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Site investigation SFR

Reprocessing of reflection seismic profiles 5b and 8, Forsmark

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Contents

1 Summary

Reflection seismic profiles 5b and 8 in the northern Forsmark area have been reprocessed with the aim of improving the images in the uppermost 500 metres in the SFR area. The main conclusion is that a new reflection (B10) has been identified that may extend below the SFR site. This reflection was not clearly observed in the previous processing. The reflection strikes approximately N25E and dips at about 35 degrees to the southeast. This orientation is similar to the set B group identified earlier /Juhlin and Palm 2005/. Note that the dip of the reflection is uncertain. On shot gathers it appears to dip at a slightly shallower angle while on the stacked sections it appears to dip at a greater angle. This discrepancy is probably due to the crooked nature of the profiles. However, reflections are clearly observed in shot gathers and its presence below SFR is highly probable.

Two new reflections were also identified further north along profile 5b (A11 and A12). These dip to the south-southeast, but would be found at a depth of 1–2 km below SFR if they extend to below the site. There are also signs of a 3rd reflection with similar orientation to the set A group identified earlier, A13, but its existence is very speculative. This reflector would intersect the surface within the SFR area.

South of the Singö deformation zone on profile 5b, another new reflection has been found, N1. The orientation of this reflection is speculative since it is not clearly seen on profile 8. It has been modelled as dipping to the north at about 35 degrees and projects to the surface south of the main SFR area.

In addition, the orientation of reflection B7 has been revised as has the lateral extent of A1. Most importantly, A1 is now interpreted not to extend to the surface and not cross the Singö deformation zone. The orientation and location of reflections are summarized in Table 1-1 and Figure 1-1.

Table 1-1. Orientation of reflections studied in this report. Reflections marked in bold font are new reflections not identified earlier. Distance refers to distance from the arbitrary origin (6,699 km N, 1,633 km W) to the closest point on the reflector where it intersects the ground surface. Strike is measured clockwise from north. Rank indicates how sure the observation of each reflection is on profiles that the reflection is observed on; 1 – definite, 2 – probable, 3 – possible.

Reflector	Strike	Dip	Distance (m)	Rank	Profiles observed on
A1	75	45	3,100	2	1, 4, 4b, 8
A11	60	40	4,500	2	1, 5, 5b, 8
A12	60	50	4,000	2	5b
A13	90	45	3,200	3	5b, 8
B7	50	15	2,200	2	1, 5
B10	25	35	2,200	2	5b, 8
N1	260	35	2,250	3	5b,8

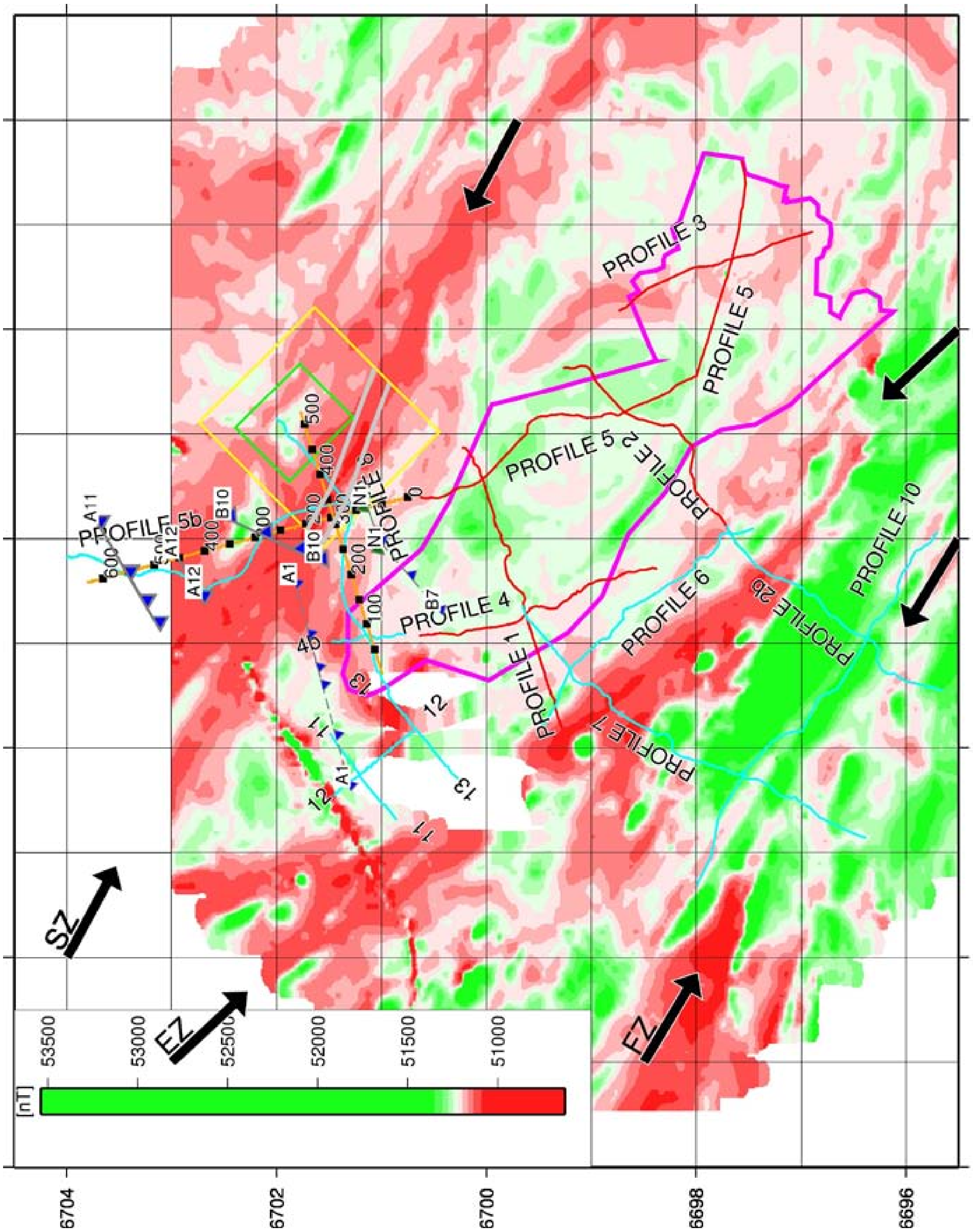

Figure 1-1. Projected reflector intersections with the surface as discussed in this report plotted on the magnetic anomaly map. All indicated reflectors correspond to relatively thin zones (5–15 m thick), except for A1. Reflectors are coded as follows: blue-rank 2, green-rank 3. A dashed line for the reflector implies that the reflector cannot be traced to the surface. Red lines are Stage 1 profiles, light blue are Stage 2 profiles, orange lines are CDP processing lines used in this study. Grey lines mark the Singö zone in the area of interest. FZ – Forsmark zone, EZ – Eckarfjärden zone, SZ – Singö zone. Figure 4-10 shows a more detailed view.

2 Introduction

In an attempt to better image reflections in the SFR area, profiles 5b and 8 from the Forsmark Stage 2 reflection seismic campaign /Juhlin and Palm 2005/ have been reprocessed. The geometry of these profiles are far from ideal for investigating if sub-horizontal reflections are present in the SFR area. To thoroughly investigate if sub-horizontal to gently dipping reflections are present in the area would require seismic acquisition in the sea. Even though the data are rather poor in the vicinity of the Singö deformation zone, the reprocessing has shown that some reflections in the near-surface were missed during the previous processing due to the crooked nature of the profiles. A processing step known as DMO smeared the data too much. The new processing allows the larger scale structure in the area to be updated. Given the crooked nature of the profiles, it is possible that pseudo-3D processing would allow even better images to be obtained.

In the pages that follow, results from the previous processing and the reprocessing are presented. A qualitative interpretation of the newly identified reflections and previously identified reflections is provided.

3 Data processing

Data from profiles 5b and 8 were reprocessed along new CDP lines. The locations of the new CDP, or stacking, lines are similar to the previous ones, but straight lines have now been used. Processing steps were similar, except that DMO has not been applied in the new processing. DMO tended to smear the data too much and some dipping events were lost in the DMO process. This is a general observation when dealing with low signal to noise ratio data and crooked profiles resulting in a large spread in the midpoints (Figure 3-1). Results from the previous processing of profiles 5b and 8 are shown in Figures 3-2 and 3-3, respectively. Results from the new processing are shown in Figures 3-4 and 3-5, respectively. The new processing parameters are shown in Table 3-1.

Table 3-1. Processing parameters used in this study for the seismic profiles.

Step	Process
1	Read SEGD data
2	Spike and noise edit
3	Pick first breaks
4	Scale by time
5	Time variant spectral equalization 60–80–250–300 Hz 0–400 ms 10–60–200–250 Hz 600–1,500 ms Window: 10 Hz
6	Bandpass filter 80–120–250–300 Hz 0–200 ms 70–100–250–300 Hz 200–400 ms 60–90–250–300 Hz 400–1,500 ms Notch: 50, 100 Hz
7	Refraction statics
8	AGC – 50 ms window
9	Median velocity filter: 2,800 m/s
10	Trace top mute 0 m: 10 ms; 1,100 m: 210 ms
11	Air blast tail mute
12	Sort to CDP domain
13	Velocity analyses
14	Residual statics
15	NMO
16	Stack (mean)
17	Trace equalization
18	F-X Decon

