Enhanced Project Statement

Sam Poulter

Working Title: Regional trends in seismic Q through the North Sea Region

Internal Supervisor
Roger Clark
r.a.clark@leeds.ac.uk
0113-34-35221
University of Leeds
LS29JT

External Supervisors		
Charles Jones	James Selvage	James Beckwith
Osokey Ltd.	Osokey Ltd.	DataJAB
charles@osokey.com	james@osokey.com	py06jab@gmail.com
RG9 1AY, UK	RG9 1AY, UK	

Project Outline:

Aims:

To produce a regional view effective attenuation as derived from stacked traces & volumes data by applying the Spectral Ratio method to stacked seismic sections around the North Sea region in the Osokey AWS platform. This can then be used to analyse for any trends at various scales.

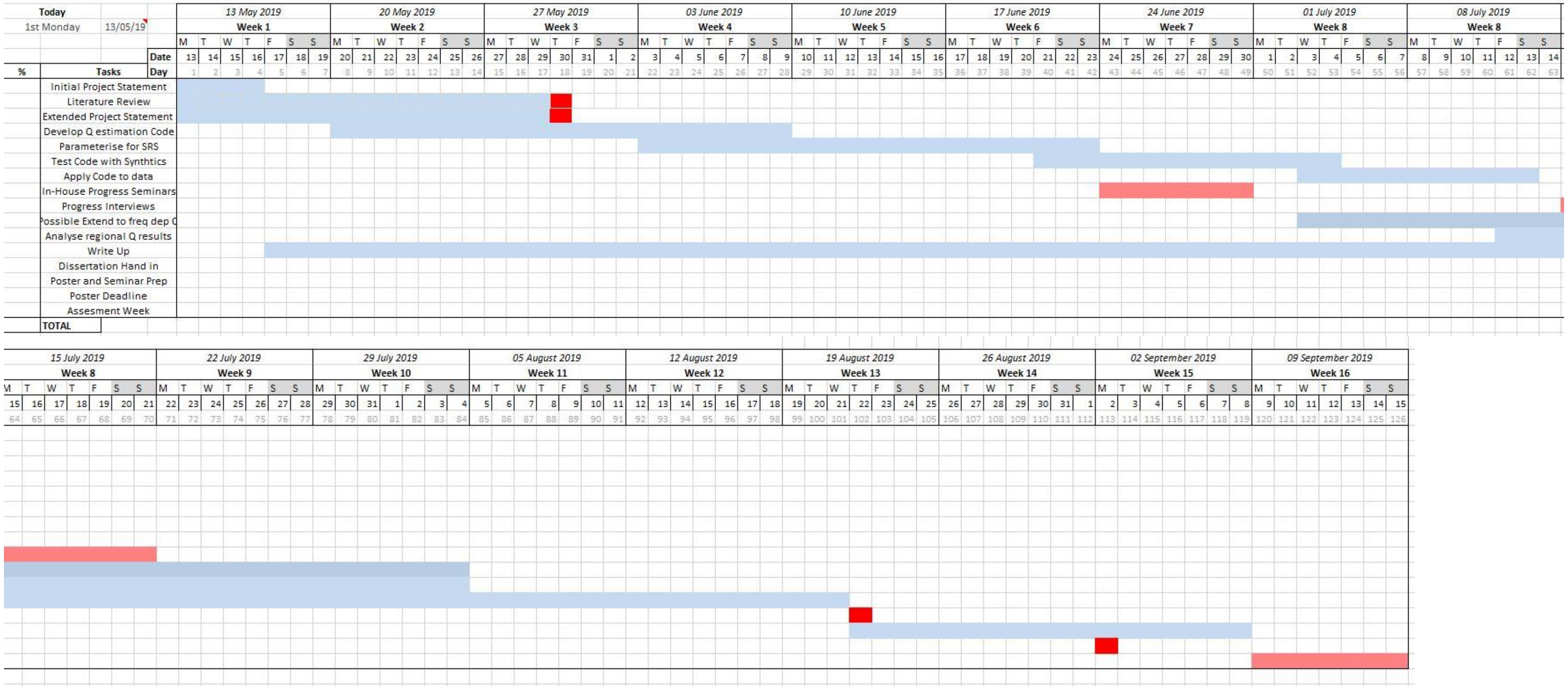
Objectives:

1. Decide which Q estimation method should be used ie Spectral ratio & Centroid Frequency
2. Develop an operational code for Q estimation.
3. Validate code by testing and applying it to synthetic wavelets.
4. Adapt code into AWS workspace and run on all UK regional lines
5. Asses any correlations of regional Q values
6. Compare Q methods impact on clustering
7. Asses if these correlations could be useful in predicting data quality and resolution

Data/Software:

MATLAB/Python

2D post stack sections


Today
1st Monday
13/05/19
13 May 2019
Week 1
20 May 2019
Week 2
27 May 2019
Week 3
03 June 2019
Week 4
10 June 2019
Week 5
17 June 2019
Week 6
24 June 2019
Week 7
01 July 2019
Week 8
08 July 2019
Week 8
Date
Day
%
Tasks
Initial Project Statement
Literature Review
Extended Project Statement
Develop Q estimation Code
Parameterise for SRS
Test Code with Synthtics
Apply Code to data
In-House Progress Seminars
Progress Interviews
Possible Extend to freq dep Q
Analyse regional Q results
Write Up
Dissertation Hand in
Poster and Seminar Prep
Poster Deadline
Assesment Week
TOTAL
15 July 2019
Week 8
22 July 2019
Week 9
29 July 2019
Week 10
05 August 2019
Week 11
12 August 2019
Week 12
19 August 2019
Week 13
26 August 2019
Week 14
02 September 2019
Week 15
09 September 2019
Week 16

Literature Review

Overview of Q

The seismic quality factor Q is used to quantify the loss of amplitude a seismic wave undergoes as it propagates through an attenuating medium (Knopoff, 1964). Q can be defined as the fractional loss of energy per cycle. (Equation 1) (Futterman, 1962).

$$\frac{1}{Q} \approx \left(\frac{1}{2\pi}\right) . \left(\frac{\Delta E}{E}\right) \text{ (1)}$$

Where $\Delta E / E$ is assumed to be a fixed loss of fractional energy and $\frac{1}{2\pi}$ is the fractional loss per cycle. Amplitude loss can be caused by dispersion effects such as geometric spreading of the wave front or energy loss at the partition of interfaces. The change in amplitude represents the fractional energy loss and be defined in terms of the absorption coefficient (Aki and Richards, 2002) α (Equation 2) and an exponential decay for a single-frequency place wave (Equation 3)

$$\alpha = \frac{\pi f}{VQ} \text{ (2)}$$

$$A(x) = A_0 e^{-\alpha x} \text{ (3)}$$

Effects on wavelet

Attenuation causes a loss of vertical resolution and results in a lower amplitude and lowers the dominant frequency of wavelets travelling through an attenuating medium. This is particularly true with Low Q materials as these have a higher drop off rate of amplitude with time.

Attenuation also has a significant phase affect as in order to have casual wavelets with an impulsive wavelet at t=0, lower frequencies must travel at slower than the high frequencies. This results in a dispersive wave where propagation velocity is frequency dependant.

Why measure Q

Due to the negative affects Q has on the wavelet phase and amplitude it is important in seismic processing to correct for attenuation (Kjartansson, 1979). With an accurate measurement of Q it can be used compensate for the loss of resolution using phase only inverse Q deconvolution (Wang, 2006) . Q estimation in 2D or 3D can also be used for Q tomography. Corrections for attenuation are also important for AVO analysis (Avseth, Mukerji and Mavko, 2005) particular at longer offsets where accurate amplitude information is needed. Also as frequency dependant Q results in dispersive velocity, acoustic impedance must also be dispersive which needs to be corrected for in order for accurate QI to be performed.

Q can also be used as an important petro physical parameter as the amount of attenuation depends on the properties of the fluid and the degree of porosity as well as rock frame properties. Variation in Q has also been shown to have a much larger variation in pressure and fluid saturation compared with the change in velocity (Koesoemadinata and McMechan, 2001) so could be better parameter for detecting these properties which are important in hydrocarbon exploration.

