CREWES channel model: Description, acquisition, interpretation and data release

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ABSTRACT

The CREWES Channel Model was created in 2008 as a 3D volume of P and S wave velocities plus density. This 3D model represents a 120m channel interval with gradient overburdens derived from the Blackfoot field in Southern Alberta, Canada. The channel was modelled after the present day Bow River and so represents no specific buried channel, but is thought to be typical. Recently this model was used to create a synthetic seismic data using a fully elastic finite difference software package. The data set contains over 1525 shot records with 3C receivers placed on a 10m by 10m grid for each shot. A 2-D line was then selected from the data as an example and to identify its processing flow. This flow includes a bulk time shift of 0.1 seconds, a mute to remove the first breaks, and a F-K filter to remove the ground roll. A pre-stack Kirchhoff migration was then applied to the data creating a section showing undulations in the reflections indicating variations in the channel interval. This data set is very large and is available to sponsors by request.

MODEL DESCRIPTION

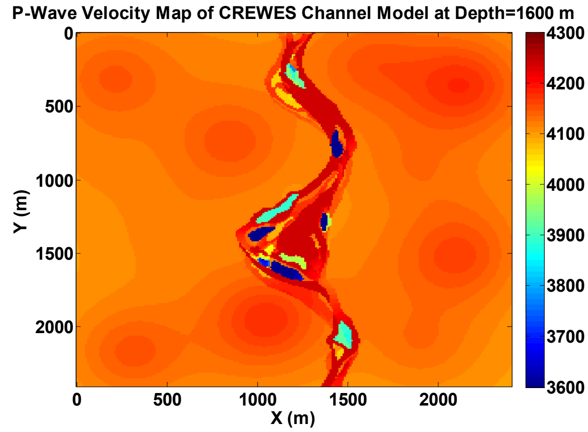

FIG 1a. P-Wave velocity map for 1600m depth

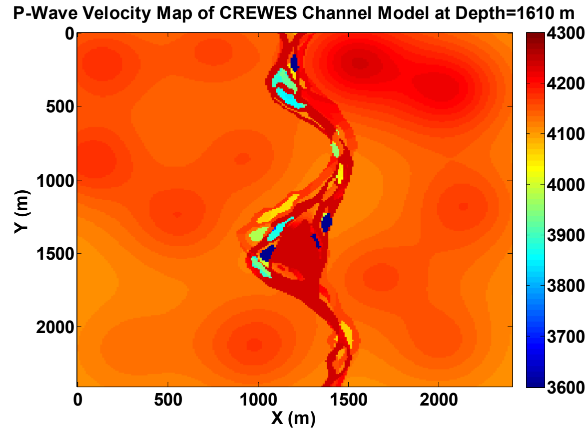

FIG 1b. P-Wave velocity map for 1610m depth

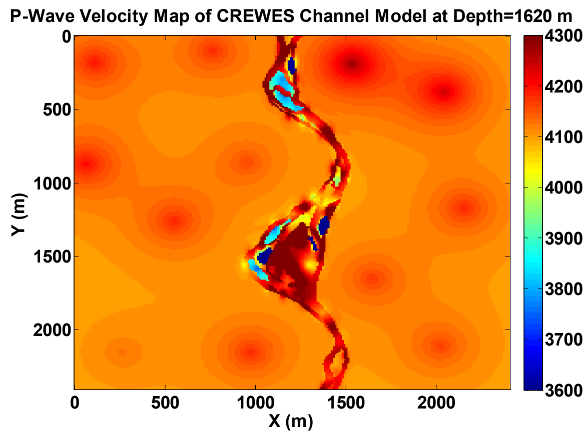

FIG 1c. P-Wave velocity map for 1620m depth

Margrave et al. (2008) created a 3D isotropic elastic model of a channel. This velocity model consisted of 5 digitized maps which were based on the Bow river in Calgary, Alberta. These maps were created with 10 meter spacing in both the x and y direction creating a 2.4 km by 2.4 km area. The channel runs parallel to the y axis, with the x axis going across the channel. The digitized maps were then run through a process called krigging, a geostatistical method of interpolation commonly used in geologic and geophysical situations. This method was used to not only smooth the digitized maps but was also used to create 8 more maps, two maps between each of the 5 original digitized maps to create a total of 13. Smoothing and interpolating results of the krigging method can really be seen in the Figure 1b, where depth is equal to 1610. This map shows mostly the channel from 1620m, Figure 1c, but is underprinted by the channel at 1600m, Figure 1a. Krigging in this case also had an undesired affect were it created round artifacts which can be seen in the krigged maps.

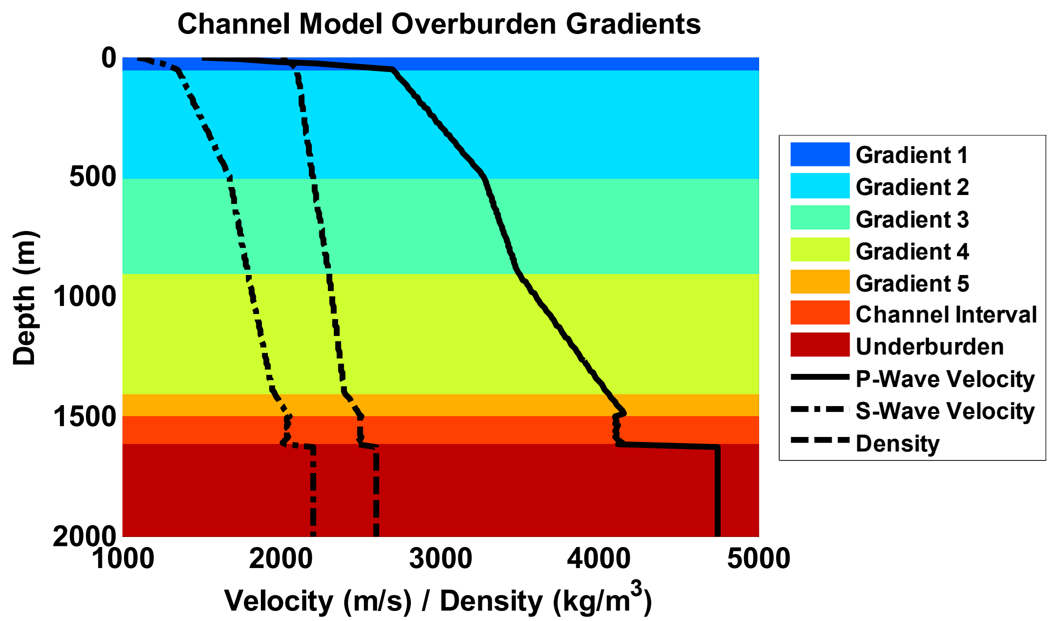

FIG 2. This figure shows the gradient overburden profile, based on the Blackfoot Field area in Alberta.

