Case study: Comparison on shear wave velocity estimation in Dickman field, Ness County, Kansas

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Summary

Higher quality shear wave velocity has been pursuing since its importance in multi-component exploration. To better monitoring CO_2 sequestration, shear wave velocity (Vs) is needed to implement elastic numerical study on the target reservoir. A number of shear wave velocity estimation methods and their corresponding comprehensive comparison are presented in this article. The survey is situated in Ness County, Kansas, and the study is supported by DOE.

Introduction

The work presented here is part of the Dickman training project, which is based on the numerical simulation to monitor movement and containment of CO_2 in the reservoir, specifically, to make better quantification and sensitivity mapping of caprock integrity and potential leakage pathways. This will be accomplished by elastic wavefield simulation based on a previous DOE-funded CO_2 sequestration study site in Ness county, Kansas (Figure 1). A major challenge to the project is that no shear velocity data in the survey. We solved shear wave velocity (Vs) (Figure 2) from compressional wave velocity (Vp) by assigning the empirical Vp/Vs ratio to litho-zones interpreted from well logs. Vs results were generated by constraining input for strata that composed of both carbonate and sandstone sections.

Many efforts have been made to estimate Vs from Vp. Greenburg and Castagna (1992) have predicted Vs of sands with different fluid saturation based on empirical relationship between Vp and Vs in brine sands, with the calculation of fluid saturation effects by Gassmann equation. Xu-white (1996) have developed different method applying Kurst-Toksös porous model to build dry rock with different pore geometry (pore aspect ratio), with constrains of measured porosity and Vp, and fluid saturation effect on velocities estimated by Gassmann equation. Shear modulus and velocity were estimated based on the dry rock model. These methods were derived mainly from sandstone-shale rocks with no consideration of carbonate strata and carbonate-sandstone interbedded strata.

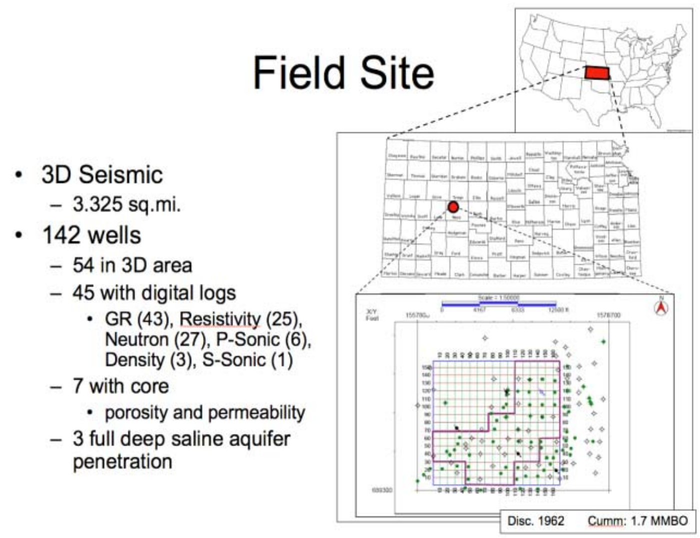

Figure 1: Dickman Field location and survey summary.

Lithology and Vp/Vs ratio assignment

Elastic wave simulation typically employs Vp, Vs and as well density for the simulation of a full seismic wavefield. Well Humphrey 4-18 was chosen as study location for 1D elastic forward modeling since it has a full log suit for lithology study and a full penetration to the CO_2 storage candidate (Figure 3). We observe that quality of density log and resistivity log of Humphrey 4-18 is not ideal, they are degraded by anomalous low and high.

Lithology and fluid volume affect the S-wave velocity and consequently the Vp/Vs ratio, and there are many mixed layers as well as pure shale, sandstone, limestone and dolomite in the Dickman section, therefore, we want to use locally lithology discriminators to determine lithology to establish elastic model. We took four logs (gamma ray (GR), density (RHOB), resistivity (RILD) and sonic (DT)) of Humphrey 4-18 into account (Figure 3) and extrapolate to the depth interval where not all logs are available.

