Comparison of 2D pre-stack and 3D post-stack migrations from the Matagami mining camp, Québec

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INTRODUCTION

Exploration for new massive sulphide deposits in mature mining camps rely almost exclusively on deep drilling to test prospective stratigraphic contacts since conventional geophysical methods are generally limited to the first few hundred metres of the subsurface (Adam *et al.*, 1997). Thus probing for new mineral deposits to greater and greater depths increases exploration costs dramatically. As a consequence, exploration companies are required to research, develop and apply alternate geophysical prospecting techniques in their search for these deeper mineral prospects (Adam *et al.*, 1997). In response to this need, Noranda Mining and Exploration Ltd. turned to seismic reflection methods as a possible alternate prospecting technique for these deeper deposits through the founding of its Seismic Technology Research Project, which was initiated in 1990.

In 1995 and 1996, Noranda Mining and Exploration Limited carried out both 2D and 3D seismic reflection surveys at their Matagami mining camp situated in north-western Quebec. The primary objective of these surveys was to resolve the seismic characteristics of the newly discovered Bell Allard massive sulphide deposit in relation to the host rocks. An important aside to the 2D reflection survey was, due to the availability of 120 unused recording channels during the acquisition, Noranda deployed 40 3C geophones at 20 metre interval to acquire multi-component seismic data from the Matagami area. Although this data is not examined in this report, the CREWES Project is hoping to process this data in the near future to test whether multi-component data is better suited to seismic exploration in mining environments.

The objective of this study was to better image the volcanic sequence stratigraphy that hosts the Bell Allard volcanogenic massive sulphide ore body which has been estimated at 6 million tonnes. In imaging the Bell Allard deposit, we hoped to compare 2D and 3D migration methods using fast frequency domain codes. Since all seismic velocities in these rocks were generally similar and large (6,000 - 6,500 m/s), we were able to use constant velocity frequency domain migration codes. There is a bad news - good news scenario associated with seismic data acquired for mineral exploration. The bad news is that the seismic reflectors tend to be discontinuous with low signal to noise. The good news is that seismic velocities are often high and constant so constant velocity migration algorithms can be implemented which have much shorter execution times.

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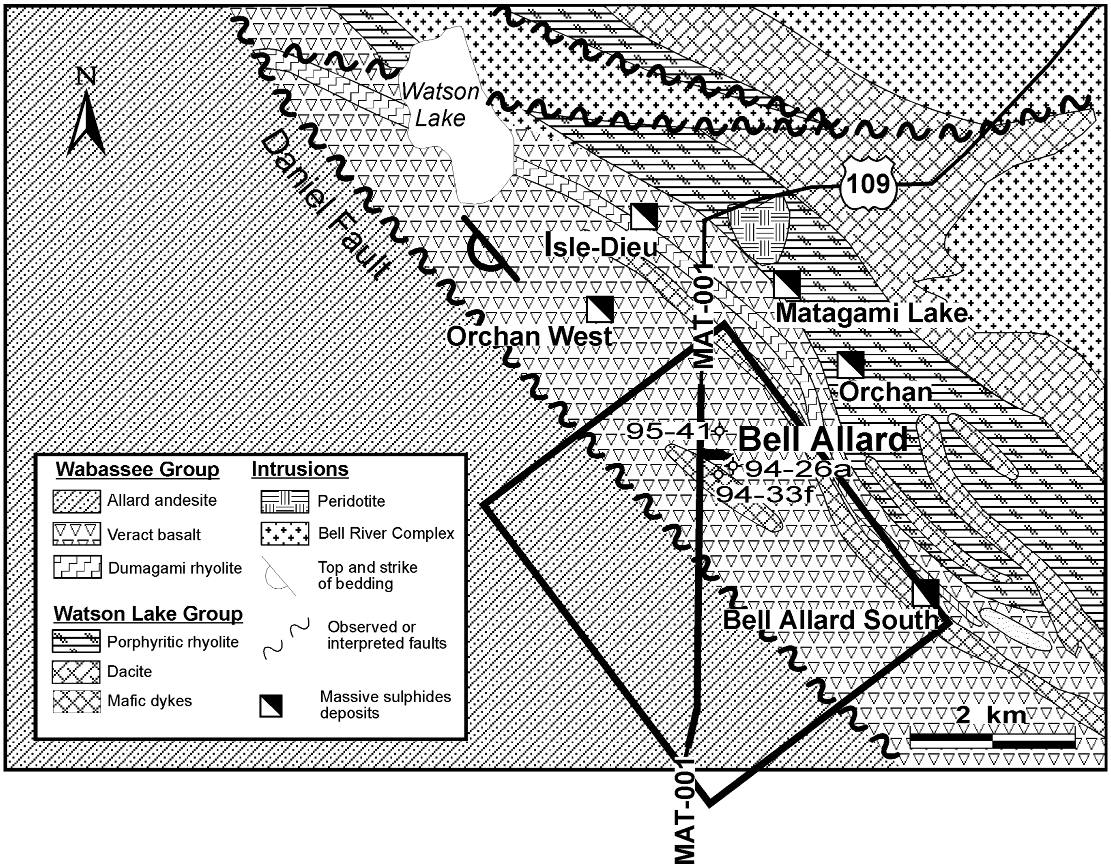

