AVO/LMR inversion and cross plotting for porous carbonates in Grosmont reservoir

John J. Zhang*
Arcis Corp., Calgary, Alberta, Canada
jzhang@arcis.com

and

Satinder Chopra, Somanath Misra
Arcis Corp., Calgary, Alberta, Canada

Summary

The porosity delineation on the cross plot of LR (Lambda * Rho) and MR (Mu * Rho) for well log data displays a specific pattern of change in the Grosmont formation, which serves as a template for porosity identification on the data volumes of LR and MR inverted from AVO analysis. The porosity predictions at well locations match the porosity well logs reasonably well.

The LR-MR cross plot indicates that the rate of changes [Δ(LR)/Δ(MR)] in LR and MR along the iso-porosity contour lines could not be accounted for by variations of the pore aspect ratio alone, which can only produce a small fraction of the observed gradient according to the Kuster-Toksoz modeling. Most likely, mineral compositions have a significant contribution. It can be shown that dolomite has a range of L (Lambda) and M (Mu) with a much higher rate of changes.

Introduction

AVO/LMR inversion provides a robust tool to extract the elastic moduli and density of rocks, which enables a more confident discrimination of lithology, porosity and pore fluids. This paper deals with its application to a carbonate reservoir.

The bitumen in Alberta has an estimate of 318 billion barrels potentially recoverable in the reservoirs of the Grosmont formation of Devonian age (Barrett and Cimolai, 2008). There are at least three types of pore spaces formed by a combination of dolomitization, fracturing and Karsting. The complex geological processes pose a challenge for us to locate oil-rich pockets of porous rocks.

In this paper, AVO/LMR inversion is presented with an emphasis on the LR-MR cross plotting to detect promising zones. The specific trend of porosity changes on the cross plot is also discussed.

AVO/LMR inversion and cross plotting

The pre-stack gathers are crucial for the subsequent AVO/LMR inversion processes. As shown in Figure 1, the synthetic angle gathers at the well location match fairly well the corresponding seismic angle gathers at the same place. This is a measure of our confidence. The gathers were used to generate P-wave reflectivity (Rp), S-wave reflectivity (Rs) and Density reflectivity (Rd) based on the linearized Zoeppritz equation (Fatti et al., 1994). These extracted reflectivities were then inverted for Ip (P-wave impedance), Is (S-wave impedance) and density. LR and MR were further calculated from Ip and Is.

The cross plot of LR and MR obtained from well logs of three locations reveals an overwhelming number of carbonates clustered between the dolomite line and limestone line or below, as indicated in Figure 2. The outliers above the dolomite line may result from inaccurate S-wave logs. Shale is lower in both LR and MR, which makes possible to separate from carbonates. The porosity contour on the cross plot for the pure carbonate is illustrated in Figure 3. It appears

