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Near-surface geophysical imaging over steeping beds, Beartooth Mountains, Montana.

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Abstract

The University of Houston conducted a geophysical field school during August 2009 at the Yellowstone Bighorn Research Association (YBRA) camp near Red Lodge, Montana. Part of the activity was to undertake a detailed geophysical study of the dipping strata near the YBRA camp. Borehole seismic and well logs, from two specially drilled shallow wells, plus a crossing seismic line were acquired. Well logs interpretation indicates a shallow layer (5m) of alluvium, a thicker carbonate layer, then a “redbed” or shaley sandstone. The VSP results indicate a P-wave velocity (V_p) for the carbonate of about 2600 m/s and an underlying (but younger) red-bed with a Vp of about 2800 m/s. From S wave traveltimes in the VSP, we estimate a Vp / Vs value of 2.2 for the limestone and 1.7 for the shaley unit. The velocities are similar in both the VSP data from two wells and a surface-wave inversion. The limestone shows an anomalously high gamma value, which might be due to uranium deposition. Initial interpretation shows the limestone-shale (redbed) encounter to be at 40 m and, from the borehole televiewer; the probable dip of the bed appears to be 45° towards the south.

Geology of the area

Southern Montana contains the highly structured region of the Beartooth the Yellowstone Bighorn Research Association (YBRA) camp area is located near Red Lodge, Montana (Figure1) in the Beartooth Mountain range. The rock sequence was folded, inverted and then torn by a strike slip fault (Figure 2). One limb of the folded Madison limestone bed is visible (Figure 3) but another limb is buried beneath the camp area. Whether the Madison limestone (Mississippian) overlies the top of Triassic Chugwater or Mississippian Amsden is still debatable (Figure 4).

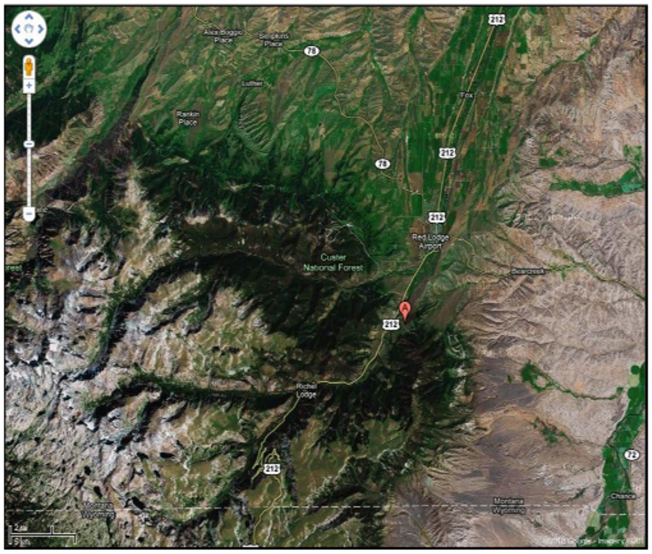


Figure 1.YBRA camp (Google satellite map)

