Integrated well-log, VSP, and surface seismic analysis of near-surface glacial sediments: Red Lodge, Montana

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Summary

We report on a suite of geophysical surveys conducted on glacial sediments near Red Lodge, Montana. The University of Houston (with assistance from University of Calgary, GEDCO, and UT-Austin personnel) conducted VSP and well log surveys in the 115m-deep, PVC-cased water well, GB-1, located on the glacial benches. The multi-offset VSP was undertaken using surface sources (an accelerated weight drop and sledge hammer) with a hydrophone string and downhole, wall-clamping, 3-component geophone. The well logs included measurements of conductivity, radioactivity (gamma ray), temperature, and sonic velocity. Sonic and VSP velocities ranged from 1500m/s in the very near surface to 3000m/s at 85m depth. A distinct black clay layer (with high conductivity, high gamma ray, and low velocity) was penetrated at 85m. High-resolution 2D and 3D seismic surveys, using a sledge hammer source, showed a number of reflectors to about 150ms two-way traveltime. On the L-plot composite displaying well log data, synthetic seismograms, and the VSP corridor stack, a reflection at 80ms correlated with the 85m interface Various other reflections in the VSP and surface seismic data were interpreted to represent glacial deposit layers and water zones (from the perforation logs).

Introduction

The study area, near Red Lodge Montana, lies in front of the Beartooth Mountains which locally comprise an overturned sequence with a thrust fold (Foose et al., 1961; Wise, 2000). During the last glacial maximum (approximately 12,000 to 20,000 years ago, and called the Pinedale), mountain glaciers formed in the Montana area (Fig.1). Slow-moving glaciers picked up and transported rock fragments (glacial till). The glacial benches in the area were formed during earlier glacial melts depositing sediment and the erosional scarps were formed by a later glacier outwash. There are three layers of glacial till deposits (Pers. comm. J. Sisson, 2010 - Fig.1). The total thickness of glacial bench is around 23m (Ritter, 1964).

Rock properties from the drillers log and our subsequent well logs in Well GB-1 indicate that the top 13m is soil and gravel. The gravel may be the youngest pulse of glacial deposits. From 15m to 25m, there is the red-color rock with an intersecting red fracture zone which may be interpreted as another pulse of glacial deposits. Below that, there is a 15m thick red rock zone, which could be Amsden bedrock (Fig.2). To assess the thickness of the overlying till and provide information on the underlying stratigraphy, we have undertaken geophysical measurements.

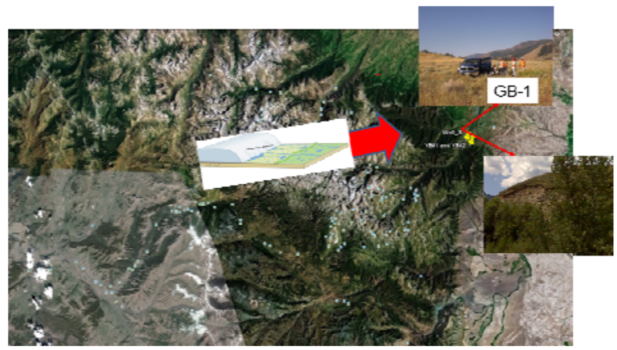

Figure 1: Geologic background of the glacial benches nearby well GB-1 and outcrop of glacial deposit.

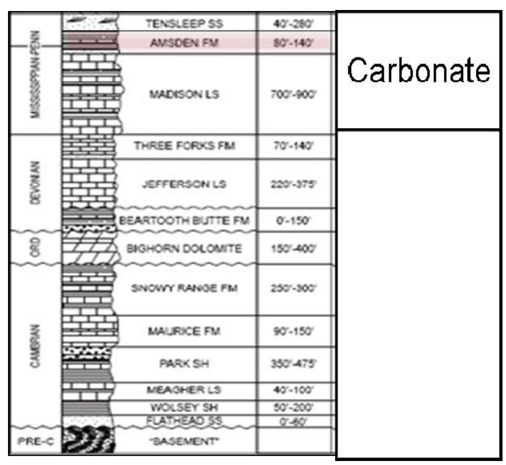

Figure 2: General stratigraphic column, near Red Lodge, Montana, with regional thicknesses (Kauffman et al., 2008, Adopt from Tania, 2010).

