Investigating Gardner’s Rule and Reflection Multiplies via Supplied Well Log Data

GOPH 557

Lab Paper 1

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Contents

Summary

The intent of this paper is to analyze supplied well log data in order to differentiate velocities and apply the Gardner Relation. The laboratory revolves around exploring different interval depths for a lower and higher speed/velocity well. The measured or actual results are then contrasted with the Gardner Rule in order to gain insight to the similarity and relationship. Further on, this exercise takes a look at reflectivities in time, focusing on the primaries and multiples. Transmission loss is also investigated to understand the relationship between smaller interval times and layers. Ultimately one of the most general and underlying goals of this lab is to raise awareness and bring to light the fundamental problem of non-uniqueness within the field of Geophysics as a whole.

Introduction

The data set that the laboratory explores is the supplied well log data is from GOPH 517 - Time Series Analysis and 1D Processing. In specific, the two wells studied were located on the Blackfoot field. Matlab software was used in order to construct visualizations and figures. Well logs, such as this, are often inadequate, incomplete or missing. This comes from the fact that sonic logs (abbreviated SON) are run more frequently than density logs. Challenges are faced to create seismograms without density information (Margrave, 2012). Gardner followed the reasonable approach of seeking an empirical relationship between P-wave velocity and density (Gardner, 1974). The empirical relationship and mathematical equation will be looked at further down when theory is discussed. Further on using Matlab still, reflectivities in time will be looked by generating figures and correlating slopes. Multiple interval times designated as Dt will also be plotted to view how transmission loss is affected. To reiterate previously mentioned, a key problem that will be seen is the difficulty of distinguishing multiples in reflectivities which loops back to the earlier, underlying mentioned problem of non uniqueness within the field of Geophysics.

Theory

To delve into the theory, it is important to review some background equations first. Interested specifically in the P-wave velocity, it is defined as the following (Aki and Richards, 1980):

$$\alpha = \sqrt{\frac{(\lambda+2\mu)}{\rho}} \qquad (1)$$

After plotting P-wave velocity vs density, Gardner sought relationship by curve fitting assorted mediums. This essentially produced the following (Gardner, 1974):

$$\rho = a\alpha^{m} \qquad (2)$$

where a and m are parameters determined by plotting log(rho) vs log(alpha). The former will be applied as a Matlab implementation to view data on how closely Gardner's Rule applies.

The relationship for the transmission loss is outlined (Margrave, 2012):

$$\text{transmission losses} = \prod_{k=1}^{n-1} \left(1-R_k^2\right) \qquad (3)$$

However in the Matlab implementation, the transmission loss was calculated directly from the seismo function (Pan, 2015).

Laboratory Procedure and Data Analysis

The exercise started with first constructing four Ricker wavelets, one for each time sample interval. Additional parameters such as maximum amplitude and dominant frequency were also specified:

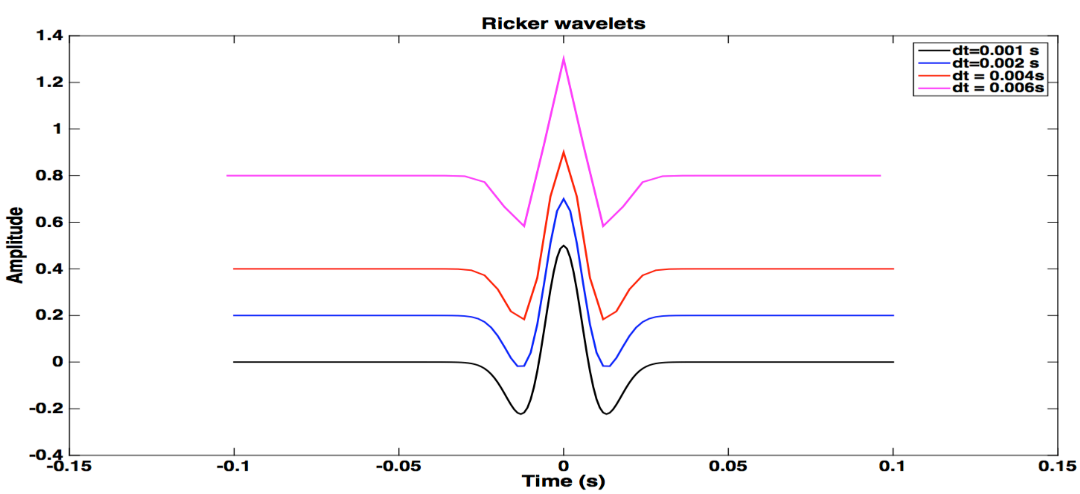


Fig 1: creating Ricker wavelets with different time samples

Synthetic seismograms were followed and then compared with the Gardner's Rule to gain an understanding of how that hypothesis relation is an acceptable standard for when densities of the subsurface may not be readily available. A high speed well (identifier 0808) vs. a low speed well (identifier 1227) are constructed with the Ricker wallets made previously:

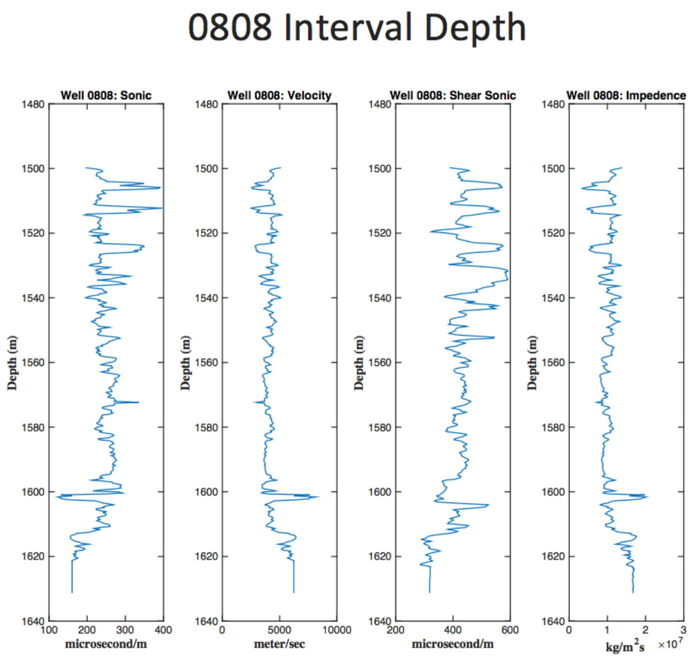


Fig 2: high speed well 0808 data

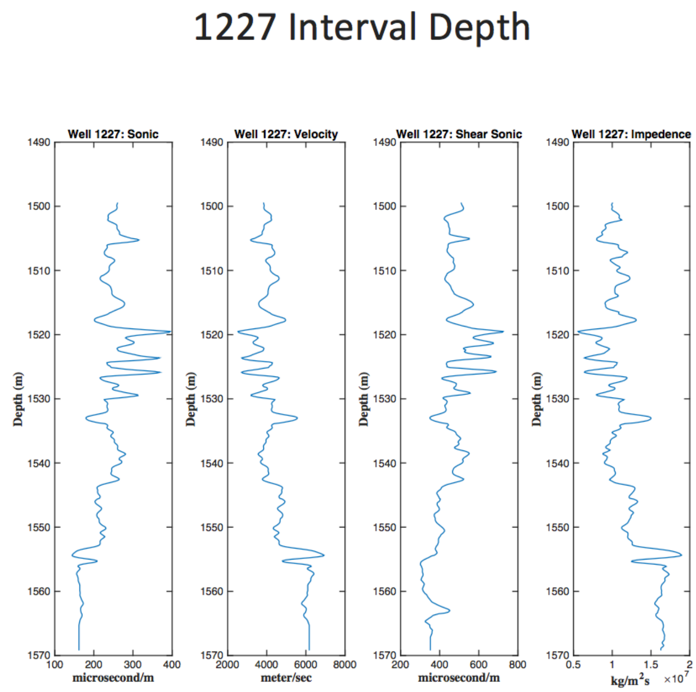


Fig 3: low speed well 1227 data analysis

Comments that can be made for the above figures are that the minimum and maximum velocities are approximately 2500m/s and 8000m/s respectively for well 0808. For well 1227, the minimum and maximum velocities are 2200m/s and 6900m/s respectively. Also to note is that from the rightmost impedance charts, a directly proportional case can be made for velocity and density (linear). Applying the equation from the theory section, Gardner's Rule can be viewed for both wells:

