Seismic and Tomographic Imaging of Bedrock Topography for Newmont Mining in Nevada

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1 Survey Overview

The objective of this experiment is to delineate the bedrock topography by 2D tomographic and reflection seismic imaging. The field is Buffalo Valley Mine in the state of Nevada (county of Lander), located at latitude - longitude coordinates of N 40.60463 and W -117.24955.

The survey conducted along the road to Buffalo Valley Mine (Figure 1, 2 and 3). The seismic line length is about 2500 m, which starts at 3.5 mile west and ends at 1.9
mile west from the mine. The data are collected in 3 parts (line A-C) over the area (Figure 4) and each part has 120 of channels at 5 m interval. The seismic source of this survey is an impactor (Figure 5). Source intervals are 20 m for line A and B, 40 m for line C. The each source line has a different length. We made 102, 70 and 20 shots respectively. The data acquisition details are summarized in Appendix B.

There are two wells along the line (Figure 6). The #125 well is at channel 48 of line C, which is at 2000 m west from the survey origin, and the #125 well is at 150 m off from west end of the line. The length between the wells is 677 m. Bedrock is expected to be at depth of several hundred meters from ground surface. It appears at 329 ft (97 m) in depth at the #125 and at 680 ft (200 m) at the #124 well.
Figure 2: Road that the seismic experiment was conducted.

Figure 3: Seismic recording unit used in this experiment.
Figure 4: (a) Source location map and source and receiver elevation of (b) Line A, (c) Line B, and (d) Line C.

Figure 5: Seismic source used in this experiment.
2 Collected Data Overview

Figure 7 shows common shot gathers (CSGs) shot at both ends of the line A. A variation in the apparent refraction velocity is shown in the figure. Figure 8 and 9 are the same figures from Line B and C. The minimum and the maximum dominant apparent velocities are about 600 and 3500 m/s respectively. An anomalous velocity, which has over 6000 m/s, is also seen in line B. Figure 10 is a zoomed-up section around first breaks. The quarter period ($T_0/4$) is about 0.008 sec, which is about 30Hz in frequency. A variation of apparent wavelength is 20 - 120 m.
Figure 7: CSGs at the both ends of Line A. Velocities of apparent refraction waves are labeled in the figure.

Figure 8: Same as previous picture except from Line B.
Figure 9: Same as previous picture except from Line C.

Figure 10: Closeup around first breaks of a CSG. The quarter period ($T_0/4$) is about 0.008 sec.
3 Tomographic Imaging

Traveltime tomography is an inversion for velocity model and is processed by first break picking followed by traveltime inversion.

3.1 First Arrival Pick

Data for traveltime tomography are first arrival times. The traveltimes are picked on CSGs with PROMAX, which is seismic data processing software. The quality of data is that the first breaks are easy to pick from traces within an offset of 350 m. Long-offset traces are noisy but the 1st through are identifiable. First break picking is conducted in the following way: first I picked only reliable first breaks on the raw CSGs and then I picked in the noisy part on the bandpass filtered CSGs.

Figure 11 and 12 show examples of picked traveltime data superposed on raw and filtered CSGs. Since noises on the long-offset traces are eliminated by bandpass filter, reliable traveltimes can be picked (Figure 12 window 1). However, I never used filtered CSG for near-offset traveltime picks because side-lobes generated by the filter hide the first breaks on the near-offset traces (Figure 12 window 2).

About 23,000 of traveltimes are obtained from 192 shots, which have 115 indepen-
dent source locations and 360 receiver locations. The number of data in each source location is shown in Figure 13. The data quality is controlled by reciprocal test in the following way:

- If $t_{ij}$ and $t_{ji}$, where $t$ denotes traveltime and $i, j$ represent source and receiver location indexes, have a larger difference than 0.004 sec, the both traveltimes are removed because $t_{ij}$ and $t_{ji}$ should be equal from the reciprocity theory.

- Traveltimes for missing sources (or missing receivers) are copied reciprocally if receivers (or sources) exist at the same locations. Figure 14 and 15 show traveltime matrices before/after reciprocity check.

After the quality check, 1469 bad picks, which has an error of 4 msec, are eliminated.

