[PS]Geophysical Investigation of the Breccias Impact on Reservoir Quality in the Madison Formation, The Beartooth Region, Montana, U.S.A.*

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Abstract

The Beartooth area in Red Lodge Montana (USA) is a highly structured area due to the Laramide orogeny that caused thrust faulting of the strata including the Madison Formation. Geologic models show the existence of different types of breccias within the formation that resulted from different brecciation processes such as tectonics and subaerial exposure. Studies of the Madison Formation propose that breccias (particularly tectonic breccias) do not improve permeability due to the cementation of these breccias. Borehole geophysical data were collected from a well drilled through the uplifted Madison Formation overlain by alluvial deposits to examine the impact of brecciation on reservoir quality. Based on the data obtained, breccias have not enhanced permeability and reservoir quality because because of considerable amounts of calcite cementation present.

The VSP data shows that part of the Madison Formation has a relatively low P-wave velocity of 2650 m/s and a high Vp/Vs ratio of 2.23. These values indicate the Madison Formation has a lower rigidity than typical carbonate rocks. Hence it is likely that brecciation has cause increased attenuation/scattering of seismic energy whilst simultaneously decreasing the rock strength or rigidity. In addition to the VSP data, the gamma ray logs in the Madison Formation show relatively high values suggesting there are considerable amounts of radioactive minerals associated with the calcite cementation. Full waveform sonic logging is used to map the breccias through seismic wave attenuation. The full waveform sonic log data shows variations in the types of the waves attenuated within the breccias, suggesting a low connectivity of the breccias.

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Geophysical Investigation of the Breccias Impact on Reservoir Quality in the Madison Formation, The Beartooth Region, Montana (USA)

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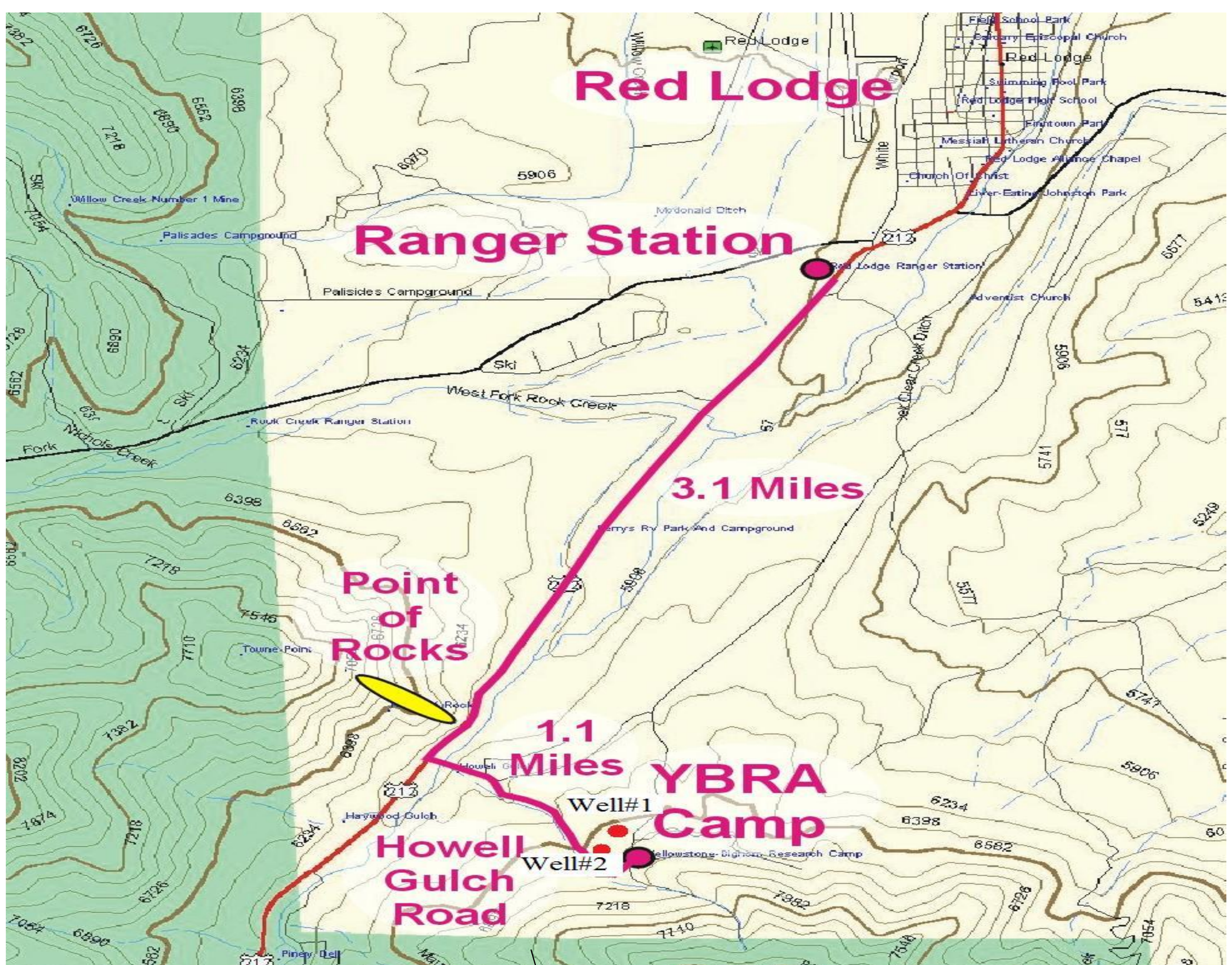
Abstract:

