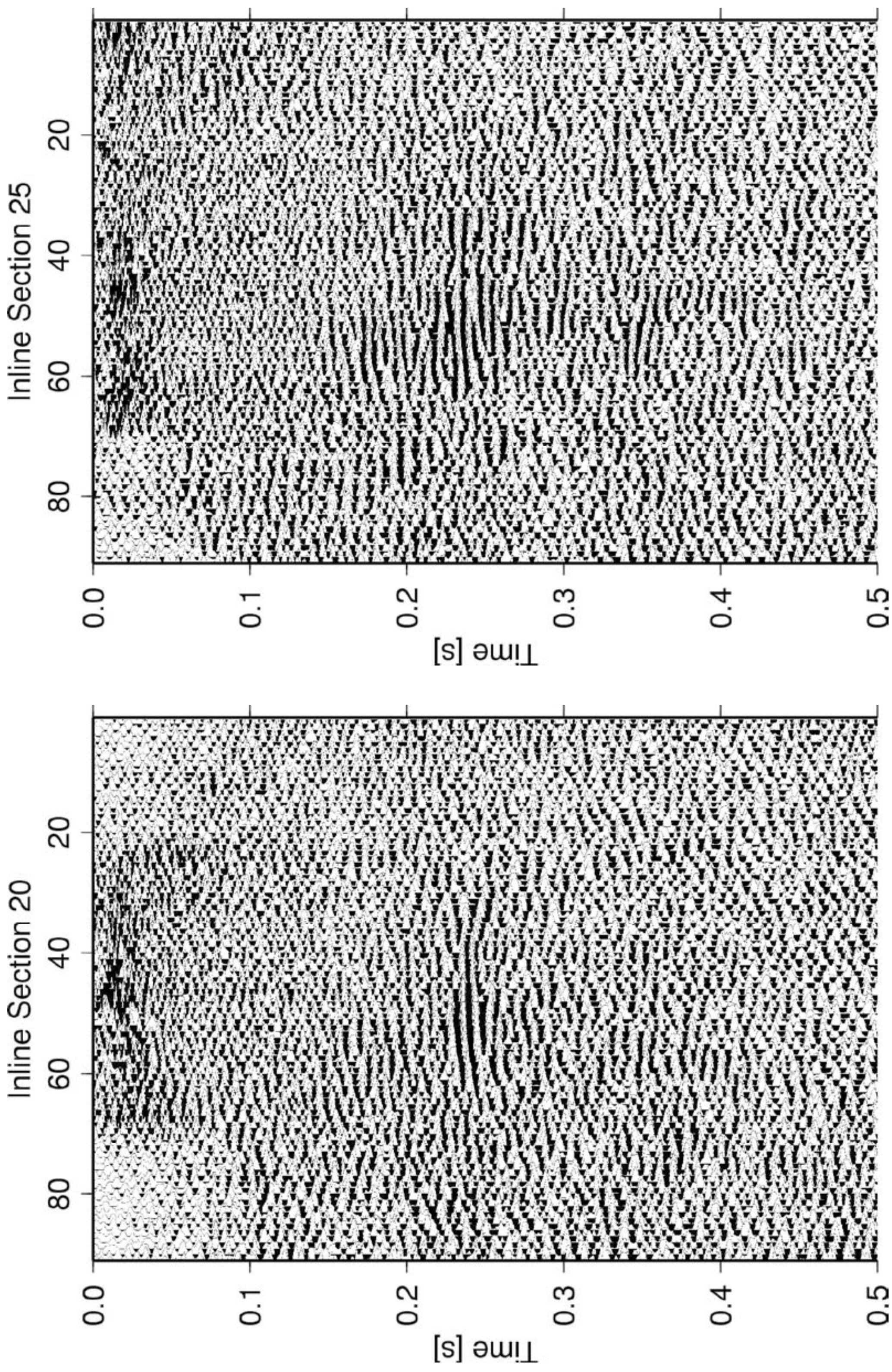

Figure 4-1. *Inline stacked sections down to 0.5 seconds using array (GSM000010) and profile data. See Figure 3-1 for location of inlines (N–S with 0 in south).*