TABLE 1. Gradients for Overburden, Vp starts at 1500 m/s, Vs starts at 1100 m/s, Density starts at 2000 kg/m^3.

Unit	Depth Interval (m)	Vp Gradient (m/s)/m	Vs Gradient (m/s)/m	Density Gradient (kg/m^3)/m
Gradient 1	0 - 50	0.04167	0.2000	0.5000
Gradient 2	60 - 500	0.7826	1.3846	4.5000
Gradient 3	510 - 900	1.8605	3.4783	4.0000
Gradient 4	910 - 1400	0.8929	3.1250	5.0000
Gradient 5	1410 - 1490	0.8333	1.0204	1.0000
Channel Interval	1500 - 1620	0.4556	-0.4776	1.3418
Underburden	1630 - 2000	0.0000	0.0000	0.0000

To create a three dimensional velocity model the krigged maps were then stacked on top of one another with a spacing of 10 meters to create a channel interval of 120 meters. The top of the channel model was placed at 1500 meters in the velocity model. Overburden gradients were then applied on top of the channel interval, Figure 2. The gradients were derived from the Blackfoot field in Southern Alberta, Canada. These gradient values can be seen in Table 1. The first gradient for the P-wave velocity is fairly steep, in order to model a fairly slow near surface. A few sections of the model can be seen in Figure 3, noticing the varying velocity values between 1500-1620 meters.

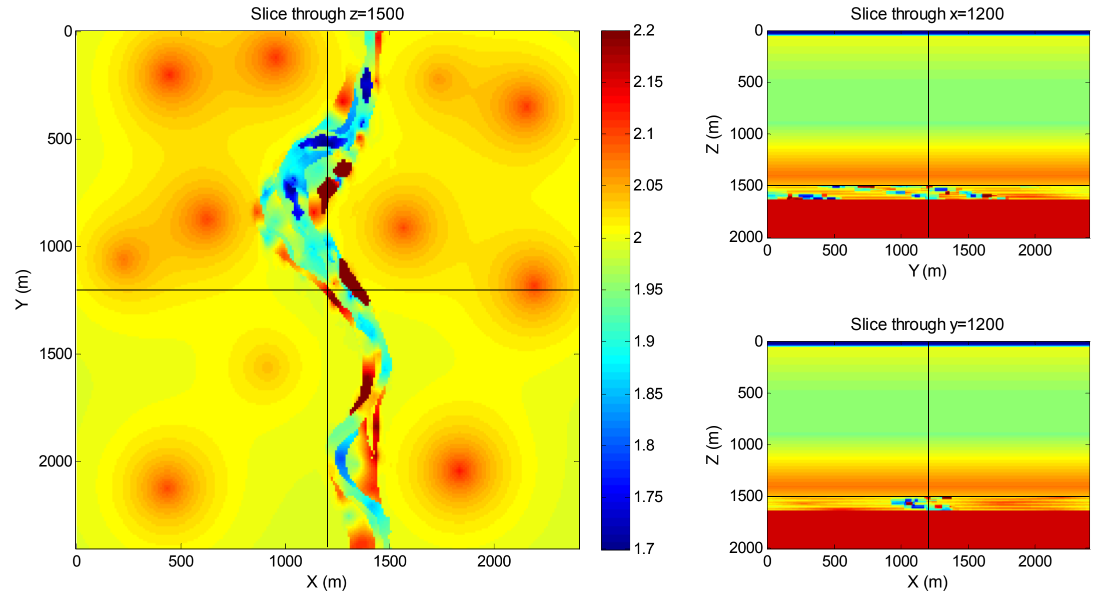

FIG 3. This figure shows the Vp / Vs ratio of the channel model in three different cross-sections. The one on the left is section where depth is equal to 1500m. The upper right section is a section that is running parallel to the channel at x=1200m. The lower left section is going across the channel at y=1200m. The crosshairs are to show where the other sections are located.

SYNTHETIC AQUISITION

To create a realistic 3D seismic dataset, Tiger, a fully elastic finite differencing software package, was used. The source wavelet was a 50 Hz Ricker wavelet, time-delayed by 0.1 seconds, given by Equation (1) and illustrated in Figure 4. The data was recorded to a total of 2 seconds with a time sample rate of 0.004 seconds. Receivers were placed on a 10m by 10m grid while the sources were arranged in lines parallel to the y-axis or N-S. These lines start at x=0m and end at x=2400m incrementing by 100m. The shots start at y=0m and increment by 40m making the total number of shots on each line equal 61 shot records. For the entire regular 3D geometry, there are a total of 1525 shot records. This geometry can be seen in Figure 5.

$$wlet(t) = (2 * \sigma^2 * (t - t_0)^2 - 1)e^{\sigma^2 (t-t_0)^2}, \text{where } \sigma = \pi 50\text{Hz},\ t_0 = 0.1s \qquad (1)$$

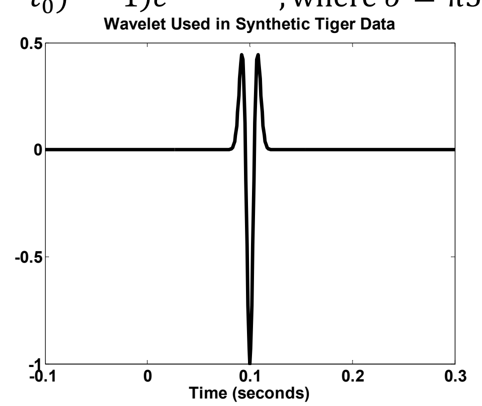

FIG 4. The wavelet used to generate the synthetic data is a time delayed Ricker wavelet pictured above.