Figure 1. Geological setting of the Matagami mining camp and the Bell Allard deposit (after Adam *et al.*, 1997).

GEOLOGICAL SETTING

The Matagami mining camp is situated in the northwest portion of the Archean Abitibi sub-province. The regional geological setting of this area is illustrated in Figure 1. In this region, the Abitibi sub-province consists of the Harricana-Turgeon belt whose volcano-sedimentary units can be grouped into twelve lithotectonic domains oriented approximately east west. The polymetallic deposits of this structural belt are found exclusively in the two domains comprised of basaltic to rhyolitic associations (Lacroix *et al.*, 1990; Adam *et al.*, 1996). These deposits are exhalative in origin and typical of the primitive Archean Zn-Cu VMS type (Lacroix *et al.*, 1990; Adam *et al.*, 1996).

Also contained within the northern Abitibi Sub-province is the Matagami volcanic complex, which was formed by two major phases of volcanism. The first phase produced rhyolites of the Watson Lake Group while the second phase produced basalts of the Wabasee Group (Beaudry and Gaucher, 1986; Adam *et al.*, 1996). The contact and hiatus between these two lithologic groups is marked regionally by the Key Tuffite, a thin, cherty, sulphidic chemical sediment horizon about 0.6 to 6 metres in thickness. The Key Tuffite was deposited during an intense period of hydrothermal circulation and is the primary exploration target as it hosts a majority of the ore bodies discovered in the camp (Piché *et al.*, 1993; Adam *et al.*, 1996). The Galinée anticline folds these volcanic rocks in an open, gently northwest plunging structure (Sharpe, 1968; Adam *et al.*, 1996). Rocks hosting the ore bodies are located on the southern flank of the anticline and are weakly deformed and dip approximately 45° towards the southwest (Piché *et al.*, 1993; Adam *et al.*, 1996). The Daniel fault is a north-west trending thrust fault, which bounds the southern flank of the Galinée anticline to the south-west and constrains the amount of stratigraphy available with respect to current economic depths (Adam *et al.*, 1996).