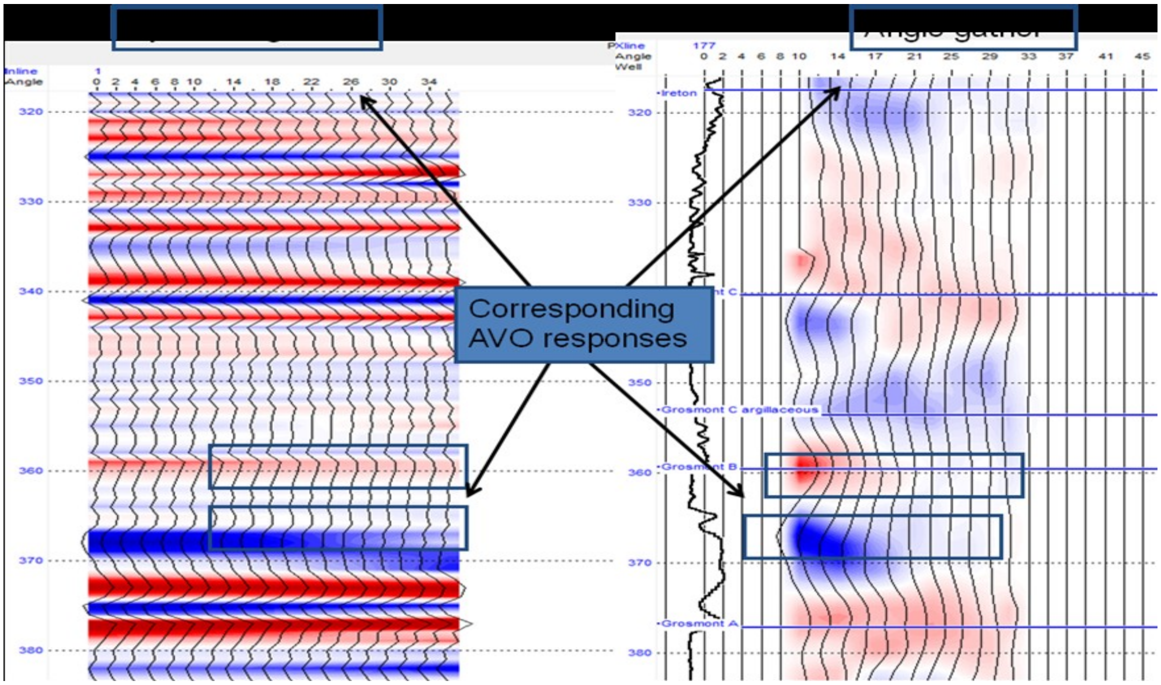


Figure 1: Synthetic and real seismic angle gathers indicating corresponding AVO responses