Apparent Attenuation

The Q value given in equation (1) actually relates to the effective attenuation (Q_{eff}) , a combination of intrinsic (Q_{int}) and apparent attenuation(Q_{app}) effects (Equation 4). (Spencer et al., 1982). It can be important to try and differentiate or understand the effect of apparent attenuation in order to QC the Q estimation result.

$$\frac{1}{Q_{eff}} = \frac{1}{Q_{int}} + \frac{1}{Q_{app}} \quad (4)$$

These include interference effects resulting from tuning of waves travelling through thin bed where the target arrival is distorted by arrivals from thin interfaces. A similar effect can also be caused by short path inter bed multiples which are not large enough to appear as separate events but distort the target wavelet. Another apparent attenuation effect is scattering which can occur in thin beds but also on pore and fracture scale. This results in a dampening of high frequencies and a lowering of amplitude.

Intrinsic Attenuation

Intrinsic attenuation has four major rock physics causes. A mechanical effect due to compression of fractures and microcracks which require energy to bend and compress that is higher than the stiffness (Dvorkin, Mavko and Nur, 1995). An effect exerted by the grain boundary, where elastic energy is lost to heat resulting in a loss of amplitude. (Johnston, Toksöz and Timur, 1979) The presence of fluid in rock pores can also cause attenuation especially if there are bubbles, or gas present. As the fluids and gasses are compressible energy is lost compressing the bubbles as the seismic wave traveling through the pore fluid.

Anelastic attenuation can also be caused at different scales by micro-, meso-, and macro scale poroelasticity (Pride, Berryman and Harris, 2004). 'Squirt Flow' mechanisms at a micro and meso scale , where energy is lost to friction and shearing when fluid is squeezed during compression as well as fluid flow in and out of fractures relative to the rock frame (Dvorkin, Nolen-Hoeksema and Nur, 1994). Seismic waves can also cause independent wave motion in the pore fluid due to peaks and troughs of the wave creating a pressure gradient. The fluid wave travels at a different velocity as the Biot Slow Wave. (Biot,1956),

As there is a large variation of scale length of attenuation mechanisms, the time scale must also vary. This would result in a Q values that changes with frequency (Sams et al 1997). and not a single constant Q values and a frequency independent value over the seismic bandwidth as is assumed in equations(1,2).

Field estimates

Attempts to measure Q for various rock types has been attempted in laboratories using sonic or ultrasonic frequencies. However, due to the frequency dependant nature of Q these Q values are not applicable to use on field data, as the frequencies used are much higher than the seismic bandwidth. Q estimation is therefore mainly done on field data such as to pre stack reflection or VSP data. (Chen et al., 2014)

This study will apply Q estimation techniques to 2D stacked seismic data as this is used as standard in industry as can be applied to large areas. However a problem with estimating Q from stacked traces is that the stacking during normal move out correction sums together traces from that have different travel paths resulting in a distorted and 'smeared' attestation signature. (Dasgupta and Clark,1998), This means components of the stacked trace will have longer travel paths and experienced greater amounts of attenuation or possibly travelled through areas of higher or lower Q. This can be attempted to be accounted for by restricting estimation methods to near- trace stacks in the common midpoint gather.

Methods of estimating

There are many methods for estimating Q these are mainly done wholly in the frequency domain or a combination in both the frequency and time domain (Tonn, 1991). Measuring seismic attenuation*,* in post stack data involves utilising a window function on a single trace in order to find the frequency spectrum at given time along the wavelet. (Reine, van der Baan and Clark, 2009). A common transform used is the Short time Fourier transform *(*Gabor,1946), which allows for frequency windows of the same length to be analysed along the entire trace.

*S*pectral Ratio Method

Q estimation can be done on post stack sections via the Spectral ratio method (Båth, 1982), by taking windows of two events along the wavelet and measuring the amplitude of the windows by converting them into the Fourier domain. The ratio decay of the amplitudes is then a function of the Q factor and the frequency so can be finding the gradient of plotting the log of the ratio against frequency.(Equation 5)

$$\ln\left(\frac{A(f)}{A_0(f)}\right) = -\frac{\pi t}{Q} f (5)$$

Centroid frequency-shift Method

As the earth acts as a low pass filter preferentially attenuating the high frequency component of the wavelet there is a decrease in the centroid frequency. (Quan and Harris 1997). For post stack data, the centroid frequency and variance can be estimated from the windowed power spectrum and compared to a window along the wavelet to estimate Q.

$$Q = -\frac{\sigma^2 \pi \Delta t}{f_1 - f_2} f (6)$$

Where σ^2 is the variance of the spectrum, Δt is the time between the centroids and $f_1 and\ f_2$are the centroid frequencies of the two windows.