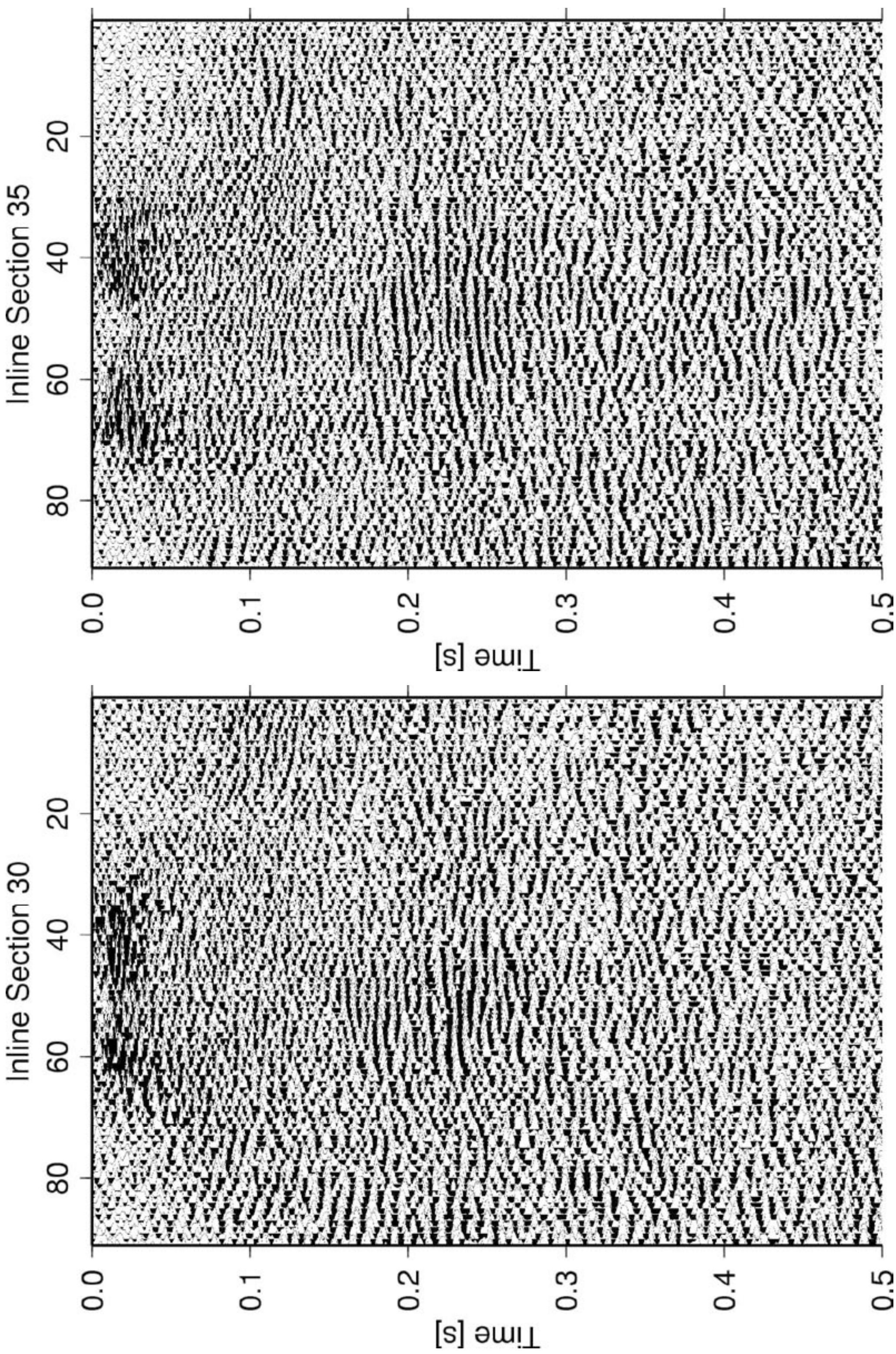

Figure 4-2. *Inline stacked sections down to 0.5 seconds using array (GSM000010) and profile data. See Figure 3-1 for location of inlines (N–S with 0 in south).*