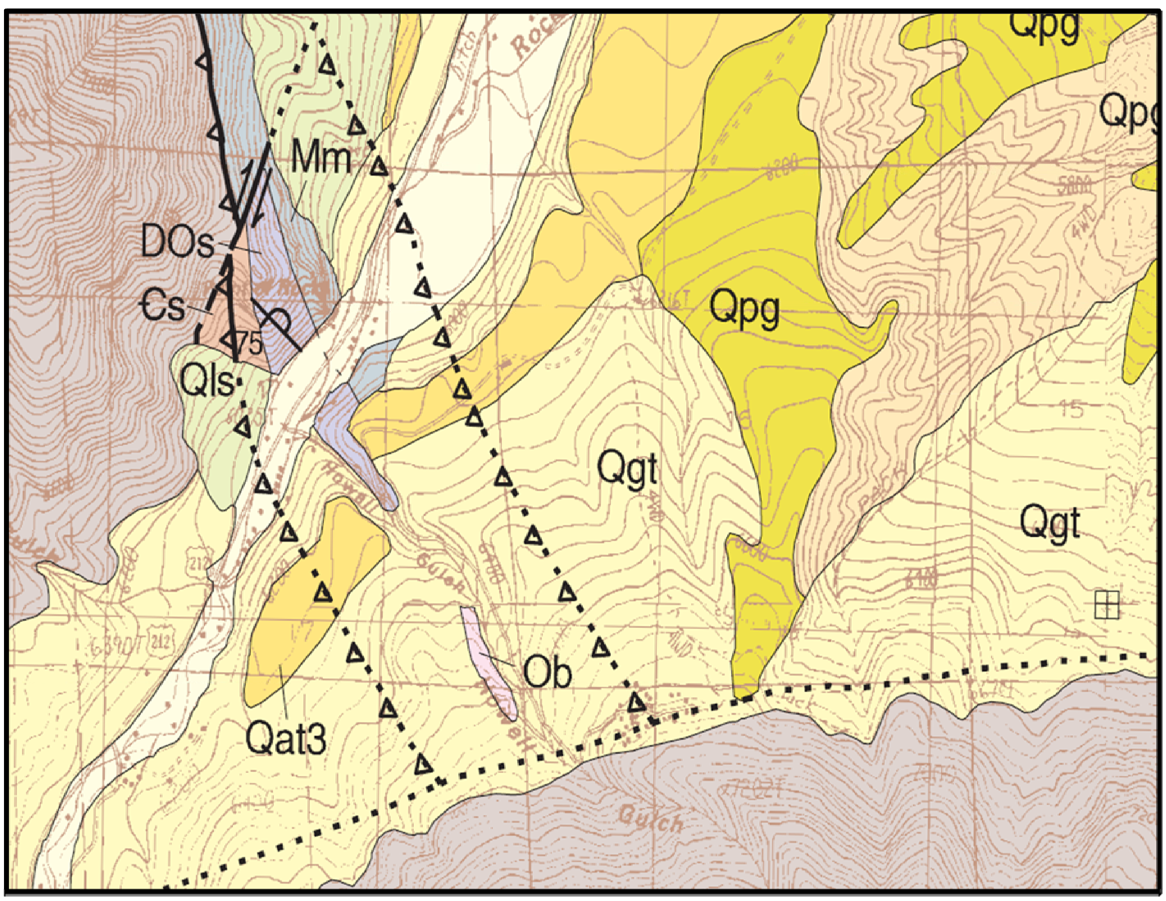


Figure 2 . Geological map of Redlodge (after D. A. Lopez,2005)

Figure 3.Subvertical Mississippian Madison LS

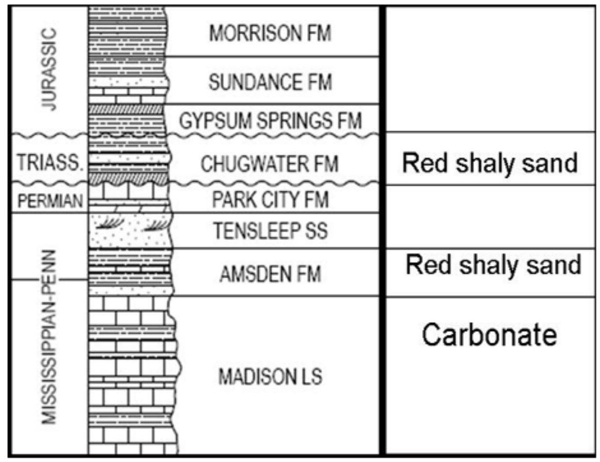


Fig 4.Simplified statigraphy (Kauffman et al.(2008)

Motive of the survey

The location and orientation of the tear fault and buried limb beneath the camp area is still debatable . Whether the Madison limestone (Mississippian) is on the top of Chugwater (Triassic) or Amsden (Mississippian) is also a matter of discussion .To get the ground truth, two wells were drilled at the camp (Figure 5) around the approximated tear zone of the overturned formations. Couple of VSP (vertical Seismic Profile) and several logs were recorded in the two wells. A 140 m long 2D seismic line was shot near the wells with East-West direction. Two perpendicular gravity profiles area also done in that area .Initial processing of all these different data set are showing consistent velocities, structures and rock properties.

3.Geophysical Survey detail

A 2d seismic survey was shot along E-W line over the highly folded beds and two wells was drilled on a suggested location (by previous geologic work) that would be in the tear zone of overturned formations (Figure 5). Geophysical logging and Vertical Seismic Profiling (VSP) survey was done in those wells.