### 3.2 Traveltime Inversion

Inversion is conducted with **PC_GUI**, which is developed by the Utah Tomography and Modeling/Migration (UTAM) consortium. The estimated velocity field and travel paths after 40 iterations under 8 smoothing schedules are shown in Figure 16. The final smoothing operator size is 10 grids (50 m) in X × 5 grids (25 m) in Z. The convergence curve (Figure 17) shows a small residual that is less than 0.008 sec, which is $T_0/4$, after 40 iterations.
Figure 11: Example of Raw CSG. First break picks are overlaid.

Figure 12: Example of Bandpass filtered CSG. A frequency band of 5-10-50-100 Hz is passed. The noise in the window 1 is attenuated. However the side-lobes increases in the window 2.
Figure 13: Number of picks over the source locations.

Figure 14: Traveltime matrix before reciprocity test.
Figure 15: Traveltime matrix after reciprocity test.

Figure 16: Tomography results: (a) tomographic image representing P-wave velocity profile, (b) ray path image representing number of rays visit to the cell.
4 Seismic Imaging

Reflection seismic data processing is conducted to delineate the bedrock topography. One of the challenges for this processing is noise suppression. Most of reflection waves from the bedrock are masked by source generated coherent noise, such as dispersing surface waves, an air wave, and ringing refractions. Since the amplitudes of these waves are stronger than those of reflection waves, coherent noise suppression and use of long-offset trace are important for this reflection seismic imaging.

Figure 18 explains the noise suppression flow. Noise elimination is conducted with bad trace editing followed by the suppression of linear noises having velocities of 340, 500, and 800 m/s from the raw CSGs. Figure 18 (b) represents after the process-
ing with PROMAX functions called the surface wave attenuation (SWA) and the air
burst attenuation. These filter enhanced some reflections in deeper pert. However, it
is still noisy in shallower part and reflections are not obvious.

Figure 18 (c) shows after FK filter and amplitude recovery. Near offset is still
noisy and reflection waves are not clearly visible. However, on the long-offset traces,
some obvious events exist. These events are wide angle reflection (or might be refrac-
tions) having a larger amplitude. However, they are usually muted in conventional
processing in several reasons. One of the reasons is that normal moveout (NMO)
creates low frequency suspicious events from the stretched long-offset events, which
does not represent actual reflectivity model. However, since our objective is to de-
lineate bedrock topography, to know the depths of refractors is more important than
to know reflectivity model. Figure 19 shows higher order NMOed CMP gathers with
a stretch factor of 30% (conventional case) and 350% (special case) that I employed,
followed by a bandpass filter.

Figure 20 and 21 compare stacked section with stretch factor of 30% and 350% re-
spectively, followed by a predictive deconvolution. Bedrock topography is not clearer
in Figure 20 than that in Figure 21. Figure 22 shows offset-limited stack, were an
absolute offset range of 200 - 600 m is used. Since an offset range that includes high
amplitude bedrock events are selected, the bedrock image is more visible in the Fig-
Figure 18: Each step of liner noise suppression flow. (a) raw CSG, (b) the surface wave attenuation (SWA) and the air burst attenuation, and (c) FK filter and amplitude recovery.

Figure 22. However, there is a data gap around the joint of Line B and C because no long-offset trace is included in these CMP gathers.

5 Interpretation

Figure 23 shows a comparison between the tomographic image and the depth converted seismic image. Figure 24 represents a composite section that the seismic image overlaid on the tomographic image. The seismic image agrees with the tomographic image. An interpretation of tomographic and seismic image is shown in Figure 25. The well data overlaied on the section also agree with tomographic and
Figure 19: CMP gather after (a) no NMO, (b) NMO with a stretch factor of 30 % and (c) NMO with a stretch factor of 350 %.

Figure 20: Stacked section with a stretch factor of 30 %.

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Figure 21: Stacked section with a stretch factor of 350 %.

Figure 22: Offset limited Stacked with an offset range of 200-600 m.
Seismic images. The followings are the interpretation summary:

- Several extensional faults can be interpreted on the bedrock in both images. An obvious fault dropped westward exists around the channel 90 of Line A. The thrown is about 460 ft (140m).

- The bedrock marker gap between the wells is explained by a fault, which has a thrown of 360 ft (100m). It is located beneath the channel 120 of Line C.

- Two topographic raises are estimated in the horst block:
  - from channel 96 of Line A to channel 30 of Line B,
  - from channel 38 to channel 100 of Line B.

- Well #125 drilled at the west side raise.