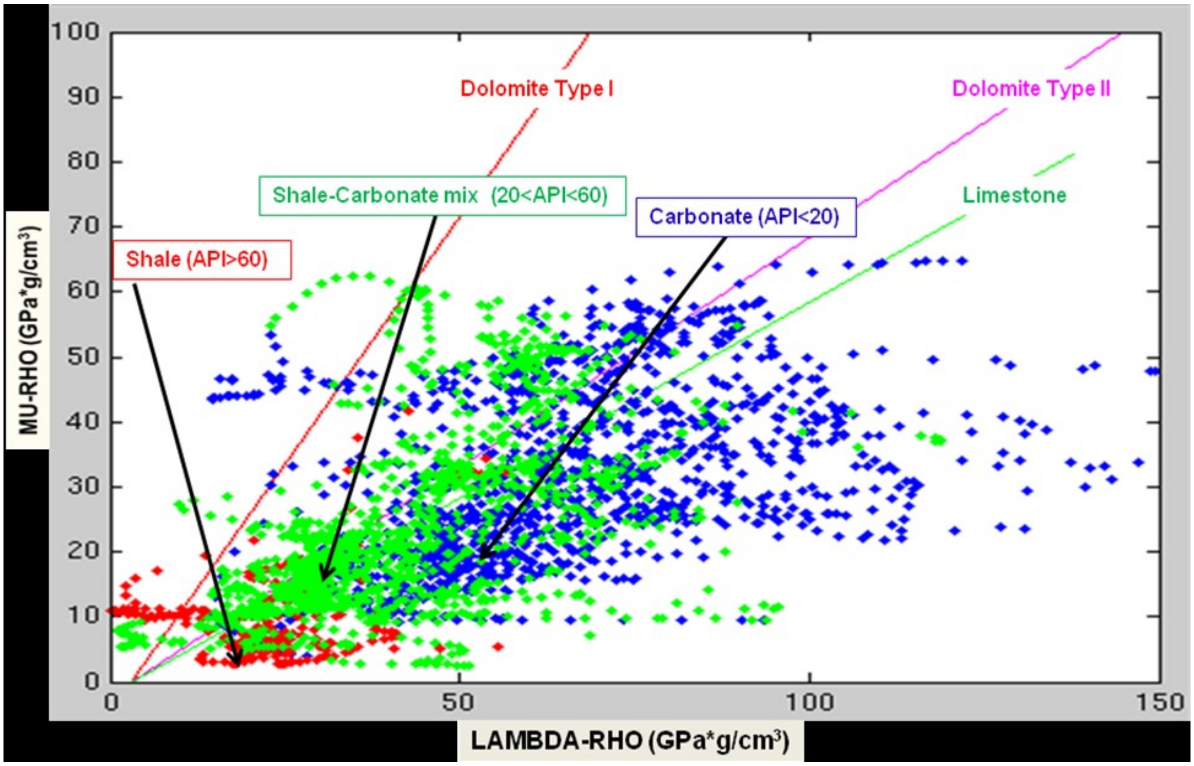


Figure 2: Cross plot of LR and MR obtained from well logs

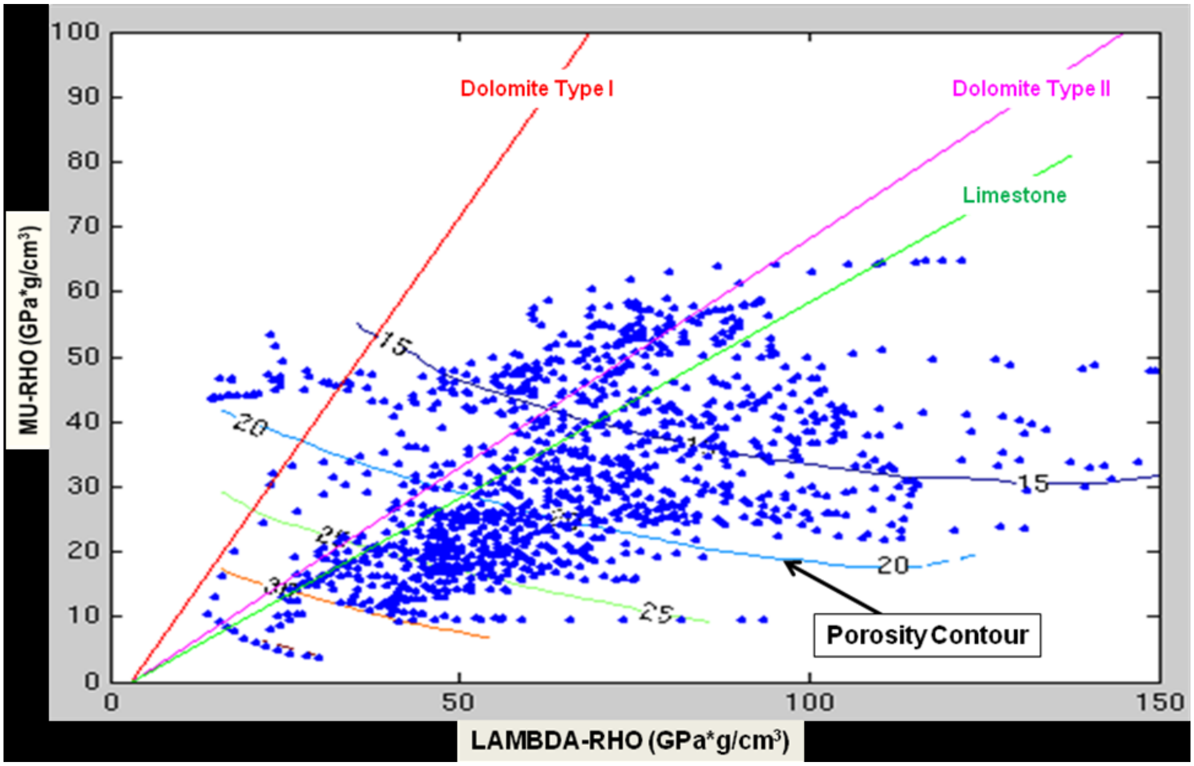


Figure 3: Porosity contour on the LR-MR cross plot for pure carbonates (API<20)

that the contours are approximately perpendicular to the dolomite line and porosity decreases with increasing LR and MR. This template predicts the porosity profile on well logs with considerable accuracy, as in Figure 4 for one well. Its application to the data volumes of LR and MR also presents a reasonable result in Figure 5.