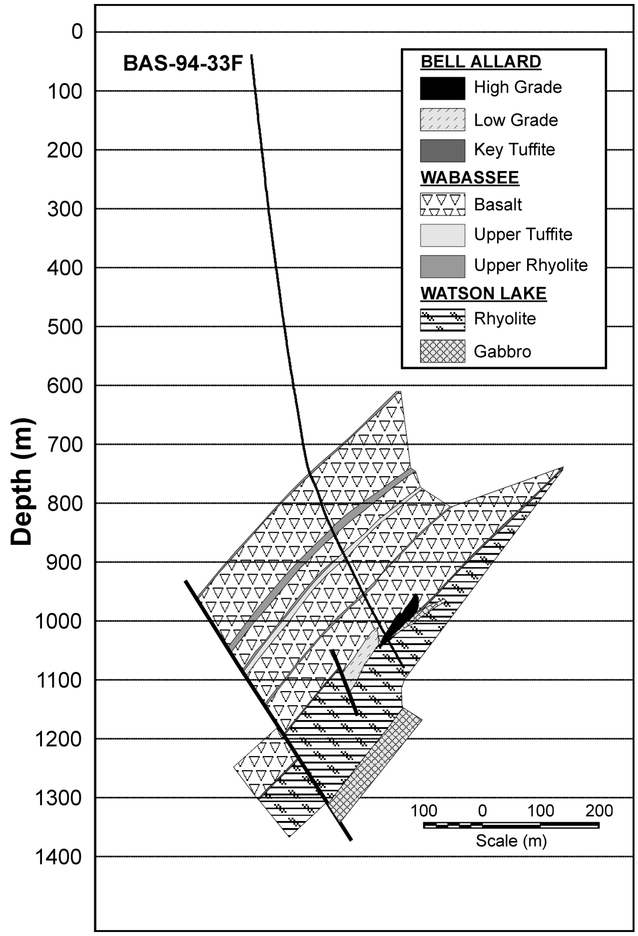

Figure 2. Structural setting of Bell Allard massive sulfide deposit (after Adam *et al*., 1997).

The Bell Allard ore body is a typical Matagami southern flank deposit being located at the Watson–Wabassee interface and characterised by classic hydrothermal alteration (Adam *et al.*, 1996). The structural setting of this deposit is illustrated in Figure 2. The deposit is terminated to the west by the northwest trending Daniel fault. The ore body is approximately 370 metres long in the strike direction and 165 metres wide in the dip direction. Drilling has identified two lenses of sulphide mineralization. The north lens is composed of high grade, Zn rich massive sulphides while the south lens is of lower grade and is comprised, in part, of conduit type mineralization (Adam *et al.*, 1996). Lens thickness averages 30 metres but can reach 60 metres in the south lens. The deposit dips at 50° to 55° towards the south and occupies depths of 900 to1150 metres. Estimated in excess of 6 million tonnes, Bell Allard is the second largest deposit discovered to date on the southern flank.

SEISMIC REFLECTION DATA

Both 2D and 3D seismic data from the Matagami camp were received from Noranda Mining & Exploration for comparison purposes in SEG-Y format. The 2D data consisted of the common source point (CSP) prestack migration of profile MAT-001 that was recorded in November of 1995 along the N-S portion of Route 109. The 3D data consisted of the unmigrated stacked volume that was processed by the Geological Survey of Canada. The 3D seismic data was acquired in April of 1996 and encompassed the previous 2D survey as well as the Bell Allard deposit. The location of the 2D and 3D surveys are shown in Figure 1.

I) Acquisition

For the 2D profile, 120 dynamite shots were recorded by 240 receiver groups located every 20 metres along the mining access road (Route 109). A 40 metre shot interval was used and the receiver groups consisted of a string of nine geophones with 10 Hz natural frequency spread over 18 metres (2.25 metres/phone). The data were recorded using a 3 second record length with 1 ms sampling rate and low and high cut filters of 4 Hz and 240 Hz respectively.

1) Prestack CSP Kirchhoff Migration
- Dips: 85°
- Aperture: 4,835 m
- Geometry: Crooked line algorithm
- Velocities: Semblance analysis
- Illumination: Balanced to theoretical hyperboloid

2) Bandpass Filter
- Type: Zero phase Ormsby
- Frequencies: 10/20-110/135 Hz

3) Trace Equalization
- Type: Multi-gate mean scaling
- Design gates: 0-300, 300-700, 700-1,300 & 1,300-2,400 ms

4) Mute Replacement
- Source: Structural stack

Table 1. Processing sequence for CSP pre-stack migration of profile MAT-001.

The 3D survey was acquired over a 20 km^2 area (4 km $\times$ 5 km) with 956 dynamite shots being recorded by up to 1900 receiver groups located along 19 receiver lines. Receiver groups consisted of a string of 6 geophones with 10 Hz natural frequency closely spaced in a 1 metre linear array. The data were acquired with a 40 metre receiver interval and a 50 metre shot interval. A recording time of 3 seconds was used with a sample rate of 2 ms and an anti-alias filter of 164 Hz was applied during recording. The 3D stacked data volume is ordered on in-line basis, with a CMP bin size of 20 $\times$ 25 metres giving a total of 200 in-lines and 200 cross-lines.

