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Broadband - The Interpreter's Friend?

M. Francis* (Schlumberger) & C. Cunnell (WesternGeco)

SUMMARY

The positive impact of broadband acquisition and processing methods on the interpretation of seismic volumes has been well documented in recent years. While most gains have been achieved by extending low-frequency content, potential pitfalls exist for interpreters at both ends of the frequency spectrum, and care must be taken to understand the effective bandwidth of data. In addition, the handling of spatial frequencies (or wavenumbers) is as important as considerations for temporal aliasing. A complex earth creates a complex seismic wavefield in all directions, and so demands a revised definition of broadband with an emphasis on spatial resolution. We contend that the time has come to adopt the concept of effective spatial broadband based on high-resolution interpretation independent of orientation, and move towards the next level in geological understanding from our seismic volumes.

Introduction

Broadband acquisition and processing techniques have positively impacted our ability to interpret seismic image volumes. A narrower wavelet gives sharper resolution and the reduction in side-lobe energy leads to a more direct view of the geology. This improves our ability to assess risk on stratigraphic traps.

As an industry, we have achieved the most progress by extending the low-frequency content, where it is easier to add octaves compared to the high-frequency end. We must take care that the frequency content observed in the data is real - it could be artificial. For example, on land, we may observe spectra that suggest contributions from frequencies below those included in the vibroseis sweep used for correlation. As interpreters, part of our task is to understand these behaviours and assess what is real.

Frequency spectra contain both signal and noise. It is often difficult for geophysicists to measure a reliable signal-to-noise ratio on the final migrated section. Methods used to measure noise often become the basis of methods to suppress the noise. As a result, the residual noise becomes closer and closer to resembling signal. Many successful methods to remove noise result from building a better interpretation, or model, of the noise that is adaptively subtracted from the record. The hope is that what remains will provide a better model of the signal.

At the high-frequency end of the spectrum, attenuation limits our ability to identify signal. As we double the frequency, the effect of attenuation increases proportionally in the log domain. With increasing depth, nominally broadband sections appear dominated by the low frequencies. We are also learning that much of the noise comes from the spatial sampling of the acquisition process. For example, near-surface noise will alias and appears as a quite different spatial frequency. We require adequate sampling to avoid such spatial aliasing, and so survey design is influenced as much by noise characterization as by signal requirements. Preserving high frequencies through imaging also demands improvement in the velocity model. For example, consider static corrections on land. As statics estimation has advanced, so has the frequency of our data. Poor alignment of events prior to stacking acts as a strong low-pass / high-cut frequency filter. In the same manner, poor alignment within a migration results in a poorly focussed image; again a powerful low-pass frequency filter.

What is broadband?

This leads us to question - What is broadband? In a one-dimensional world, such as an organ pipe, the pressure wave is constrained. However, real earth geology is a complex 3D world, so we must consider what happens to our signal in such environments. Signal weakens with distance from the source, due to both attenuation and spreading of the wavefront. Complexity in the seismic wavefield results from large-scale macrostructures as well as distortions caused by smaller geologic features located closer to the source and receivers. Our assumptions about simple, vertically propagating waves no longer apply. We must expand our definition of broadband to encompass spatial resolution in all directions (Figure 1). This, in turn, places new demands on the methods required to sample and reconstruct the seismic wavefield.

As we improve our sampling and broaden the spectrum, we recognise that there are many layers of complexity to be resolved. As we solve one issue, the next comes to view as we edge closer to the truth. For example, we recognize that velocity is not isotropic, and so anisotropic algorithms are now the norm. We are adding elastic algorithms and derivation of uncertainty. As computational power increases, we may tackle dispersion as well.

The ‘effective bandwidth’ of our data is in part response to our ability to mould or shape our seismic data to any model of bandwidth we choose. A model is not reality. Consider sparse-spike inversion. If we invert data using this model, the result is a set of discrete spikes. The resulting spectrum spans all frequencies. This is the spectrum of the model not the input data. Applying models to our data allows us to distort the apparent bandwidth. A model can extend or contract the apparent bandwidth. However, the input data may contain information over a limited range of frequencies. If we could accurately measure the signal-to-noise of each frequency, we could identify the uncertainty in the measurement of each frequency and, hence, decide if it helps raise the value of our data. When we reach a frequency where the information content decreases, we can say that this frequency is no longer part of the effective bandwidth. As interpreters, we compare filter panels to choose filters for our final interpretation. When the noise is stronger than the signal, we have reached a limit of the effective bandwidth.