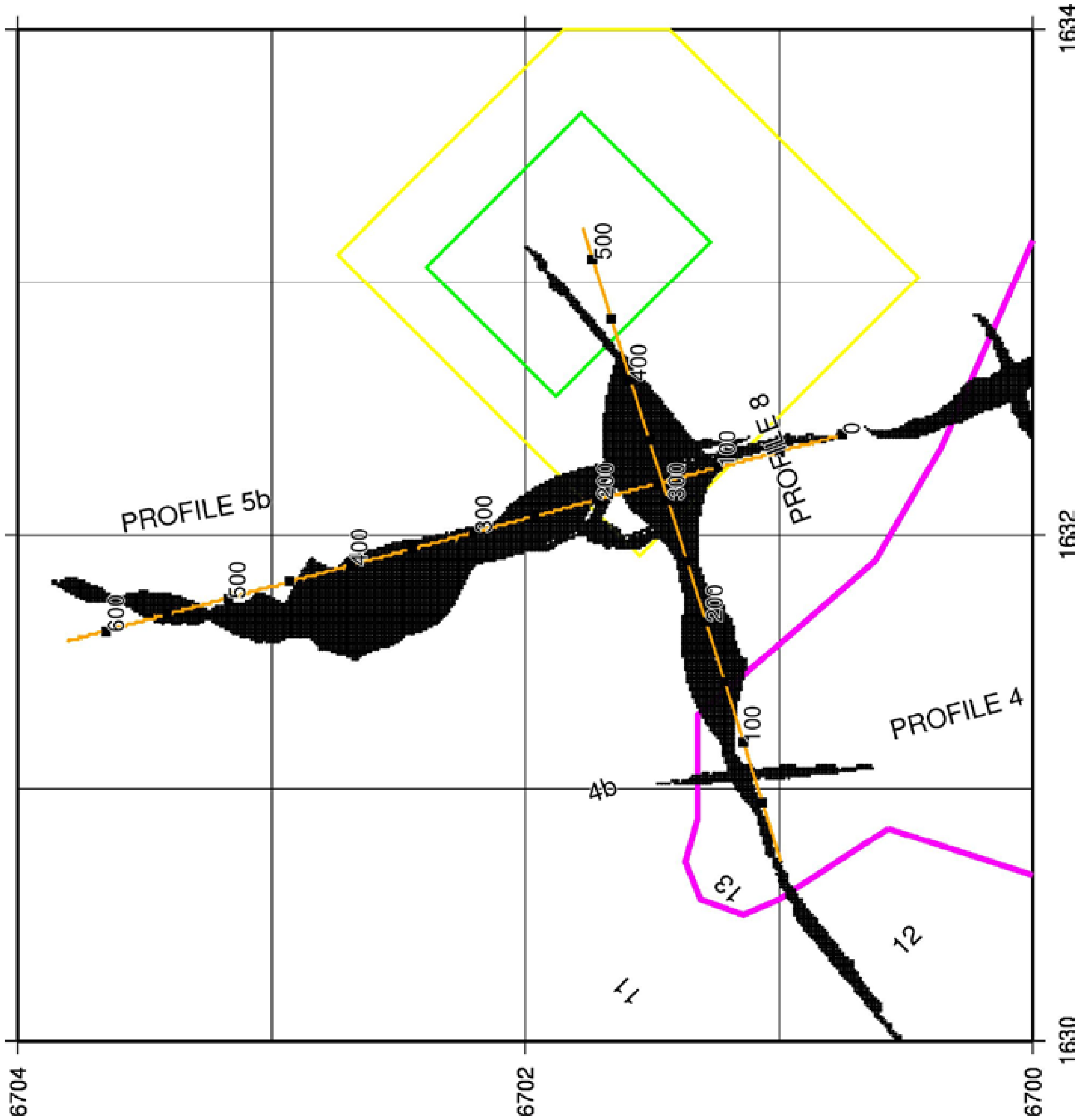

Figure 3-1. Location of midpoints along the profiles. The shorter crossing set striking N-S at X=~1631 is from profile 4b while the one striking ENE-WSW at Y=~6700 is from profile 1. Area marked with yellow line = SFR regional model area. Area marked with green line = SFR local model area

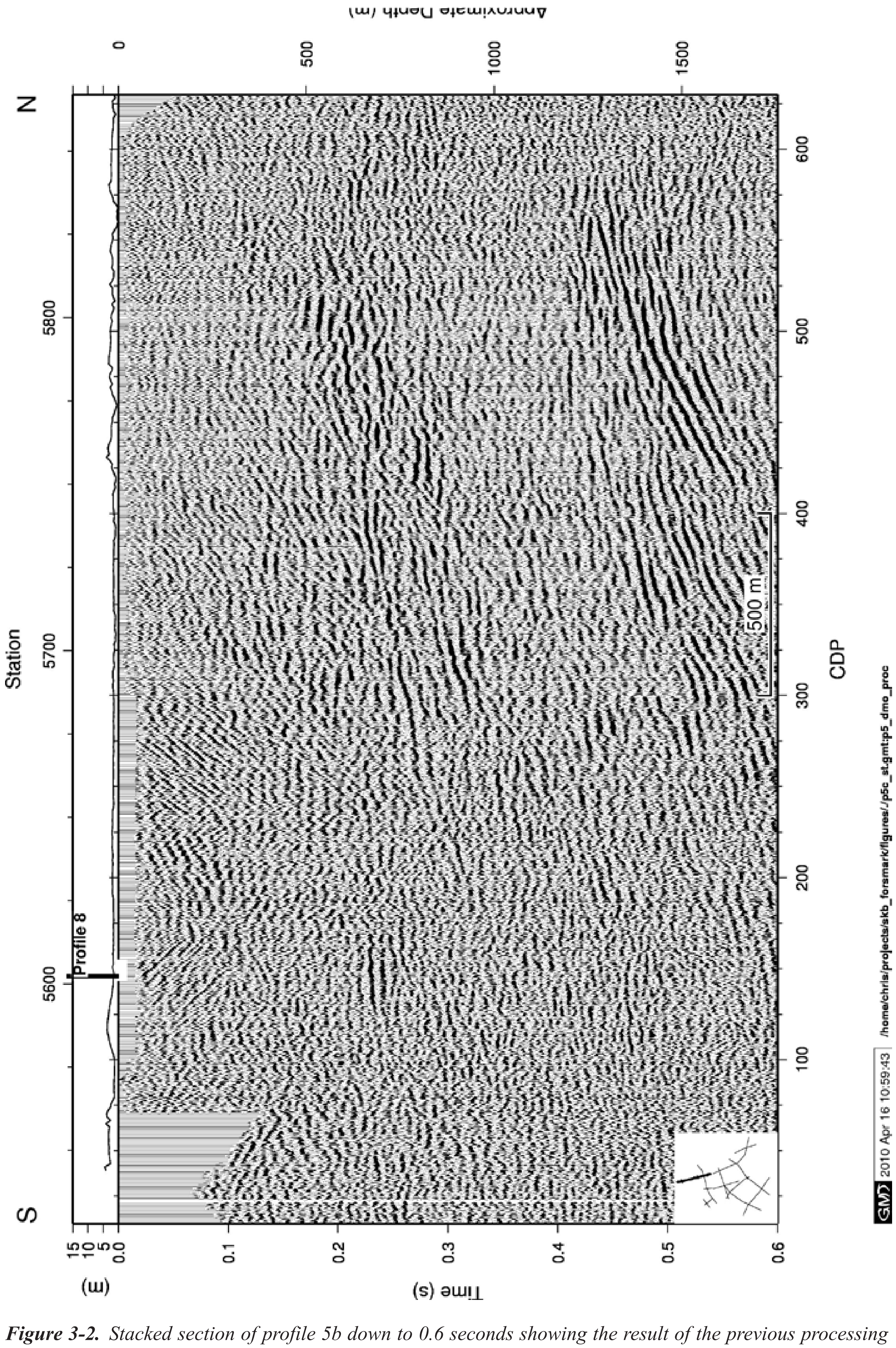

__Figure 3-2.__ Stacked section of profile 5b down to 0.6 seconds showing the result of the previous processing presented in /Juhlin and Palm 2005/. Location of section indicated in lower left corner.

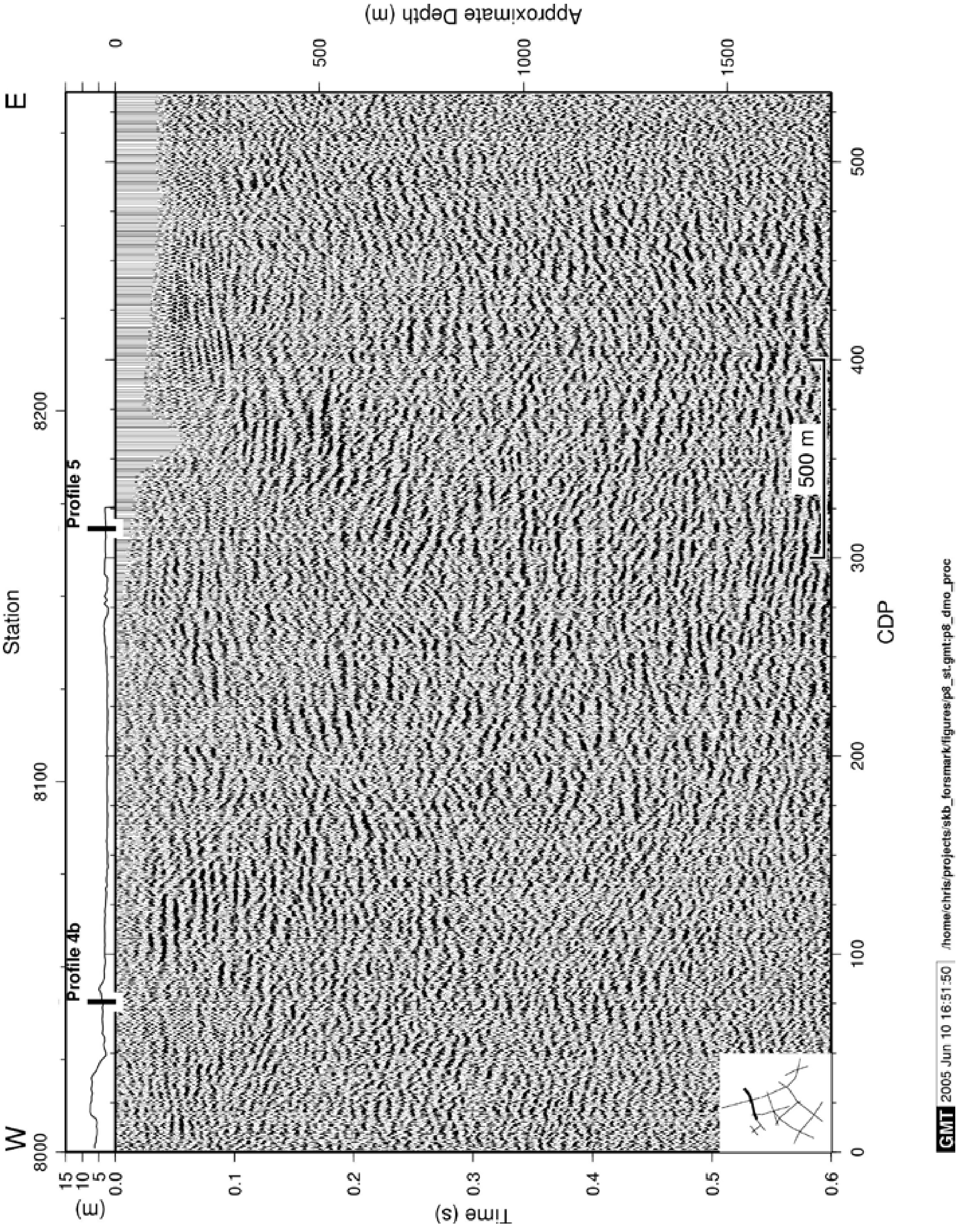

Figure 3-3. Stacked section of profile 8 down to 0.6 seconds showing the result of the previous processing presented in /Juhlin and Palm 2005/. Location of section indicated in lower left corner.