4.Data Acquisition

VSP and Well logs: The coordinate of the wells are about 45°11’15”N, 109°14’55”(YB1) and 45°11’14”N, 109°14’56 (YB 2). The Separation of the two well is 6.7 m.The depth of YB 1 is 30 m and YB 2 is 60 m. YB 1 was initially drilled 100 m but the bottom 60 m was lost due to well failure. For the VSP surveys, we used two Geostuff 3C wall-clamping receivers on wirelines (Figure 6) and a 10 lb hammer seismic source. The VSP geophones were wall-clamped at the bottoms of wells YB-1 and YB-2 (at 30m and 60m, respectively) and drawn up at half-meter intervals to a final top depth of 0.5m (Figure 7). When the geophone in YB-1 reached 0.5m, it was dropped to the bottom 30m depth again and acquisition continued by pulling up both geophones up until they were both at 0.5m. In this way, a repeat 30-meter VSP was obtained in YB-1 for every one of the 60-meter VSP recorded in YB-2. A 24-channel EGG Geometrics Geode was used to simultaneous record six seismograms from both wells. The sampling interval and record length were set to 0.5ms and 1000ms. (Table 1)

Figure 6 . Vertical Seismic Profiling gears

No of well	2 (YB1 &YB2) Cemented and cased (PVC)
Location of the wells	YBRA camp
Distance between wells	6.3 m
Well depth	Yb1 :30 m , Yb2 :60 m
Type of sensor	3 component down-hole locking geophone.
Recording unit	Dell Tough book laptop
Sampler and digitizer	Geostuff and geode
Controller software	Seismodule by Geometrics
Sampling interval	0.5 ms
Record length	1.0 s
Source	10 lb Hammer
Shot location	3.77 m from YB2