Conclusions

The time has come to adopt a more extensive concept of effective *spatial broadband*, where the criteria for broadband includes the ability to provide high-resolution images of geological features irrespective of their orientation in the earth. This is complemented by the range of wavenumbers (in x, y, and z) over which useful information content contributes to the image volume.

As interpreters, we welcome new insights gained from seismic data as they lead to more discrimination of lithology and rock properties. For example, amplitude variation with angle helps us separate velocity and density. Understanding of pressure-wave and shear-wave velocity helps predict fluids. We now interpret pore pressure and geomechanical properties. Azimuthal anisotropy helps us identify stress and fracture systems. Each of these tools makes demands on the fidelity of the data.

Acknowledgments

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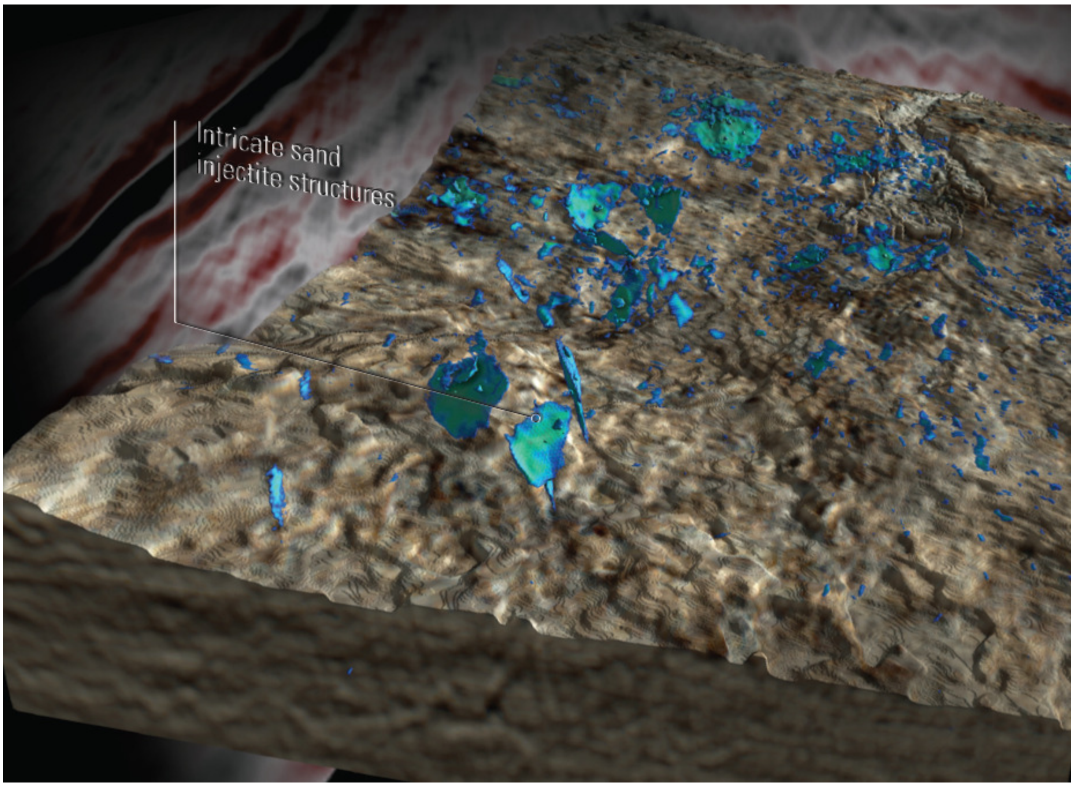

Figure 1 *High spatial resolution in all directions aides imaging and provides improved understanding of complex 3D geometrical structures such as these geobodies interpreted as thin sand injectites from the North Sea.*