II) Processing

The 2D profile, MAT-001, was pre-stack migrated in June 1996 by Ulterra Geoscience Ltd. using shot records prepared by Spectrum Seismic Ltd. Specific information on the pre-processing applied to these shots is not known but would assume that a processing sequence similar to that applied to the 3D data would have been used. In addition to the data, Noranda also provided a paper copy of the 2D profile. This copy detailed the processing sequence applied to produce the pre-stack migration from the pre-processed shots and this sequence is listed in Table 1.

As previously mentioned, the 3D stacked volume provided by Noranda for migration purposes was processed by the Geological Survey of Canada. The processing sequence used to produce the 3D stacked data volume is listed in Table 2.

III) Migrations of the 3D Data Volume

The Matagami data volume is characterised by a homogeneous velocity field with little lateral velocity variation (Adam *et al*., 1997). In addition, sonic logs acquired from boreholes 95-41, 94-33f and 94-26a drilled on the Bell Allard deposit exhibited only slight variation in P-wave velocity. Velocities in these three boreholes averaged between 6,000 and 6,500 m/s over the intervals logged. Based on this information, it was decided to migrate this data at a constant velocity of 6,250 m/s using the Gazdag phase-shift algorithm.

The Gazdag phase-shift implementation is a frequency-wavenumber migration that produces both time and depth migrated sections. The phase-shift method can only handle vertically varying velocities (i.e. no lateral velocity variation). The method involves a coordinate transformation from frequency (the transform variable associated with the input time axis) to vertical wavenumber (the transform variable associated with the output depth axis), while keeping the horizontal wavenumber unchanged (Yilmaz, 1987).

1) Shot Editing
2) True Amplitude Recovery
3) Spiking Deconvolution
- Operator Length: 100 ms

4) Bandpass Filter
- Frequencies: 35-130 Hz

5) Energy Balancing
- Window Length: 3 s

6) First Break Mutes
- 30 ms below the first break picks

7) Refraction Static Corrections
- Datum: 300 m ASL
- Replacement Velocity: 6,000 m/s

8) Residual Static Corrections
- Maximum power autostatics

9) NMO Correction
- Corrected at 6,100 m/s (constant velocity)
- 50% stretch mute

10) DMO Stack
11) Bandpass Filter
- Frequencies: 35-130 Hz

12) FX Deconvolution
- Trace Operator: 5×5 traces
- Window Length: 1,500 ms

Table 2. Processing sequence for stacked Matagami 3D volume.

Fourier transform methods in migration were introduced by Stolt (1978). Gazdag (1978) published his work on the phase-shift method, which led to a further understanding of wave field extrapolation in the transform domain. Frequency-wavenumber (*f*-k) migration is not easily explained from a physical view point and the reader is referred to the work of Chun and Jacewitz (1981) to provide better insight into the principles of *f*-k migration.

Figure 3 presents a flowchart of the phase shift method. Downward continuation involves a pure phase-shifting operation $\exp(-ik_z z)$ and, at each depth step, z, a new extrapolation operator with the velocity defined for that z value is computed (Yilmaz, 1987). As for any other migration, the imaging principle (t=0) needs to be invoked at each extrapolation step to obtain the migrated section. The imaging principle refers to the fact that the wavefront shape in space at t=0 corresponds to the reflector shape for the wave field generated by an exploding reflector (Yilmaz, 1987). The imaging condition t=0 is met by summing over all frequency components of the extrapolated wave field at each depth step. The procedure of downward continuation and imaging is repeated until the entire wave field is migrated.