Gardner relation

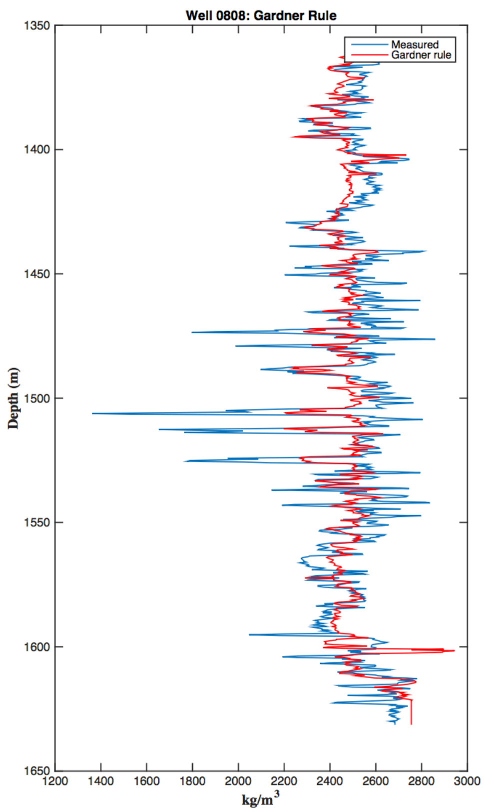


Fig 4: Gardner overlapping actual Well 0808

Gardner Relation

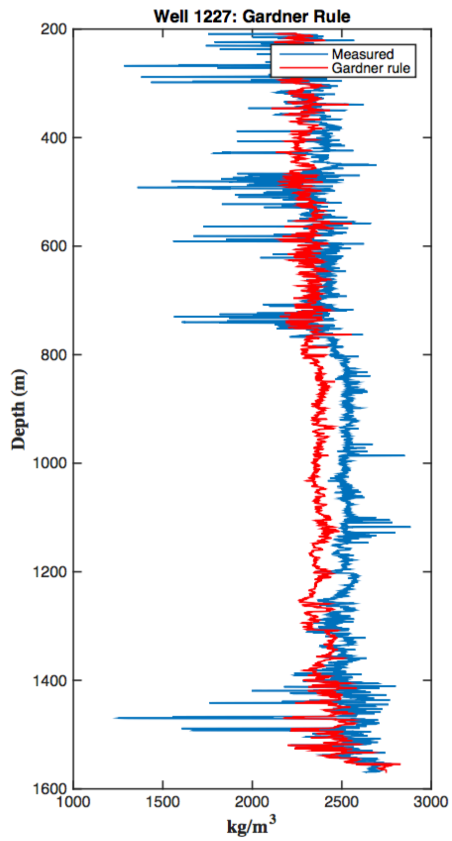
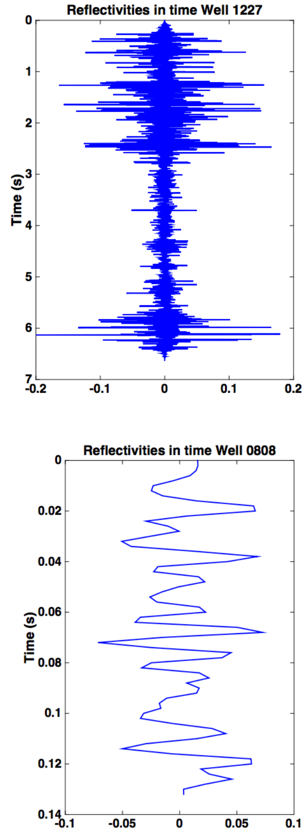


Fig 5: Gardner overlapping actual Well 1227

Analyzing the Gardner plot, a strong correlation is made with the actual data. However, a point to note is that for ‘extreme’ density values such as very high and very low, discrepancies are seen. At times, Gardner Rule ‘over’ and ‘underestimates’.

Moving along to plotting reflectivities, it is here where difficulty may arise in order to distinguish multiples. Closely spaced events or thinner layers would be ultimately harder to resolve. Smaller interval time also corresponds to greater transmission loss and more layers, which ultimately contribute to greater difficult in resolving non uniqueness.