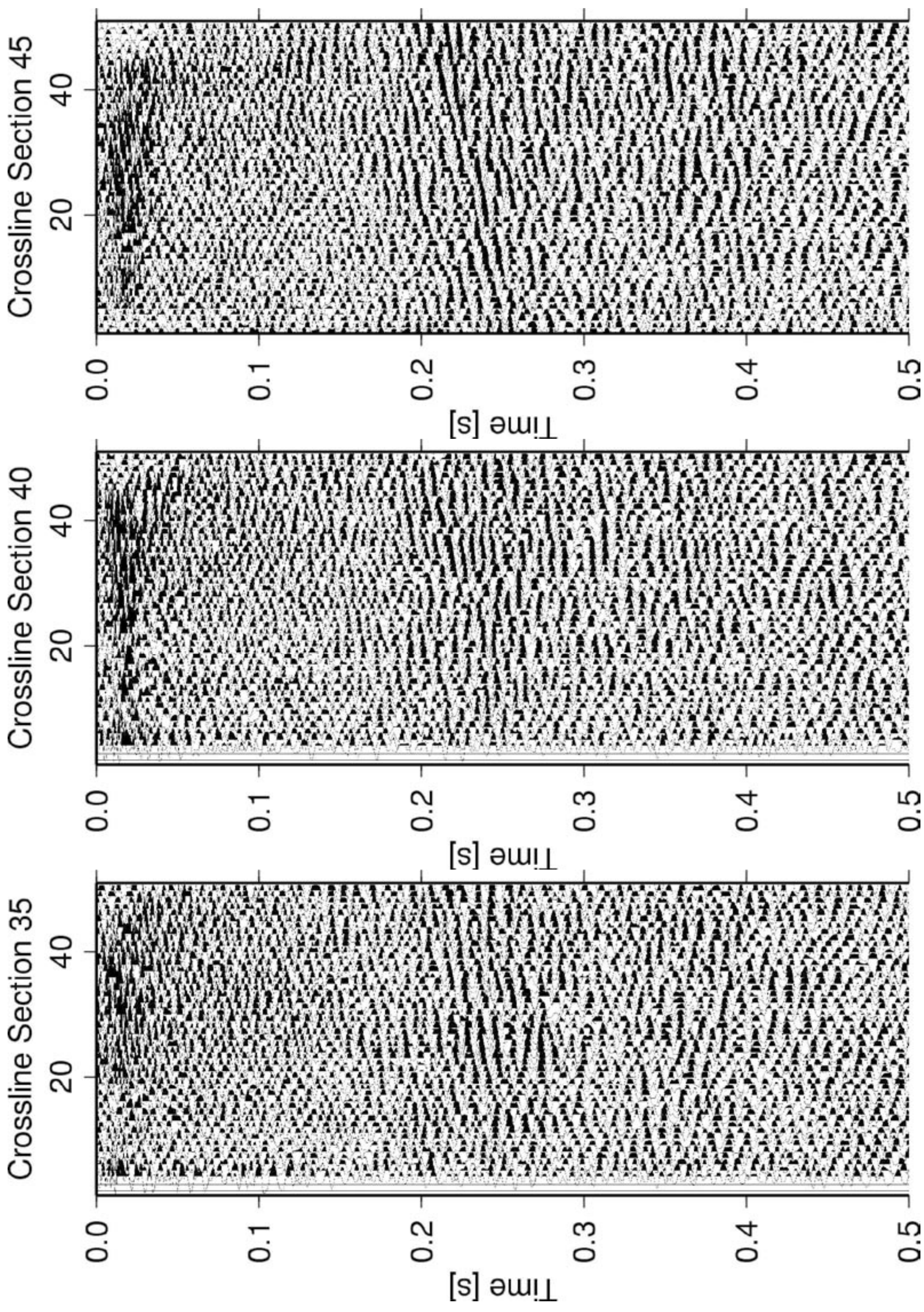

Figure 4-3. *Crossline stacked sections down to 0.5 seconds using array (GSM000010) and profile data. See Figure 3-1 for location of crosslines (W–E with 0 in west).*