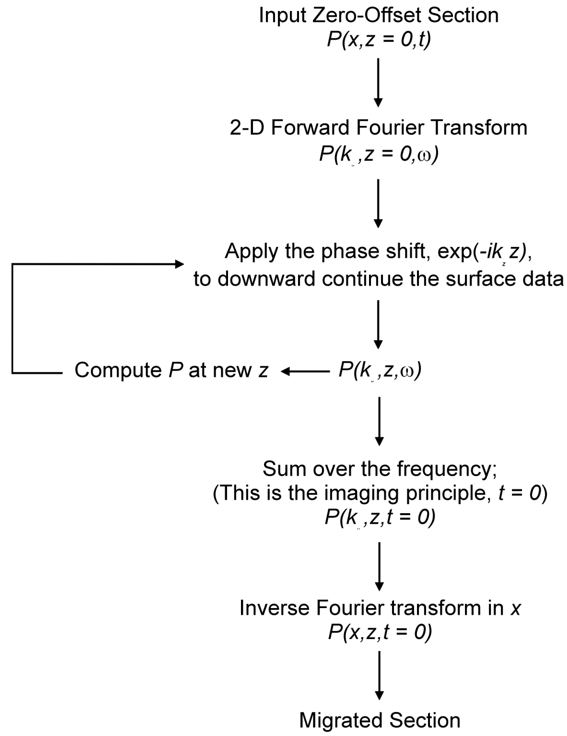

Figure 3. Flowchart for the Gazdag phase-shift method of migration (after Yilmaz, 1987).

In order to reduce the edge effects inherent with the migration process, a simple linear data taper was applied to the stacked volume prior to migration. This taper consisted of applying a scalar between 0 and 1 to the all amplitudes of the first and last 20 traces of each in-line and cross-line contained within the data volume. As a consequence, the 20 × 20 trace areas forming the four corners of the data volume had these scalars applied twice (i.e. doubly tapered) since the tapering process was applied in an in-line and cross-lines basis (or visa versa) via an in-line or cross-line sort.

Both 2D×2D and 3D migrations were performed on the tapered 3D stacked volume using the *ITA/Insight* post-stack seismic processing software. Also, it should be noted that only the first second of the data volume was migrated. The particular *Insight* processors used to carry out the 2D×2D and 3D migrations was *psmig_fast* and *psmig_3D* respectively. For the 2D×2D migration, each of the individual in-lines contained within the data volume were first migrated. This intermediate result was then re-sorted to cross-line domain and the migration repeated for each of the individual cross-lines. The final migrated result was then re-sorted back to the in-line domain returning the data volume to its original sort order. This method of applying 2D post-stack processes to 3D data volumes on an in-line and cross-line basis can be easily automated using the *Insight* software by setting up a special pre-stack and post-stack job flow which complement each other when executed.

IV) Data Visualisation

With the migrations completed, the pre-stack migration of the 2D profile, MAT-001, and both the 2D×2D and 3D migrations were input to the *Photon SeisX* interpretative software package for visualisation purposes. This allowed interactive 3D viewing of the migrated volumes as well as extraction of arbitrary 2D profiles from these two volumes along the original MAT-001 profile for visual comparison purposes.

Since the original 2D MAT-001 profile acquired along the mining access road was recorded at ½ the receiver interval of the subsequent 3D survey (20 m vs. 40 m), the final stacked section inherently had a greater number of traces than the arbitrary 2D sections extracted from the migrated 3D volumes. Thus, in order to properly compare the 2D pre-stack migration with the 2D×2D and 3D post-stack migrations, it was necessary to decimate every 3rd trace from pre-stack migration. This ensured a similar visual character for all three migrated sections as their total number of traces was made approximately equal.

DISCUSSION

A comparison of the data from the 2D survey along the line MAT-001 with the 3D data volumes generally showed that the signal quality of the 2D survey was superior to the 3D survey. This was due to much better receiver coupling for the 2D survey acquired along the road as compared to the 3D survey which had the majority of its receivers planted in peat bog. Superior quality of signals made the pre-stack migration of the 2D profile (Figure 4) as useful the migrations of the 3D data volume. In migrating the 3D volume, a comparison of 2D×2D migrations (Figure 5) with the 3D migration (Figure 6) showed that the 3D migration was superior.

CONCLUSIONS

A comparison of the 2D data with the 3D data indicates the importance of geophone coupling. The superior receiver coupling with the 2D survey as compared to the 3D survey meant that the 2D migration were often as useful as the migrations of the noisy 3D data set. The fact that seismic velocity is consistently high meant that fast frequency domain migration methods, such as phase-shift migration, could be effectively used. Fortunately, there was useful seismic reflection energy from the area of the ore body. The best images obtained this far were from the 2D pre-stack migration and the 3D phase-shift post-stack migration.