The Beartooth area in Red Lodge Montana (USA) is a highly structured area due to the Laramide orogeny that caused thrust faulting of the strata including the Madison Formation. Geologic models show the existence of different types of breccias within the formation that resulted from different brecciation processes such as tectonics and subaerial exposure. Studies of the Madison Formation propose that breccias (particularly tectonic breccias) do not improve permeability due to the cementation of these breccias. Borehole geophysical data were collected from a well drilled through the uplifted Madison Formation overlain by alluvial deposits to examine the impact of brecciation on reservoir quality. Based on the data obtained, breccias have not enhanced permeability and reservoir quality because because of considerable amounts of calcite cementation present.

The VSP data shows that the Madison Formation in the study has a relatively low P-wave velocity of 2650 m/s and a high Vp/Vs ratio of 2.23. These values indicate the Madison Formation has a lower rigidity than typical carbonate rocks. Hence it is likely that brecciation has increased attenuation/scattering of seismic energy whilst simultaneously decreasing the rock strength or rigidity. In addition to the VSP data, the gamma ray logs in the Madison Formation show relatively high values suggesting there are considerable amounts of radioactive minerals associated with the calcite cementation. Full waveform sonic logging is used to map the breccias through seismic wave attenuation. The full waveform sonic log data shows variations in the types of the waves attenuated within the breccias, suggesting a low connectivity between the breccias.

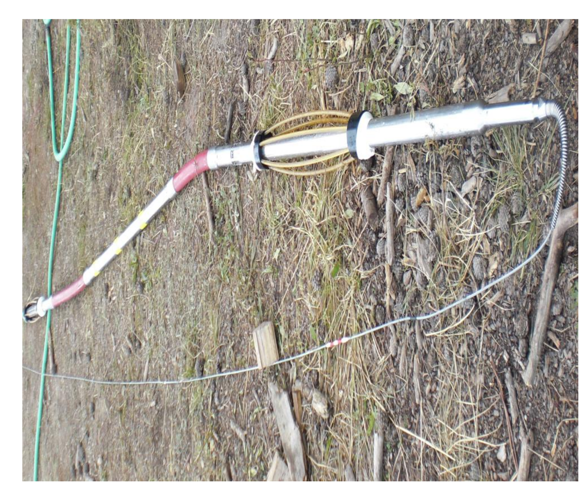
Study Area:



•Red Lodge Montana is near the Beartooth Mountains and close to the Elk Basin.
•It is a highly structured area because of the Laramide orogeny.