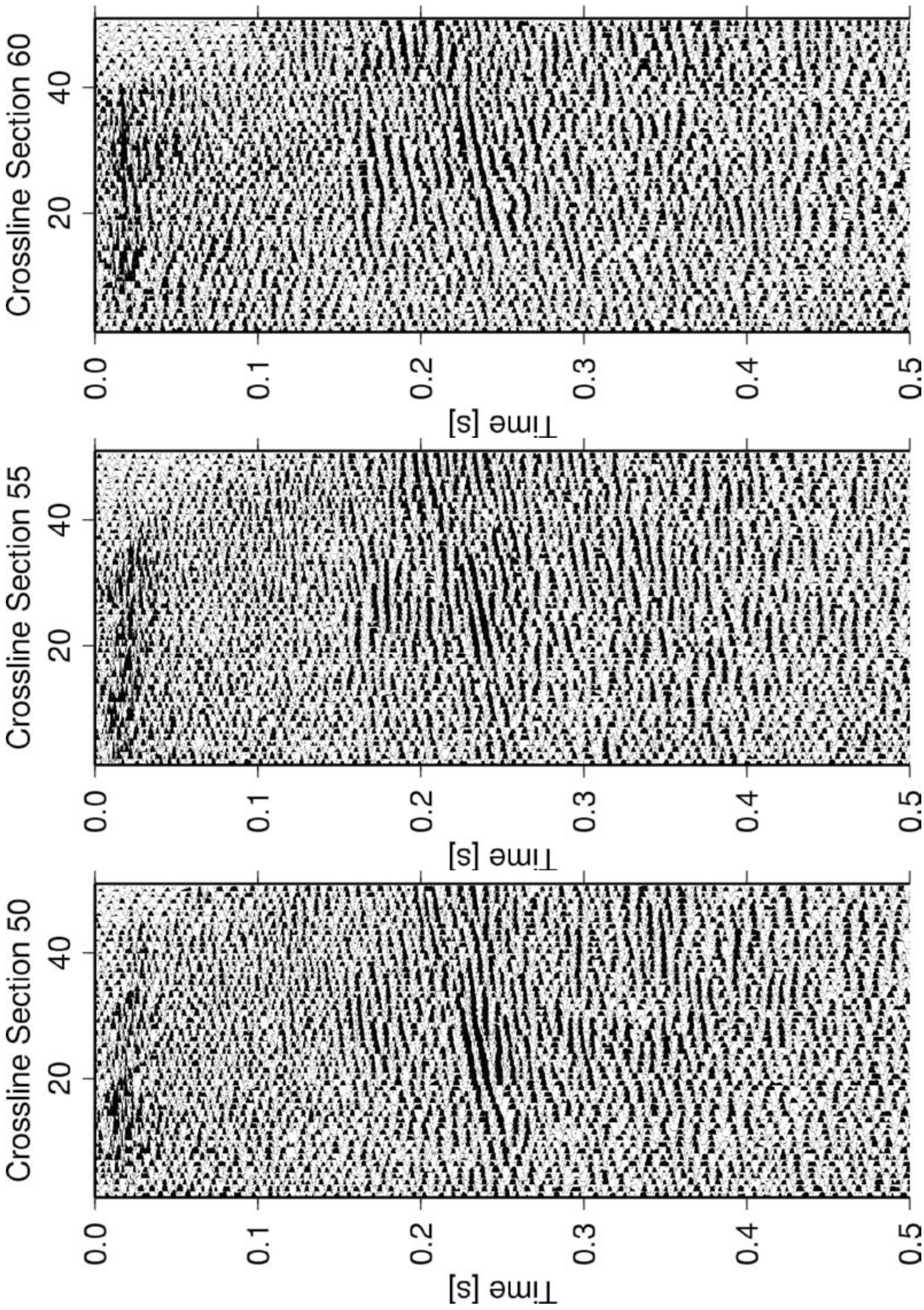

Figure 4-4. *Crossline stacked sections down to 0.5 seconds using array (GSM000010) and profile data. See Figure 3-1 for location of crosslines (W–E with 0 in west).*