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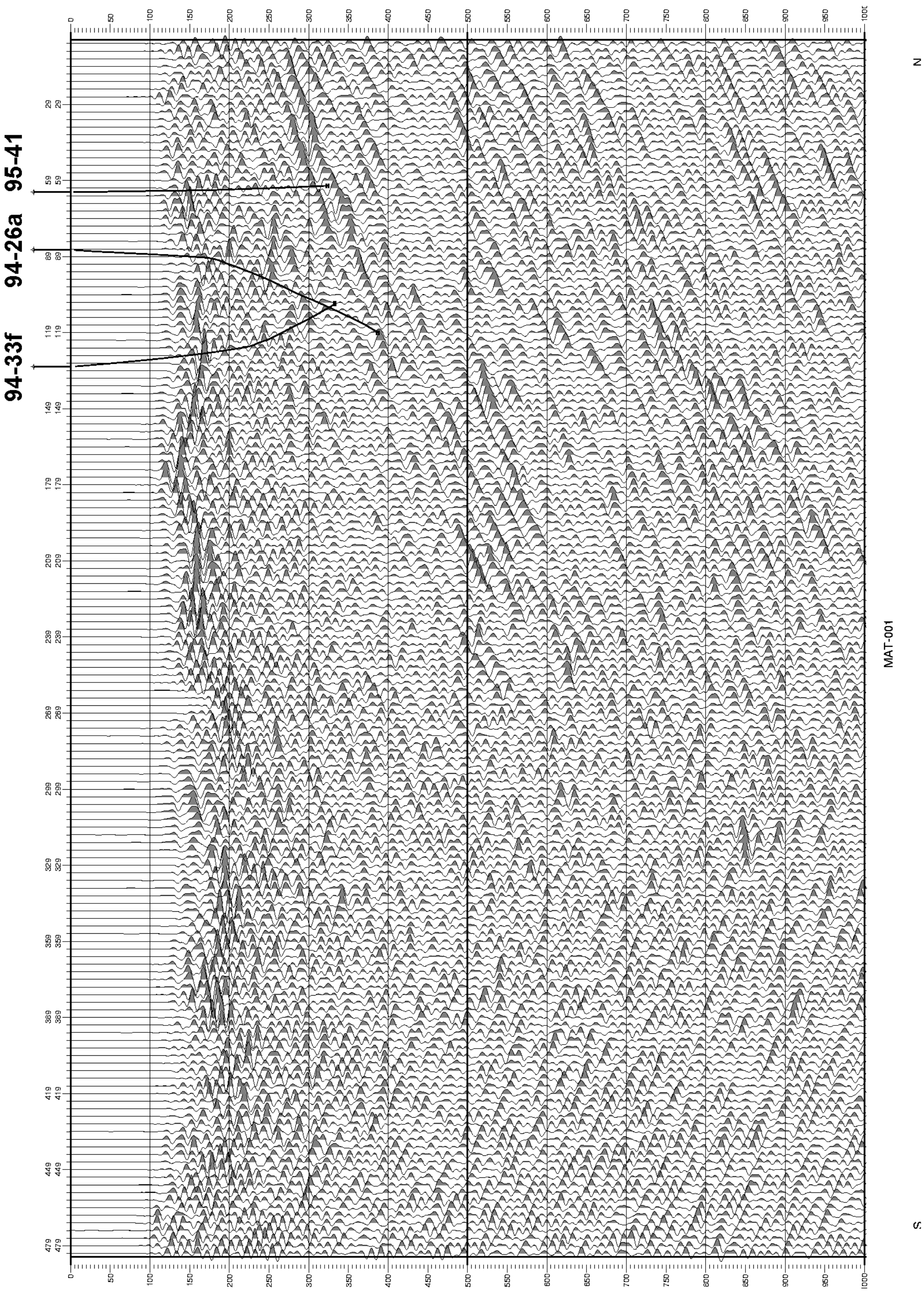

Figure 4. The pre-stack migration of the 2D profile MAT-001. The deviations for the boreholes illustrated in Figure 1 are indicated by the solid black lines.