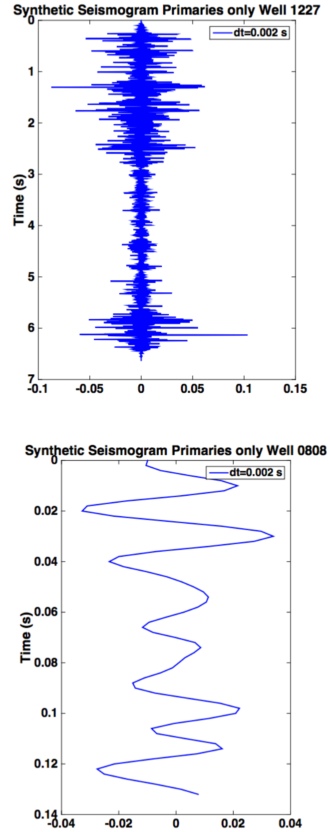


Fig 6:Reflectivities in time for Wells 1227 and 0808

Fig 7:seismogram construction for primaries only Wells 1227 and 0808

Due to the shallow or 'nonthick' nature of the 0808 well, it is hard to see much detail and information in the plotted figures of the well sample, reinforcing the problem where a multiple layer case in this specific well would be extremely difficult to distinguish. Transmission loss is also studied;

Transmission Loss

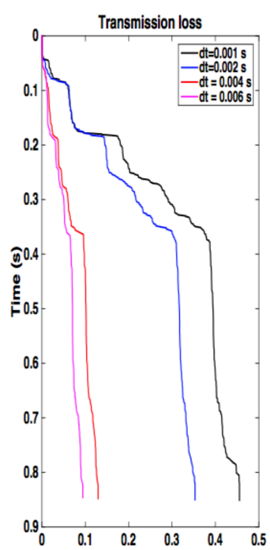


Fig 8: transmission loss as a function of time

Smaller interval time Dt implies more layers, which then leads to more terms being multiplied in the transmission loss geometric formula outlined in the theory section. Since the terms being multiplied are smaller than one, smaller interval time thus leads to greater transmission loss which is seen quite clearly in the plot above.

Discussion

To briefly recap the results and figures generated by the Matlab implementation of Gardner's Rule and reflectivity multiplies, a lot of correlations were found. Firstly, the Gardner Rule hypothesis was generally seen as applicable. It had a similar profile in the plotted figure when compared to actual results. Though it is worthy to mention that at the 'extremes' of the density numbers, it did over/under estimate the values.

In terms of reflectivity multiples, the exercise helped illustrate the underlying problem of nonuniqueness within Geophysics. The inclusion of multiples is very crucial to exploration seismology. These events have undergone more than one reflection. They are produced in the data gathering process when the signal doesn't take a direct path from the source to the geologic event and finally back to the receiver on the surface. This causes the signal to arrive back at the receiver at an erroneous time, which, in turn, causes false results and can result in data misinterpretation. The strong multiple effect observed is a reasonable prediction of real data. In reality, free surface multiples and internal multiples occur which the interpreter must be mindful of. Seeing a strong multiple effect thus in these wells can paint a picture of this phenomena which occurs in real world application. One must be careful when constructing parameters and constants to improve (or at least lessen) the affect of resolving events. In the case of a thin well log, it can be hard to resolve the layers and as such, a longer interval time Ricker wavelet may be necessary.

In this section it would also be helpful to go over a few key assumptions made and boundary conditions. One of the assumptions made to use the P wave velocity equation in the theory section was to assume a homogenous, isotropic, elastic solid medium for the subsurface. Stationary convolution and linearity of convolution is also assumed (Margrave, 2012). The noise is random, white noise. In terms of the boundary condition, we assume a homogenous half space extending downward with depth.

For future discussion, a fair number of improvements can be made to the paper. More well logs should be investigated with more consistent thicknesses. Exploring and implementing more complex mathematical models that eliminate some our of assumptions. More sample rate which would in turn produce a greater scope of Ricker wavelets could also be helpful.

Conclusion

Bringing it together, the paper aimed to illustrate Gardner’s Rule and how it can be used as a fairly accurate model for extrapolating well log data given the restriction on density. Even though in the specific exercise density was given in the data set, the Gardner Relation was investigated to gain an understanding as to how and why it could be implemented.

Further, reflectivity multiples were evaluated and the laboratory aimed to raise awareness into the issue of nonuniqueness. Further study discussion topics were mulled over to improve the experiment for next time and a recognition was given to the important assumptions and boundary conditions the lab employed in order to create our models.

References

Gardner, G.H.F., Gardner, L. W., and Gregory, A.R., 1974, Formation velocity and density - the diagnostic basis for stratigraphic traps

Margrave, G, F., 2012, Methods of Seismic Data Processing: GOPH 557 Course Notes

Aki and Richards, Quantitave Seismology Theory and Methods, 1980,