Table 1. VSP geometry information

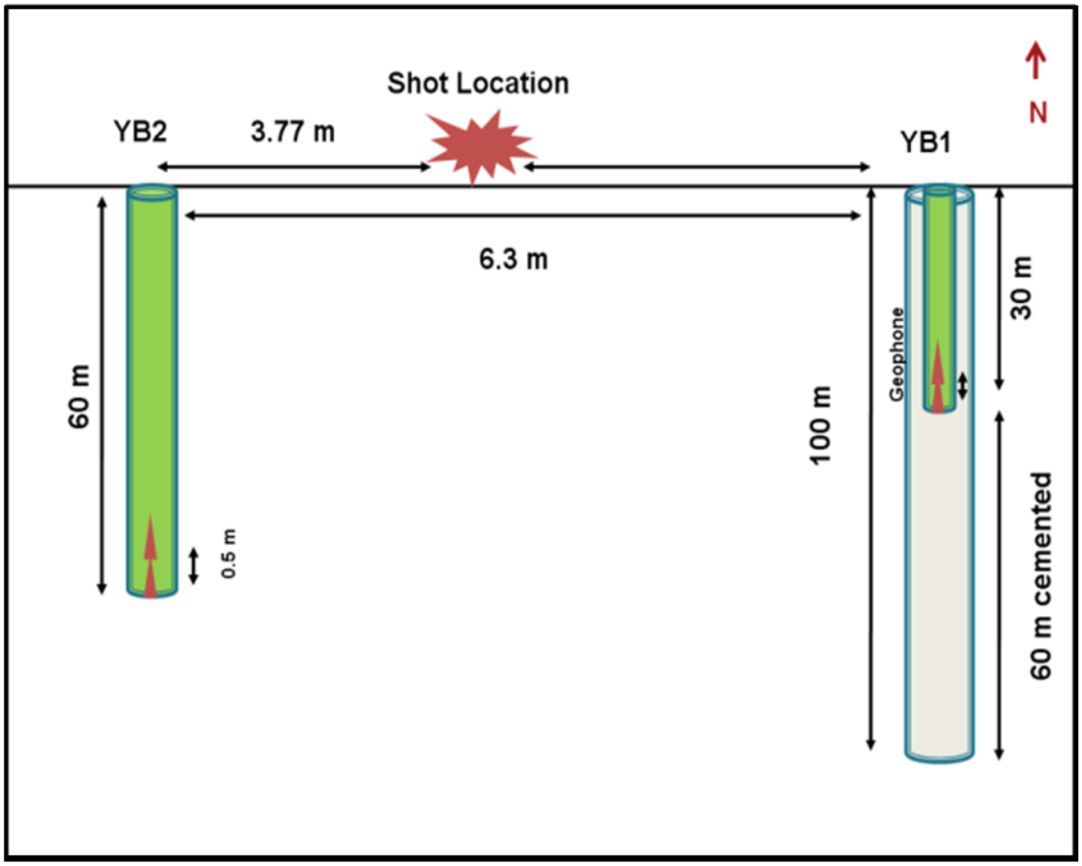


Figure 7 . Vertical Seismic Profiling geometry

Several logs has been run in YB1 and YB2 including natural gamma, resistivity, full wave sonic, Acoustic televiewer and neutron porosity. YB1 was initially logged by century geophysical (Figure 8).Both the well was logged with Mount Sopris Matrix logging system, and natural gamma ray, temperature, induction natural gamma-ray, temperature, induction conductivity, and full-waveform sonic logs were run. SP and point source resistance could not be acquired because of the PVC casing.The full-waveform sonic (FWS) logging tool consists of two piezoelectric transmitters (Tx-A and Tx-B) separated by 9 feet (3m). Three piezoelectric receivers Rx-1, Rx-2, and Rx-3) spaced 1 foot (0.3m) apart are centered between the transmitters.During acquisition, the piezoelectric transmitters were operated in the monopole configuration and generated sonic pulse with dominant frequency of about 15 kHz. Six high-frequency seismograms were recorded every 10 centimeters with a logging speed of about 3 meters per second.

FWS seismograms for receivers Rx-1, Rx-2, and Rx-3 for transmitter Tx-A from well YB 2 (Figure 9) .A 50-inch acoustic

Figure 8 . Logging gears

televiewer log was run in YB1 (Figure 10). This device is generally used to generate an oriented image of seismic velocity variation and wave amplitude. These images are then examined and highlighted to reveal fractures, bedding planes and orientation of those features.

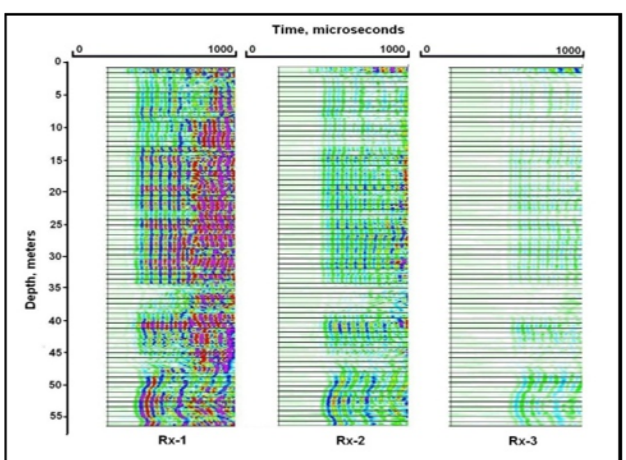


Figure 9:Full waveform sonic seismograms in YB-2, for three receivers Rx-1, Rx-2, and Rx-3.

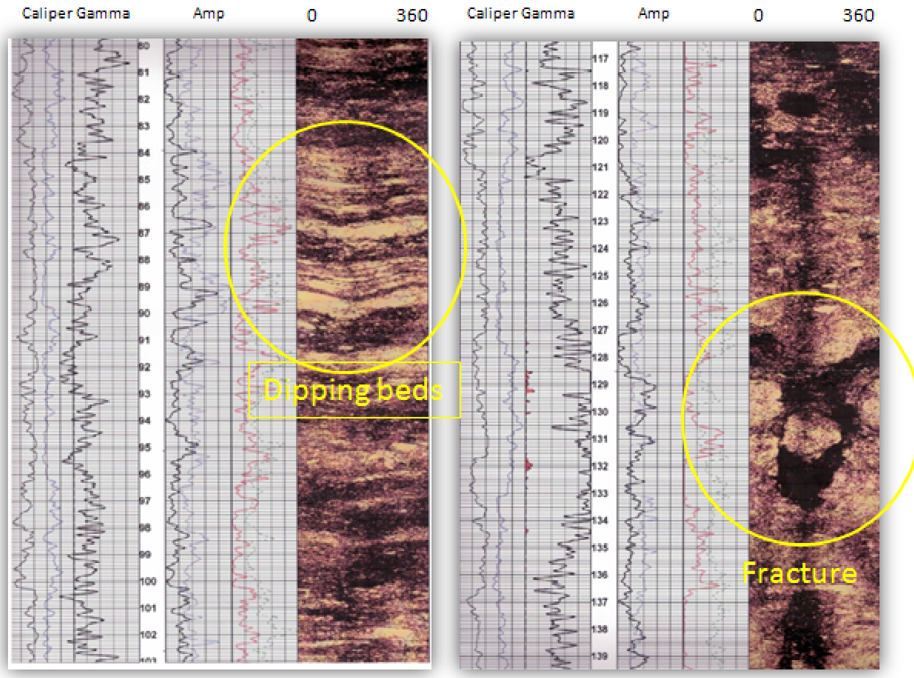


Figure 10 . Televiewer log showing dipping beds and fractures.