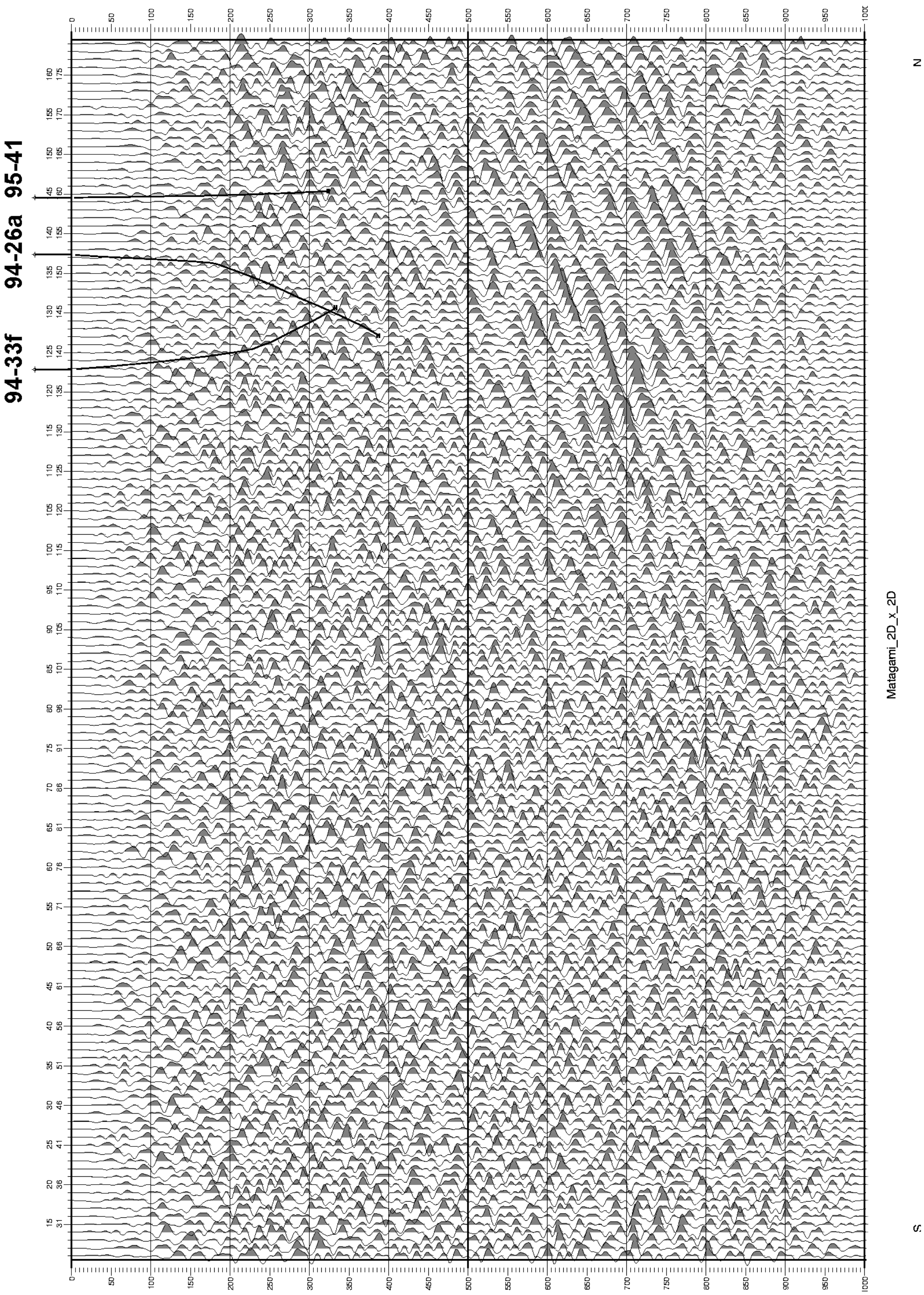

Figure 5. The 2D×2D post-stack migration of the 3D data volume generally did not show reflections which were coherent as compared to the 3D post-stack migration. The deviations for the boreholes illustrated in Figure 1 are indicated by the solid black lines.