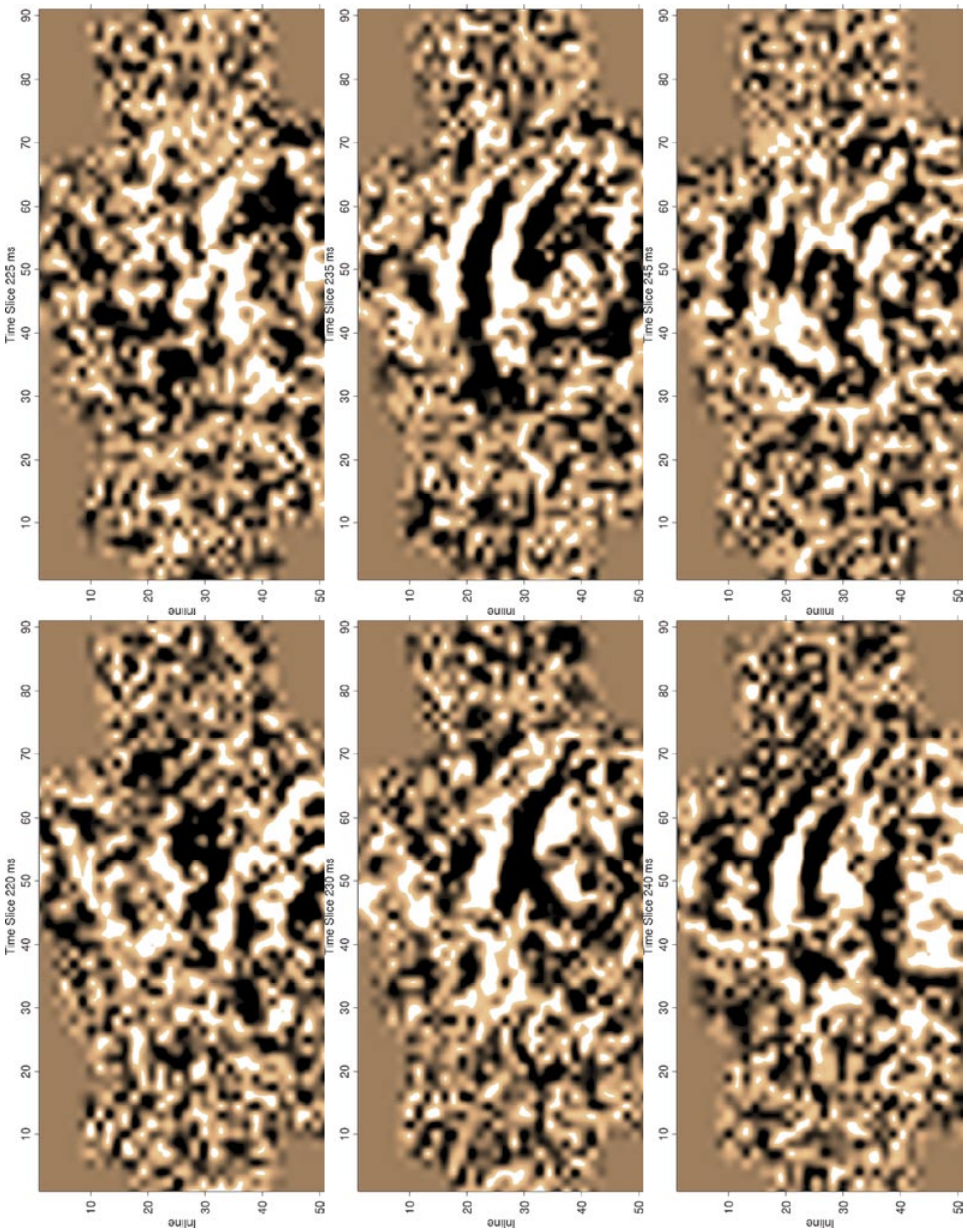

Figure 4-5. *Time slices at 220, 225, 230, 235, 240 and 245 ms. See Figure 3-1 for location of inlines and crosslines. The sections are oriented to conform to a map view so that north is towards the top and west towards the left.*