Surface seismic:

48 channels 2D line was shot with Stratavisor recording unit near the well in an East-West direction (Figure 11) Geophone internal was 3 m. The source used was a 40 lb accelerated weight drop with a source interval of 3 m; the data was shot every half station (Table 2).

Figure 11 . Seismic survey gears

Line Location	YBRA camp near 70 m from well 2 (camp location:45º11'15"N 109º14'55")
Line orientation	E-W
No of geophone	48 vertical geophones
Source	100 lb accelerated weight drop
Recording unit	Stratavisor
Geophone interval	3 m
Source interval	3 m (between geophones)
Sampling	0.25ms
Record length	1.0 s
No of shots/station	4

Table 2. Seismic survey parameters

Gravity survey:

Figure 12. La Coste & Romberg G 670

A La Coste & Romberg G 670 relative gravimeter was used to measure gravity along the road and down the hill from the well .The intention was to capture any major change in density profile (carbonate to shale) in EW or NS direction (Figure 12). The profiles are plotted and shown in figure 13 . The EW profile shows high density away from the well but there was no density chance in the cross profile .

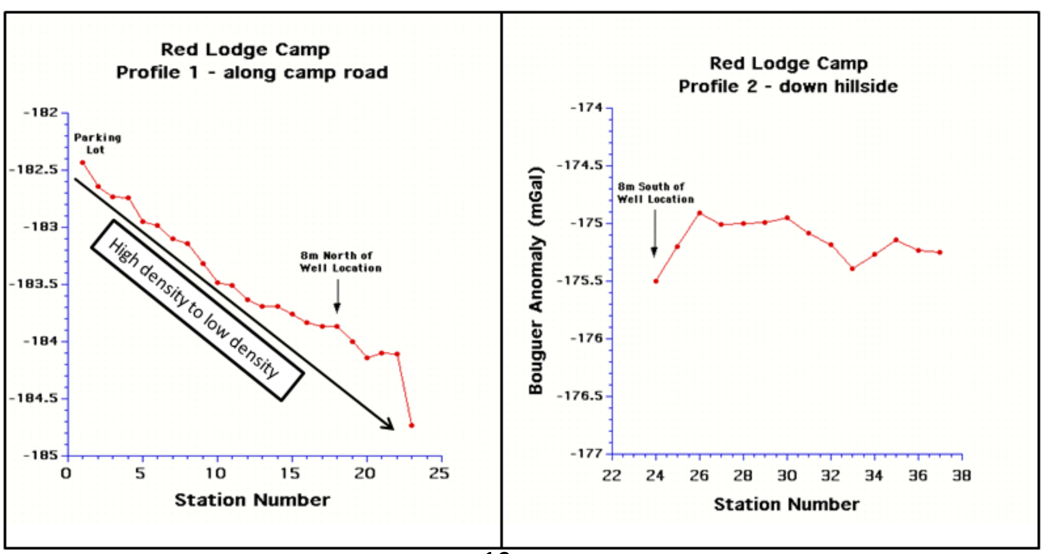


Figure 13 . Gravity profile along and across the well

Well log interpretation

After plotting the logs we interpret the gamma log is very high considering carbonate. After 43 m(136 ft) there is a sudden increase of gamma count followed but a decrease but overall higher gamma count indicating a shale formation (Figure 14).