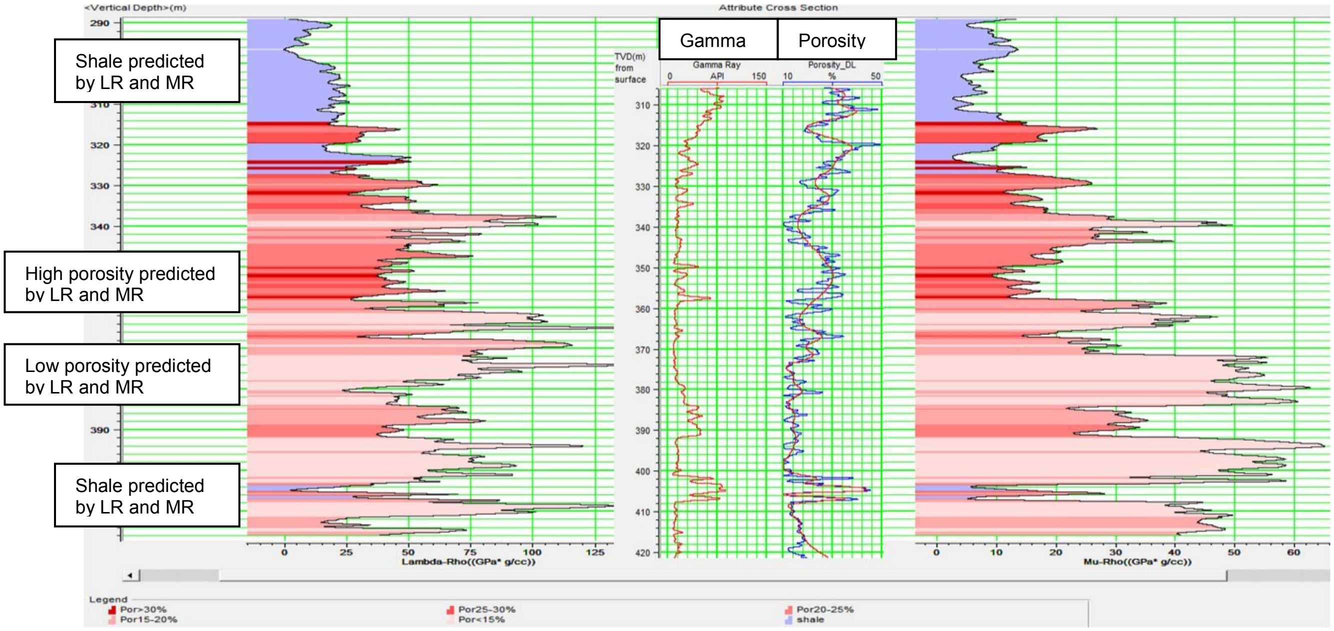
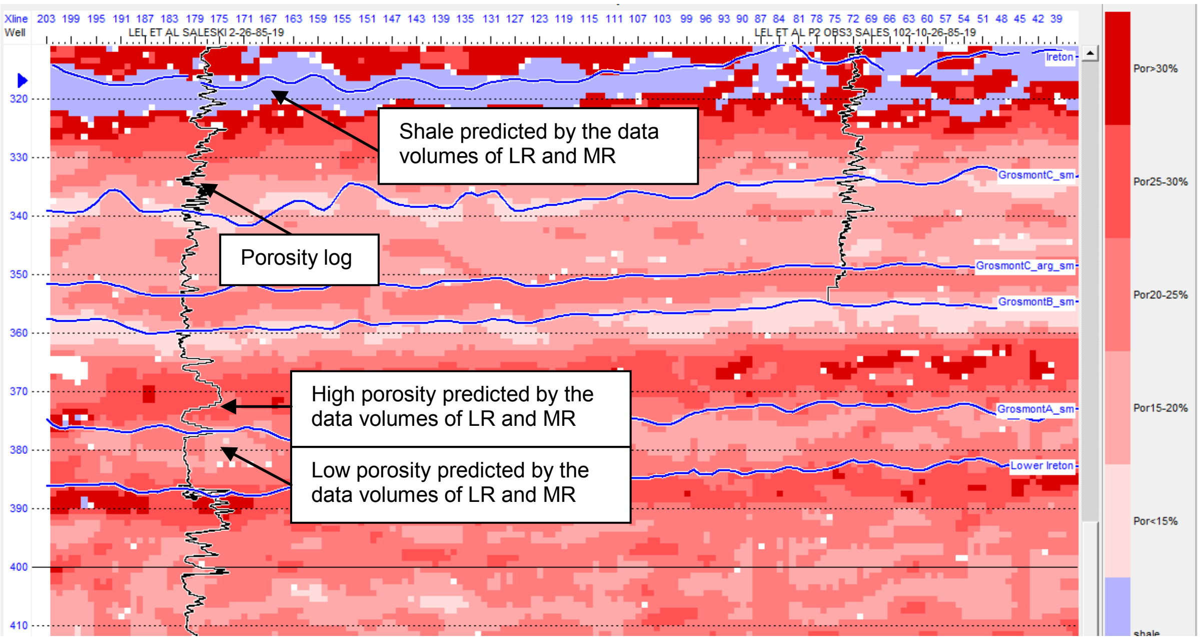