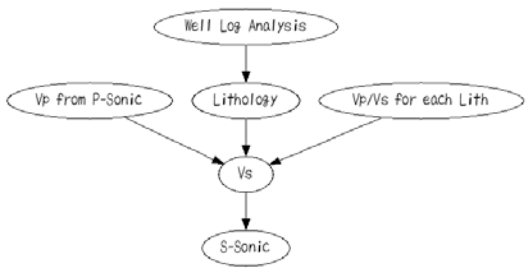

Figure 2: Flow diagram for estimation of shear wave sonic of Humphrey 4-18. Vp/Vs Ratios were taken from published studies.

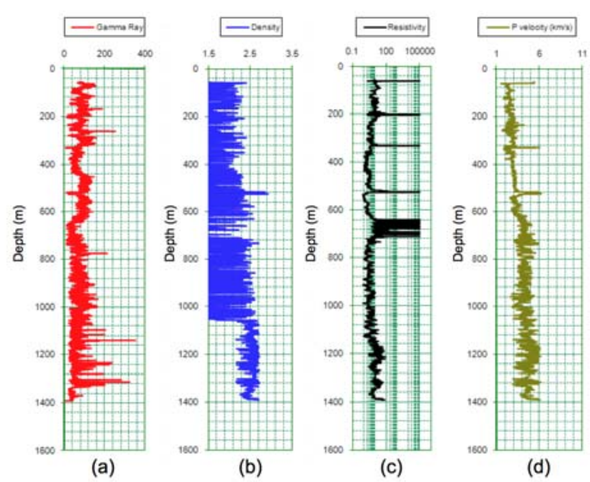

Figure 3: Humphrey 4-18 well logs. (a) gamma ray, (b) density, (c) resistivity, (d) sonic.

A simple index based on 3 logs to break the section into 4 or 5 discrete lithologies. We used gamma ray (GR) log, and photo-electric (PE) log and porosity log (practically NPOR+DPOR/2) as filters:

a. Gamma Ray (GR) was used to identify shale, sandstone, and carbonate based on cut-off values.

b. Carbonates were further filtered by PE log to distinguish limestone or dolomite. The PE log reads the size (area) of the reflecting surfaces of minerals. Pure calcite is the largest, reading around 5. Pure dolomite is smaller around 3.14, and pure sandstone is 1.9. Given a limestone-dolomite mixture the PE value of 5 was rarely seen (mostly between 3.3 and 4.4).

c. The resulting four lithologies are filtered by the porosity (using an imperial criterion, say using 5% and 20% as threshold values) to categorize lithology zones. There are 4* 3=12 types of different litho-zones, and the thickness of index varies with thickness of each litho-zone.

d. For each zone interval, say "porous sandstone", "tight limestone", we can assign Vp/Vs ratio based on table 1.

Who Conducted Measurement	Lithology	Vs/Vp
CONOCO Lab	Carbonates	0.42 to 0.50
	Sandstones	0.51 to 0.58
	Shales, Claystones	0.58 to 0.65
Schlumberger	Limestone, dolomite, and anhydrite in various proportions	0.53 to 0.55
	Sandstones and conglomerates with minor carbonates	0.60 to 0.63
Welex (Kithas, 1976)	Limestone	0.53
	Dolomite	0.56
	Sandstone	0.59 to 0.63
	Shale	0.56 to 0.59
	Dolomite, anhydrite	0.52 to 0.55

Table 1: Some empirical relationships between lithology and Vs/Vp ratio.

In figure 4, the shear wave velocity estimated by this method is shown by black curve. The predicted S wave velocity is consistent with P wave velocity in trend. The anomalies in shallow depth are caused by the low quality of input logs, especially the two anomaly high values at round 320m and 520m corresponding to the anomaly high values in sonic log at the same depth.

