2018-19 CSEG Distinguished Lecture Tour

This national tour is sponsored by the Canadian Society of Exploration Geophysicists (CSEG) Foundation and presented by a distinguished member of the society. The goal of the tour is to promote the science and application of geophysics and to highlight a topic of current interest.

David Gray
2018-19 CSEG Distinguished Lecturer

David is Senior Geophysical Advisor in the Global Exploration arm of CNOOC Int'l, working on prospects in Guyana and Atlantic Canada, as well as on 4D monitoring across the portfolio. In 2015, David was the honouree of the 4th annual CSEG Symposium, where he was recognized for his contributions to value in geophysics. David has made significant contributions to: quantitative interpretation, where three AVO equations have his name on them; seismic fracture characterization, where in 1999 he related azimuthal variations in 3D seismic to fractures in the borehole and where he holds a patent; and, in seismic geomechanics, where in 2009 he showed that all three principal stresses can be estimated from 3D seismic data and where he also holds a patent. Educated at the University of Western Ontario (BSc 1984) and the University of Waterloo (MMath 1989), David moved on to do geophysical research for Veritas and CGG for 22 years, after which he joined Nexen's Oil Sands division as a Senior Technical Advisor. David is a member of SPE, SEG, CSEG, EAGE, and APEGA. He has published and presented more than 140 papers. In his spare time, David likes to spend time with his family, play volleyball, and participate in grassroots motorsports.

An Unconventional View of Geoscience

The world needs geoscientists. The American Geoscience Institute predicted a need for about 10% more geoscientists in 2024 relative to 2014, but this was before industry layoffs (Status of the Geoscience Workforce 2016). The number of layoffs and workforce demographics likely means a greater need for geoscientists to do the work that will be required. Resulting jobs will be spread across all industries, including: scientific services, mining, oil and gas, agriculture, education, government, etc.

In the western world, industries that traditionally employ geoscientists are being criticized for their practices. You can address these issues by promoting the value of the geoscience you are learning, especially to friends and family. Think outside the box when presented with opportunities to show what geoscience can do. This lecture shows some examples of how to use this unconventional view of geoscience to benefit society, your employers, and your peers. I will give examples of my successful use of unconventional geoscience, including: protection of the environment; creation of new technologies for prediction of fractures, oil reservoir production, and geomechanics; and, effective use of social media. All these employ knowledge and experience gained from my geoscience education and career. Your geoscience education and experience can also be used in your own unconventional ways to enrich society.

The Gray Lexicon

This lexicon was assembled by the 2015 CSEG Symposium Committee as both a summary of Dave Gray's contributions to exploration geophysics, and as educational tool. The observations and lessons contained herein are stated simply and without caveat. As with almost all applied geophysical work, there are limitations of validity to these points. Our work is inductive, tempered by error, difficult to apply properly, and often very… Gray.

AVAZ method is only capable of detecting cumulative effects of swarms of aligned fractures (not individual fractures) which are close to vertical (>65°). These conditions frequently exist in fractured reservoirs.

Gray, D. and Todorovic-Marinic, D., 2004, Fracture Detection using 3D Seismic. SEG/EAGE Research

AVAZ works because 1. Fractured rocks perpendicular to fractures are weaker (more compliant) than fractured rocks parallel to the fractures. 2. fluid filled fractures behave like a spring (aka HTI – horizontally transverse isotropic).

Gray, D. and Todorovic-Marinic, D., 2004, Fracture Detection using 3D Seismic, SEG/EAGE Research Workshop on Fractured Reservoirs

Primary requirement for AVAZ is that some of the seismic waves hit the reservoir at sufficient angle from vertical (at least 30° in inline direction). Usually achievable if maximum offset in equal to depth. The higher the angle range in seismic data the better the signal to noise ratio will be.

Gray, D. and Todorovic-Marinic, D., 2004, Fracture Detection using 3D Seismic, SEG/EAGE Research Workshop on Fractured Reservoirs

Attributes and meanings:

- *Estimated anisotrpic gradient = crack density*
- *Estimated azimuth of anisoptropic gradient minimum = strike of fractures*
- *Estimated P wave Reflectivity = compressibility*
- *Estimated S wave Refelctivity = shear rigidity*

Gray, D., Boerner, S., Todorovic-Marinic, D. and Zheng, Y., 2003, Fractured Reservoir Characterization using AVAZ on the Pinedale

The higher the angle range in seismic data the better the signal to noise ratio will be.

Gray, D. and Todorovic-Marinic, D., 2004, Fracture Detection using 3D Seismic, SEG/EAGE Research Workshop on Fractured Reservoirs

Well properties that suggest that oil is being produced from a connected fracture system are 1. cumulative production > original oil in place estimates 2. low matrix porosity 3. strong pressure support.

Gray, D. and Todorovic-Marinic, D., 2004, Fracture Detection using 3D Seismic, SEG/EAGE Research Workshop on Fractured Reservoirs

Geologists (core analysis) can help resolve the ambiguity in the AVAZ equation.(90° ambiguity in fracture strike or sign ambiguity in change of crack density)

Gray, D. and Todorovic-Marinic, D., 2004, Fracture Detection using 3D Seismic, SEG/EAGE Research Workshop on Fractured Reservoirs

The envelop of anisotropy gradient can be used to remove the effect of phase from the data.