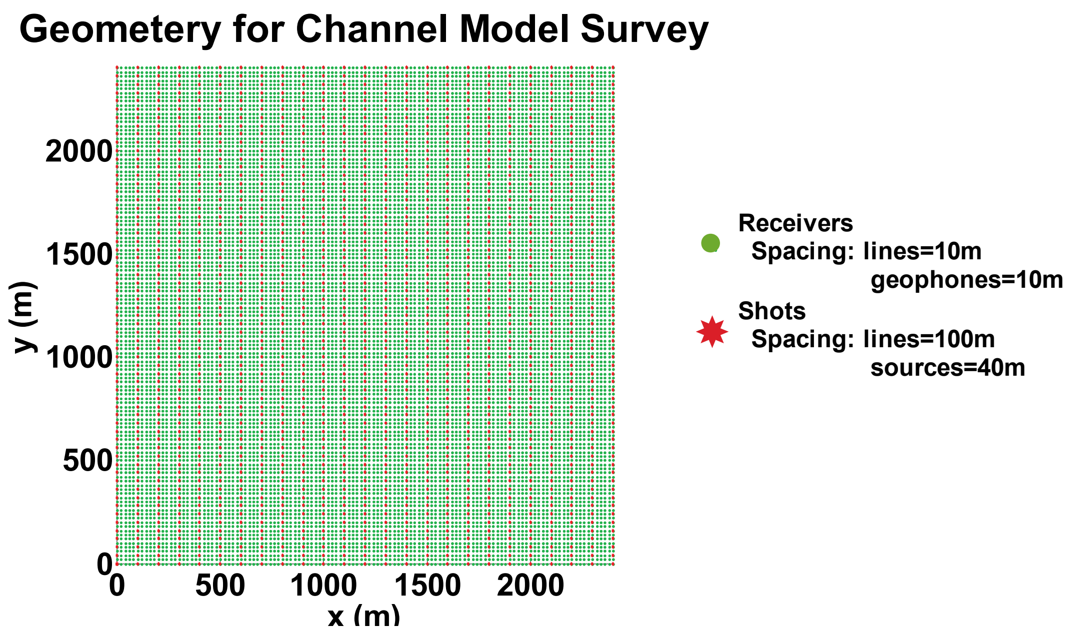

FIG 5. This figure shows the geometry of the synthetic survey. The geophones were lain on a 10m by 10m grid, these are represented by the green dots. The shots were lain in lines

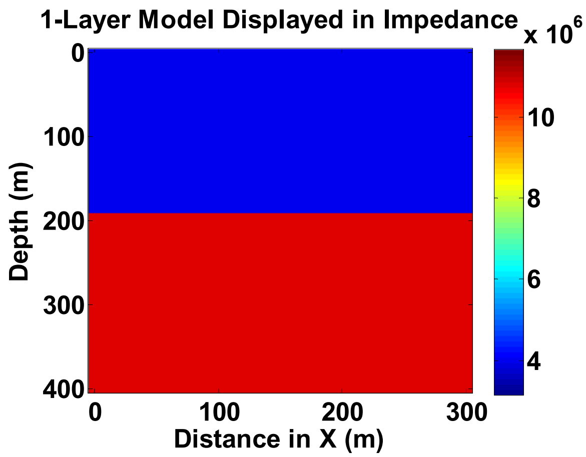

Fig 6a. The P-wave impedance for a 1-layer model. The higher impedance layer is on the bottom where as the lower impedance layer is on the top.

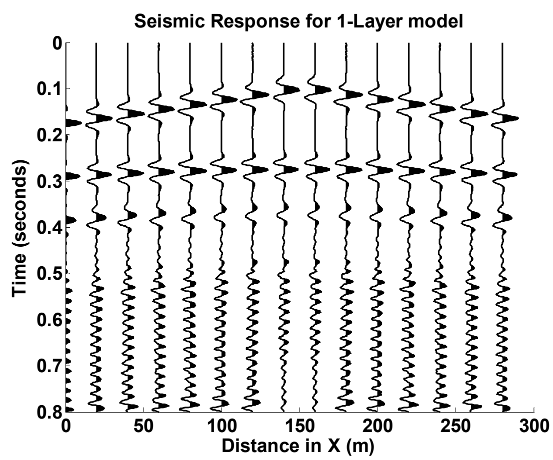

Fig 6b. The vertical seismic response for the 1-layer model. The response for a positive impedance contrast, points to the right. The data is delayed by 0.1 s due to the time shift in the wavelet.

Since the wavelet has a reverse polarity a simple experiment was done to see the response of a positive reflectivity contrast. The model can be seen in Figure 6a, this shows the P-wave Impedance of the model, note that the lower layer has a higher impedance than the upper layer. Figure 6b shows the seismic response as calculated in Tiger. Note that the central peak of the Ricker wavelet points to the right for a positive impedance contrast between two layers. Also this plot shows that the data has been shifted 0.1 seconds due to a time delay in source wavelet. This delay will need to be corrected for with a bulk time shift static correction.

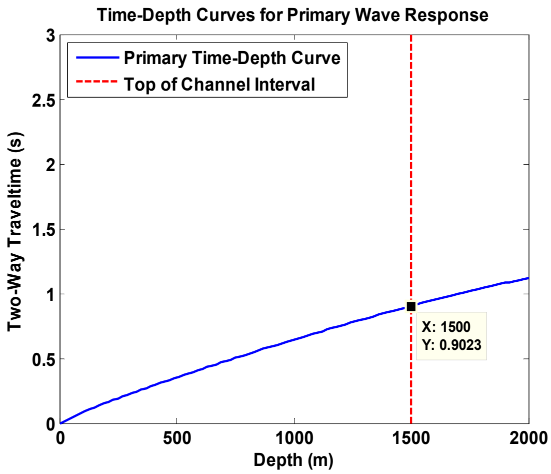

FIG 7a. This figure shows the time-depth curve for the primary waves. Using this it should take about 0.9023 seconds to the top of the channel (indicated by the intersection of the blue and red lines).

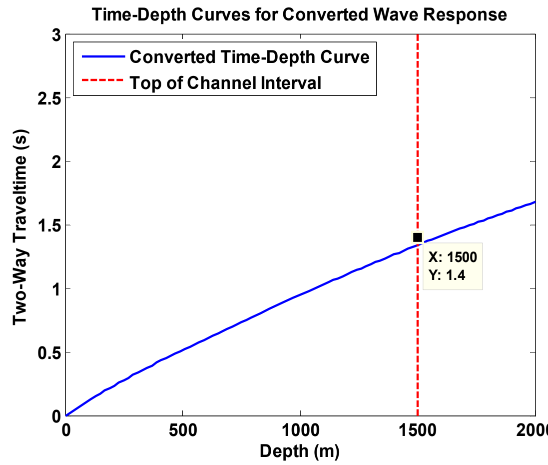

FIG 7b. The converted wave time-depth curve is represented in this figure. The first converted wave reflection of the top of the channel should arrive at about 1.4 seconds.