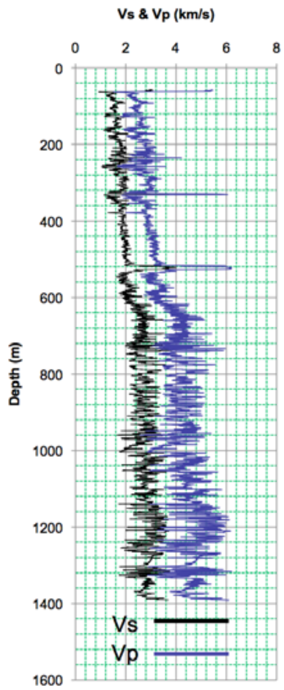

Figure 4: Estimated shear wave velocity of Humphrey 4-18 by geology constrain method.

Vs estimation by other methods

The effort was also made to estimate Vs in empirical Vs estimation method, Gassmann method, and Xu-White method. As same for the local geology constrain Vs estimation, Vp input is also sonic DT log of Humphrey 4-18 for these three Vs estimation methods, figure 5 shows the three estimated Vs by the corresponding method. The clay content is estimated from gamma ray log and the water saturation is from resistivity log and the porosity from density log. An average Vs over the three estimated Vs is then obtained, and figure 6 shows a cross plot of Vp and average Vs of Humphrey 4-18, the horizontal axis is average Vs and vertical axis is Vp. 8761 data sample are taken into account in the plot, and they match a linear relationship in general, the gradient of the linear relationship is around 1.624 which agrees with the sandstone domination geology in the survey. The standard deviation is 0.9693.

Discussion

The target strata in Dickman Field contains three sections in depth with different lithology, the Fort Scott and voila formation, which are in depth around 500m and 1000m respectively, indicate the depth where the changes begin: from surface to the Fort Scott formation, the strata are dominated by sandstone-shale (depth ranges around 0 to 500m), in this section Vs by four methods agree each other (see figure 7), The relative difference of prediction is less than 5% except a few less than 10%; in middle depth section from Fort Scott formation to Viola formation with interbeded shale and carbonate, Vs results gave diverse trend due to different sensitivity of lithology. In deep section beneath Voila which is dominated by carbonate, predicted Vs by empirical method gave overestimation systematically and tells the local calibration may be necessary. Our preliminary results show a good agreement to the sandstone-shale dominated shallow section. Further analysis is in progress for other sections with different lithology.

Conclusion

To better monitoring CO2 storage, we investigate various strategies to estimate shear wave velocity to establish optimal elastic model for subsequent multi-component processing. The estimated shear wave velocity results show well consistence in trend, and low percentage in differing, which assure us the reliability of the Vs we obtained.

Acknowledgement

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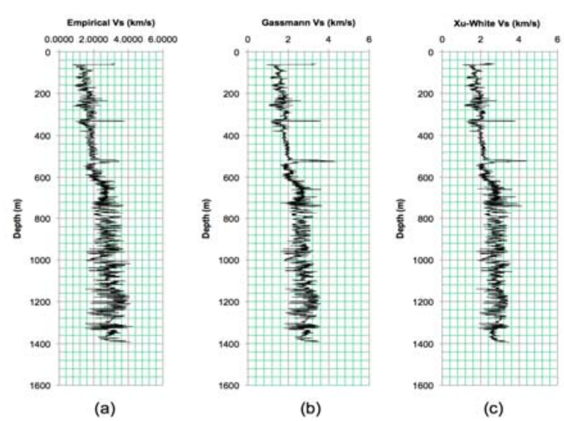


Figure 5: Estimated Vs by (a) empirical method, (b) Gassmann method and (c) Xu-White method.