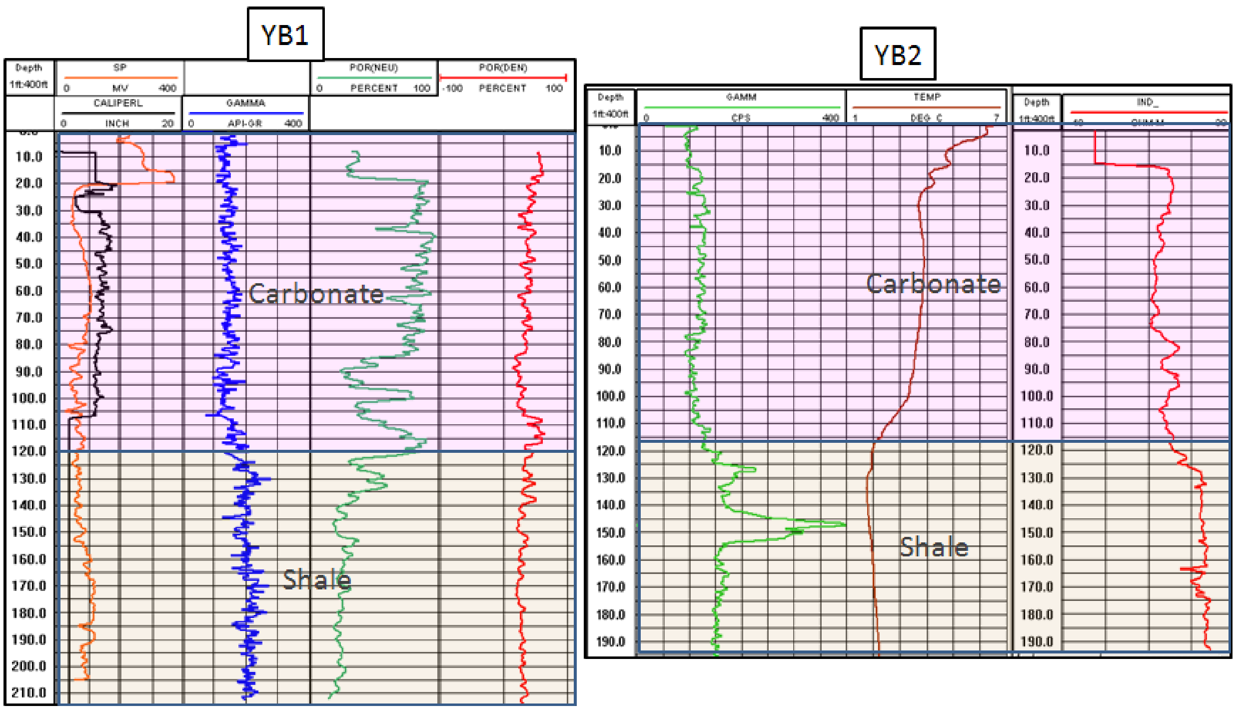


Figure 14 . Well log plot from well 1 and well 2

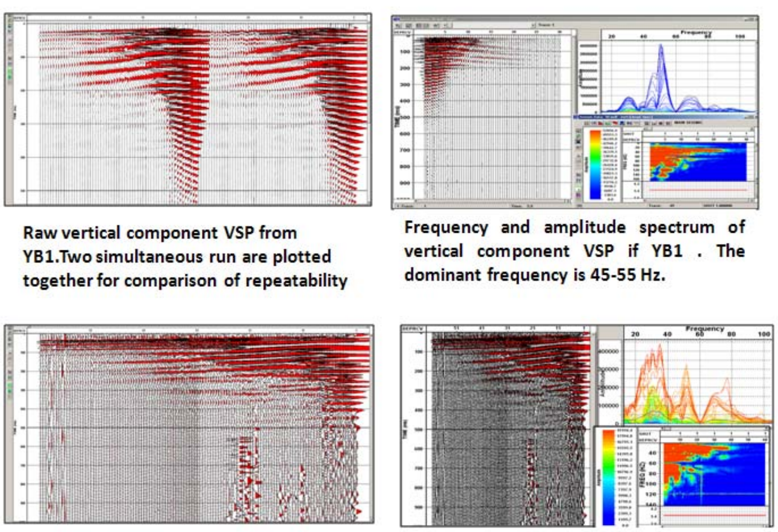
- The Conductivity log shows increase conductivity about 40 m.
- Neutron porosity log showing major porosity decrease after 40 m indicating high fracturing in carbonate (Figure 14). The feature at about 43-44 m (136 ft) is also present in porosity log as highly porous zone.

- Sonic televiewer shows evidence of dipping bed (dipping towards south) (Figure 10) .The dip of the bed is about 45º towards south. There is a major fracture is seen around 42-43 m (136 ft) in the televiewer image.

- The plot of the travel time of the three components of the full wave sonic shows a change (low velocity) at about 40 m velocity is about for carbonate (Figure 9).

VSP data Processing and Analysis:

Two near-offset VSP surveys were processed. A single source was used to record in both wells simultaneously to develop a better idea about the repeatability of the data. The source was located in the middle of the two wells, the signal as well as noise was almost same in both the wells. The dominant frequency is about 40 Hz. We plotted the shot gathers for both wells and compared by subtracting from each other in same depth interval. The amplitude spectrum of the raw shows two linear high frequency noise (120 Hz and 180 Hz). We use a band pass filter with 10-100 Hz pass frequency and 5 Hz taper. For the near offset 3CVSP than all the components are separated (one vertical and two horizontal components) using Hodogram analysis. After rotation, most of the P and SV energy is redistributed to Hmax (the radial) . There was little P energy left on Hmin due to some reverse polarity first arrivals, which is typical signature for steep dipping bed reflections. P and S wave Velocity



Raw vertical component VSP from YB1.Two simultaneous run are plotted together for comparison of repeatability

Frequency and amplitude spectrum of vertical component VSP if YB1 . The dominant frequency is 45-55 Hz.