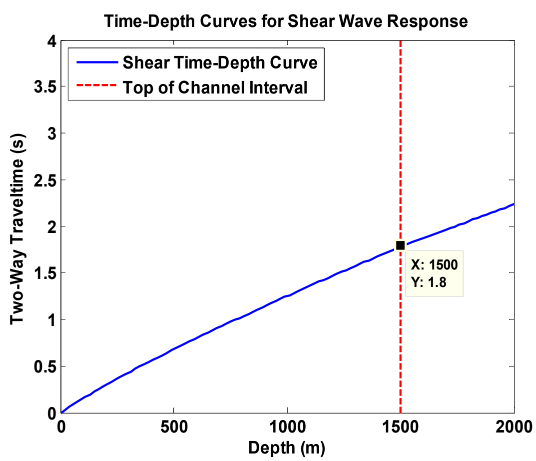

FIG 7c. This figure shows the time-depth curve for the shear waves. The first reflection of the shear wave off the top of the channel interval would arrive at about 1.8 seconds.

Figures 7a, 7b and 7c show the time-depth curves for the primary, converted and shear waves. These curves were not computed before the seismic experiment was done and therefore it has become evident that the shear response was not captured for all offsets. The near offsets of the shear wave were recorded at 1.9 seconds on the raw data but the maximum time recorded was only 2.0 seconds so but only offsets less than 800 m were captured in the data. This experiment has been planned to be repeated in the summer of 2011, with some changes to the overburden, at which time the full shear response will be recorded.

2-D LINE PROCESSING AND INTERPRETATION

An additional shot line was also calculated along x=1200m, on this line the shots started at y=20m and then incremented by 40m such that on the x=1200 line there are shots every 20m starting at y=0m. A 2-D line was extracted in this area with both shot and receiver spacing being 20m, figure 8, shows the location of the line with respect to the channel and figure 9 shows the Vp/Vs ratio along the line. The entire receiver array was live for each shot so this was a roll-in, roll-out, acquisition geometry. This line was then processed using VISTA by Gedco.

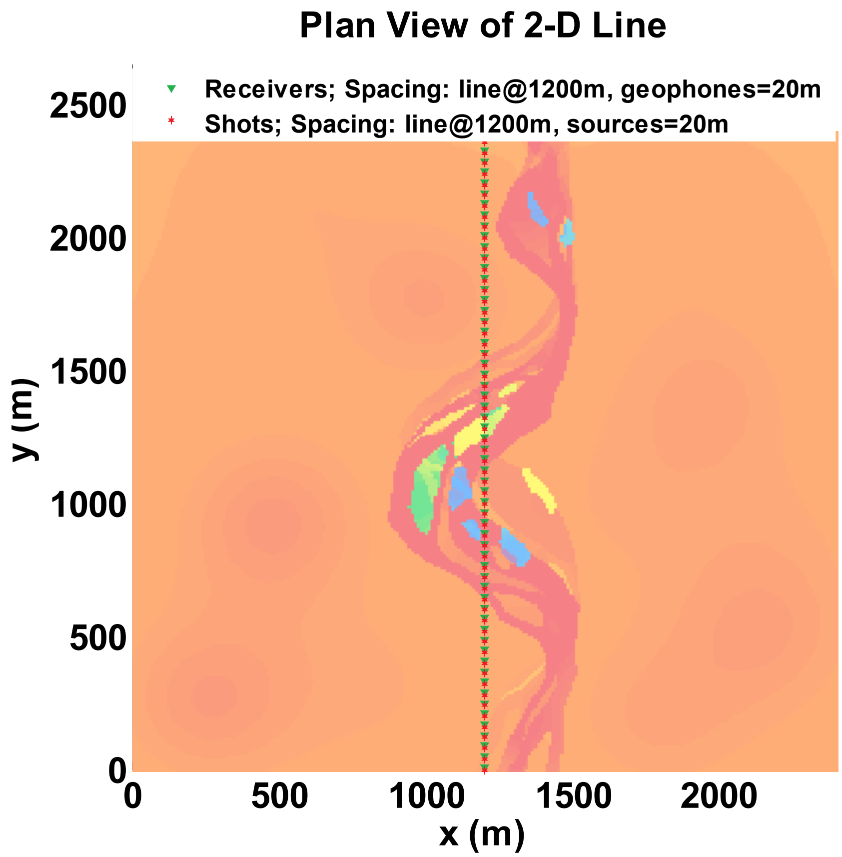

FIG 8. This figure shows the location of the 2-D line with respect to the channel. The receivers and shots are spaced every 20m, with the shots starting at 0m and the receivers starting at 10m.

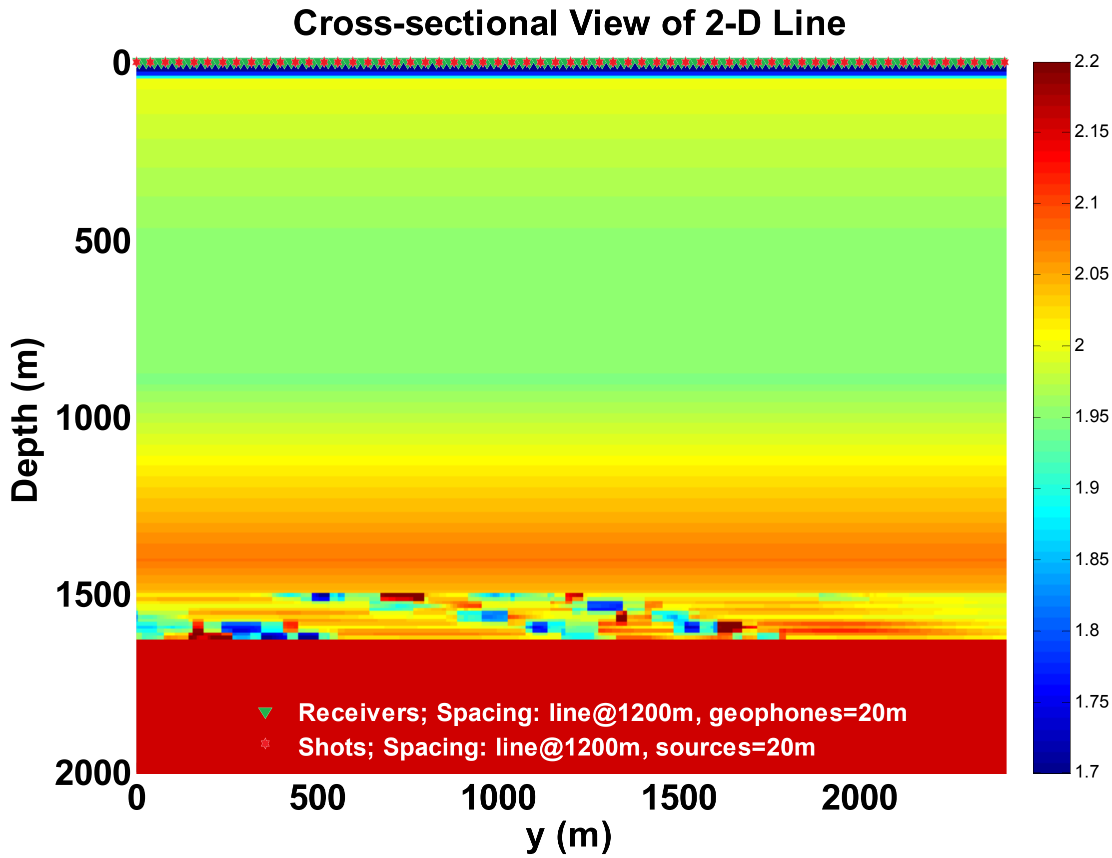

FIG 9. This figure shows the Vp/Vs ratio from the 3D model for the 2-D line. The receiver and source locations are also located on the figure top. The channel interval at 1500m -1600m indicates promising target areas.

