Introduction

A key principle for understanding and interpreting seismic images of the subsurface reflectivity is that seismic waves are basically sensitive to three bulk rock properties: compressibility, rigidity and density. Recording both wave modes allows better separation of these three properties, thus providing more accurate estimation of the desired reservoir characteristic such as lithology, porosity, fractures or fluid discrimination.

Information about the subsurface is carried by P-wave and S-wave propagation. The advantage in using both P- and S-waves is that the two wave modes possess different sensitivities to the bulk rock properties. S-wave propagation is sensitive only to rigidity and density, while compressional-wave propagation is sensitive to rigidity, density and compressibility. As a generalization, P-wave propagation changes both the shape and volume of a subsurface element while S-waves change the shape only. One manifestation of these two modes of propagation is that P-waves tend to have a higher sensitivity to fluids in the pore space. Similarly, factors such as open fractures more strongly affect rock rigidity. Since S-waves are more sensitive to rigidity changes, they are more suited for fracture characterization. Interpreting both P- and S-wave reflectivity offers the ability to discriminate lithology, porosity, fractures and possibly fluid content.

Key improvements to MC technology

A number of barriers historically inhibited the acceptance and growth of multicomponent technology. These include:

- lack of interpretation and analysis tools;
- poor data quality; and
- immaturity of data processing techniques.

Further, expertise and experience with multicomponent methods have resided with a very few in the industry. A number of advances in data acquisition, processing and interpretation have significantly improved the general usability and viability of multicomponent technology. Advances in multicomponent acquisition equipment (Mougenot, 2004; Maxwell et al. 2001) and processing algorithms have fueled an important improvement in the quality of converted-wave data.

Purpose-built multicomponent MEMS (Micro Electro Mechanical System) sensors have vastly improved attributes including:

- Digital single-sensor (point receiver) recording
- Improved vector fidelity
- Broadband linear phase and amplitude response
- Low harmonic distortion

Converted-wave data are inherently more difficult to process than P-wave data due primarily to the asymmetry of the travel path. Standard processing techniques for P-wave data are not directly applicable and both algorithms and processing flows require modification. Significant improvements in converted-wave processing algorithms and methods are now producing improved subsurface images and facilitating more effective integration of P- and S-wave data. Further work remains in developing and implementing true vector processing methods for the full elastic wave field to fully exploit the value of converted-wave data. Such methods must necessarily treat data processing and interpretation in a parallel rather than serial manner.

The success and sustainability of multicomponent methods is ultimately tied to value demonstrations and to development of interpretation tools and work processes which allow shear-wave information to be effectively utilized. Specialized elastic wave interpretation packages are helping to promote the extraction of information from multicomponent data.

Multicomponent applications

The literature provides a broad range of converted-wave applications (Stewart et al., 2003; Tatham, 2002). Additionally, Veritas DGC has actively pursued the development of applications over the past two years. Three of these are discussed in
USA Carbonate 3C3D Test – Fractured Gas Reservoir
Replacing a subset of receiver groups in a P-wave 3D survey with three-component single-
sensors provides a method of examining both the feasibility of PS-wave recording and its
capacity to determine the orientation of horizontal stress through azimuthal anisotropy. This
carbonate test example displays strong mode-converted reflections at the depths of interest,
and demonstrates all the expected characteristics of shear-waves in azimuthally anisotropic
media.

Detecting the presence of azimuthal velocity anisotropy is important because measurements
of “fast” and “slow” S-wave polarizations can be related to open fractures and crack-like pore
structures in the subsurface. The potential benefits of PS-wave data for fracture
characterization, the methods of analysis, and examples of its application are well-
documented in the literature (Gaiser and Van Dok, 2002; Li, 1998; Van Dok et al., 2001).
Nonetheless, the viability of PS-wave acquisition in any specific geological environment or
geographical location is often in doubt. An embedded multicomponent test, where
conventional geophone groups are either replaced by or co-located with single-sensor 3C
MEMS receivers, can be a cost-effective method of evaluating 3C technology.