- Well #124 drilled at the hanging wall block.

6 Conclusion

Seismic and tomographic imaging of bedrock are conducted for Newmont mining in Nevada. The both results clearly show a faulted bedrock topography 50-250 m below surface.
Figure 23: Comparison between the tomographic image and the seismic image. The seismic section is depth-converted from the time section shown in Figure 22.

Figure 24: Composite section that the seismic image overlaid on the tomographic image.
Figure 25: Interpretation of the composite section in Figure 24.

A Appendix: Data Acquisition Summary

A.1 Receiver Lines

- Receiver line started at the western side and ended at eastern side of the study area.

- We used tree lines, they are arranged back to back (i.e. offset between last geophone of first part and first geophone in second part = offset between last geophone of second part and first geophone in third part = geophone interval = 5m) near-offset traces (Figure 12 window 2).

- Each part (part A, B, and C) is conducted using 120 channel

- Geophone interval is 5 m.
A.2 Shot line

- For part A
  - We made 102 CSGs,
  - 1st shot is at 560 m west of 1st geophone,
  - shot interval was 20 m,
  - CSG # 28 was the last shot (20 m) before the 1st geophone,
  - CSG # 29 is located at the 1st geophone
  - CSG # 58 is located at geophone # 117
  - CSG # 59 is located 5 m east of geophone 120
  - We continued shooting every 20 m till CSG # 102

- For part B
  - We made 70 CSGs, with shot interval = 20 m
  - We started shooting 680 m west of the 1st geophone of this part
  - CSGs 1 - 34 are all west of 1st geophone with shot interval = 20 m
  - CSG # 35 is located at 1st geophone of this part
  - CSG # 64 is located at geophone # 117
  - CSG # 65 is located 5 meters east of geophone 120
  - We continued shooting every 20 m till CSG # 70
• For part C

  – We made 20 CSGs, with shot interval = 40 m
  
  – CSG # 1 is at geophone # 1
  
  – CSG # 15 is geophone # 113
  
  – CSG # 16 is 5 m east of geophone # 120
  
  – We continued shooting every 40 m till CSG # 20

The data are collected by Serif Hanafy, Shendong Liu, Ge Zhan, Paul Gettings, and Derrick.

B Appendix: Format of coord.temp

The file coord.temp is required for the PC_GUI. The file is expected to be in the m folder, which is in the program home directory. The following explains the file format:

62 4.82000 352.970 348.150 700.000 ns,xmin,xmax,xmax-xmin,zmin

1310.00 610.000 62 zmax,zmax-zmin,nrmax

1 4.82000 700.000 33 is,xs(is),zs(is),nr(is)

.
62  21.2700  1310.00  45    is,xs(is),zs(is),nr(is)
344.704  770.000  3.05126E-02  1    xr(1,ir),zr(1,ir),t(1,ir),1

344.907  1090.00  5.01151E-02  1    xr(1,ir),zr(1,ir),t(1,ir),1
344.480  700.000  2.92766E-02  1    xr(2,ir),zr(2,ir),t(2,ir),1

ns--------total number of source.
xmin------minimum X coordinate.
xmax------maximum X coordinate.
xmax-xmin--the model length in x direction.
zmin------minimum Z coordinates.
zmax------maximum Z coordinates.
zmax-zmin--the model length in z direction.
nrmax------maximum number of receivers for a single source.
is--------source number.
xs(is)-----source coordinates in x direction.
zs(is)-----source coordinates in z direction.
nr(is)-----receiver number for this source.
xr(is,ir)--x coordinate for receiver ir of source is.
zr(is,ir)--z coordinate for receiver ir of source is.
t(is,ir)---traveltime for the receiver ir of source is.
1---wt?----No information.

Note: the receiver positions and traveltimes should be in the order of the
source number, i.e. all the receiver information of the first source followed
by all the receiver information of the second source, and so on...

References:

Drygulch Refraction Traveltime Tomography Lab:
http://utam2.geophys.utah.edu/ebooks/yuegg522/experiment/drygulch/index.html

get_coord_temp.m:
http://utam2.geophys.utah.edu/ebooks/yuegg522/experiment/drygulch/get_coord_temp.m

README FILE FOR REFRA-2D:
http://utam2.geophys.utah.edu/ebooks/yuegg522/experiment/drygulch/refra-2d.txt