Figure 10 shows the raw shot 61 which is at the center of the 2D line. There are two high energy events that have been identified as Event 1 and Event 2. The first thing that needs to be done with the data is to apply a bulk time static shift to correct for the time shifted wavelet. Figure 11 shows the static correction and a gain and AGC applied. More events can now be identified. Using a synthetic trace to identify the events, Event 3 is the channel interval, Event 4 is the change between gradient 2 and 3, and Event 5 is the change between gradient 3 and 4. The events at about 1.4 seconds are the converted wave response and the events at the about 1.8 seconds are the shear response as predicted in Figures 7b and 7c. Events 1 and 2 are very strong and overprint the channel layer therefore need to be removed. Event 1 can be removed from the data by creating a mute, but when Event 2 is removed with a mute it cuts off a significant amount of the channel interval. Therefore Event 2 will be removed using an F-K filter, Figure 12, and 13 shows the muted and F-K filtered data for shot 61 and shot 5, respectively. Figure 14 shows a post-stack normal move out corrected, Kirchhoff migrated section, the variability in the channel layer can be seen by the undulatory reflections at about 0.95 seconds. Normal move out common midpoint gathers were used in an amplitude variation with offset study...

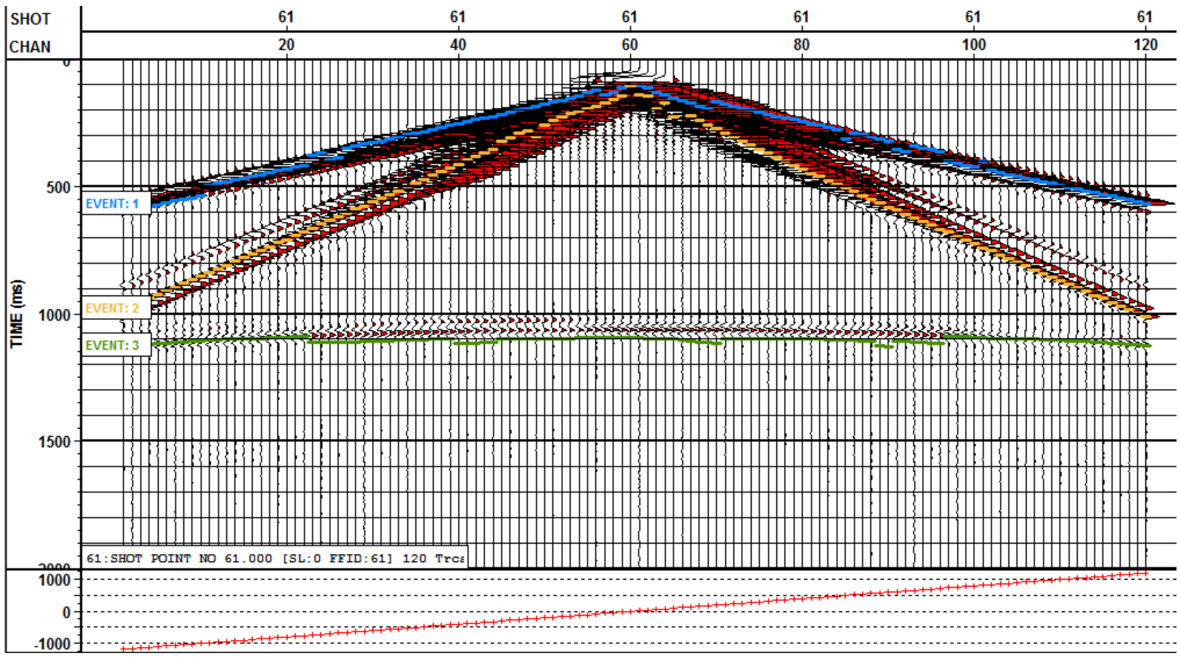

FIG 10. This figure shows the raw shot 61. Event 1 is the first breaks, indicated by blue. Event 2 is ground roll and is indicated with orange.