Methodology:

VSP using 3C geophones



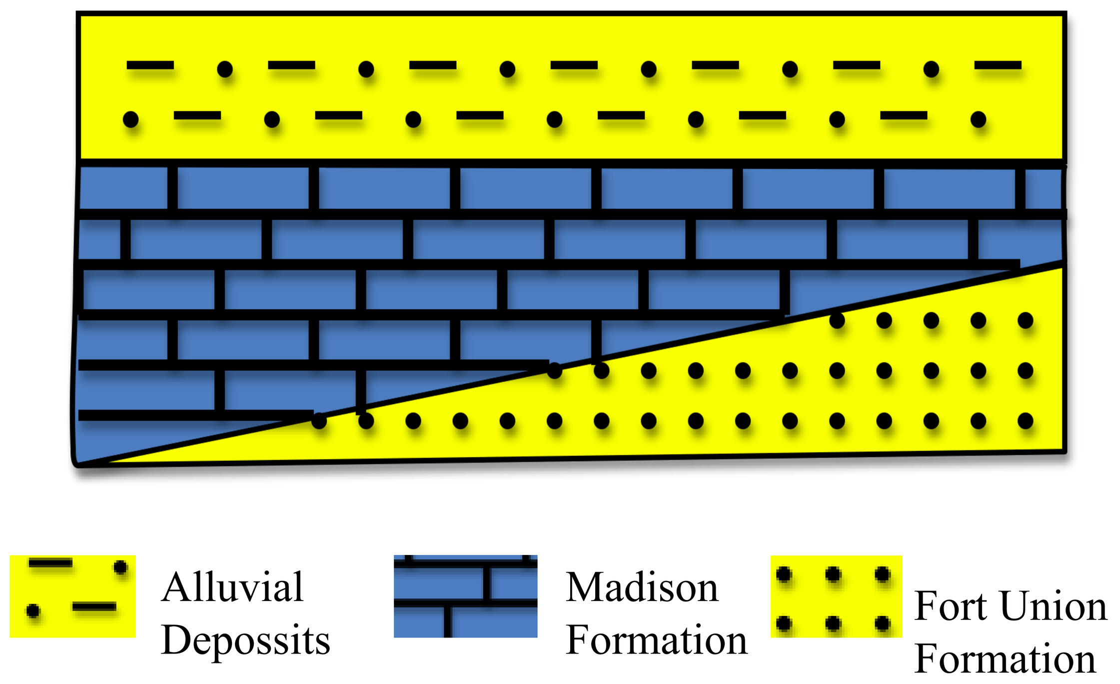
Full Waveform Sonic

Gamma Ray Logging

Drilled Well

The following data were collected from a shallow well drilled to study the Madison Formation in the area:
•VSP using 3C geophones to determine Vp and Vs and determine some rock properties based on them.
•Gamma ray log to examine any lithological or mineralogical changes down the borehole.
•Full waveform sonic log to observe the propagation of different types of seismic waves through the rocks.

Geologic Background:



Schematic Diagram of the strata encountered in the study area down the borehole

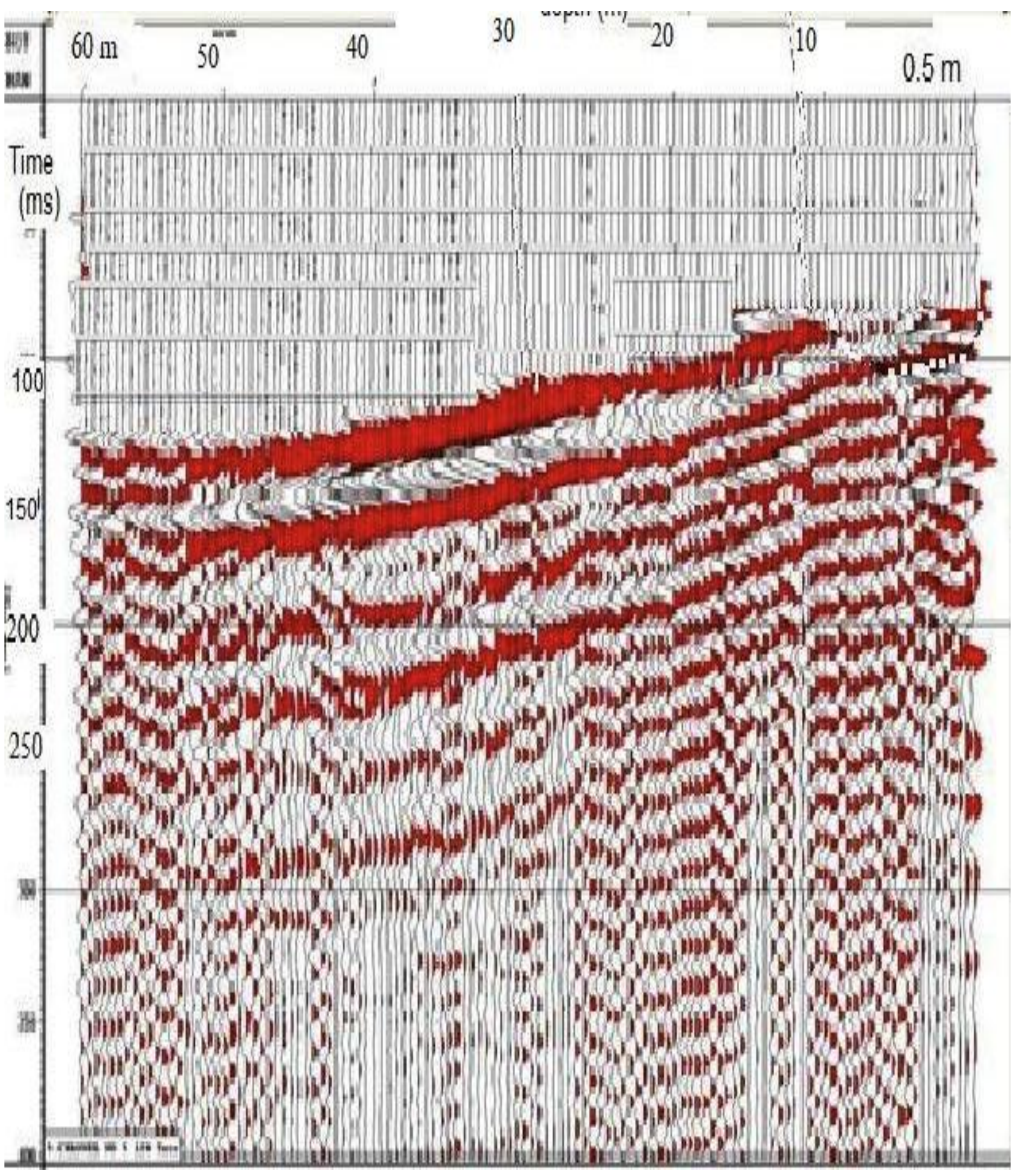
•The Madison Formation was deposited in the Early Mississippian in a carbonate ramp extending from New Mexico to Canada (Westphal et al., 2004) .
•Following the deposition is a period of subaerial exposure resulting in a time gap of 20 m.y.
•The Madison Formation was brought to its loaction in the study area by the uplift associated with the Laramide thrusting from the Late Cretaceous until the Eocene (Westphal et al., 2004 and Lopez, 2005) .