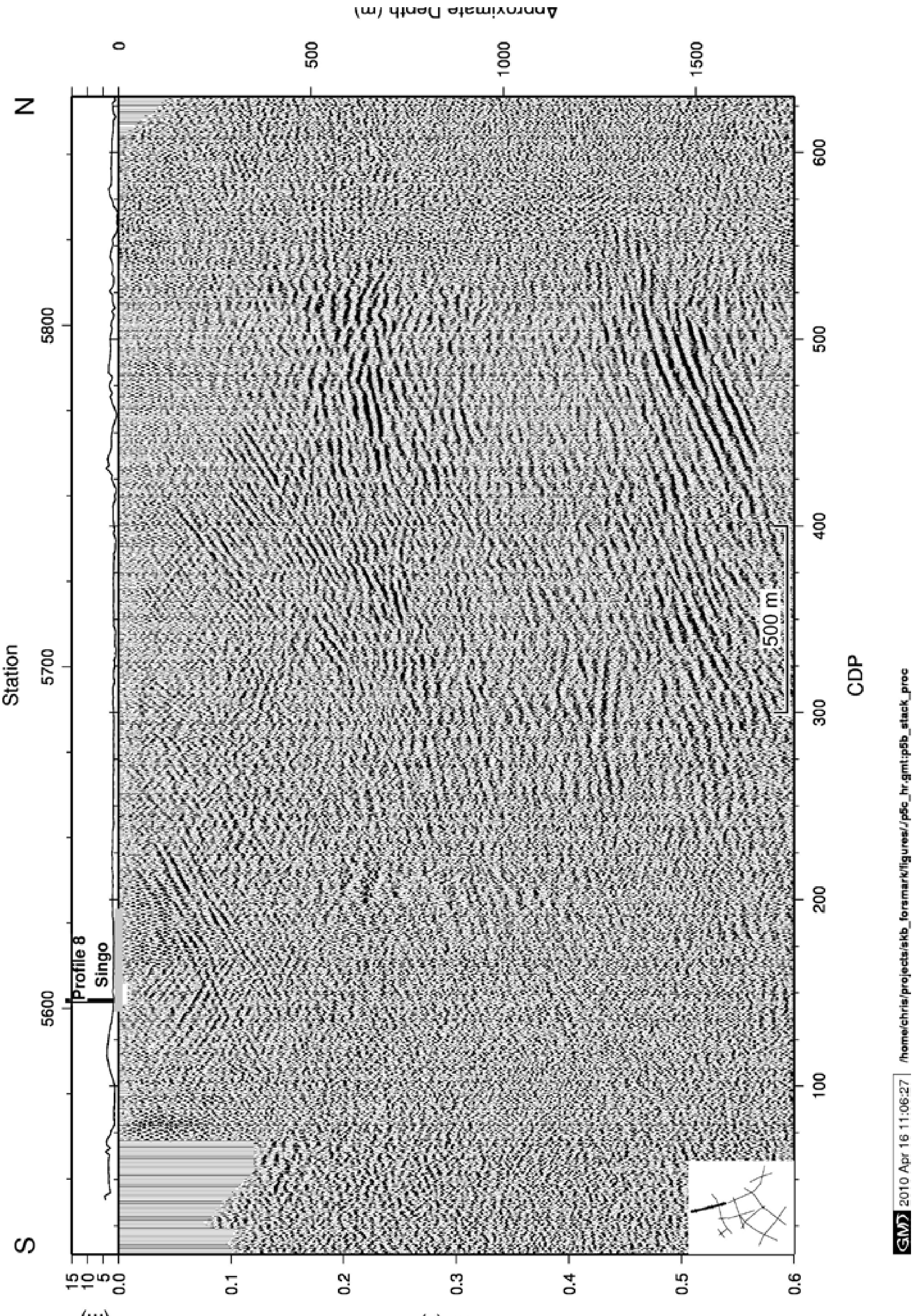

Figure 3-4. *Stacked section of profile 5b down to 0.6 seconds showing the result of the new processing. Location of section indicated in lower left corner. The intersections with profile 8 and the Singö deformation zone are marked.*

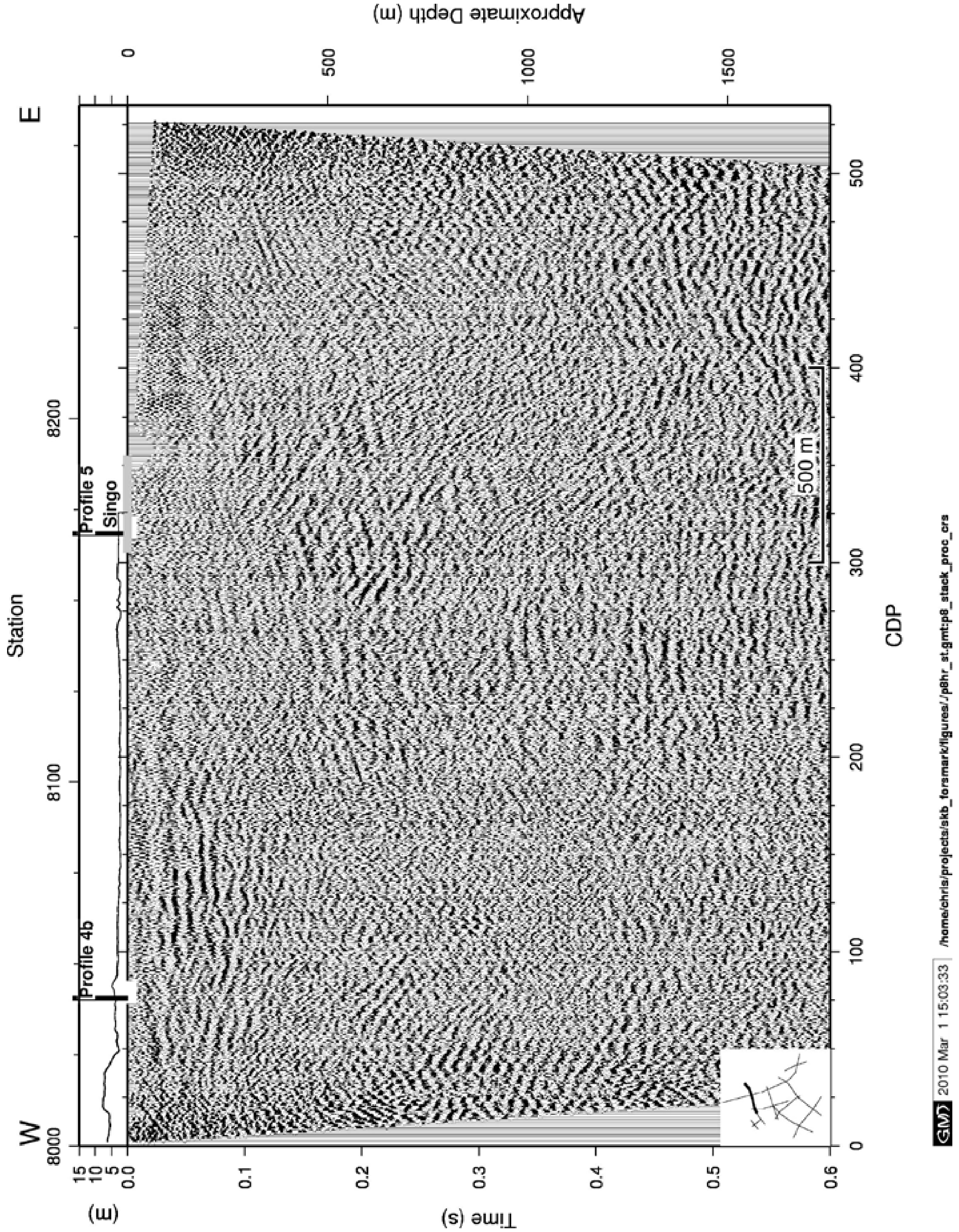

Figure 3-5. Stacked section of profile 8 down to 0.6 seconds showing the results of the new processing. Location of section indicated in lower left corner. The near-surface banded appearance is due to the applied F-X deconvolution. The intersections with profiles 4b and 5b and the Singö deformation zone are marked.

4 Interpretation

In the interpretation that follows it is assumed that the reflectors can be modelled as plane interfaces. If reflections from the same plane interface can identified on two crossing seismic profiles then the orientation of the plane can be determined. The seismic sections from the new processing, as well as some of the other profiles near SFR, were used for this purpose in this study. Where the profiles cross, reflections from the same plane should appear at the same time. If the reflections are limited in their lateral extent then the reflections may not extend to the crossing point and it is more difficult to judge if two reflections are coming from one and the same interface on two different profiles. Given that the data are quite noisy in the SFR area, a considerable amount of subjectivity has gone into identifying reliable reflections and correlating them between profiles.

B10

The reflectivity is rather diffuse and weak where profiles 5b and 8 cross (Figure 4-1). Only one relatively clear reflection zone can be correlated between the two profiles. This reflection, B10, is modelled as dipping at 35° to the southeast (Table 1-1) which is less than the observed dip on the stacked seismic sections (Figure 4-2). The reflection is clearly observed on the new processing for profile 5b (Figure 4-3), although there appear to be a set of reflections parallel to it at the same location. This set may be artifacts due to the crooked nature of the profile. On profile 8, the reflection is less clear, but on shot gathers from profile 8, where the reflection is sometimes clearly seen, a good match is found between the modelled and observed reflection traveltimes (Figure 4-4). The discrepancy on the stacked sections can be explained on the basis that the reflection originates from out-of-the-plane of the profiles and that the acquisition line is crooked, resulting in artifacts during the stacking process. The clear presence of the reflection in the shot gathers implies that a high degree of confidence can be placed in the presence of a reflector below SFR at depths corresponding to that of B10. However, the exact strike and dip are somewhat uncertain as shown by the poorer match between the modelled traveltimes and observed reflectivity in profile 5b (Figure 4-3). The fact that B10 reflections are coming from out-of-the-plane of the profile and the large lateral spread in midpoints along the profile (Figure 3-1) may explain this lack of agreement.

A11 and A12

Reflections A11 and A12 were not clearly observed along profile 5b on the previous processing due to the smearing effects of the DMO operator when crooked line data are processed. These reflections are only clearly observed along newly processed profile 5b (Figure 4-3) so their orientations are somewhat uncertain. There are some signs of sub-horizontal reflectivity at corresponding traveltimes on profile 8, implying that they lie nearly within-the-plane of profile 5b. This orientation is also consistent with the set A reflections previously identified. It is quite likely that the modelled orientations in Table 1-1 are close to the true orientations for reflections A11 and A12. Both these reflections project up to the surface at topographic lows (Figure 4-3), suggesting they may be generated at fracture zones.