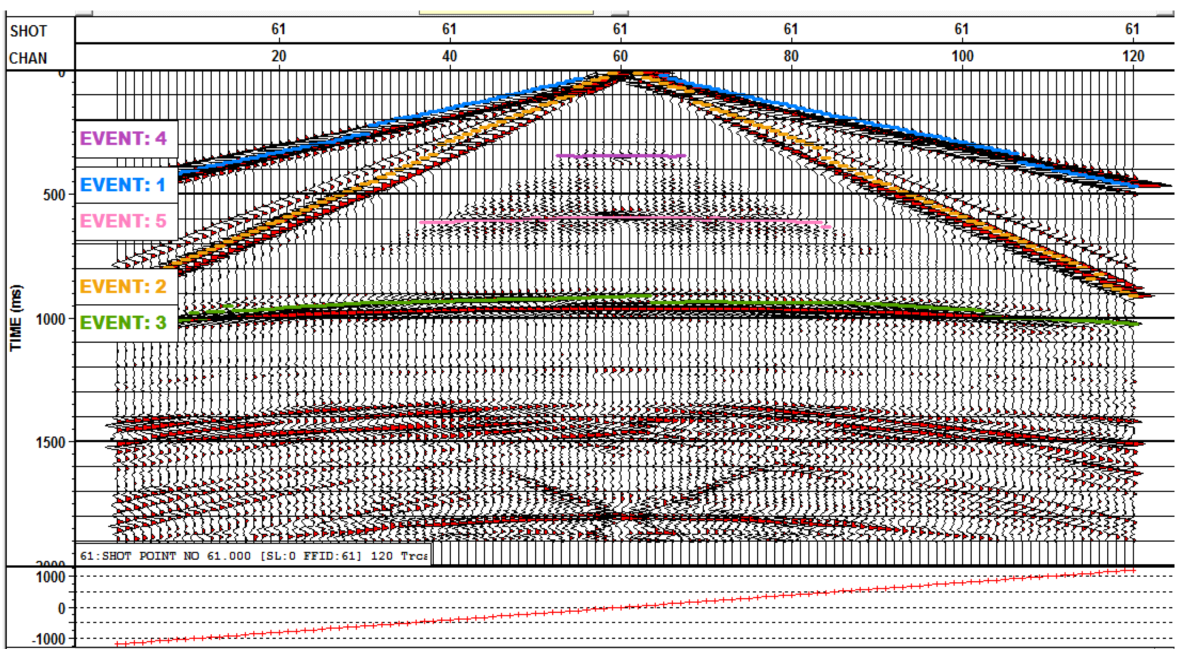

FIG 11. Shot 61 with 0.1 second bulk time shift, gain and AGC applied. Event 3 is the channel interval, indicated in green. Event 4, indicated in purple is an event created by the change in gradient 2 to 3. Event 5 is the gradient change between gradient 3 and 4; this event is indicated by pink.

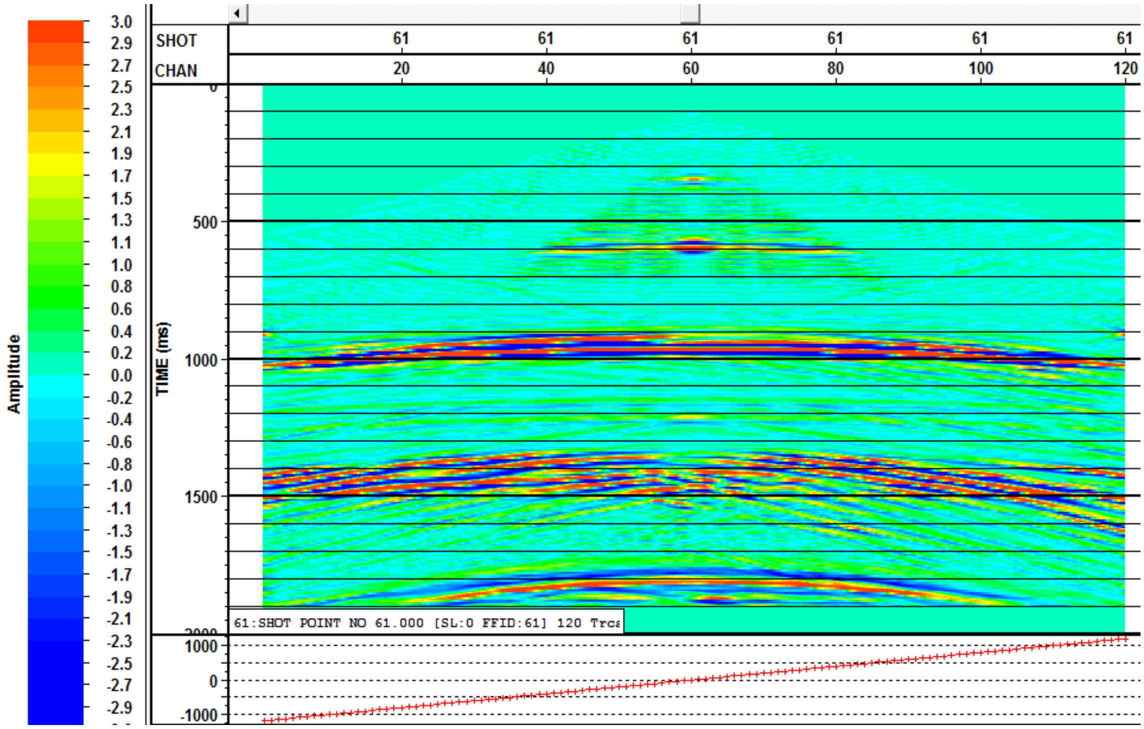

FIG 12. This figure shows the 61st shot record that has had a mute to kill the first breaks and an F-K filter to remove the ground roll.

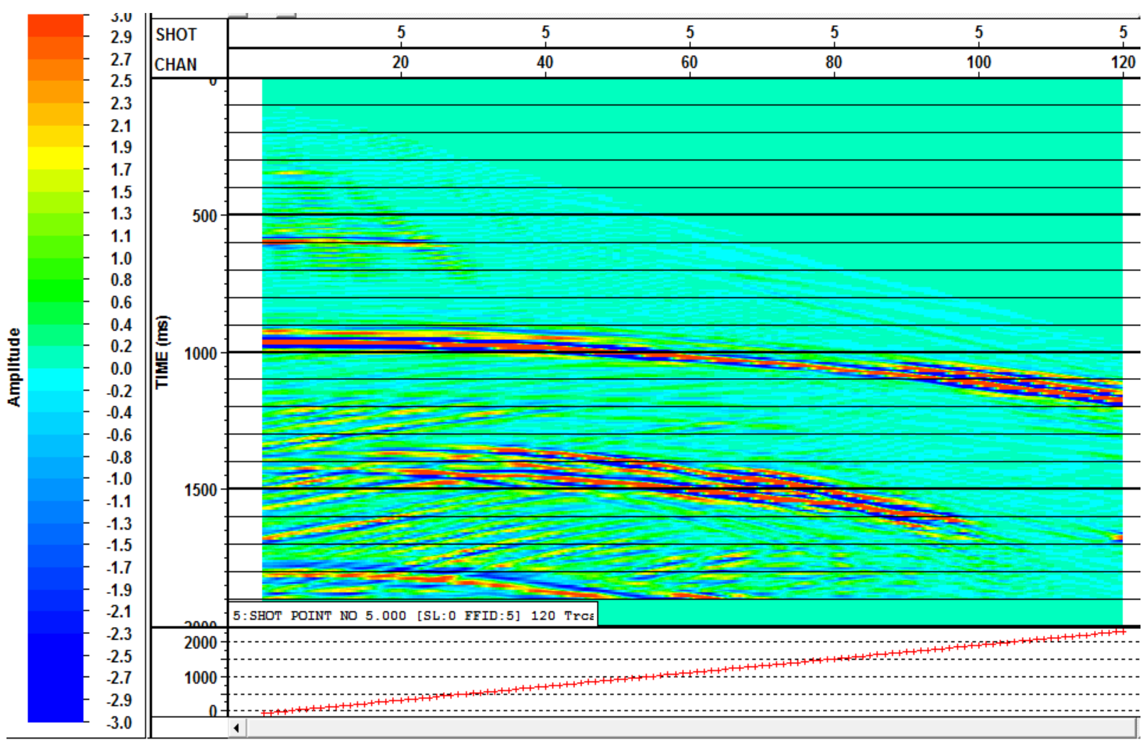

FIG 13. This figure shows the 5th shot record that has had a mute to kill the first breaks and an F-K filter to remove the ground roll. Using an F-K filter to remove the ground roll allowed the data on the channel interval to remain