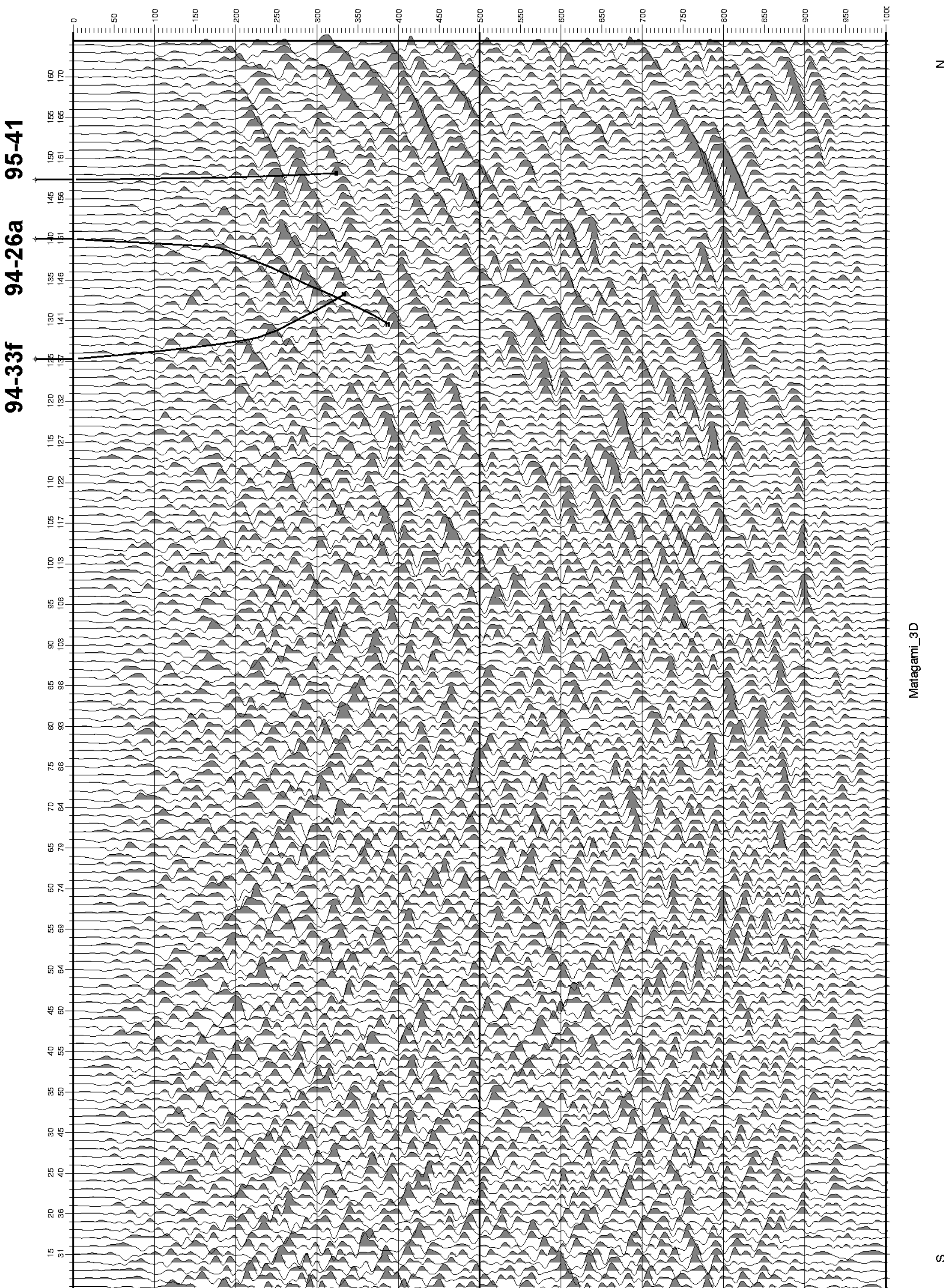

Figure 6. 3D post-stack migration of the 3D data volume. The deviations for the boreholes illustrated in Figure 1 are indicated by the solid black lines.

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