A13

There are indications of a reflection with apparent opposite dip to reflection B10 on profile 8 (Figure 4-5). It is difficult to correlate this reflection onto profile 5b, but it may have a similar apparent dip on this section as B10. If this is the case, then this reflection will intersect the surface within the SFR area, the only one to do so. However, the existence and geometry of this reflection is very uncertain. Therefore, this reflector is not included in any interpretation.

A1

Reflection A1 has in the past been projected up to the surface and extended over the Singö deformation zone (Figure 4-6). Reexamination of the seismic data show that this is probably not the case. Along profile 4b, the A1 reflection is capped by the sub-horizontal reflections L1 and L2 (Figure 4-7). The orientation of these reflections are well constrained since they are also clearly observed on profile 8. There are no clear signs of the A1 reflection on either profile 8 or profile 5b. A major question remains concerning whether this reflector is lithological in character, related to the high frequency of amphibolite lenses and dyke-like bodies that have close to where the reflector projects to the surface, as well as at the base of borehole KFM08A. However, it may well be that this reflector does not extend to the surface and the only way to determine the nature of it is a dedicated borehole though it.

B7

Reflection B7 was earlier modelled as striking (N25E) in a more north-south direction (Figure 4-6) compared with the present study. The new orientation presented in this report better matches the observed traveltimes of the reflection (Figure 4-8). It is not clear if the reflector extends up to the surface since it cannot be followed to the surface, along either profile 1 or profile 5, the profiles upon which is observed on. Note that the reflection projects into the SFR area. However, the geometry of profiles 5b and 8 do not allow a reflection with this orientation to be mapped in the SFR area (Figures 4-5 and 4-9).

N1

N1 shows up as a relatively short north-dipping reflection on profile 5b (Figure 4-3). It is not clearly observed on profile 8, but there are some very weak indications of gently west dipping reflections where N1 is expected to be observed. Based on these weak indications the reflector has been oriented as striking close to W-E and dipping at about 35° towards the north. This northerly dip is nearly unique in the Forsmark area, which makes the N1 reflection quite anomalous if it is real (Figure 4-11).

M1 and M2

Both the M1 and M2 reflectors were in the past modelled as extending far across to the south side of the Singö deformation zone. Reexamination of the seismic data indicates that these reflectors may not extend south of this zone (Figures 4-3 and 4-5). However, the seismic data along the profiles is quite poor to the south of the Singö deformation, so there remains some uncertainties. Until higher quality data can be acquired, they are now modelled as not extending over the entire lengths of profiles 5b and 8. However, even with their current more limited extensions, they may still be present directly below the Singö deformation zone if they have been identified correctly on profile 8 (Figure 4-11). Note that M1 and M2 are do distinct reflections, but zones of reflectivity. The short high amplitude signals below the modelled reflections (Figure 4-3) may represent more mafic rocks with limited lateral extension.

C1 and C2

Reflectors C1 and C2 are still interpreted as crossing the Singö deformation zone at depth, even if they are not very clearly imaged south of the zone (probably due to the poorer data quality in this area). However, they correlate well between profile 5 and profile 5b (Figure 4-11) and can be observed over much of the Forsmark area /Juhlin and Palm 1995/.

Figure 4-10 shows a more detailed view of where the reflections discussed in this report project to the surface. Figure 4-11 shows the calculated reflection points as determined from modeling the reflections on the stacked sections. The reflection points correspond to those points on the reflector plane that are the shortest distance from the surface CDP point to the plane. Therefore, straight lines on the surface, where the reflection is observed, map onto straight lines on the reflector plane. For example, line C2.51 shows the location of the reflection points on reflector C2 from profile 5b in map view. The calculated reflection points are at a depth of about 3 km. The actual reflection points will be different due to the crooked nature of the profiles. However, the figure gives a general idea of the coverage in the area. This coverage is very sparse, but most indications are that none of the reflectors cross the Singö deformation zone except for the deeper (c. 3 km deep) C1 and C2 reflectors.

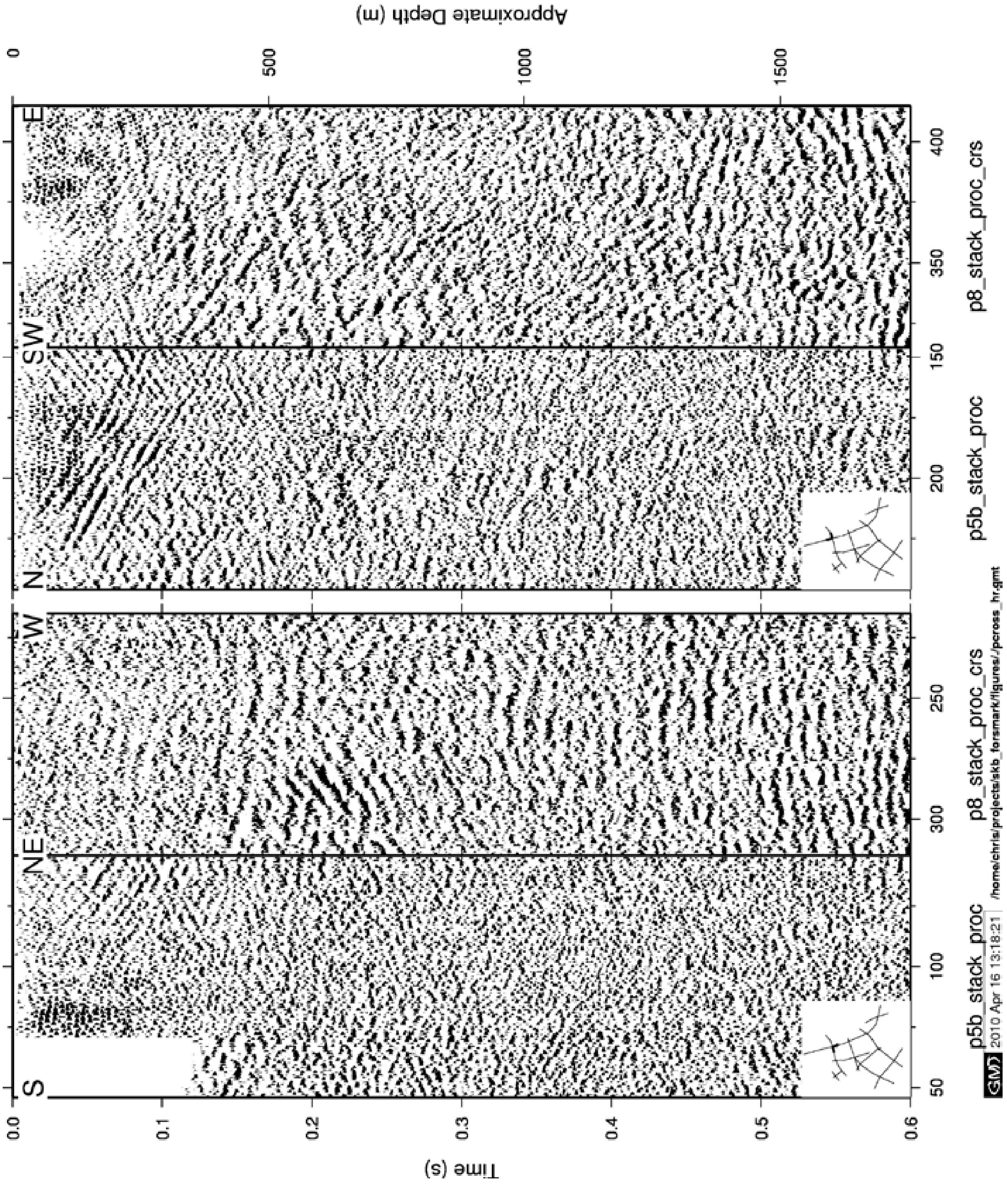

Figure 4-1. Parts of profiles 8 and 5b viewed from the north (left) and the south (right).

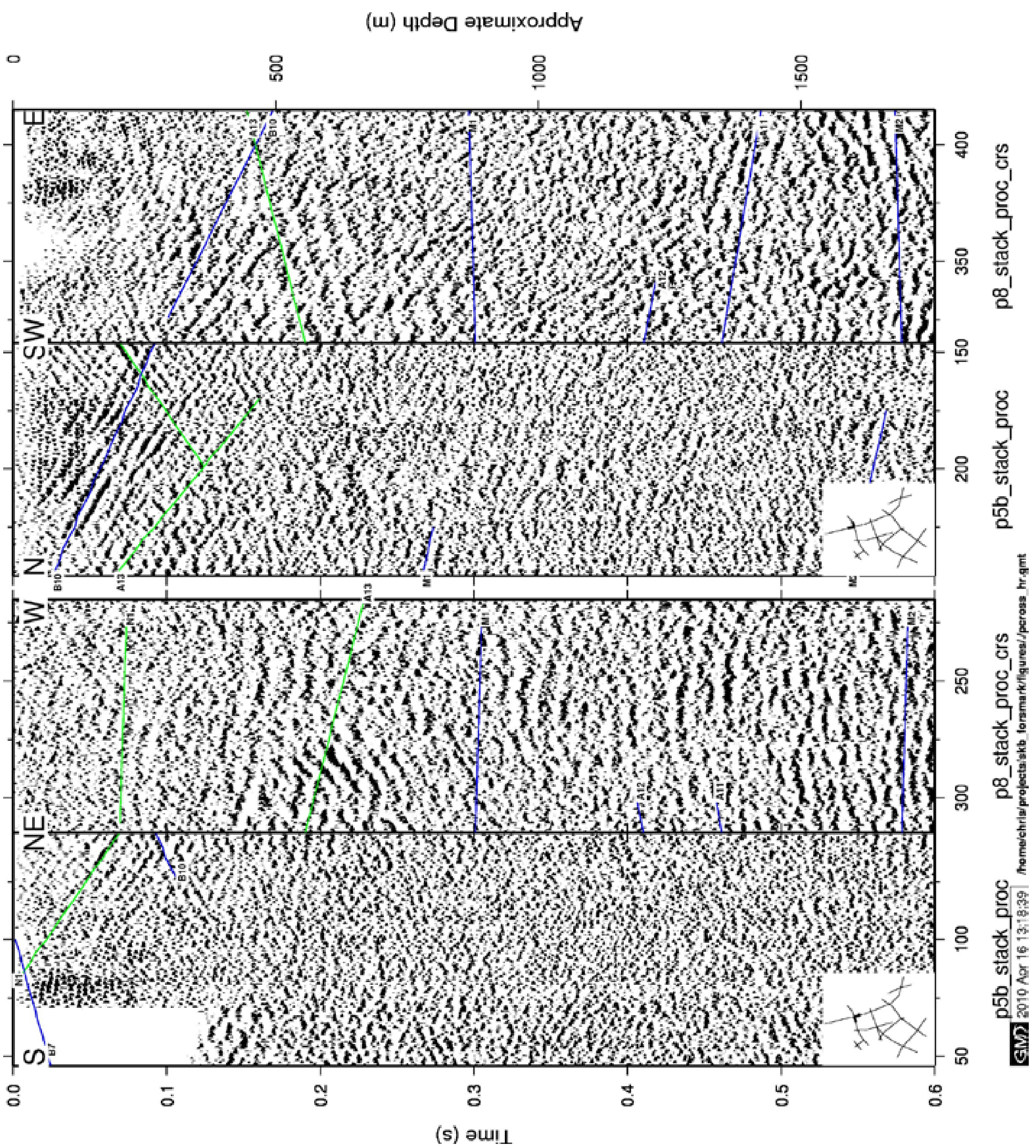

Figure 4-2. *Parts of profiles 8 and 5b viewed from the north (left) and the south (right). Picked reflections are plotted on top of the seismic sections.*