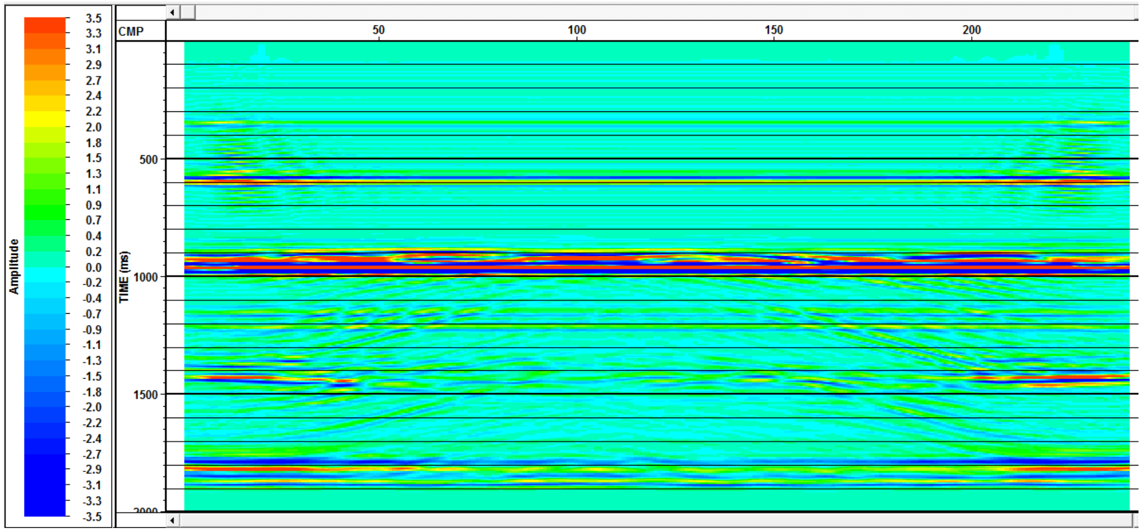

FIG 14. This figure shows a post-stack Kirchhoff migration. The channel interval is at about 0.9 seconds and shows undulations that can be attributed to the varying channel sands.

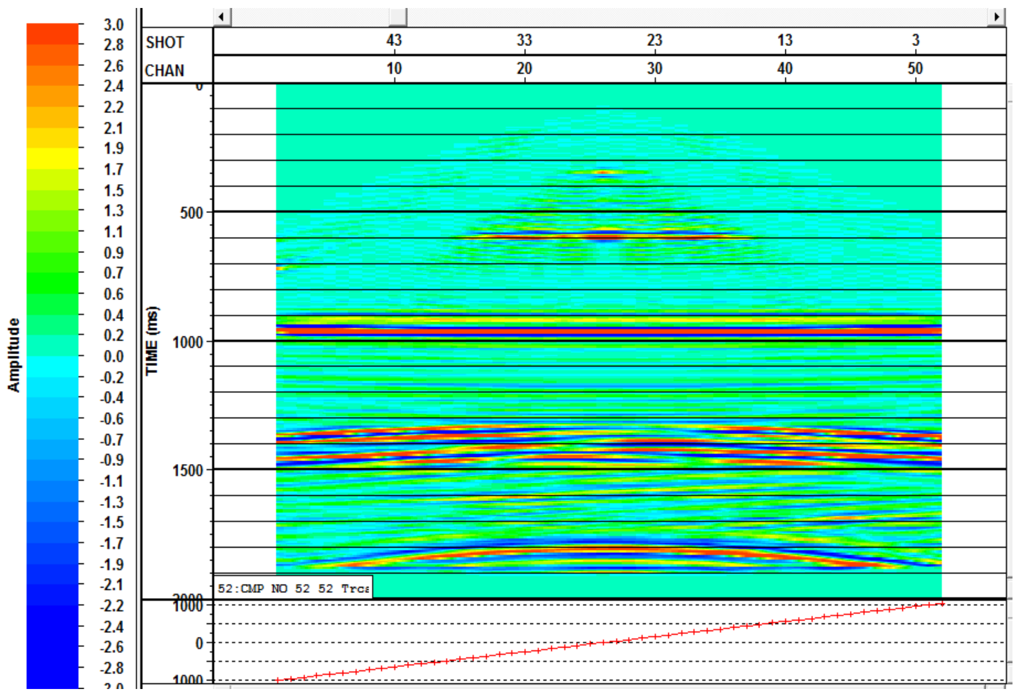

FIG 15. This figure shows a common midpoint gather for 510m and has been normal move out corrected. The area of interest is from 0.9 seconds to 1.0 seconds as this is the channel interval.

Figure 15 shows a common midpoint gather at 510m. At 510m horizontally and at 1500m depth, the Vp/Vs ratio is low and the impedance model has a negative contrast with the layer above it. Therefore the response of the top of the channel at this CMP gather would be negative, so a trough would be picked. Figure 16 shows the amplitude variation with offset for the trough at about 0.9s. It can be seen in this figure that the picked values follow the expected values, calculated from the Zoeppritz equations fairly well until higher offsets. The color bar shows that these higher offsets also occur on the edges of the section, so the divergence of the trend could possibly be correlated with the effects of removing the ground roll with an F-K filter. Figure 17 shows another common midpoint gather for 1300m were the Vp/Vs ratio is low and the p-wave impedance is also low. This contrast occurs at 1530m in depth. The picked amplitude response for this gather was then compared to that predicted from the Zoeppritz equations. The picks, seen in Figure 18 do not follow the expected values as well but still show a corresponding amplitude decrease with offset.