The azimuth stacks derived from this embedded test display all the expected characteristics of
azimuthally anisotropic PS-waves (Figure 1). The radial component shows azimuthal
variation in arrival times of the various reflections, with the fastest arrivals occurring
approximately east-west, and the slowest arrivals north-south. The transverse component –
which would be free of reflections in isotropic media – shows polarity reversals separated by
azimuths without reflections at both N80°E and N170°E. The “phase flip” semblance display
permits the orientation of the symmetry planes to be determined graphically; however, a 90-
degree ambiguity remains. This is resolved through the azimuthally varying travel-time of the
radial component, in which travel-time minima coincide with the fast-shear axis (or isotropy
plane) and travel-time maxima coincide with the slow-shear axis (or symmetry-axis plane). In
this case, the fast shear axis is N80°E, which represents the maximum horizontal stress
orientation (Todorovic-Marinic et al., 2005). A typical output display for fracture
colors to provide a measure of fracture intensity.

Long Lake 3C3D – Heavy Oil Play
A second example of multicomponent applications is from the shallow heavy oil sands of
Alberta, Canada. Production is from bitumen-saturated, Cretaceous-age sands within a fluvial
valley-fill depositional system. The productive formation, the McMurray, is 80m thick at a
depth of 220m in the 3C3D survey area. The method of extraction involves drilling pairs of
horizontal wellbores, vertically separated by 5m, injecting steam into the upper wellbore and
producing the heated bitumen via the lower wellbore. A main source of economic risk is
shale plugs and layers interfering with the injection/extraction process by imposing
impermeable barriers to fluid flow.

3C3D data were acquired using digital MEMS sensors and integrated with the available well
control. Seismic inversions of both the PP and PS data were input into the Veritas -Hampson-
Russell EMERGE algorithm to produce an estimate of shale volume. A cross section through
the shale volume is shown in Figure 2. Four wells are integrated into the profile showing the
measured sand/shale volumes from log control. There is excellent agreement between the
seismic shale volume estimate, using PP and PS data, and the corresponding well information
(Gray et al., 2005).

Improving P-wave Data Quality
3C data can also be important in improving the quality of the P-wave image. For onshore
applications, a source-generated surface wave known as ‘ground roll’ can be particularly
bothersome. Historically, large arrays of single-component geophones were used in 2D
seismic acquisition to attenuate surface waves but these can produce an attendant loss of
image resolution. In 3D acquisition, fewer geophones are deployed at each receiver location for economic reasons leaving the task of surface wave attenuation to processing algorithms. Unfortunately, these algorithms are highly dependant on spatial sampling and velocity discrimination between the undesirable “noise” and desired reflected signal. By recording the 3D particle motion using 3C sensors, polarization filters can be employed to attenuate ground roll and other surface waves. For example, ground roll can be attacked by detecting and exploiting its characteristic elliptical particle motion, in contrast with the linear particle motion of reflection signal. The detection and subsequent removal places no demand on potential costly increases in spatial sampling since polarization filtering is a single-sensor operation.

An example of improved P-wave data quality using single-sensor MEMS seismic data and polarization filters is shown in Figure 3. Two 2D seismic profiles are shown. Section A is recorded using conventional geophone sensors deployed as 12 element linear arrays at 50m intervals. Section B utilized a single 3C MEMS sensor at 25m intervals with polarization filtering applied to improve resolution by attenuating surface waves. These 2D profiles traverse a shallow thrust. The faults and steeply dipping base of the thrust are better imaged using the 3C MEMS single sensors (Ronen et al., 2005).

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References

Figure 1. Azimuth stacks of radial and transverse component. Radial data shows “fast” and “slow” S-wave arrivals along the symmetry axes delineated by the nulls in the transverse component panel. These data indicate the “fast” S-wave polarization azimuth is N80°E, interpreted to be the orientation of maximum horizontal stress in the study area.

Figure 2. Shale volume estimate from P-wave (PP) and converted S-wave (PS) data.

Figure 3. Comparison between conventional geophone array data at 50m group interval (A) and single-sensor MEMS data at 25m group interval (B) with polarization filter applied to attenuate surface waves (ground roll).