Multicomponent technology: the players, problems, applications, and trends

Summary of the workshop sessions

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The 2000 SEG/EAGE Summer Research Workshop drew a large proportion of participants from contracting firms (Figure 1a). The affiliation of first authors was also largely from contractors (Figure 1b), with the remainder of participants and first authors being evenly distributed between oil companies and academia. If these statistics can be taken as a genuine cross-section of the geophysical community, they indicate that contractors have the most interest in multicomponent technology. It would also appear that they perform most of the research work. More than 40% of the papers presented in the workshop were related to processing, model building, and imaging with *PS* waves, thus indicating where the current emphasis on research and applications lies. Less emphasis was observed in other important areas of application for multicomponent technology, such as lithology, fluids, fracture characterization and time-lapse studies.

Interestingly, although the workshop took place in the U.S. heartland, participants from Europe, Canada, and Latin America combined exceeded the number of U.S. nationals in attendance (Figure 1c). Could this signify that interest in shear-wave technology is higher outside the United States? It would seem so, especially in view of the fact that the activity generated by the multicomponent acquisition in the United States to date has been less than in the rest of the world, particularly in Europe.

It is noteworthy that contractors kept that level of effort and interest during the 1999-2000 downturn, despite the fact that they do not consider the technology to be a commercial success. This may indicate that

Table 1. Results of the shear-wave poll*

Geologic/geophysical problem	Proven	Possible	Improbable	Abstain
	←	%		→
Imaging below gas clouds	100			
Imaging targets of poor *PP* reflectivity	86	14		
Lithology delineation: clastics	56	44		
Increase shallow resolution (<1000m depth)	56	40	4	
Fracture characterization (orientation and density)	46	54		
Fluid discrimination	33	67		
Detection of shallow gas	17	83		
Imaging faults	15	85		
Imaging below salt	14	85	1	
Density estimation	12	88		
Pore pressure prediction	8	92		
Stress characterization	8	91	1	
Reservoir monitoring	4	96		
Detection of shallow-water flows		100		
Lithology delineation: carbonates, evaporites		100		
Imaging below basalt		97	3	
Imaging below chalk		97	3	
Increase deep resolution (>1000m depth)		90	10	
Imaging with multiples	13	65		22
Gas hydrates		89		11
Imaging complex structures (overthrust)		80		20
Formation strength (drilling hazard)		64	4	32
Permeability estimation		55	20	25
Coal-bed methane	4	48		48

**The numbers indicate the percentage of workshop attendees that selected each category. Detailed definitions of* proven, possible, improbable, *and* abstain *are given in the text.*

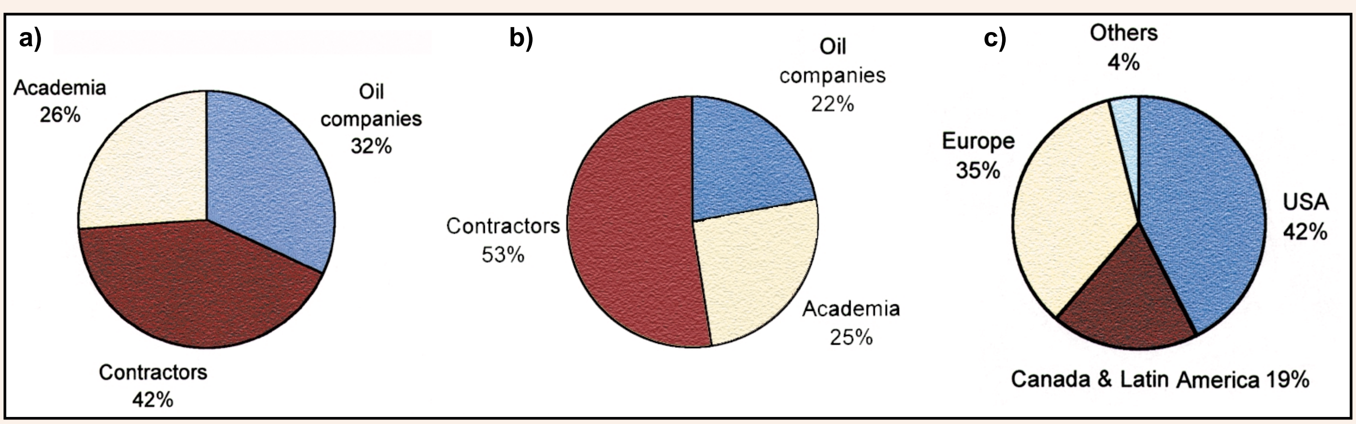

Figure 1. Participants at the Boise workshop grouped by (a) professional affiliation, (b) affiliation of the first author of the papers presented, and (c) geographic provenance.

if the technology does not become profitable to contractors in the near future, more than half of the worldwide effort being made for its advance may be dropped.

