Introduction to this special section: Multicomponent seismic

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A seismic source excites a rich variety of elastic waves in the Earth, so it seems reasonable to try to use them all to create a more compelling picture of the subsurface. While P-wave imaging has been enormously successful in this regard, there are conditions when it is less so. But, the demands of energy discovery and recovery require an increasingly comprehensive portrayal of reservoir lithologies, stresses, fractures, and fluids. The multicomponent seismic method is a superset of conventional seismic technology and has the potential to answer to some of these demands. Recording horizontal motion, as well as vertical vibrations and pressures, allows further capturing of the full seismic wavefield, and the additional resultant pictures can provide greater comprehension of subsurface properties, fluids, and their changes. We might liken this to a more complete conversation with "loud" waves (P-waves arriving first with high amplitudes) and "shy" waves (S-waves with lower voices and a more complicated message).

Multicomponent seismic exploration (usually using both P- and converted-wave events) has received a variable degree of attention, success, and acceptance in our industry. There have been stirring results in imaging through gas-obscured areas, finding sand-rich zones in clastic sequences, and determining fracture zones and orientations. Beyond these, the multicomponent seismic method (using a three-component sensor on land or four-component detector on the ocean bottom) has been demonstrated as an effective technology for a range of objectives, including direct hydrocarbon detection, delineation of fluid (water, gas, fizz) changes, improved reservoir characterization and management, estimation of saturation and pressure changes, drilling hazard identification, and improved illumination of reservoir using wide azimuths, to name a handful.

What can make multicomponent seismic useful and how? Conventional seismic surveys (with a vertical receiver on land or pressure sensor in the sea) record mostly P-waves while multicomponent seismic surveys record and analyze both P- and S-waves. Basic seismology teaches us that S-waves cannot travel through water, so seabed recording cables or nodes are used for multicomponent marine data. Not towing a marine cable has advantages in many offshore areas.

Once the 3C or 4C data are recorded, the next step is processing, which may be several times more intensive than conventional P-wave analysis. However, several independent pictures (P-wave, and fast and slow S-wave sections or volumes) will be produced. An improved subsurface understanding is the reward for this greater effort. In the multicomponent world, accurate velocity analysis, statics estimation, anisotropic assessment, and imaging all require careful handling. Advancements in algorithms, computing power and storage, and visualization have helped in this pursuit.

The slow acceptance (or perhaps better said, cautious advancement) of multicomponent seismic by our industry is related to several factors: the added cost of acquiring the two horizontal components on land and three extra components offshore, the complexity of processing the S-wave types and increased data volume, the few multicomponent interpreters and restricted educational base, and the small (but growing) number of "slam-dunk" successes. However, multicomponent seismic technology has come a long way over the last three decades. And many current case studies demonstrate that the cost of multicomponent seismic was often well worth the expense.

The eight articles included in this special section discuss different aspects of multicomponent seismic exploration ranging from case studies, to processing advances, time-lapse modeling and S-wave splitting, and show how the multicomponent technology universe is expanding.

Dang et al. ("Delineating oil sand reservoirs with high-resolution PP/PS processing and joint inversion in the Junggar Basin, Northwest China") demonstrate how three-component 2D profiles helped in discriminating false and real bright spots in Chepaizi area in Junggar Basin in northwest China. AVO attributes from PP and PS gathers are derived and the prestack joint PP-PS inversion reconciles the V_p/V_s values from both traveltime and amplitude information. The derived V_p/V_s values, fluid factors, and Poisson's ratios at target zones clearly characterized the reservoir as well as false bright spots.

Leiceaga et al. ("Enhanced density information from prestack inversion of multicomponent seismic data") analyze the potential of using 2D-3C multicomponent data from Campos Basin, Brazil, for density estimation. They demonstrate the advantage of simultaneously inverting PP and PS data using a global optimization algorithm and a nonlinear cost function. Their results show that the addition of PS data to the inversion process improves the density estimation accuracy and increases frequency content.

Jenkinson et al. ("Joint PP-PS angle-stack analysis and AVA inversion in Grane Field, offshore Norway") describe aspects of a workflow for joint PP-PS angle stack analysis and its application to the reprocessed Grane OBC angle-stack volumes. The reservoir is difficult to recognize on the conventional P-wave data and so the PS data help with the interpretation. The objection of sand-shale discrimination was better achieved with joint PP-PS inversion, but the results suffered as the P-angles were too small and also because the velocity gradients in the overburden lead to imaging issues and possible PSTM, PP, and PS data sets showing lateral misalignment. The S-impedance volume from a single PS-angle stack provided the best sand/shale discrimination.

In "The case for separate sensor processing: meeting the imaging challenge in a producing Mideast carbonate field," Reilly et al. emphasize the importance of alternative process-

ing strategies that could replace more conventional approaches. The authors demonstrate that, for the 2C OBC data being used for the case at hand, separate processing of hydrophone and geophone sensors provided a better understanding of the impact that geology can have on the seismic wavefield, which in turn led to significantly improved results in imaging. This strategy also has a bearing on the workflows that may be adopted for seismic attribute and inversion analysis.

The unconsolidated, low-velocity interval material in the near-surface can cause time delays in the propagating S-waves. Roy et al. ("S-wave velocity and statics from ground-roll inversion") use the dispersion properties of ground roll to study the variation of frequency versus phase velocity. The inversion of dispersion curves for the fundamental mode provides the near-surface S-wave velocity structure, which is then used to infer S-wave receiver statics. Using their methods on five different data sets in varying geological settings in the United States and Canada, the authors show the usefulness of ground-roll inversion to obtain more accurate (and automatic) statics.

Wang et al. ("Ups and downs of ocean-bottom seismic processing: applications of wavefield separation and up-down deconvolution") discuss the advantages of up-down deconvolution for multicomponent data. Its application requires accurate separation of the recorded pressure wavefield into its upgoing and downgoing components. Although the method is strictly valid only for a horizontally layered medium, it works well for slightly dipping sea floor with quite complex subsurface structure. Compared with the conventional PZ (hydrophone-geophone) summation, the up-down deconvolution is able to attenuate the source-side multiples. In addition, the up-down deconvolution improves the 4D repeatability of time-lapse ocean-bottom data.

Sodagar and Lawton ("Time-lapse multicomponent seismic modeling of CO_2 fluid substitution in the Redwater Devonian, Alberta, Canada") evaluate the possible seismic changes with CO_2 injection in the Devonian Redwater reef, northeast of Edmonton, Alberta, Canada. The authors build a 2D geological model of the Redwater reef and investigate its response in terms of the PP and PS synthetic seismic sections for the baseline model as well as after replacement of brine with CO_2. As expected, the time-lapse analysis demonstrates the amplitude differences of the seismic data, before and after CO_2 fluid substitution.

Cary et al. ("What causes so much azimuthal anisotropy in the near surface?") demonstrate shear-wave splitting on land 3C-3D data sets from Canada in highly unconsolidated sediments that comprise various heavy oil plays. The authors show that the observed shear-wave splitting correlates well with the change in topography—a 60-m hill on the surface of a 3D survey appears to cause a 40-ms time delay between the fast and slow split shear-wave arrivals observed on the surface. Thus, near-surface layers which exhibit strong horizontal transverse isotropy cause shear-wave splitting on PS data.

We hope that readers find the articles interesting and informative, as they represent some of the latest reports on different aspects of multicomponent seismic data. ..TLE