Data available (Well logs, VSP, 2D/3D surface seismic)

The suites of open-hole geophysical logs (conductivity, gamma, temperature, full wave sonic) were acquired in GB-1. Gamma ray and resistivity logs delineated the shale/sandstone bedding. The character of the full-waveform sonic first arrival times has similarities to the other logs (Fig.3). We also shot 2D and 3D surface seismic surveys. There is a clear reflection at the red fracture zone at 35m depth. The 2D seismic profile with 400m long (N50E) was acquired near the well GB-1. It totally has 192 receivers with 5m spacing. The source with 10m shot spacing. The signal record length was 600ms with 0.125ms sampling rate (Fig 4). The sweep of the vibrator is 15-160Hz, with a 3 fold source stack. The frequency of 2D seismic is about 100Hz. We did both AWD and vibrate truck 2D seismic acquisition, the vibrate truck 2D seismic image has been chosen in this study. For 2D seismic, there are three preliminary processing steps. Edit bad traces, edit geometry and refraction statics. After refraction analysis, there are two layers in the near surface (0m-45m) velocity model.

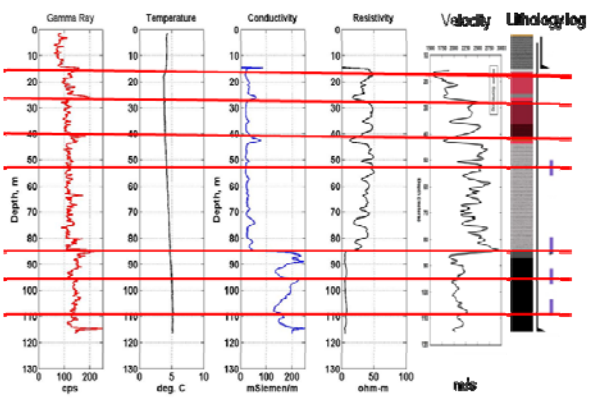

Figure 3: Geophysical logs from the GB-1 as acquired in 2010.

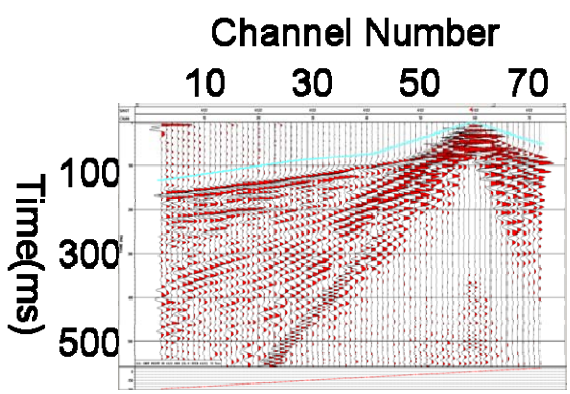

Figure 4: Typical shot record from the 2D seismic survey. The traces with 0.125ms sample rate and 600ms time length and the first break was picked in blue line. The inherent noise caused by ground roll.

The lithology log shows the well encounters about 13m of unconsolidated overburden and then goes through Red rock and a fracture zone (Fig. 5). Vertical seismic profiles (VSPs) were acquired in the Red Lodge GB-1 using an accelerated weight drop (AWD) and hammer as sources with a wall-clamping 3-component (3C) geophone and hydrophones as receivers (Fig. 6). The wall-clamping 3C geophone was placed at depths ranging from 4m to 114m with half-meter intervals. A hydrophone string covered the depths from 6m to 112m with half-meter intervals.

The purpose of this study is to interpret the VSP, surface seismic, and well log data and tie them to the glacial till thickness and other near-surface features. The 3m east offset VSP with accelerated weight drop source and 3C geophone was selected in this study. Low signal-to-noise ratios characterized the hammer source VSP data, so we did not use them in this study. The locking geophone with the AWD source gave data with good signal-to-noise ratios, but the hydrophone results appear strong affection of tube waves. The VSP was chosen to get the VSP image is the one with the 3C geophone and the AWD source at 3m offset. A selection of the Walk-away VSP with hydrophone array at common depth gather will be processed into AVO curve in the future study.

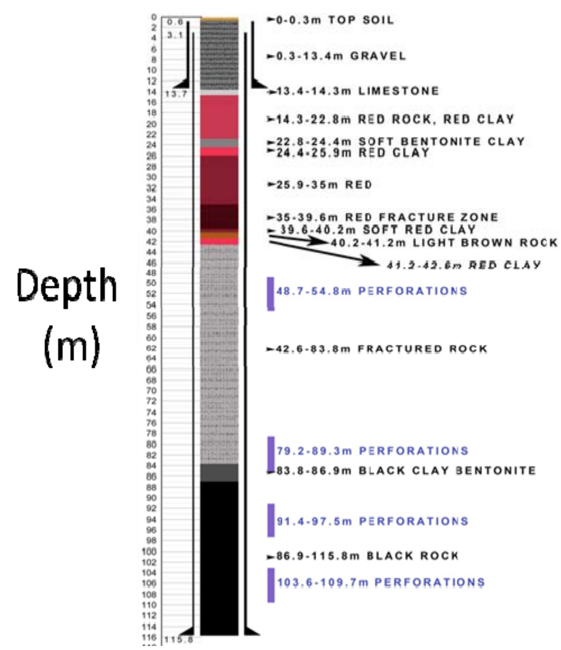

Figure 5: Lithology and casing program of the well GB-1 (from B H Drilling Comp. drilling report).