Session summaries. Chairmen of the different workshop sessions were asked to report on the highlights of the topics presented and/or discussed in their sessions. These highlights draw an interesting picture of where we stand today from a technical point of view.

From design to data acquisition session—chaired by R. Michelena and R. Stewart. Although the seafloor environment is generally characterized by clean data, the quality of land data has yet to be improved. Low-frequency seismic information, essential for deriving elastic rock properties, is now becoming possible with the use of new geophones. Point receivers are preferable to receiver arrays in terms of the azimuthal response and for the derivation of statics corrections. Patch geometry and wide-azimuth information are desirable for data processing, imaging, and analysis of the anisotropy. Commercial software is available for designing converted wave surveys.

Case studies session—chaired by P. Cary and D. Ebrom. Converted waves can aid the interpretation of fluid and lithology variations, and their AVO analysis can detect shallow-water flows. Geotechnical shear measurements should be combined with converted-wave reflection surveys. Various processing methods are available to analyze and remove the effects of spatially and depth-varying shear-wave birefringence. Sometimes layer-stripping techniques have to be used to unravel the birefringence phenomenon in depth.

Velocity estimation and model building session—chaired by R. Garotta and S. Ronen. The idea of independently processing the positive and negative offsets is widely accepted. Polar anisotropy cannot be ignored when building the velocity model. It is unclear whether the model building is easier for the *SS* mode than for the converted *PS* mode. In general, we should understand why multicomponent technology has not been a financial success for the contractors, despite the proven successes.

3-C AVO and inversion session—chaired by R. Benson and R. Van Dok. The density of the subsurface can be estimated from the combined use of *PP* and *PS* data. 3-C AVO has the potential to separate pressure effects from fluid effects. High-resolution estimates of the V_P/V_S ratio can be obtained by using amplitude in addition to traveltime information. Joint *PP* and *PS* inversions are more robust than independent inversions.

Converted wave processing session—chaired by J. Gaiser and P. Y. Granger. Experience shows that deriving shear-wave static corrections is a serious problem because they are typically larger and different than *P*-wave statics, and they can have a strong influence on the average V_P/V_S, γ_0, field, and near surface azimuthal anisotropy. Although it was generally agreed that the determination of γ_0 or matching equivalent *PP* and *PS* events should be done at the imaging or focusing stage of processing, it was recognized that it needs to be done as early as possible for statics. *PP* and *PS* waves should be matched not only for processing but also for interpretation and reservoir characterization purposes. If azimuthal anisotropy is present in the overburden, there can be static time-shift differences between the slow and fast shear waves, resulting in a layer-stripping problem for the near surface. Two data sets were made available to the workshop participants: Gulf of Mexico Mahogany 4-C 2-D line (courtesy of Schlumberger) and East Texas Caddo 3-C 2-D line (courtesy of Mitchell Energy). Although more than 20 groups worldwide requested these two data sets, only four presented the Mahogany 4-C results and three presented the Caddo 3-C results. These indicate a general lack of adequate software and experience for *PS*-wave processing.

Lithology and fluids session—chaired by D. Lawton and C. MacBeth. Among the benefits of multicomponent surveys for time-lapse studies are the separation of saturation and pressure effects in both isotropic and anisotropic cases, the estimation of density changes, the estimation of variations in the total stress field inside and outside the reservoir, and pore pressure prediction. In the shallow part of the section, the vertical resolution obtained with *PS* waves is generally better than that obtained with *PP*, the crossover depth being about 1000 m. More work is needed on estimating/interpreting *PP* and *PS* attenuation. Interpreters need confidence limits on the parameters estimated from *PS* data. Multicomponent technology can be applied to CO_2 and other acid gas (e.g., methane) sequestration problems. There is a need for developing a better understanding of the *PS* amplitudes, because sometimes we observe large *PS* amplitudes at offsets smaller than those predicted by the theory.

Searching for better images in time and depth session—chaired by W. Goodway and N. Moldoveanu. Imaging subsalt using towed cables can be improved by identifying the converted-wave energy; modeling studies can help determine the type of converted waves present. If differences in velocities and images obtained from *PP* and *PS* data are due to a bulk shift generated by small shear-velocity variations in shallow sediments, such a shift should be removed before velocity analysis and migration. The effect of vertical variation in the V_P/V_S ratio has less impact on common conversion point (CCP) dispersion than the dispersion induced by transverse anisotropy with a vertical axis of symmetry. Time imaging of converted waves can be improved by determining more accurate moveout and binning parameters. 2.5-D *PP* and *PS* scattering angle depth migration in weak VTI media and 3-D prestack depth migration using Deregowski's loop are among the most recently proposed algorithms. Complex 3-D elastic models (similar to the SEG/EAGE models) are needed to understand spatial/temporal errors, sensitivities of various prestack depth migration work flows, and CCP positioning errors.