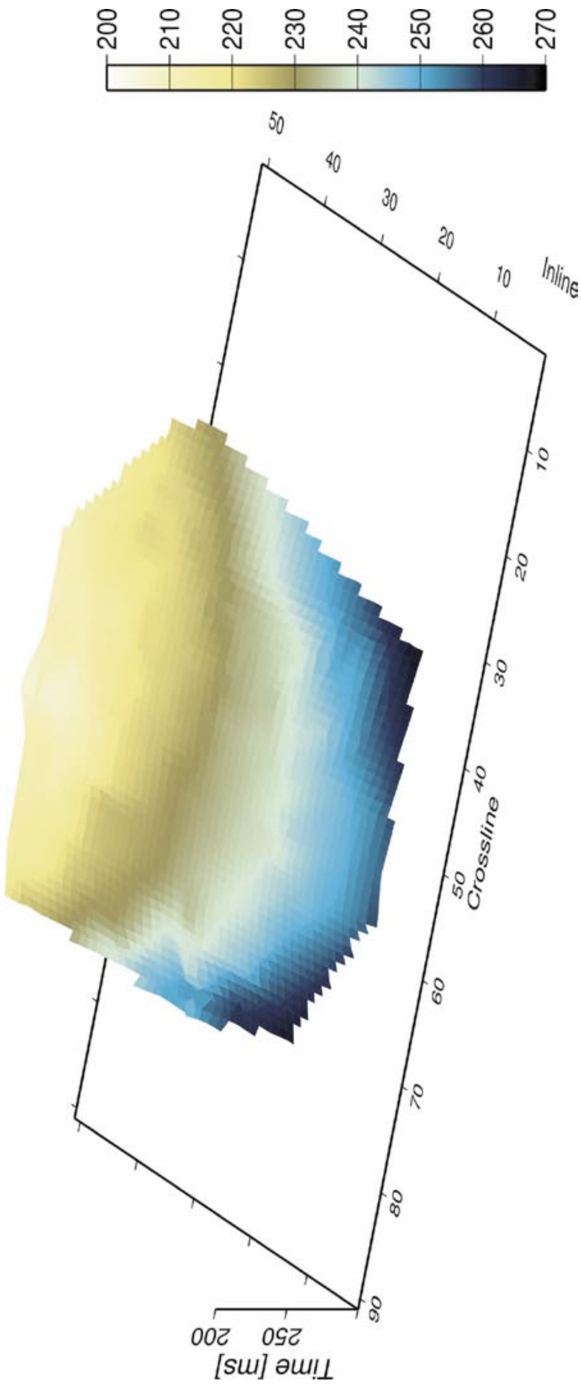

Figure 4-6. *Traveltime surface of the E1 reflection. The reflection has an anticlinal lensoidal form with a hinge line running along crossline 50. Colour scale refers to ms.*