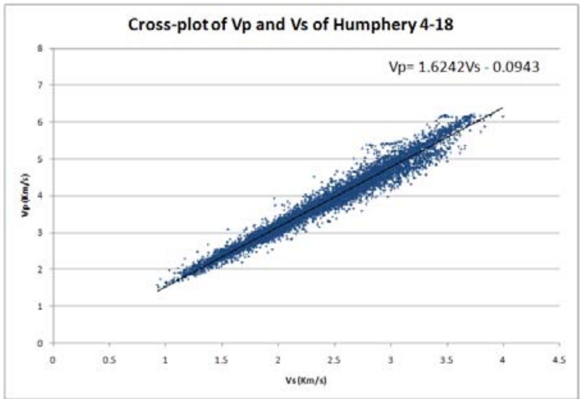


Figure 6. Cross-plot of Vp and average Vs of Humphrey 4-18.

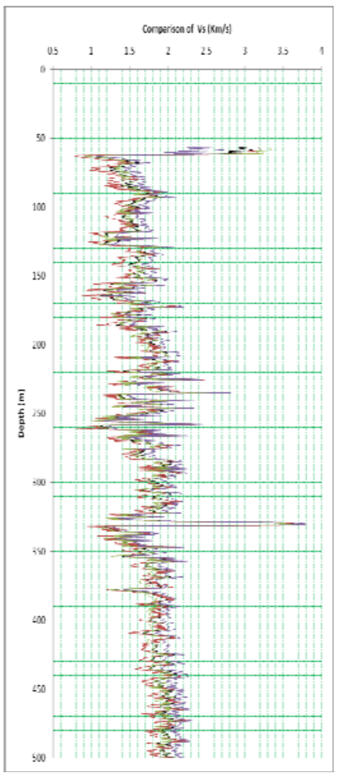
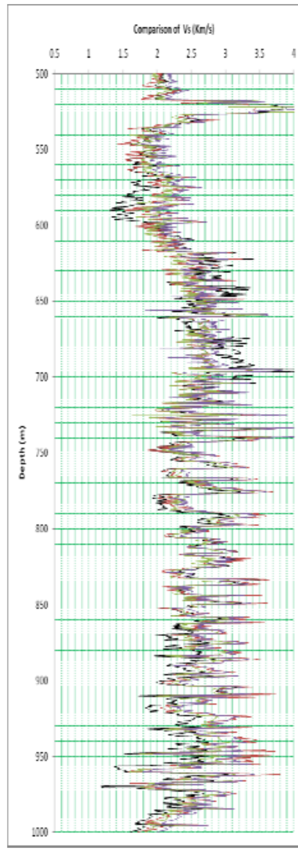


Figure 7. Comparison of Estimated Vs in depth between 0~ 500m by geology constrain method (in black), empirical method (in red), Gassmann method (in green), and Xu-white method (in purple).



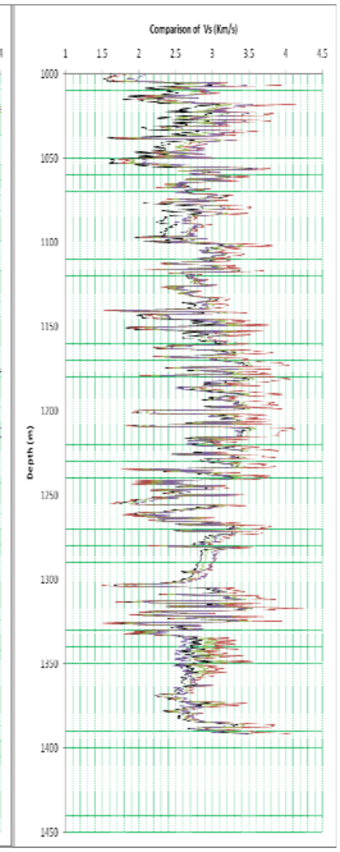


Figure 8 (on left). Comparison of Estimated Vs in depth between 500 ~1000 m by geology constrain method (in black), empirical method (in red), Gassmann method (in green), and Xu-white method (in purple).

Figure 9 (on right). Comparison of Estimated Vs in depth between 1000 ~1450 m by geology constrain method (in black), empirical method (in red), Gassmann method (in green), and Xu-white method (in purple).

EDITED REFERENCES

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