Breccias:

Three types of breccias can be found in the Madison Formation

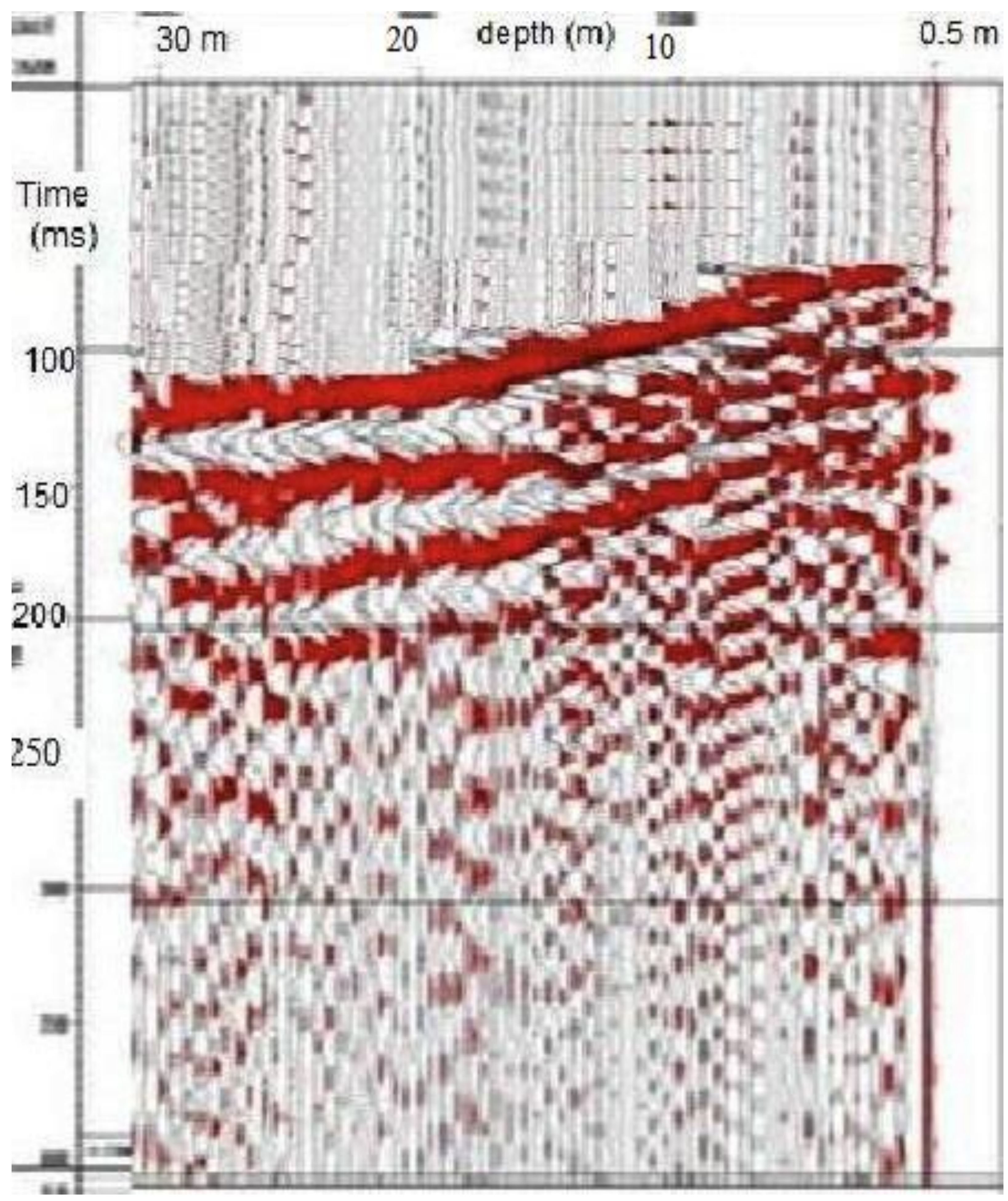
Dissolution Breccias	Tectonic Breccias	Collapse Breccias
These breccias resulted from post-depositional subaerail exposure	These are thought to be dissolution breccias caused by Laramide thrusting	These ones are caused by the collapse of evaporites
•They started as erosional karst topography overprinting the formation. •They are cemented with a red silt matrix (Demiralin et al., 1993) . •They are highly cemented.	•They are very common and dominant in the thrusted strata such as the study area. •The cement of these breccias is typically calcite. •Fractures, which typically have potential of improving reservoir quality, are commonly induced by these breccias.	•This type of breccias has a clay-matrix. •The degree of cementation of these of breccias is high.