Shear-wave poll. During the final discussion session, chaired by S. Spitz and L. Thomsen, attendees were asked to vote on whether they thought multicomponent technology could help to solve a variety of geologic problems of interest to the oil industry. One of the following four options could be selected for each problem:

Proven: Items under this category have been clearly demonstrated to add value in several geographic areas and expect probable success in other geographic areas.

Possible: Synthetic and/or preliminary field data indicate that within the next five years, items under this category shall be demonstrated with many field case histories.

Improbable: the success of items under this category to be unlikely.

Abstain: The participant was either not familiar with the problem or had no clear opinion about the success. No examples of the application of multicomponent technology to solve these problems were presented in the workshop.

Table 1 shows the percent of workshop attendees polled. A majority considered that imaging below gas clouds, imaging targets of poor *PP* reflectivity, delineation of clastics, and increased shallow resolution are problems in which the multicomponent technology has proved to be effective. Fracture characterization was considered a proven application by approximately half of attendees. Other areas that at least 15% of attendees considered to be proven are fluid discrimination, detection of shallow gas, and imaging faults not visible by conventional *PP* data.

Future research areas. Workshop attendees considered that more professionals should become active in the application of multicomponent technology and that further insight into the following areas is desirable:

Acquisition. Wide-azimuth recording, vector fidelity for each receiver location as deployed, acquisition hardware (such as receivers, sensor accelerometers, and cables), marine shear-wave source, acquisition design, SEG standards for multicomponent data, near-surface (less than 200 m) rock properties.

Processing. Derivation of *PS* statics corrections, shear-wave estimation, *PS* imaging, accurate *PS* binning, multiple attenuation for converted waves, depth imaging, on-board processing and quality control, effects of anisotropy (high- and low-order symmetries) on *PS* data processing and interpretation.

Interpretation. Correlation of *PP* and *PS* data, joint inversion of *PP* and *PS* data in terms of the elastic parameters, specific 3-C interpretation tools, 3-D elastic forward modeling, estimation of uncertainty in the parameters derived from *PP* and *PS* data.

Recognition is made of the importance of borehole seismic data, logs, cores, and other geologic and production information to provide substantial aid in the processing and interpretation of the shear-wave data. The attendees also discussed the need for having a data set made available to the industry to further our understanding in these areas. Bill Goodway from Pan Canadian offered a multicomponent data set from the Weyburn Field as one possibility. Synthetic data sets, in which the depth model is known, were also discussed as an alternative.

A new beginning? The workshop was advertised with the inquiring title of "Recent Advances in Shear Wave Technology for Reservoir Characterization: A New Beginning?" and prompts an answer to this question in light of the proceedings. What led us to decide upon such a title? Most experienced professionals in this area have been through several cycles of interest in multicomponent technology—from land data of the early 1980s to today's predominantly offshore focus. It is natural to relate this cyclicity to the current interest and to ask whether there is anything different about what is happening today.

In the past, multicomponent technology made little progress as a useful seismic method because shear-wave sources are prohibitively expensive for most exploration and reservoir characterization budgets. Also, *SS*-wave data are often below required resolution limits. Although the economic and S/N benefits of *PS* technology have made the current cycle more feasible, it is far from being an economical success for contractors. Many oil companies are unwilling to invest in new technology until it is proven, thus placing the financial burden squarely on the contractor's shoulders. Previously, oil companies invested in the development of new technologies (e.g., 3-D), but in the current cost-cutting climate, these resources are unavailable.

Nevertheless, the Boise workshop has shown that the new generation of activity is characterized by several areas of successful application to be justified by positive business arguments. Our shear-wave poll also indicates that the majority of workshop participants agreed that further uses for multicomponent technology will become reality in the near future, particularly in some key areas of reservoir description. Indeed, there was an optimistic feeling at the workshop for sustained growth in multicomponent (shear-wave) technology and that the current cycle appears to mark a new beginning. Although the potential for this technology is great, much work still remains before it becomes financially viable for both contractors and oil companies. E

Acknowledgments: This paper is a composite from the work of many individuals during the week of the workshop. First, we thank our fellow session chairmen for helping us extract the highlights of the sessions. We also thank Heloise Lynn for her insights on how to conduct the poll during the final session. In addition she also wrote the definitions for the proven, possible, *and* improbable *categories that were used during the poll. Shuki Ronen compiled the final results of the poll that later became Table 1 after some minor changes. The Research Committee would also like to thank all those who participated in the organization of this very successful workshop. Finally, a particular vote of thanks goes to the University of Boise for the time and effort spent in organizing the excellent field trip during our midconference break.*