Azimuthal Seismic Velocities and Field Fracture Mapping, Southern Moose Mountain

Mohammed Al Duhailan*
University of Calgary, Calgary, AB
maalduha@ucalgary.ca

and

Don Lawton
University of Calgary, Calgary, AB, Canada

Summary

This study investigated the variation of near-surface velocities derived by the inversion of first arrival data from a 3D seismic survey. A refraction interpretation method was used to analyze the refracted P-wave from shot-receiver pairs confined to different azimuthal sectors. Azimuthal velocity variations were interpreted in terms of the orientation of fracture systems in the Moose Mountain structure in the southern Canadian Rocky Mountains. Field mapping was undertaken to integrate the seismic interpretation with the dominant fracture pattern measured in carbonate rocks outcropping in southern Moose Mountain. Refraction velocity analysis revealed the existence of azimuthal anisotropy of (9%) in P-wave velocities with the fast velocity subparallel to structural strike. Field mapping of fracture data confirmed that the dominant fracture pattern is (type-2) fold-associated fracture pattern in which the fractures are oriented in a direction parallel to the structural strike.

Introduction

Moose Mountain, located within the Foothills, west of Calgary, is a surface anticline that exposes mainly Mississippian carbonates of the Rundle Formation. The structure is one of the prominent topographic features in the foothills of southern Canadian Rocky Mountains and is a good example of a doubly plunging anticline that can be observed at the surface. Figure 1 is a map of the area showing the general surface structural configuration.

The study is considered as an example of utilizing the concept of refraction seismology to detect the near-surface fractures. Both geological and geophysical interpretations were done to study the effect of near-surface fracture systems on refracted P-wave velocities by picking first-arrival seismic travel times in a 3-D reflection survey. The velocities were then related to field mapping of fracture trends evident in carbonate rocks in the southern Moose Mountain area.

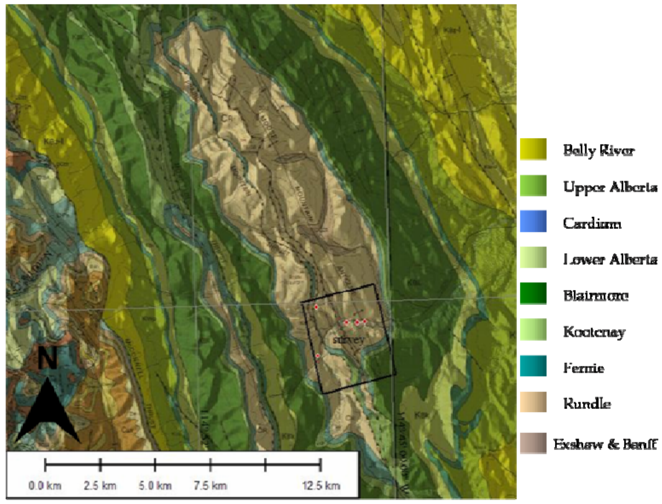

Figure 1: Surface geological map of the Moose Mountain area (modified after McMechan, 1995). The map shows an overlay of the digital elevation model in Global Mapper software. The seismic survey area is shown by the rectangle and red dots are the locations where fractures were measured.

Fracture Mapping

Within the survey area, three structural components can be observed: (1) a relatively broad anticline that is plunging southeast and located on the eastern area of the survey “eastern anticline”. This is the southern portion of the whole Moose Mountain anticline, (2) a tightly folded anticline bounded by two thrusts to the east and west, and is located in the middle of the survey area “western anticline”, and (3) the hanging wall of the major thrust (Prairie Mountain Thrust) and was called in this study “hanging wall” domain. Fracture data were measured at several localities (Figure 1) using the line traverse method. The fracture data were plotted on a rose diagram and overlain by the bedding attitude plot. The dominant trend of fractures is NW-SE which is subparallel to the trend of the axial plane of the Moose Mtn Anticline (336°) (Figure 2).

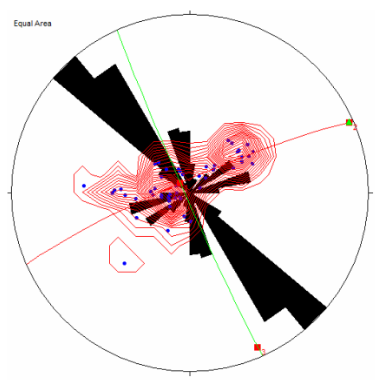

Figure 2: Rose diagram plot of fracture data (n=204). Notice the dominant fracture set trending NW-SE which is subparallel to the fold axial plane (red great circle).