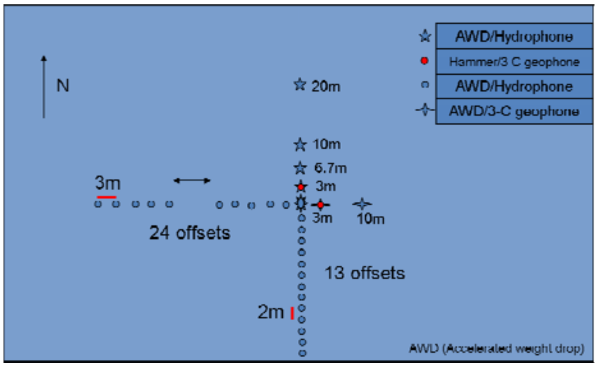

Figure 6: Base map of the well GB-1 VSP surveys.

Near-offset VSP processing

VSP acquisition geometry and first break picking

The VISTA seismic processing package was employed for analyzing the data. An essential step in VSP processing is the geometry input. This was done by sorting the data stacks according to Channel Number (primary sort) and Depth of Receiver (secondary sort) by creating proper trace headers.

The borehole receiver contains two horizontal components and one vertical component. The two horizontal components are named X and Y while the vertical component is named the Z component. The reflected upgoing P-waves were much stronger and clearer on the Z component compared to those on the X and Y components. There was not enough upgoing energy in the X and Y components to be processed, so we focused only on the vertical Z component. The near-offset VSP (3m offset) with the AWD source used the 3C geophone placed at depths ranging from 4m to 114m with half-meter intervals. The sampling time was 0.5ms.

Well GB-1 was close to a local electric power line, and we have experimented with notch filters to attenuate the attendant 60Hz noise. An Ormsby band pass filter with corners at 30-60-150-300Hz and 500ms automatic gain control (AGC) were applied to the Z component for display. A principal use of VSPs is to determine the variation of seismic velocity with depth (Stewart, 1984). The first break times were picked on the raw vertical Z component as is shown on Figure 7. Interval velocities are calculated by dividing the straight-line distances from source to receiver by the picked first arrival times. The resulting interval velocities show that P-wave velocities are in the range from 2000 to 3500m/s (Fig. 8). The VSP interval velocities follow the same trend as those on the sonic velocity log (sonic velocities ranged from 1500m/s in the very near surface to 3000m/s at 85m depth).

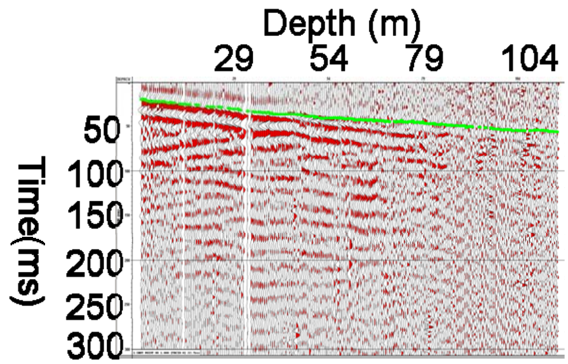

Figure 7: First break picking from the vertical component, display with AGC and Ormsby bandpass filter (30-60-150-300Hz).

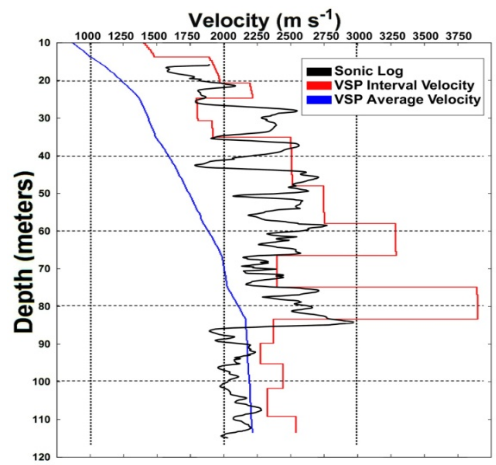

Figure 8: Sonic log, VSP interval and VSP average velocity comparison from the well GB-1.