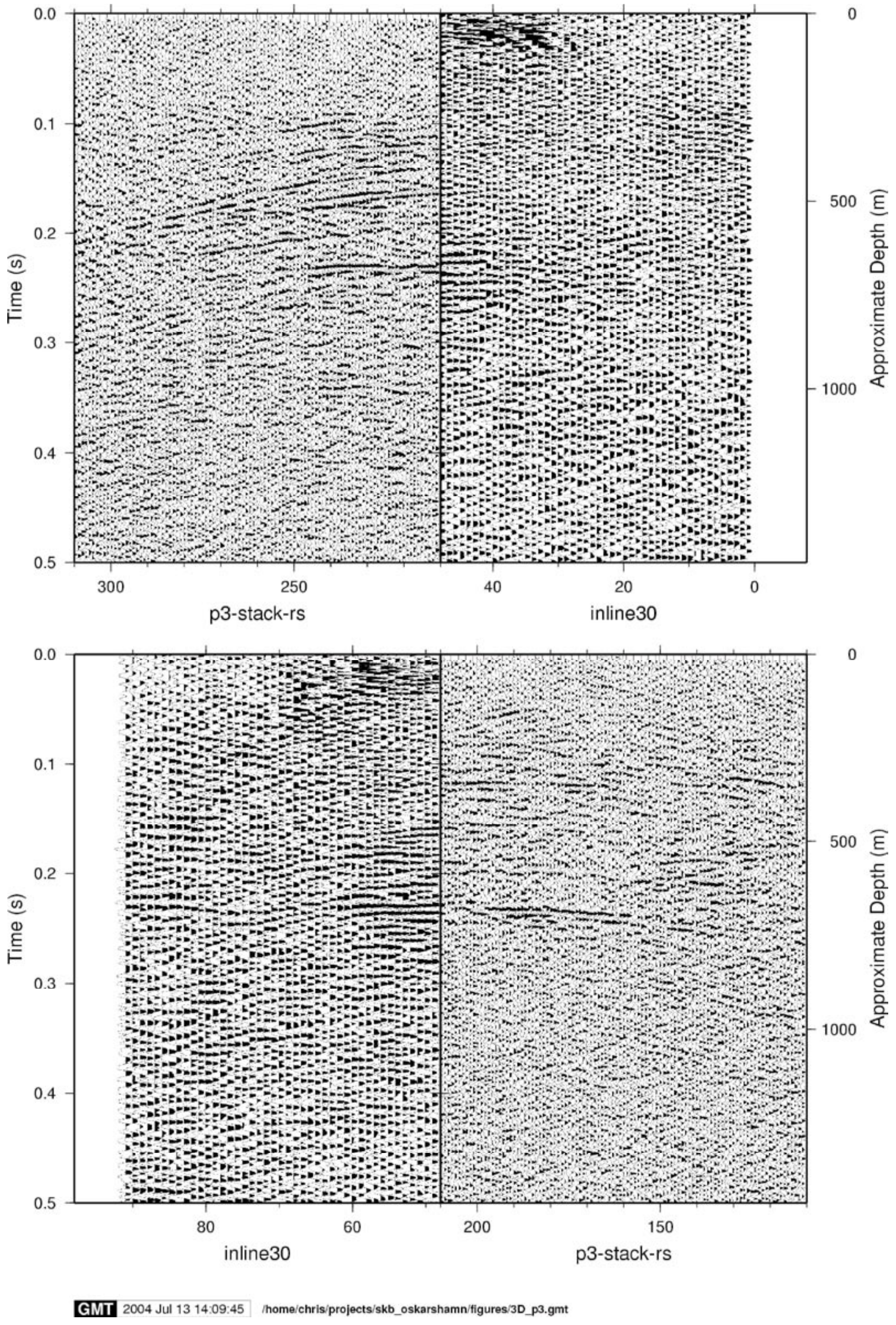

Figure 4-7. *N–S sections showing the correlation between profile 3(LSM000197) and the 3D volume along inline 30.*