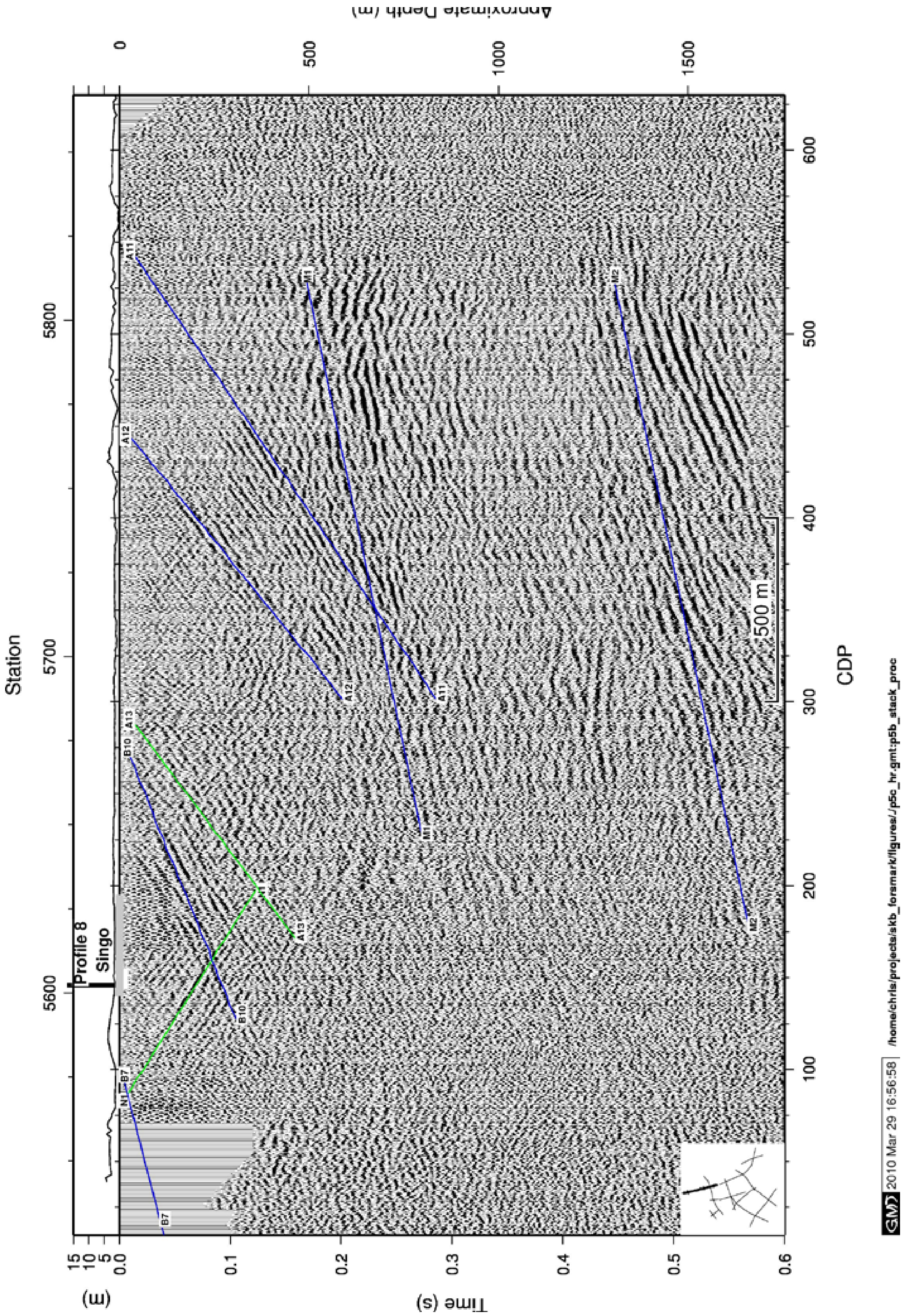

Figure 4-3. Stacked section of profile 5b down to 0.6 seconds showing the result of the new processing. Picked reflections are plotted on top of the seismic section. Location of section indicated in lower left corner.

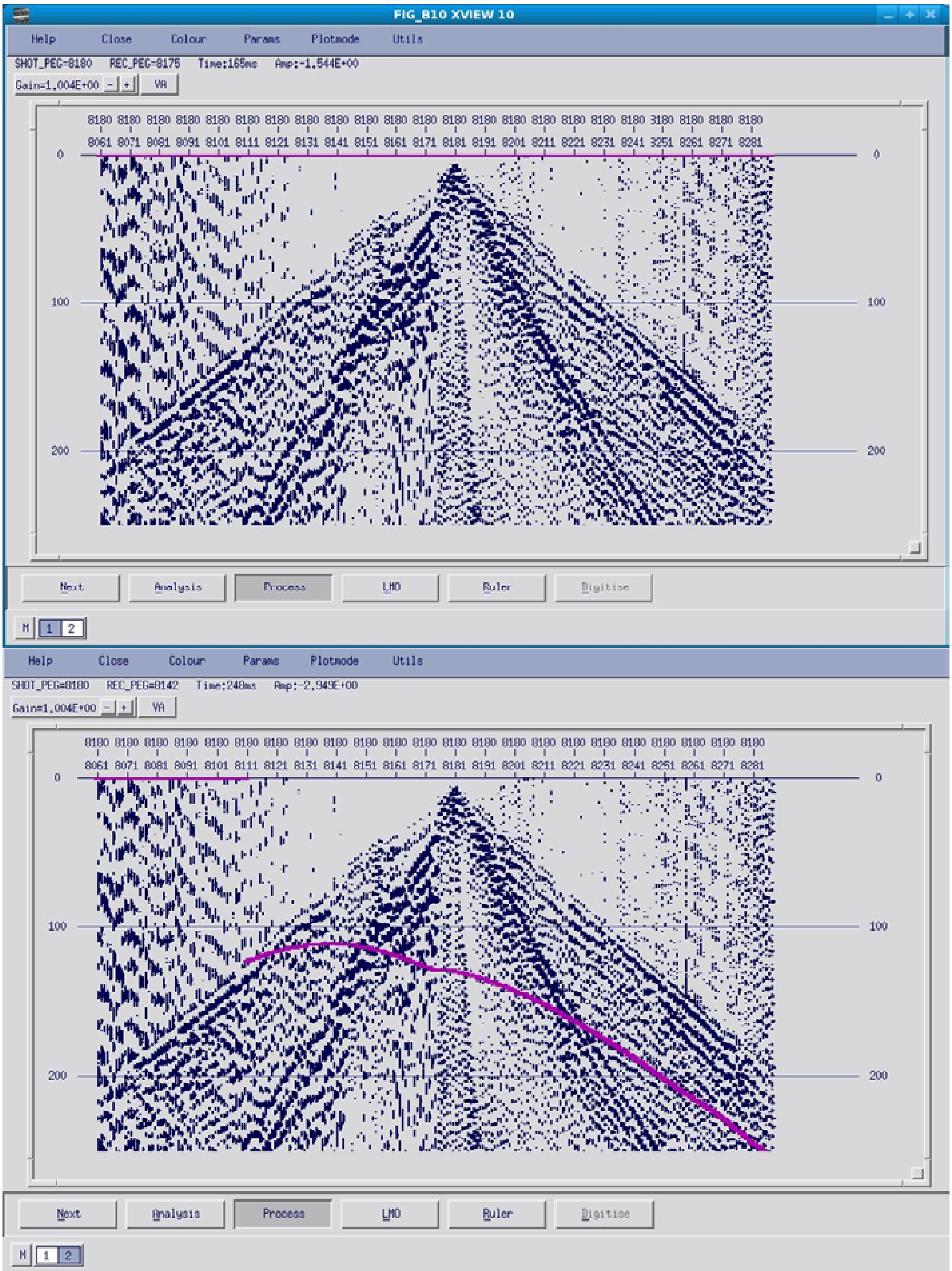

Figure 4-4. *Shot gather from profile 8 showing a clear reflection (blue arrow) interpreted as originating from B10. Purple curve in lower plot shows modeled traveltimes for reflection B10 with the geometry given in Table 1-1.*