Raw vertical component VSP from YB2.

Frequency and amplitude spectrum of vertical component VSP of YB2 . The dominant frequency is 35-40 Hz.

Figure 15 . VSP raw plot and frequency spectrum

inversion for well YB1 and YB 2 are calculated from the first break picks (Figure 15). Same velocity is used for NMO correction and V_P/V_S Ratio calculation. The upgoing and down going waves are separated using median filter , due to the steed dips , upgoing waves are not prominent. We made a ray trace synthetic model to understand wave interaction in a steep dipping near offset VSP case and it shows a complex interfere of waves.

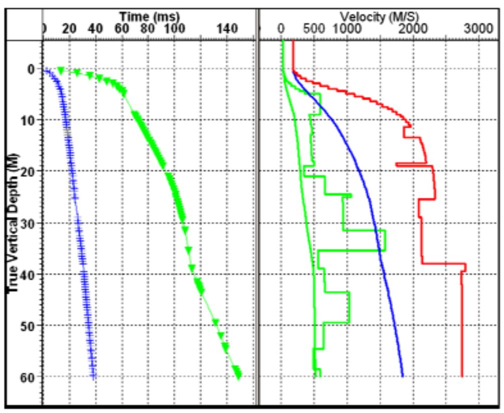


Figure 16 a. P and S wave velocity inversion VSP (YB2) from first break peak Left window is showing first breaks plot for P (blue cross) and S (green triangle). Right window is showing average velocities are in smooth curves (blue for P and green for S wave) and interval velocities (green for s and red for P wave velocity).

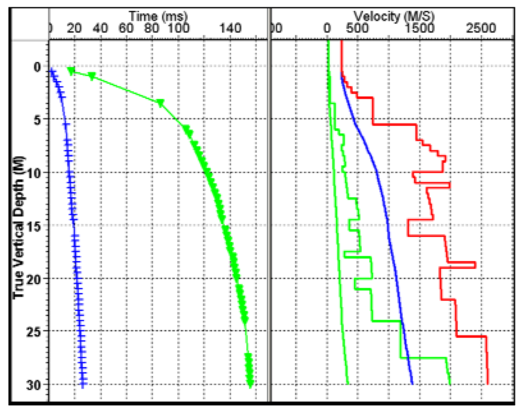


Figure 16 b.P and S wave velocity inversion VSP (YB2) from first break peak Left window is showing first breaks plot for P (blue cross) and S (green triangle). Right window is showing average velocities are in smooth curves (blue for P and green for S wave) and interval velocities (green for S and red for P wave velocity).

Multichannel Analysis of Surface waves (MASW) method:

The near-surface S-wave velocity structure can be made using dispersion properties of surface waves .Then these dispersion curves are inverted using MASW method (Park et al., 1999). This method first creates dispersion curves (frequency vs phase velocity of Rayleigh waves) using dispersion properties of surface waves then these dispersion curves are inverted. For fundamental mode creating an S wave near surface velocity structure. In this case, a 1D-velocity structure for a single-shot gather has been provided which shows comparable velocities (Figure 17)