Moose Mountain 3-D Seismic Survey

A 3-D seismic survey with 3-component receivers was acquired over Mississippian carbonates in the Moose Mountain area (Figure 3).

Moose Mountain 3-D	
Recorded for:	HUSKY ENERGY
Processed by:	KELMAN
Source:	DYNAMITE
# of Shots:	281
# of Receivers:	1129
Shot interval:	100 m
Receiver interval:	35 m
# of Shot lines:	7
# of Receiver lines:	11
Shot line interval:	560 m
Rec. line interval:	400 m
Bin size:	17.5 x 50
# of INLINES:	81
# of XLINES:	195

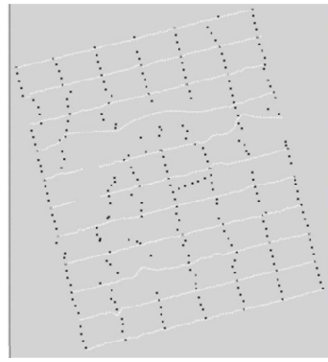

Figure 3: Moose Mountain 3-D survey layout. Dark circles are shotpoints and white lines are the receiver lines.

Workflow

Analysis of this survey was divided into stages (Figure 4) that include preparing the data for first arrival travel time estimation, dividing the data into groups of different azimuth sectors (Figure 5), and evaluating refracted P-wave velocities using the inversion method. The sectoring was based on the dominant fracture orientation.

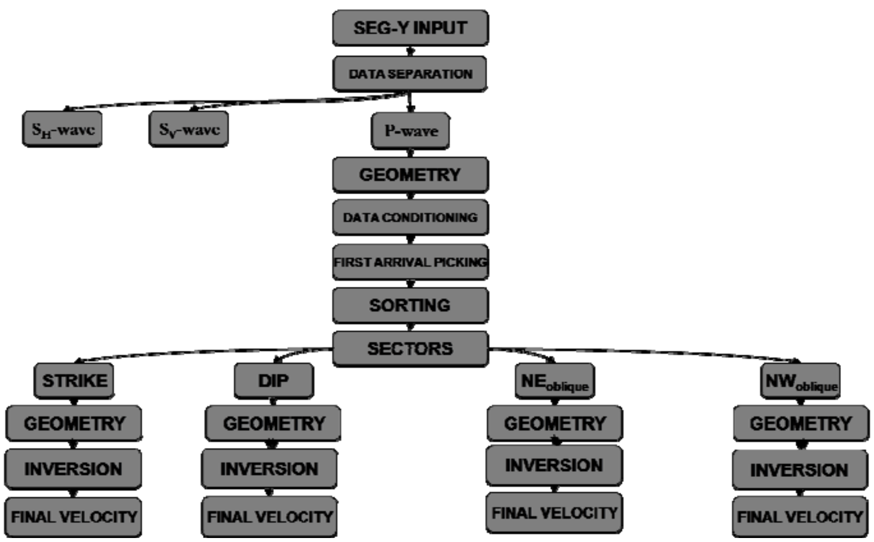

Figure 4: Data analysis workflow.

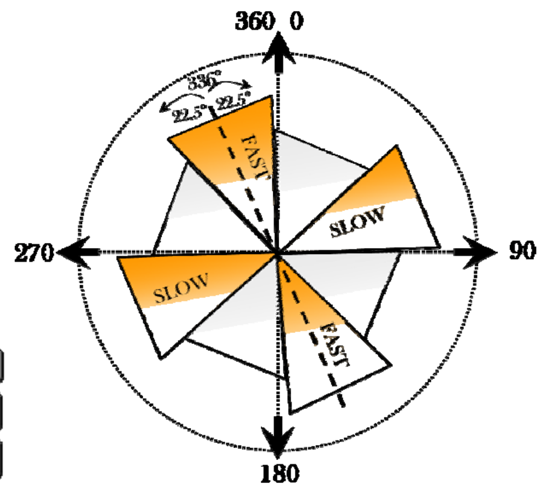

Figure 5: Azimuth sectors.