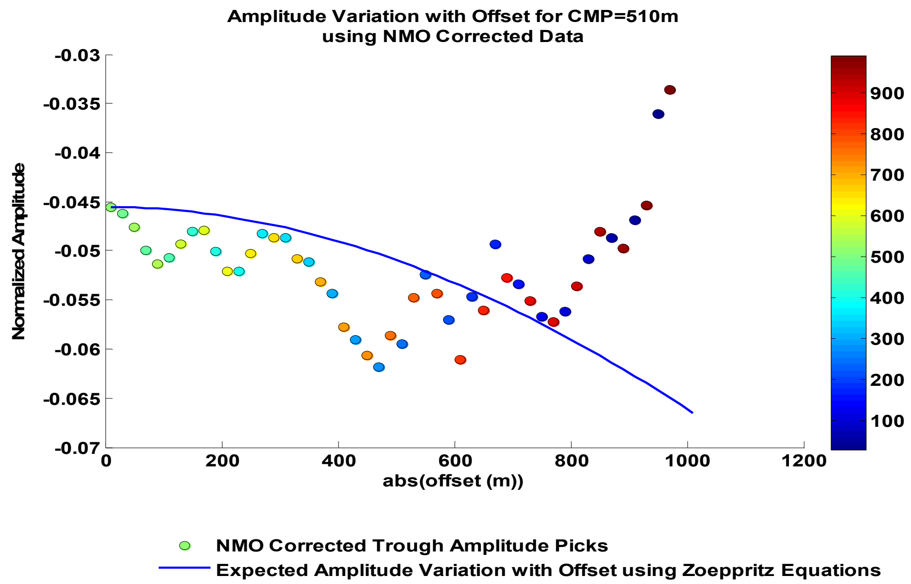

FIG 16. This figure shows the amplitude variation with offset for a common midpoint gather at 520m using normal move out corrected data. The impedance contrast at the 520m gather was negative resulting in a trough being picked. This point in the model also had a low Vp/Vs ratio. The blue line is the theoretical, expected result where as the coloured dots are measured. The color of the dots indicates the y-coordinate of the geophone that recorded the data.

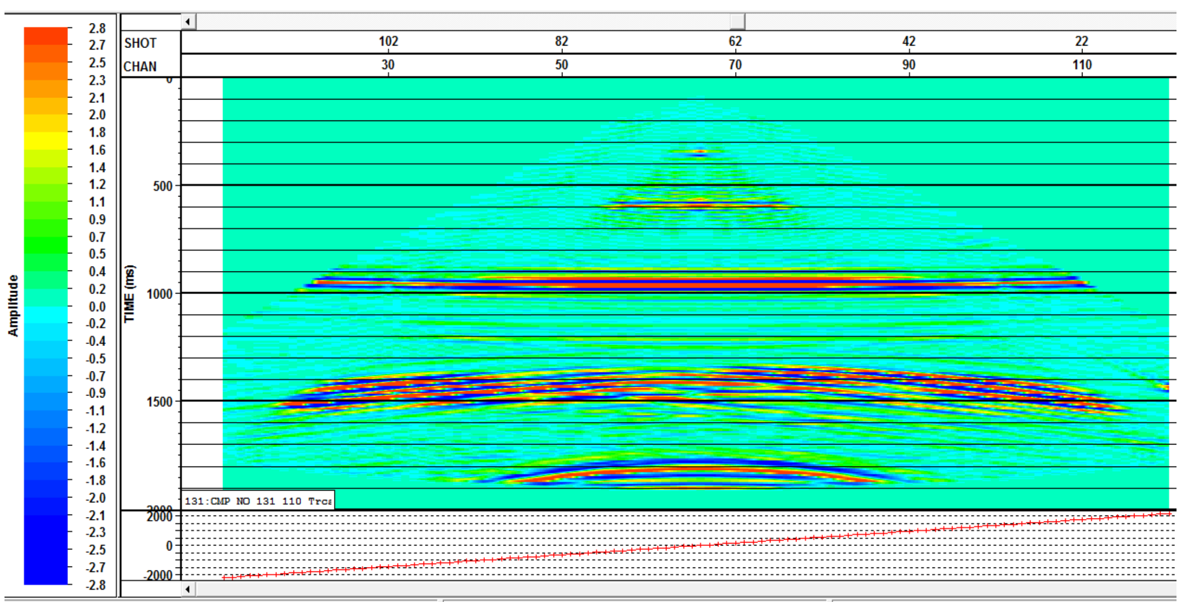

FIG 17. This figure shows a common midpoint gather for 1300m and has been normal move out corrected. The Trough that was picked for the amplitude variation with offset study is at about 0.9 seconds.

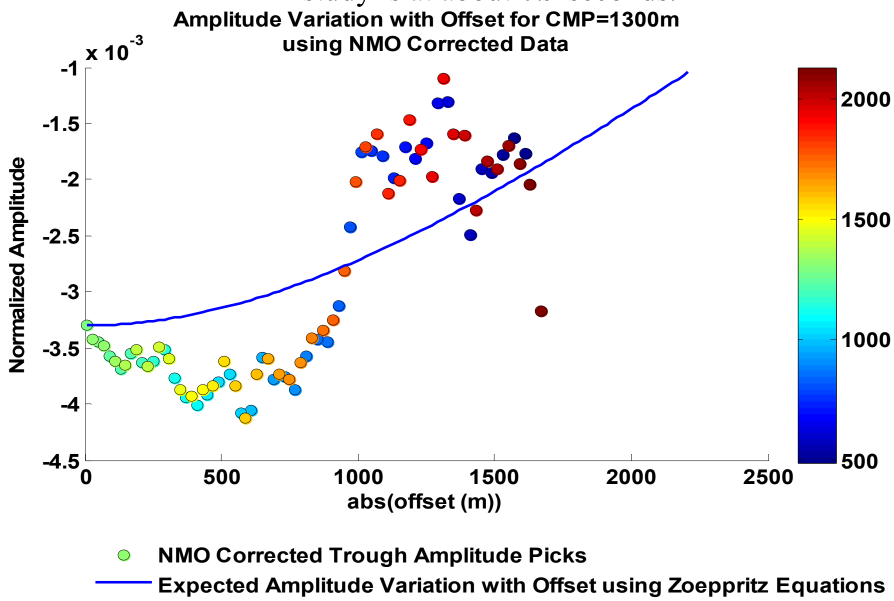

FIG 18. This figure shows the amplitude variation with offset for a common midpoint gather at 1300m using normal move out corrected data. At this common midpoint in the model there is another negative impedance contrast and a low Vp-Vs ratio creating a possible target. The blue line is the theoretical, expected result where as the coloured dots are measured. The color of the dots indicates the y-coordinate of the geophone that recorded the data.

DATA RELEASE

The data is being prepared for distribution in two forms. The total data set, consists of 1525 SEG-Y files containing the 10m by 10m grid for each shot. This data set is about 0.55 Terabytes. The second data set is an abbreviated version, with receiver and shot line spacing at 100m and a receiver interval of 20m and shot interval of 40m. This geometry can be seen in FIG . This data set is about 9.2 Gigabytes and is available in SEG-Y format. Due to the size of the files this data set is available by request only. Please contact the CREWES technical manager to request the data.

REFERENCES

Margrave, G. F., Taylor, S., and Cooper, J. K., 2008, Towards realistic 3D elastic models of Canadian channel and reef structures: in the 20th Annual Research Report of the CREWES Project.