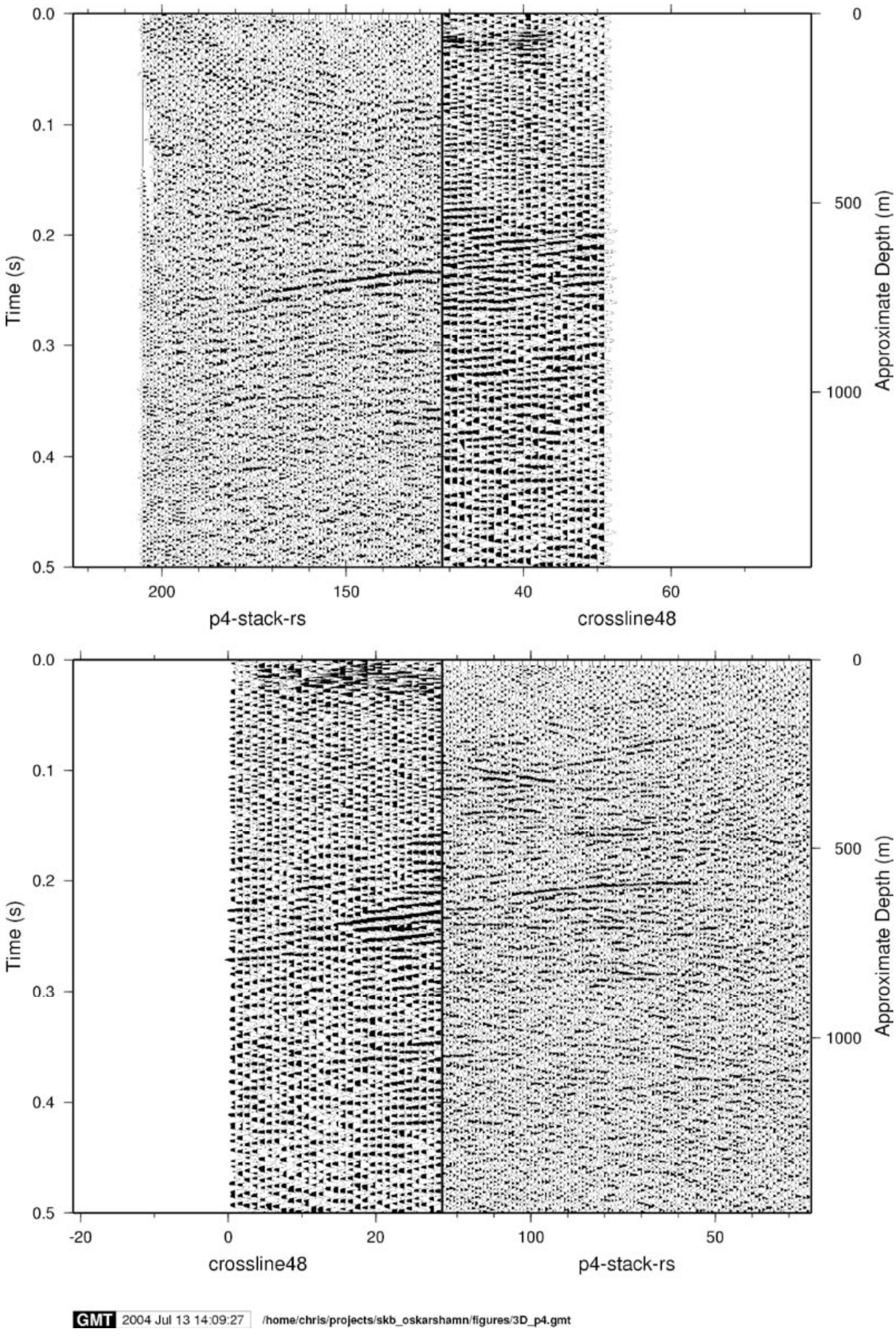

Figure 4-8. *W–E sections showing the correlation between profile 4(LSM000198) and the 3D volume along crossline 48.*

5 Discussion and conclusions

5.1 Acquisition

The acquisition geometry used in this project was far from ideal compared to the desired geometry of a 3D survey since the main purpose of the array was to acquire information on the bedrock velocity below the array. Highly irregular distributions of fold, offsets and azimuths result in a biased image. In addition, the areal extent of the survey is limited, implying that the offset range is significantly less than that required for imaging down to depths of 1 km. Finally, the station spacing of the array was too course, resulting in that 10×10 m bins had to be used for processing. Recommended bin size is 5×5 m.

5.2 Processing

Although the acquisition was not optimal, processing has led to an image of the E1 reflection that is useful for understanding its geometry. Other reflections have not been imaged as clearly since the processing has focused on the E1 reflection. The constraints of the acquisition also result in a poor near-surface image. DMO and migration have not been tested. By applying these methods and/or focusing on imaging dipping reflections it may be possible to obtain a 3D image of the B1 south dipping reflection that shows up clearly on the DMO stacked and migrated profile 3 (LSM000197) sections in /4/.

5.3 Interpretation

The geometry of the E1 reflection suggests that it originates from a mafic lens. This interpretation is supported by its high amplitude suggesting a strong impedance contrast. The lens appears to have been folded and has now the form of an anticline with a W–E running hinge axis.

5.4 Recommendations

The present study shows the potential of 3D seismic imaging applied to hardrock construction design. The present results suggest a number of other studies that could be done to prepare for a true 3D seismic survey. These include:

- Test DMO and migration methods for imaging steeply dipping reflectors.
- Take into account the potential of the VIBSIST source in 3D seismic data acquisition. It may be possible to significantly reduce the costs of a 3D survey.
- Perform seismic modelling of the E1 reflection to determine its spatial distribution.
- Study how to improve the image in low-fold areas.

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