VSP Data:



VSP record of the vertical component of the geophone

•The first arrivals on the zero offset VSP represent the downgoing P-waves which has a slope that changes in accordance to the change in the velocity of the encountered strata.
•The top and the base of the Madison Formation were picked at 5.5m and 33 m down the borehole, respectively, based on the change of the slope of the first arrivals.
•Traveltime inversion was applied to determine the P-wave velocity in the Madison Formation which is 2650 m/s.
•This velocity is lower than the typical P-wave velocity of carbonate rocks usually within the range between 5900 m/s to 6100 m/s (Middleton, 2003) .



VSP record of one of the horizontal components of the geophone

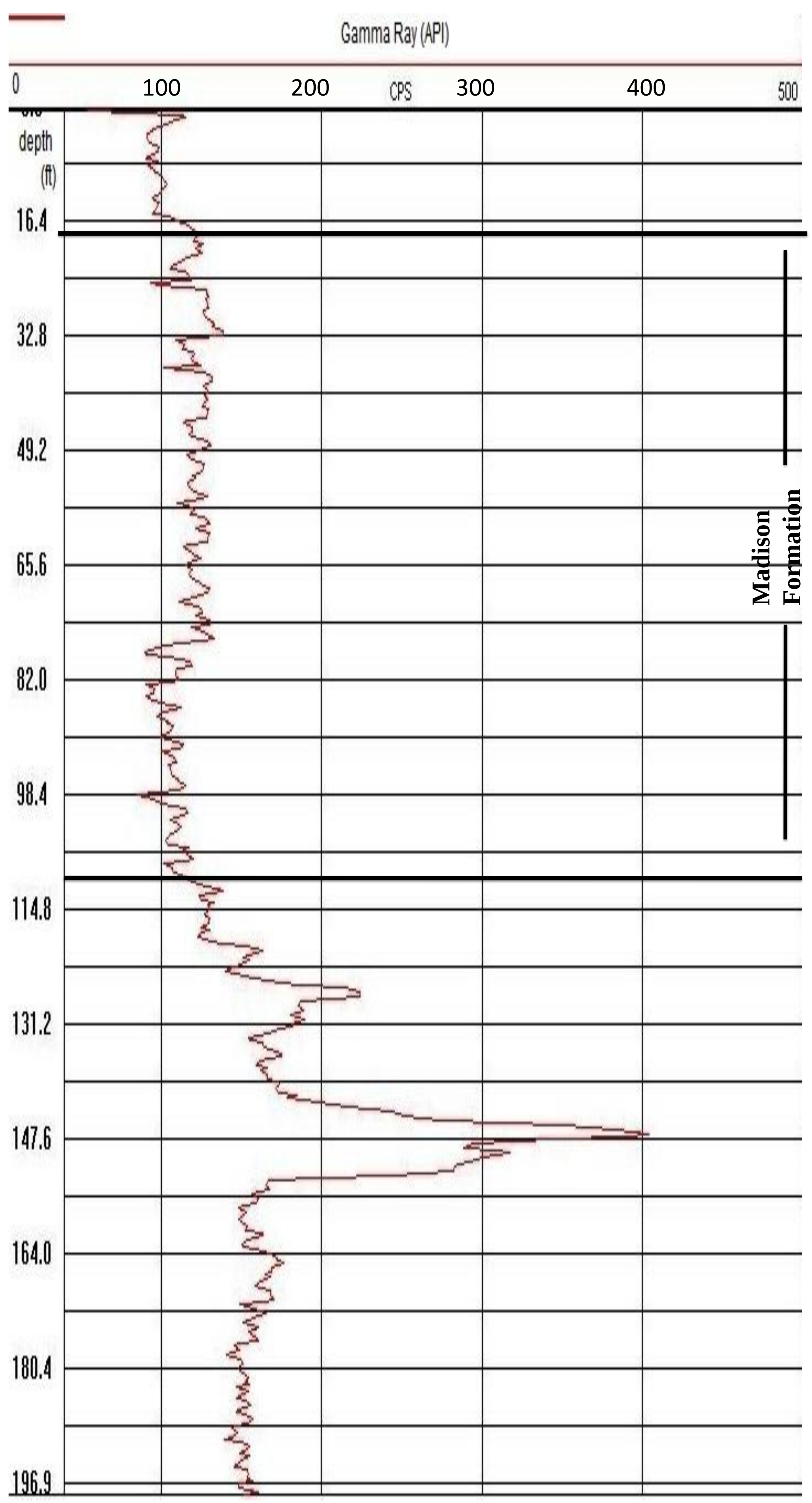
•The same Traveltime inversion method was applied to the horizontal component data to estimate the velocity of the S-wave.
•The same picks of the top and the bottom of the Madison Formation from the vertical component were utilized.
•Based on this method, the velocity of the S-wave turned out to be 1190 m/s.