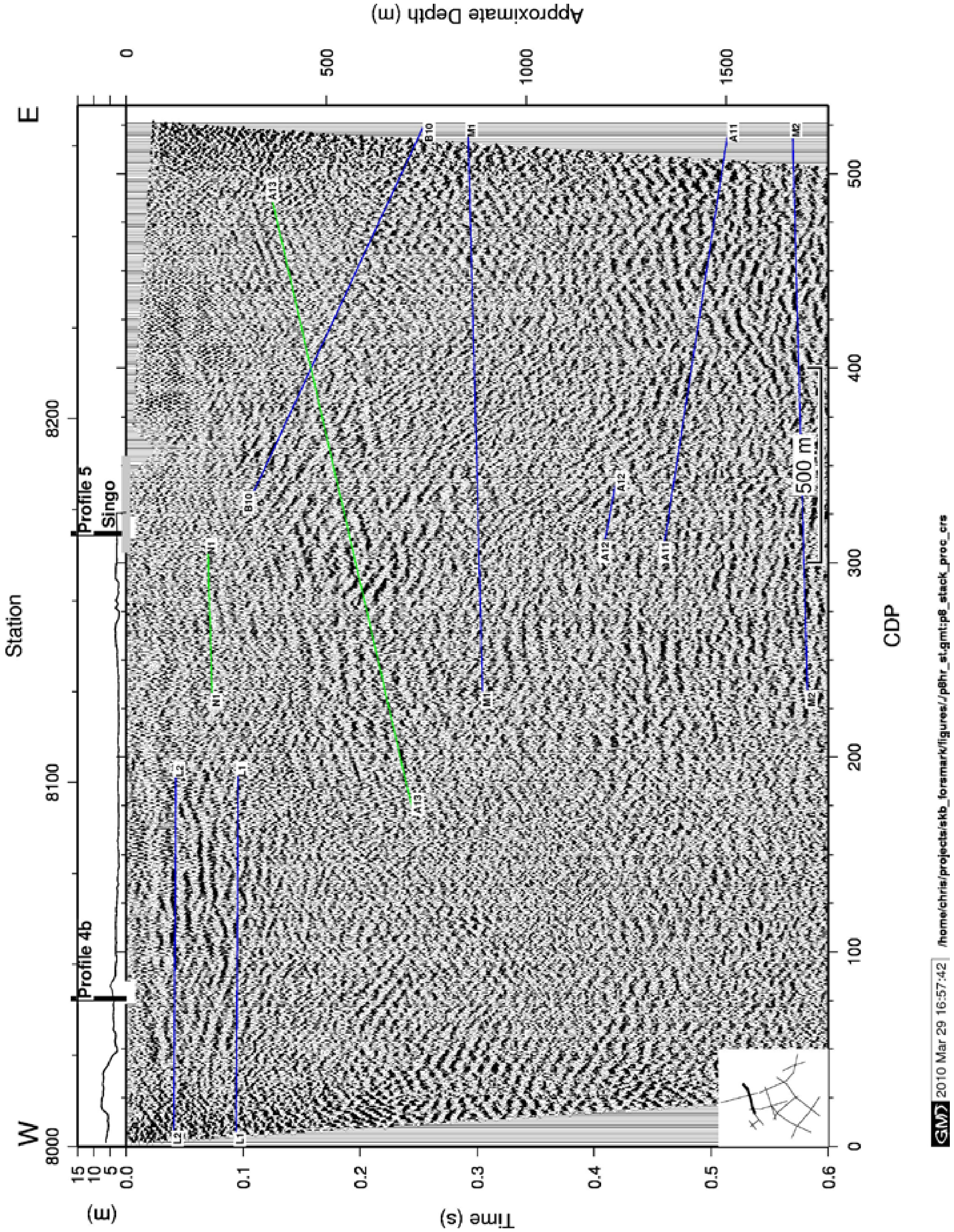

Figure 4-5. *Stacked section of profile 8 down to 0.6 seconds showing the result of the new processing. Picked reflections are plotted on top of the seismic section. Location of section indicated in lower left corner.*

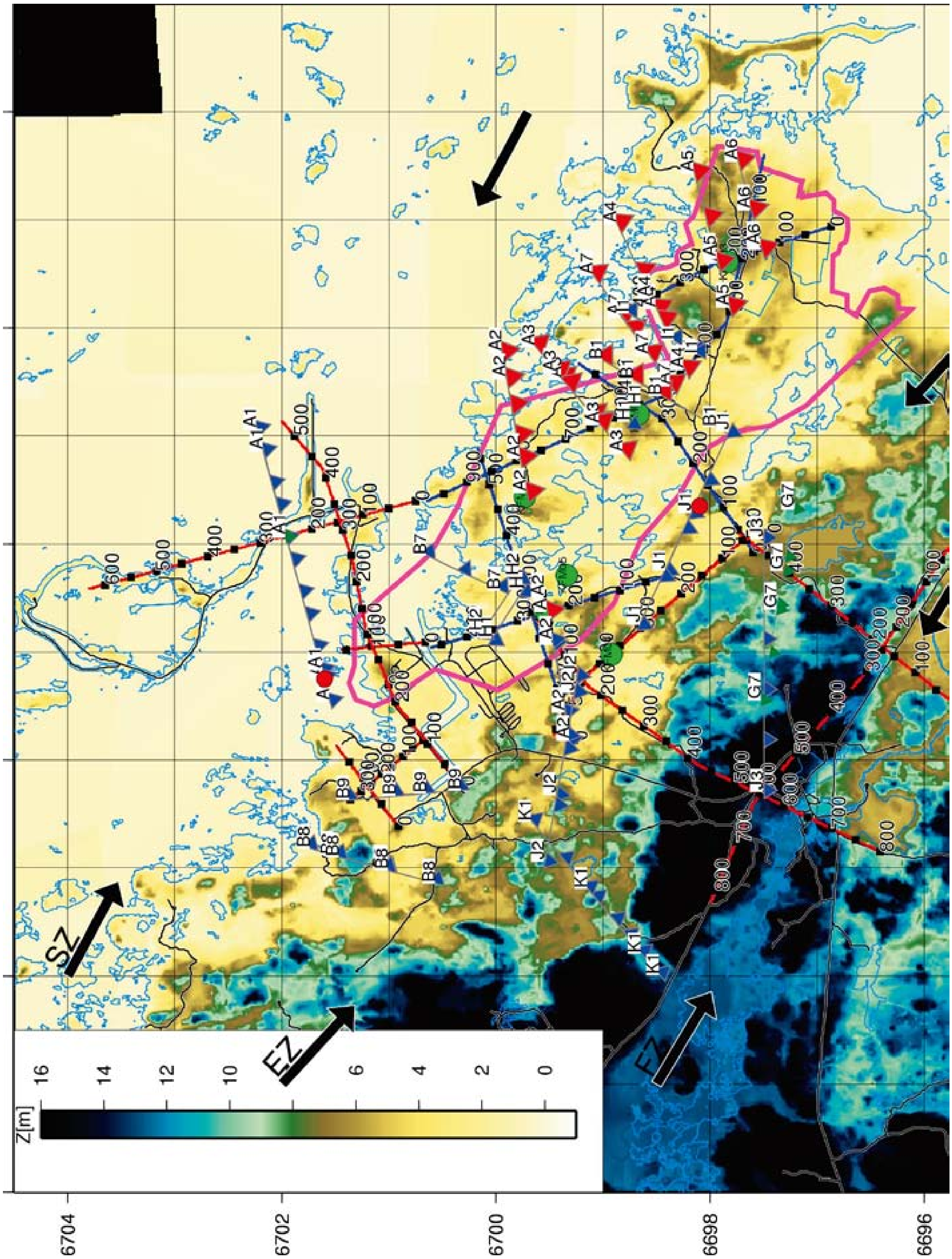

Figure 4-6. Projected reflector intersections with the surface as picked in Stage 1 and Stage 2 and plotted on the topographic map. All indicated reflectors correspond to relatively thin zones (5–15 m thick), except for A1. Shown also are where the A1 and the J1 reflectors project to the surface (red dots) along the extension of their respective profiles. Reflectors are coded as follows: red-rank 1, blue-rank 2, green-rank 3. FZ – Forsmark zone, EZ – Eckarfjärden zone, SZ – Singö zone.

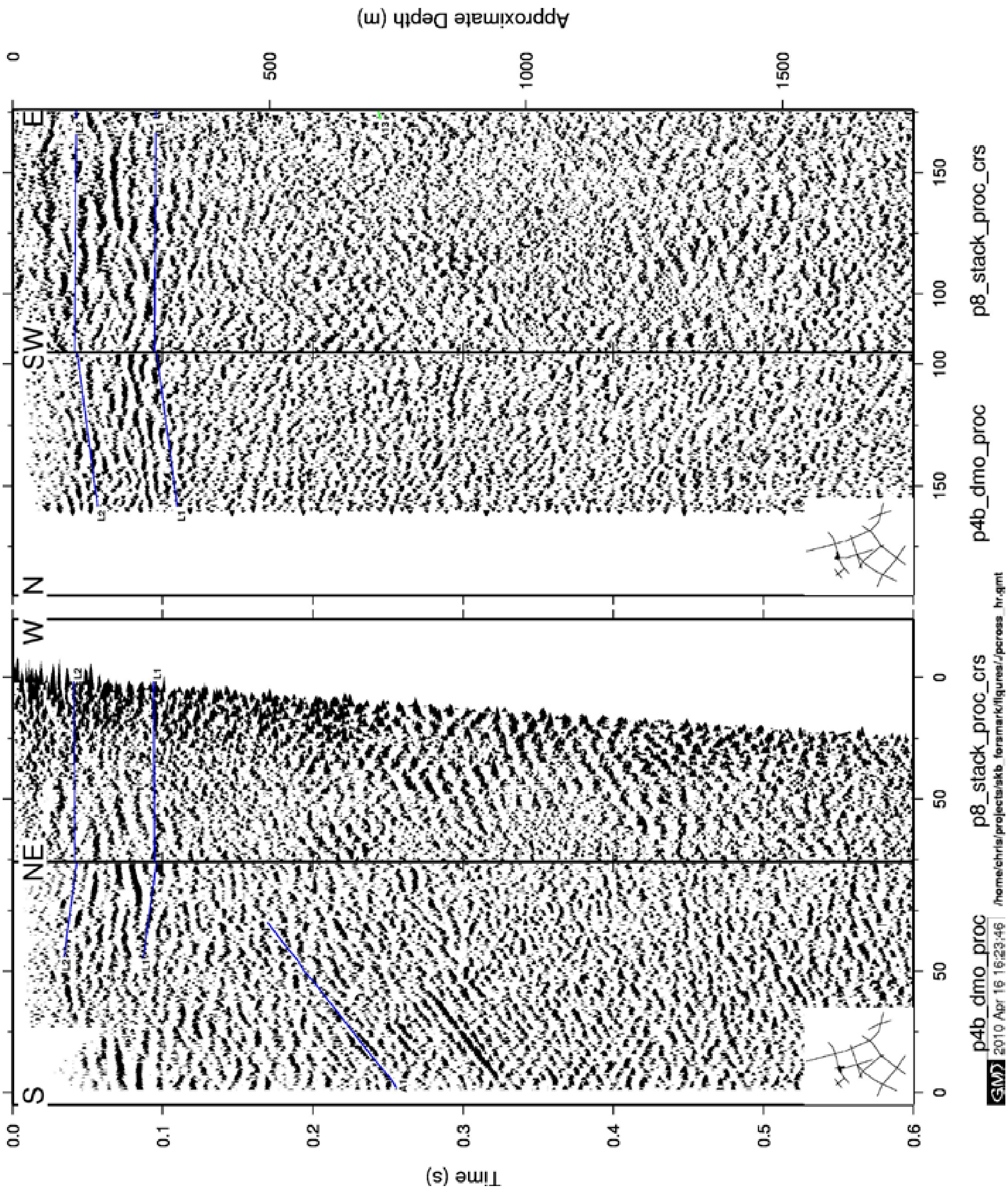

Figure 4-7. *Parts of profiles 4b and 8 viewed from the south (left) and the north (right). Picked reflections are plotted on top of the seismic sections.*