Wavefield separation using median filtering

The next major processing step was to separate the downgoing from upgoing wavefields. The raw Z component was flattened to a 100 ms datum by subtracting the first break times from each trace (Hinds, 1996). Median filtering was chosen to separate the wavefields. The traces of a selected window were organized in ascending amplitude, and the middle value of the sequence is picked as the filtered value (Stewart, 1985). By subtracting the downgoing wave from the total field, we obtained the upgoing wavefield. A 21-point median filter proved best at isolating the downgoing events and, after subtraction, produced the most continuous and coherent upgoing events (Fig. 9). Muting was then applied to the first 100ms of the resulting gather showing upgoing events.

Deconvolution
The next step was to deconvolve the data using the downgoing direct wavefield to estimate the source signature. The deconvolution windows started at 0 ms and extended to 300 ms. This wide window was chosen because the data was found to not contain significant multiples within it. The deconvolution operator designed using the downgoing traces was then applied to the upgoing wavefield to get an estimated reflectivity series. After deconvolution, both upgoing and downgoing events appear to be sharper and better defined. And a 21-trace median filter was been applied to the deconvolved upgoing reflection events to flatten and enhance the reflectivity (Fig. 10).

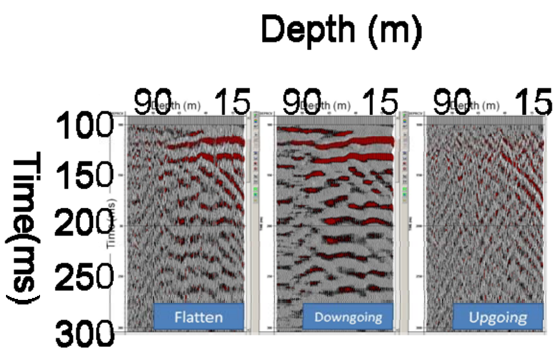

Figure 9: Wave field separation, display with AGC.

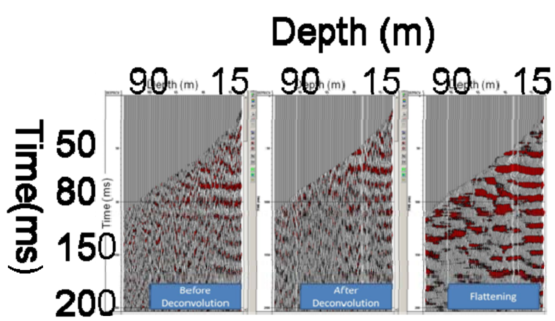

Figure 10: Decon. of upgoing wavefield, display with AGC.

Corridor stack
The upgoing P wavefield was converted into Two Way Time (TWT) by adding the first break time to every trace twice. This step produced the final estimate for the reflection coefficient series. In the field data, there is substantial of noise in the pre-stack profile. The corridor is the window along the edge, to avoid noise from the whole data profile. A corridor mute of 150 ms window length is applied to the data. Then the corridor muted data were stacked into one trace, and repeated 10 times for display (Fig. 11).

Conclusion

Different data types correlated reasonably well with stratigraphy encountered in the well GB-1. Seven events can be identified on the geophone VSP. Event 2 and 3 are interpreted as two glacial deposits. Event 4 and 6 are interpreted as boundary of glacial to upper Madison LS, and upper Madison LS to lower Madison LS. Event 5 and 7 are the fractured water tables. At 90m, there is black low velocity layer, it has been interpreted the bottom part of the Madison LS.

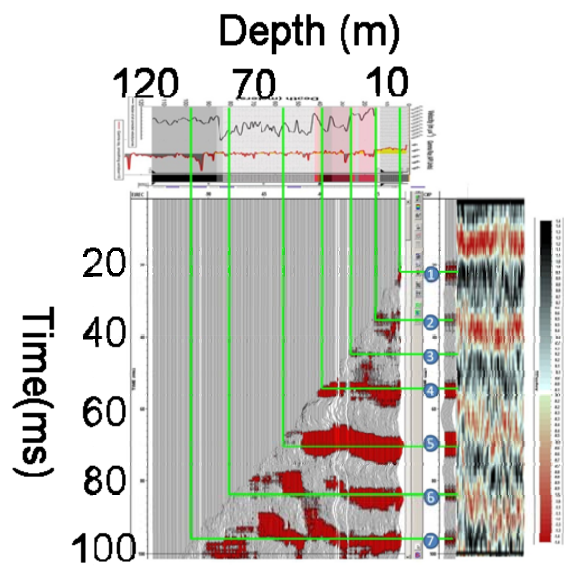

Figure 11: L-plot of VSP and sonic & gamma logs, and VSP corridor stack correlated with surface 2D seismics (stacked with 2500m/s velocity).

Acknowledgments

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EDITED REFERENCES

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