Interpretations of the VSP findings:

•Vp/Vs of the formation is 2.23.
•This Vp/Vs is significantly higher then the typical value of Vp/Vs of carbonate rocks usually between 1.78 to 1.99 (Middleton, 2003) .

•The significantly high value of the Vp/Vs of the formation suggests lower rigidity of the formation compared to typical carbonate rocks.
•This drop in rigidity is most likely to have resulted from brecciation.
•This degree of brecciation has to be high and most likely fractures are induced because it reduces of the rigidity of the whole formation.

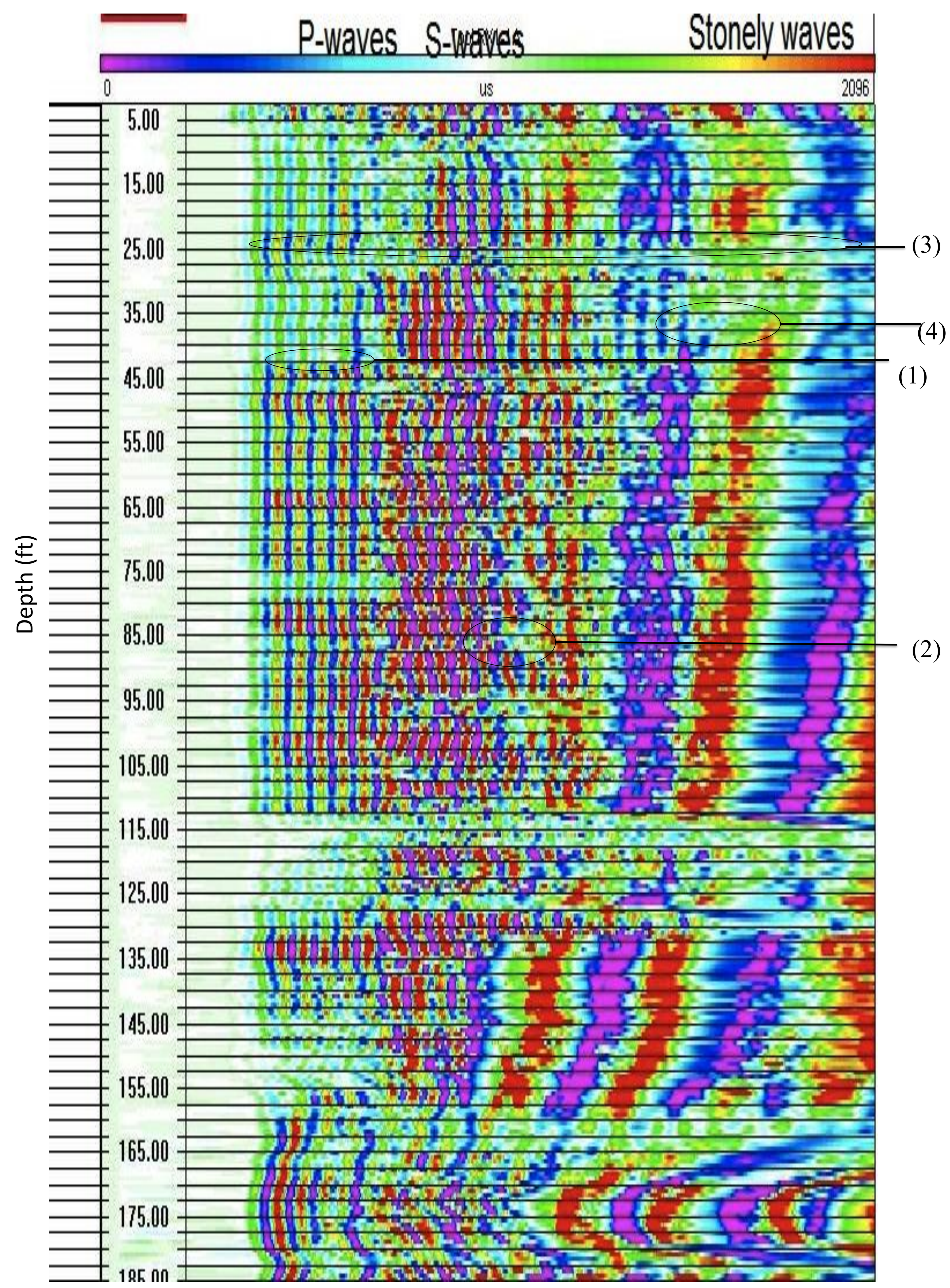
Gamma Ray Log:



Gamma ray Log

- The gamma ray log shows a very high value for the Madison Formation which is anomalous.
- This anomalous value is suggested to be related to secondary mineralization associated with the calcite cement of the breccias (Hart, 1958) .

Full Waveform Sonic Log:



Full waveform sonic log showing different attenuation patterns: (1) P-wave attenuation, (2) S-wave attenuation , (3) attenuation of all the wave types and (4) Stonley wave attenuation.

- Zones of attenuation of the seismic energy show selectivity to certain types of waves.
- Each type of waves indicates attenuation in a certain direction which implies that the attenuation of a certain type of waves implies that the spatial extension of a zone of attenuation is highly limited in a certain direction or orientation.
- Therefore, the zones of attenuation, which are breccias in this case, are limited in terms of spatial continuity and they are in the form of isolated compartments.

Implications on the Reservoir Quality:

- The gamma ray value shows that there is significant cementation of the breccias.
- The impact of that cementation can be seen on the signature of the breccias in the full waveform sonic log.
- Based on the full waveform sonic log, the breccias that are likely to induces fractures and causes attenuation of seismic energy are distributed in a pattern of isolated compartments.
- These breccias do not enhance the permeability of the Madison Formation in the area and hence they do not improve the reservoir quality there.

Conclusions:

- The Madison Formation in the study area provided a good geologic analogue to understand the impact of breccias on the reservoir quality of the Madison Formation.
- It can be seen that permeability and reservoir quality are not enhanced by any type of brecciation, as proposed by other geologic studies (Kartz et al., 2006 and Westphal et al., 2004) .
- Although this is a borehole study that aimed to image permeability of breccias, similar methodology can be applied by utilizing multi-component surface seismic and seismic attributes in a more sophisticated fashion to study complex and heterogeneous reservoirs, which are a typical characteristic of carbonate reservoirs.

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