Advanced spectral attributes: decomposition, broadening, and inversion

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Spectral analysis of seismic traces has existed since the earliest days of seismology. A new paradigm in the use of spectral information has developed over the last fives years beginning with the pioneering work of Greg Partyka, Kurt Marfurt and others at Amoco Research. The fundamental change in thinking has resulting from workstation technology that has allowed the rapid computation and visualization of Fourier spectra calculated with small windows as a continuous attribute. This process is referred to as ***spectral decomposition***. Such spectra are dominated by local reflectivity patterns. Anomalous geological features such as channels and hydrocarbon filled reservoirs can have anomalous frequency responses. Thus, visualizing the data at discrete frequencies may reveal anomalous or diagnostic behavior not readily apparent on the broad-band seismic data. Recently, wavelet transform techniques have been used to reveal spectral characteristics of individual composite reflections. A number of examples will be shown to illustrate differences in frequency response of composite reflections caused by thin hydrocarbon reservoirs. It is interesting to note that, for thin reservoirs, seismic attenuation is a secondary effect and frequency spectra are dominated by the reflectivity spectra. The result is that low impedance gas reservoirs often have anomalously high peak frequencies that can be used as a diagnostic hydrocarbon indicator. For thicker reservoirs, attenuation may be observable if the spectral decomposition method is relatively free of interference effects. Spectral decomposition allows the calculation of new spectral attributes such as peak frequency, amplitude at peak frequency, bandwidth, spectral variance, skewness etc. These attributes can be very helpful in multiattribute analysis for reservoir characterization. The amplitude at peak frequency is not the same as the waveform peak amplitude. Notably, for an isolated layer, the amplitude at peak frequency is independent of tuning and more useful for direct hydrocarbon indication than peak amplitude. A variety of spectral decomposition methods exist including the discrete Fourier transform, the maximum entropy method, the continuous wavelet transform, matching pursuit decomposition, global optimization, and basis pursuit. Most other methods are variations of the above. In our experience, a cousin of basis pursuit, called exponential pursuit, has the best combination of temporal and spectral resolution, speed, and lateral stability.

According to the Widess thin-bed model (which consists of an isolated thin layer) the peak frequency of the seismic response is higher than that of the wavelet; below 1/8th of a wavelength the seismic response becomes the derivative of the wavelet and does not change shape with changing thickness. Our experience with spectral decomposition has led to the surprising conclusion that the Widess model of thin bed response is a very special case that is very different from most combinations of reflection coefficients. When the reflection coefficients at top and base of a thin bed are not exactly equal and opposite a more general behavior is observed where the peak frequency decreases as thickness decreases below the tuning frequency. This tells us that the seismic response is more sensitive to thin beds than thought previously. In fact, we find that encoded in the spectral decomposition of a seismic trace is information that exceeds the bandwidth of the actual seismic signal and allows us to make inferences about than beds that are far thinner than classical limits of seismic resolution. Such knowledge can be used to remove the seismic wavelet without magnifying noise and can thus be used to produce high resolution reflectivity sections that are far superior to conventional seismic sections in resolution and interpretability. Spectral inversion for reflections coefficients produces broad band images. Filtering these back to two or three times the original seismic bandwidth produces “spectrally broadened” seismic sections that are generally more interpretable and higher resolution than the original seismic data.

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John P. Castagna specializes in exploration geophysics research and development. He is widely known for his work in direct hydrocarbon detection and reservoir characterization. He joined ARCO's well logging research group in 1980. He served the company in a number of research, exploration, field-development and management positions. In 1982, he was named technical coordinator for Sonic Logging Research; in 1986, log analyst for Reservoir Engineering Services; in 1987, technical coordinator for Rock Physics Research; in 1988, director of Geoseismic Interpretation Research; and in 1989, manager of Seismic Analysis Research. In 1990, he transferred to Vastar Resources where he was responsible for development and extension of major offshore Gulf of Mexico fields and exploration of surrounding acreage. He later joined ARCO International Oil and Gas Co., with responsibility for offshore China and Russia exploration. Dr. Castagna returned to ARCO Research in 1995 and was assigned as visiting research scientist at the Geotechnology Research Institute of the Houston Advanced Research Center, where he was principal investigator for research projects funded by the Gas Research Institute, the Energy Research Clearing House and a consortium of energy companies. Also in 1995, he was named Distinguished Lecturer for the Society of Exploration Geophysicists (SEG), delivering the fall lecture on "Applied AVO analysis: use and abuse of amplitude variation with offset." He has served the SEG in various other capacities including chairman of the Leading Edge editorial board, First Vice-President, and technical program chairman for the 2003 Annual Convention in Dallas. His book, *Offset-Dependent-Reflectivity: Theory and Practice of AVO Analysis*, is an SEG bestseller. He has also served as Associate Editor for *Geophysics*.

In 2000, Dr. Castagna founded Fusion Geophysical, a geophysical contractor specializing in integrated seismic analysis.

Dr. Castagna is a graduate of Brooklyn College, where he earned a bachelor of science degree in geology in 1976 and a master's degree in high temperature geochemistry in 1981. He completed his doctoral degree in exploration geophysics at the University of Texas at Austin in 1983. His main technical interest is quantitative seismic analysis in exploration and reservoir characterization.