These methods assume a frequency independent constant Q model however these estimation methods can be extended for frequency dependant Q. (Beckwith, Clark and Hodgson, 2017)

References

Aki, K., and P. G. Richards, (2002), *Quantitative seismology*, 2nd ed.: University Science Books.

Avseth, P., Mukerji, T. and Mavko, G. (2005). *Quantitative seismic interpretation*. Cambridge: Cambridge University Press.

Båth, M. (1982). *Spectral analysis in geophysics*. Amsterdam: Elsevier.

Beckwith, J., Clark, R. and Hodgson, L. (2017). Estimating frequency-dependent attenuation quality factor values from prestack surface seismic data. *GEOPHYSICS*, 82(1), pp.O11-O22.

Biot, M. A., (1956a), Theory of propagation of elastic waves in a fluid-saturated porous solid. i. low-frequency range: The Journal of the Acoustical Society of America, 28, 168–178. 3

Chen, Z., Chen, X., Wang, Y. and Li, J. (2014). Estimation of Q factors from reflection seismic data for a band-limited and stabilized inverse Q filter driven by an average-Q model. *Journal of Applied Geophysics*, 101, pp.86-94.

Dasgupta, R., and R. A. Clark, (1998), Estimation of Q from surface seismic reflection data: Geophysics, 63, 2120–2128.

Dvorkin, J., Mavko, G. and Nur, A. (1995). Squirt flow in fully saturated rocks. *GEOPHYSICS*, 60(1), pp.97-107.

Dvorkin, J., R. NolenHoeksema, and A. Nur, (1994), The squirtflow mechanism: Macroscopic description: Geophysics, 59, 428–438. 5

Futterman, W. (1962). Dispersive body waves. *Journal of Geophysical Research*, 67(13), pp.5279-5291.

Gabor, D., (1946), Theory of communication. part 1: The analysis of information: Electrical Engineers - Part III: Radio and Communication Engineering, Journal of the Institution of, 93, 429–441.

Johnston, D., Toksöz, M. and Timur, A. (1979). Attenuation of seismic waves in dry and saturated rocks: II. Mechanisms. *GEOPHYSICS*, 44(4), pp.691-711.

Kjartansson, E. (1979). ConstantQ-wave propagation and attenuation. *Journal of Geophysical Research*, 84(B9), p.4737.

Koesoemadinata, A. and McMechan, G. (2001). Empirical estimation of viscoelastic seismic parameters from petrophysical properties of sandstone. *GEOPHYSICS*, 66(5), pp.1457-1470.

Knopoff, L. (1964). Q. *Reviews of Geophysics*, 2(4), p.625.

Pride, S., Berryman, J. and Harris, J. (2004). Seismic attenuation due to wave-induced flow. *Journal of Geophysical Research: Solid Earth*, 109(B1).

Quan, Y., and J. M. Harris, (1997), Seismic attenuation tomography using the frequency shift method: Geophysics, 62, 895–905. 88

Reine, C., van der Baan, M. and Clark, R. (2009). The robustness of seismic attenuation measurements using fixed- and variable-window time-frequency transforms. *GEOPHYSICS*, 74(2), pp.WA123-WA135.

Sams, M., Neep, J., Worthington, M. and King, M. (1997). The measurement of velocity dispersion and frequency-dependent intrinsic attenuation in sedimentary rocks. *GEOPHYSICS*, 62(5), pp.1456-1464.

Spencer, T. W., J. R. Sonnad, and T. M. Butler, (1982), Seismic Q — Stratigraphy or dissipation: Geophysics, 47, 16–24.

Tonn, R., (1991), The determination of seismic quality factor Q from VSP data: A comparison of different computational methods: Geophys. Prosp., Vol. 39, 1-27

Toverud, T., and B. Ursin, (2005), Comparison of seismic attenuation models using zero-offset vertical seismic profiling VSP data: Geophysics, **70(2),**

Wang, Y. (2006). Inverse Q -filter for seismic resolution enhancement. *GEOPHYSICS*, 71(3), pp.V51-V60.