Results

As a result of the analysis, P-waves traveling between shot-receiver pairs trending nearly along the strike of the structure were found to have a faster velocity than the P-waves traveling in the dip direction. Both the fast velocity model (strike sector) and the slow velocity (dip sector) were plotted versus the control points that have been used to create the velocity models of shallow carbonates (Figure 6). The spatial distribution of the anisotropy parameter ε is shown in Figure 7. The final two velocity models that were derived by the GLI inversion are illustrated Figures 8 through 9. The area of greatest confidence in the analysis is within the rectangles since control points in these regions will have the optimum offset and azimuth distributions. A mean value of ε was calculated to be around 9%

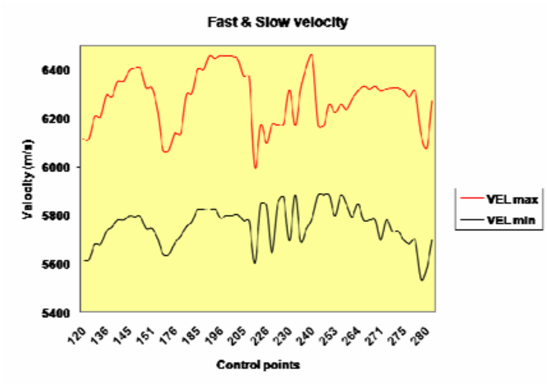

Figure 6: Fast (Red curve) and slow velocity (black curve).

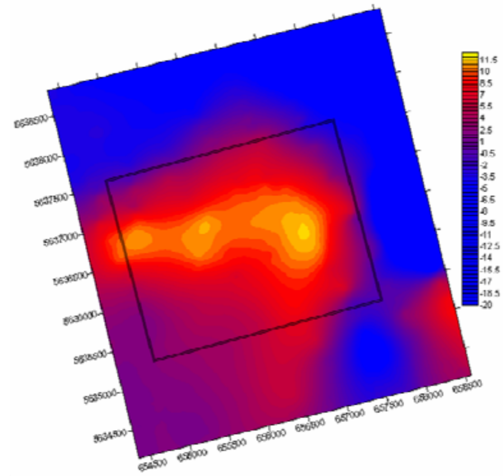

Figure 7: Map showing spatial variations in ε.

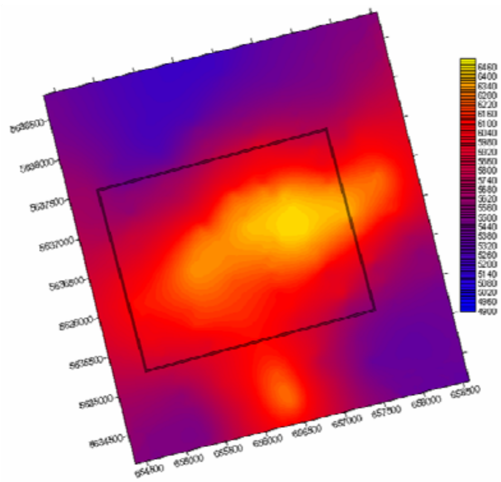

Figure 8: Velocity of the strike sector.

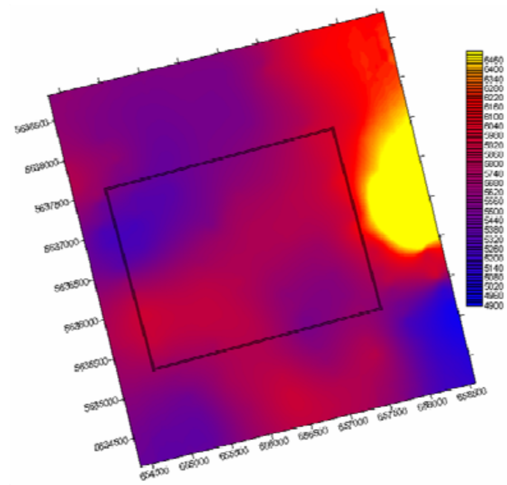

Figure 9: Velocity of the dip sector

Conclusions

Both geological and geophysical interpretations were done to study the effect of near-surface fracture systems on refracted P-wave velocities by picking first-arrival seismic travel times in a 3-D reflection survey and to correlate with fracture analysis on outcropping carbonate rocks in the southern Moose Mountain area. Azimuthal refraction velocity analysis revealed the existence of azimuthal anisotropy of (9%) in refracted P-wave velocities with the fast velocity subparallel to structural strike. Field mapping of fracture data show that the dominant fracture pattern is (type-2) fold-associated fracture pattern in which the fractures are oriented in a direction parallel to the structural strike.

Acknowledgements

We would like to thank the Fold-Fault Research Project members for their support of this project. Also, we gratefully acknowledge the support for this study by sponsors of FRP. We thank Husky Energy, Devon Canada and Enerplus Resources for providing access to the seismic data.

References

McMechan, M.E., 1995. Geology, Rocky Mountain Foothills and Front Ranges in Kananaskis Country, Alberta. Geological Survey of Canada, Map 1865a