Figure 4: Porosity predictions from LR and MR on well logs



Shale predicted by the data volumes of LR and MR

Porosity log

High porosity predicted by the data volumes of LR and MR

Low porosity predicted by the data volumes of LR and MR

Figure 5: Porosity predictions on the data volumes of LR and MR indicating their fit to well logs

Interpretation of iso-porosity contour lines

A careful examination of the porosity contours in Figure 3 shows that along the iso-porosity lines, LR and MR are inversely proportional to each other and the rate of changes [$\Delta(LR)/\Delta(MR)$] goes as high as 3. According to the Kuster-Toksoz forward modeling (Zhang, 2001), variations of the pore aspect ratio can introduce a maximum of 2/3 gradient. The rest are most likely from changes in mineral compositions. Dolomite ranges in (L, M) from (35, 51.6) to (64.9,45) GPa (Mavko et al., 1998). These different types of dolomite exhibit the rate of changes up to 4.5. With these two factors, the pattern in Figure 3 can be modeled using KT equations.

Conclusions

The porosity contour on the LR-MR cross plot for well logs demonstrates a specific pattern, which was successfully employed to identify porosity using LR and MR from well logs and from AVO/LMR inversion. LR changes inversely with MR along the iso-porosity contour lines, which is believed to result from both different types of dolomite and variations of the pore aspect ratio.

Acknowledgements

We'd like to thank an anonymous data sponsor for allowing the contents to be presented.

References

Fatti, J. L., Smith, G. C, Vail, P. J., Strauss, P. J., and Levitt, P. R., 1994, Detection of gas in sandstone reservoirs using AVO analysis: A 3-D seismic case history using the Geostack technique: Geophysics, 59, 1362-1376.

Barrett, K., and Cimolai, M., 2008, Geology and bitumen recovery potential of the Grosmont formation, Saleski, Alberta: CHOA Technical Luncheon (Reservoir & Production).

Mavko, G., Mukerji, T., and Dvorkin, J, 1998, The rock physics handbook: Tools for seismic analysis of porous media, Cambridge University Press

Zhang, J., 2001, Time-lapse seismic surveys: Rock physics basis, MSc. Thesis, University of Calgary