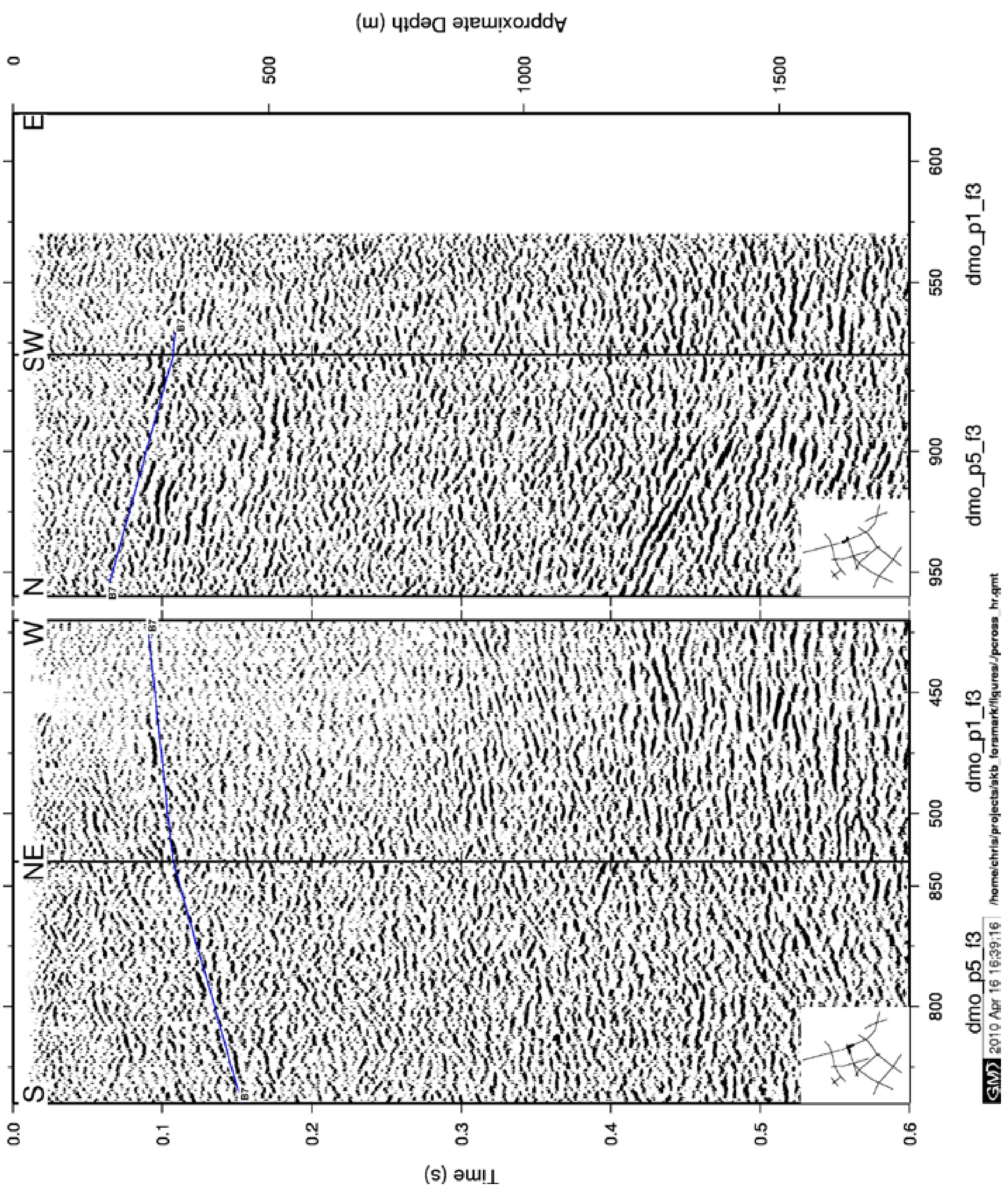

Figure 4-8. Parts of profiles 1 and 5 viewed from the north (left) and the south (right). Picked reflections are plotted on top of the seismic sections.

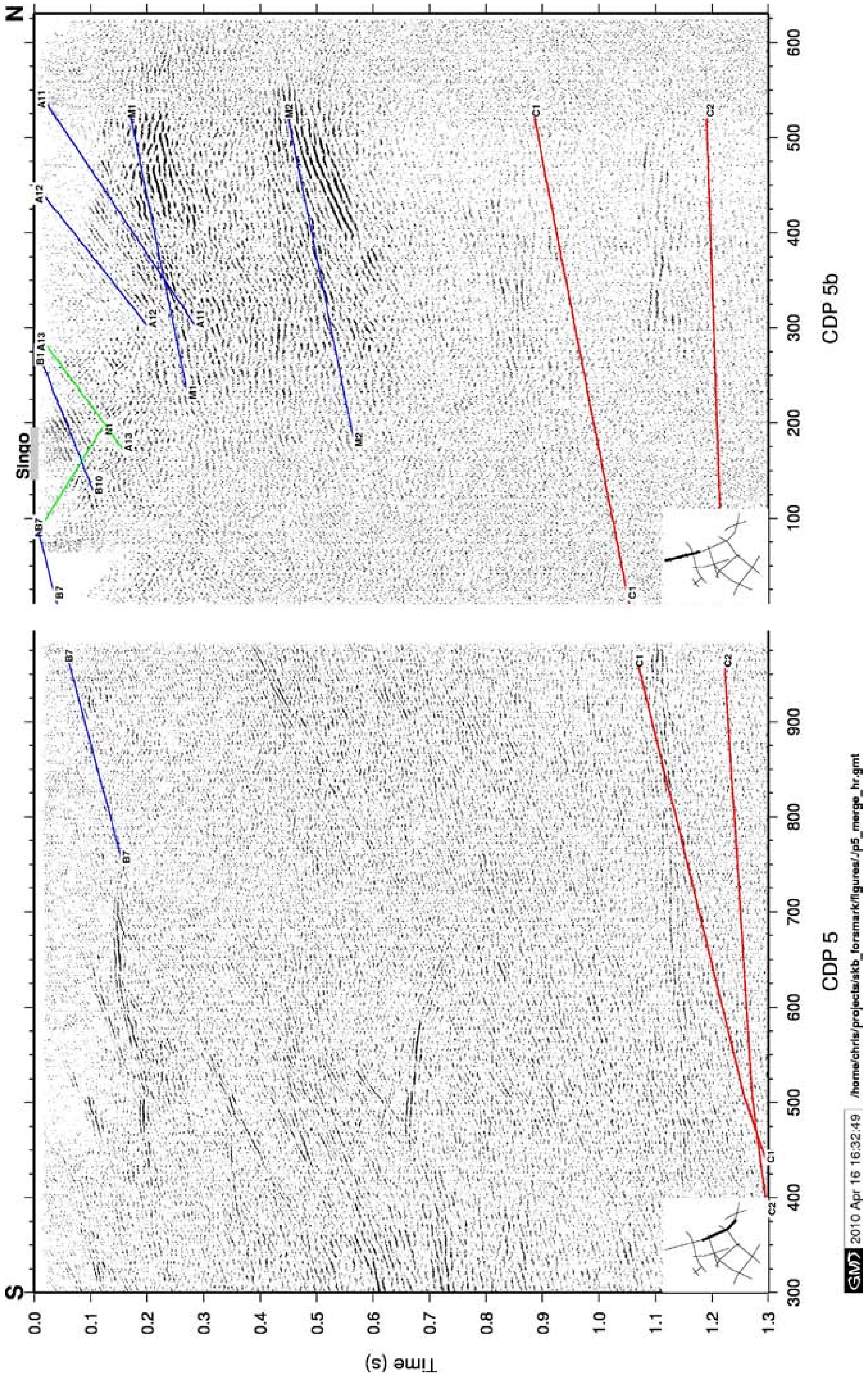

***Figure 4-9.** Merged northern part of profile 5 and profile 5b. Picked reflections are plotted on top of the seismic. Reflection B10 and A11 are extended on to profile 5 to show the general nature of their expected dip on the section. They cannot be clearly identified on this section. Location of sections indicated in lower left corner.*