Gray, D., Boerner, S., Todorovic-Marinic, D. and Zheng, Y., 2003, Fractured Reservoir Characterization using AVAZ on the Pinedale Anticline, CSEG

Sandstone has a higher shear rigidity than shale.

Gray, D., Boerner, S., Todorovic-Marinic, D. and Zheng, Y., 2003, Fractured Reservoir Characterization using AVAZ on the Pinedale Anticline, CSEG

EUR and/or cumulative production can be used as fracture indicators.

Gray, D., Boerner, S., Todorovic-Marinic, D. and Zheng, Y., 2003, Fractured Reservoir Characterization using AVAZ on the Pinedale Anticline, CSEG

A mud log can be a good indicator of fractures

Gray, D., Boerner, S., Todorovic-Marinic, D. and Zheng, Y., 2003, Fractured Reservoir Characterization using AVAZ on the Pinedale Anticline, CSEG

Fractures produce azimuthal anisotropy; so do coal cleats

Gray, D., Boerner, S., Todorovic-Marinic, D. and Zheng, Y., 2003, Fractured Reservoir Characterization using AVAZ on the Pinedale Anticline, CSEG

Compressibility Reflectivity

$$R(\theta) = \left(-\frac{1}{4} + \frac{1}{3}\frac{\beta ave^2}{\alpha ave^2}\right)(sec^2\theta)\frac{\Delta C}{Cave} + \left(\frac{\beta ave^2}{\alpha ave^2}\right)\left(\frac{1}{3}sec^2\theta - 2\sin^2\theta\right)\frac{\Delta\mu}{\mu} + \left(\frac{1}{2} - \frac{1}{4}sec^2\theta\right)\frac{\Delta\rho}{\rho}$$

Gray, D., 2005, Estimating Compressibility from Seismic Data, 67th Mtg.: Eur. Assn. Geosci. Eng., P025.

Applying a post stack amplitude inversion to compressibility reflectivity results in an estimate of compressibility. Calculate the combined compressibility of a rock fluid system to improve estimates for volume of oil

Gray, D., 2005, Estimating Compressibility from Seismic Data, 67th Mtg.: Eur. Assn. Geosci. Eng.,

Best practices for azimuthal AVO compliant processing workflow for 3D land data:

1. Azimuthal velocity corrections
2. Azimuthal spherical divergence corrections (aka azimuthal scaling)
3. 5D interpolation
4. Migration of COV's (ideally COV tile size <200m)

Gray, D., Schmidt, D., Nagarajappa, N., Ursenbach, C. and Downton, J., 2009, An Azimuthal-AVO-Compliant 3D Land Seismic Processing Flow, Expanded Abstracts of the 2009 Joint CSPG/CSEG/CWLS Conference,

Bani is related to crack density.

Gray, D. Observations of Seismic Anisotropy in Seismic Gathers, 2007, 69th Mtg.: Eur. Assn. Geosci. Eng., Extended Abstracts

COVs are natural tools that allow the maintenance of azimuth and offset information through migration

Schmidt, D., Gray, D., Li, X., Trad, D. and Downton, J., 2009, Improving the Image: 5D Interpolation and COV Gathering of a MegaBin Survey,

5d interpolation of MegaBin surveys and COV migration in WCSB improves the ability to image subsurface structure

Schmidt, D., Gray, D., Li, X., Trad, D. and Downton, J., 2009, Improving the Image: 5D Interpolation and COV Gathering of a MegaBin Survey,

Estimate principle stresses from Seismic data (Sv, Shmin, Shmax) using $\sigma_x = \sigma_z\gamma_5(1+\gamma)1 + Ez_N - \gamma_z$ *and* $\sigma_y = \sigma_z\gamma_5(1 - Ez_N + \gamma_1 + Ez_N - \gamma_2)$ Gray, F.D., 2011, Methods and systems for estimating stress using seismic data.

COCA (common offset-common azimuth) cube is an important tool for QC of azimuthal velocity anisotropy and azimuthal amplitude anisotropy attributes

Gray, D., Schmidt, D., Nagarajappa, N., Ursenbach, C. and Downton, J., 2009, An Azimuthal-AVO-Compliant 3D Land Seismic Processing Flow, Expanded Abstracts of the 2009 Joint CSPG/CSEG/CWLS Conference,

Optimal zones for hydraulic fracking = Shmax/Shmin Gray, F.D., 2011, Methods and systems for estimating stress using seismic data.

Azimuthal anisotropy occurs in the near surface weathering layer and varies in time therefore differences in anisotropy between seismic surveys may be a very sensitive 4D indicator of reservoir stress variations due to production

Gray, D. Observations of Seismic Anisotropy in Seismic Gathers, 2007, 69th Mtg.: Eur. Assn. Geosci. Eng., Extended Abstracts

Gray Value

The Value of Integrated Geophysics Committee, of which David Gray is a member, states that the value of seismic is related to the relevance and reliability of the seismic data. Dave Gray's contributions can be classified as contributions to reliability or to relevance.

Reliability

- Color correction deconvolution
- Interpolation studies for AVO and azimuthal analysis
- COV for azimuthal analysis
- AVO processing workflows
- COCA displays
- Use of correct angle ranges for AVO and AVAz

Relevance

- AVO
- AVAz
- Fracture inference and Bani
- Fracture inference and rock properties
- EUR estimation
- 4D analysis
- Heavy Oil Quality or productivity indicator
- Density as most relevant in heavy oil plays
- Stress, fractures, and completions