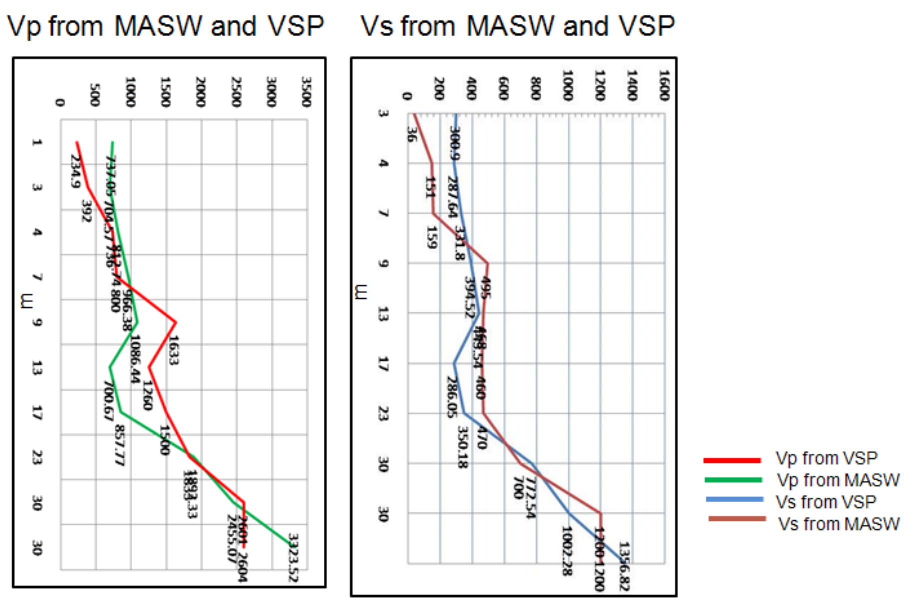


Figure 17 : Comparison of computed velocities and Vp/Vs plots from surface Waves (MASW method) and VSP.

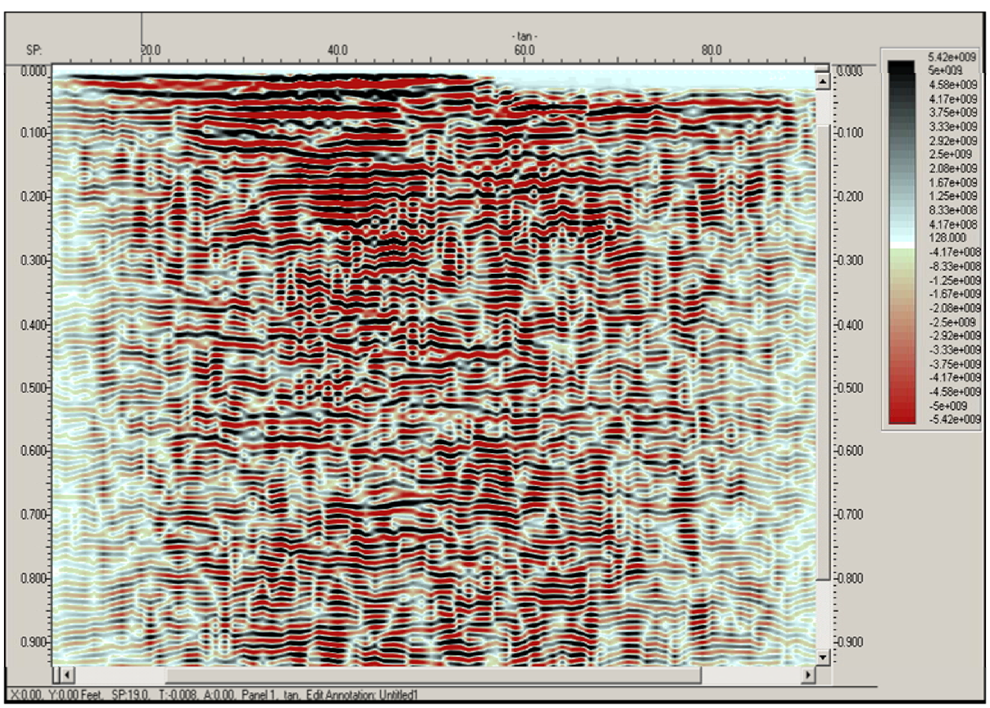


Figure 18. 2D line near well YB 2

8. Conclusion

- The carbonate (Madison LS?) shows a lower velocity (2600 m/s) than the competent shale beneath (2800 m/s).
- The high gamma ray count in carbonate indicates radioactive impurities.
- There is a highly fractured zone at about 130 ft (39m). The petrophysical and seismic evidence indicate the transition from carbonate to red shale occurs around 40 m.
- The dip of the formation is about 40-45° towards the south.
- Near-surface velocities from surface seismic MSAW and VSP are repetitively consistent.
- Processed 2D line shows no structure as the line was shot parallel to fault (Figure 18).
- A Vp / Vs value of 2.2 for the limestone and 1.7 for the shaley unit.

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10. Reference:

Kauffman, M., 2008, A brief history of the Yellowstone-Bighorn Research Association (YBRA) geologic field camp, Red Lodge, Montana:Northwest Geology, 37, 1-4.

Lopez.A.D, 2005; Geologic Map Of The Red Lodge Area,Carbon County, Montana;Montana Bureau of Mines and Geology Open-File Report MBMG 524.

Park, C. B., R. D. Miller and J. Xia, 1999, Multichannel analysis of surface waves: Geophysics, 64, 800-808.

Stewart, R.R., S.Khan., J. Wong., S.A. Hall, and C. Liner,2010 Geophysics field education: Better learning by doing, Montana: The Leading Edge.