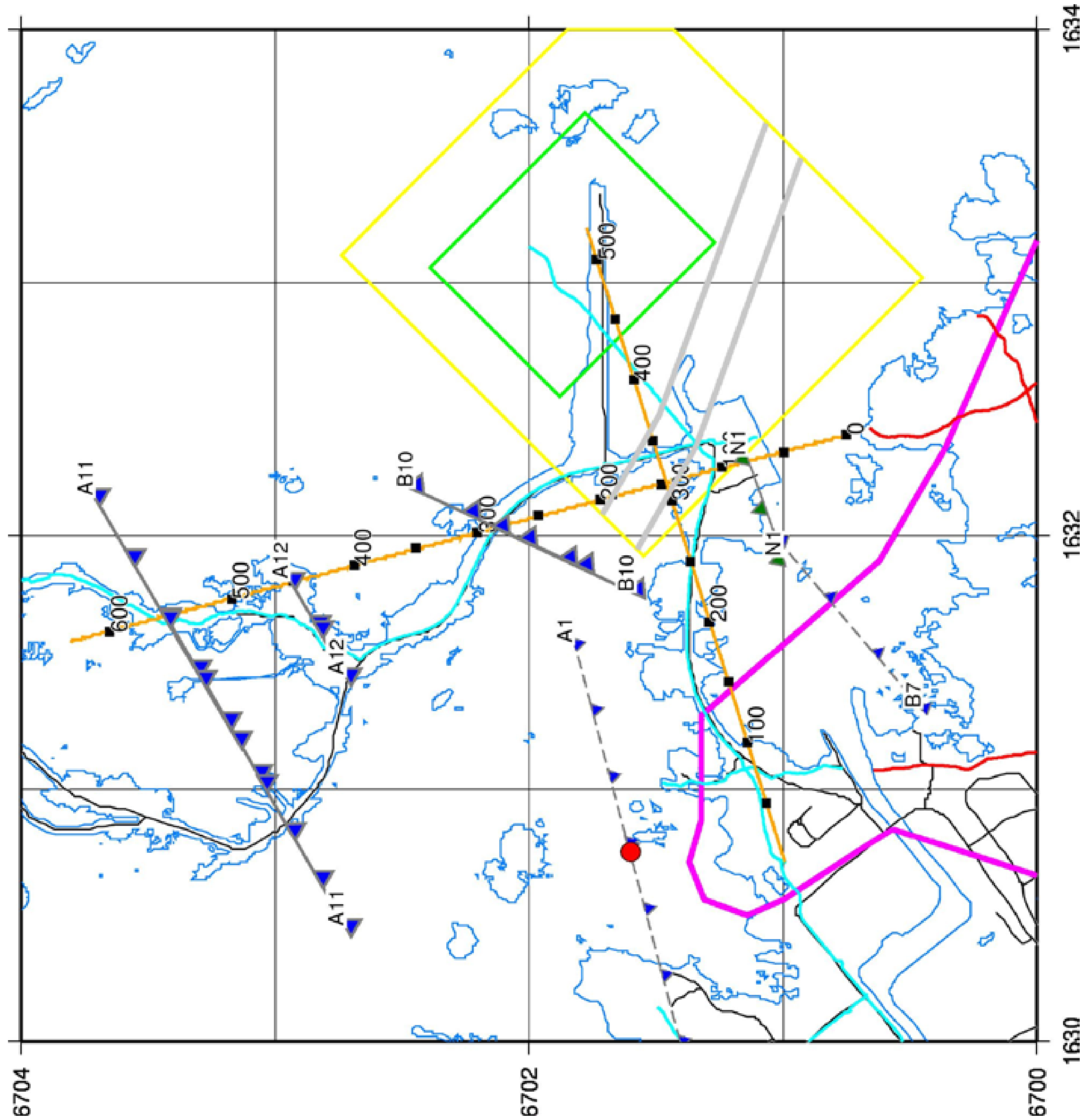

Figure 4-10. Locations of where the reflections discussed in this reports project to the surface. The B10 reflector dips at about 35° below the SFR site. It has an orientation similar to the set B reflections (see Figure 4-6). Dashed lines indicate that a reflection does extend to the surface. Grey lines mark the Singö zone within the area of interest.

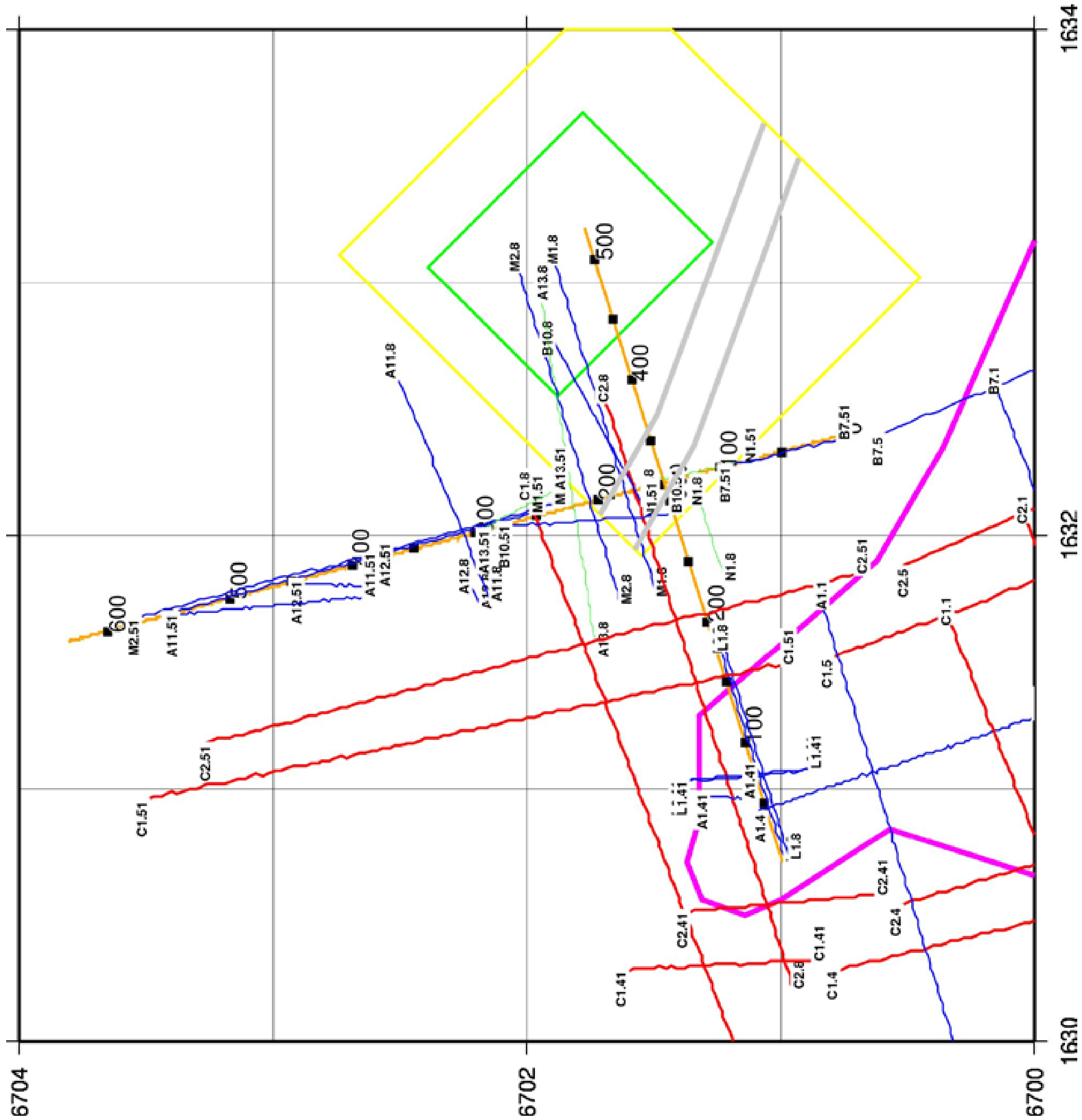

Figure 4-11. *Location of the sub-surface reflection points for the reflections discussed in this document. Points are named by reflector (R) and profile (P) observed on as R.P, for example reflection points for reflector A11 observed on profile 8 are given the code A11.8. The lines show where the reflection points map onto the reflector planes in map view. In 3D the lines will also have a dip. The cartoon in Figure 4-12 shows how the mapping is done. The distance to the reflection points on the reflector is determined by the traveltime to the reflector along the profile. If the orientation of the reflection is known then the reflection points can be mapped without ambiguity. Grey lines mark the Singö deformation zone within the area of interest.*

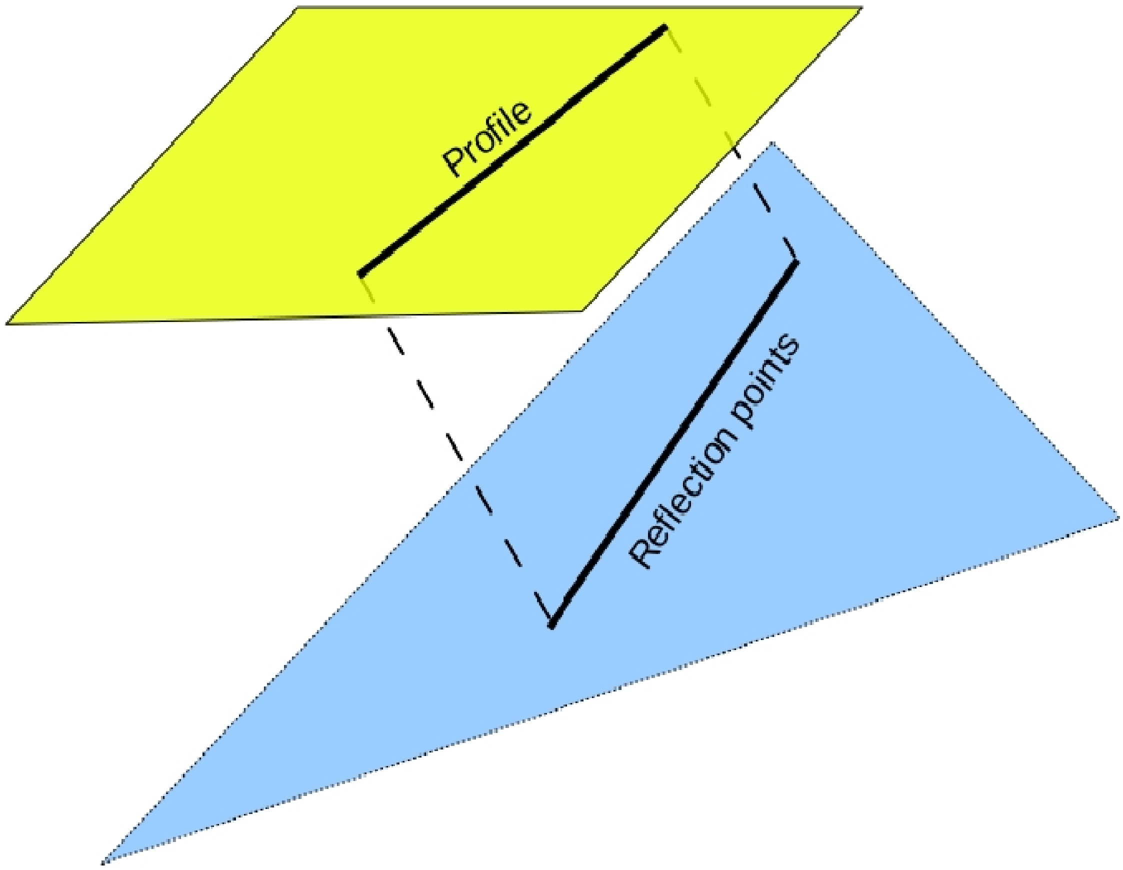

Figure 4-12. Cartoon showing the location of the sub-surface reflection points relative to where reflections are observed on a surface profile. If the orientation of the reflection is known, then actual reflection points will map onto a line on the reflector plane.

5 Potential future work

Apart from acquiring additional seismic data in the SFR area, there are two studies that could be carried out.

1. A modelling/processing study to determine more reliably the dip of B10. Reflections from B10 would be modelled in 3D and the synthetic data processed until a match is obtained between the synthetic and observed stacked sections and shot gathers. At present, the estimated dip of B10 is highly uncertain.
2. Further processing of data from profiles 5b and 8 in 3D in the area where they cross. There is significant midpoint scatter here (Figure 3-1) and it may be possible to obtain a 3D image of the sub-surface in this area. This could also help to better constrain the dip and orientation of reflection B10.

It should be pointed out that the data quality immediately south of the Singö deformation zone are of rather poor quality and that only acquisition of new data using more powerful sources can determine whether or not reflectors in the uppermost 1–2 km pass through the Singö deformation zone at depth.

References

Juhlin C, Palm H, 2005. Reflection seismic studies in the Forsmark area, 2004: Stage 2. SKB R-05-42, Svensk Kärnbränslehantering AB.