Seismic Research Focusing on Unconventional Gas Resources

Exploration Geophysics Laboratory

The Exploration Geophysics Laboratory (EGL) at the Bureau of Economic Geology focuses on developing and applying multicomponent seismic technology. EGL research concentrates on multicomponent data acquisition, processing, and interpretation.

Data Acquisition

EGL designs, implements, and manages multicomponent seismic data-acquisition programs. Testing of equipment and field procedures is done annually at the Devine Test Site approximately 40 miles southwest of San Antonio. Present field tests focus on demonstrating that full-elastic wavefields can be acquired using vertical-force sources (vertical vibrators, vertical impacts, and shot-hole explosives). These tests utilize data acquired simultaneously with vertical 3C-receiver arrays in wells and horizontal 3C-receiver arrays on the Earth surface. Data are acquired with both 3C geophones and 3C solid-state accelerometers, and with both cable-based and cable-free recording systems, to determine benefits and limitations of specific sensors and recording systems.

Data Processing

In most research projects, EGL utilizes commercial seismic data-processing shops and also implements proprietary, in-house data-processing strategies. This philosophy allows EGL to better monitor the growth of data-processing expertise across the industry and to compare in-house concepts with those of leading data-processing companies. A fundamental principle of elastic-wavefield physics is that S-wave modes are far more sensitive to azimuthal anisotropic rock properties, such as fractures, than are P-wave modes. Because fractures are so important in unconventional resource plays, EGL data-processing research focuses on determining azimuthal anisotropic attributes expressed by S waves. The general S-wave analysis that is stressed is to determine the polarization directions of fast-S and slow-S modes and the magnitude of the time delays between these two S-wave modes. The polarization direction of the fast-S mode generally defines fracture azimuth, or in other instances, the azimuth of maximum horizontal stress. The magnitude of slow-S time delay relative to fast-S time across a fractured interval tends to be proportional to fracture density.

Data Interpretation

EGL implements the science of elastic-wavefield seismic stratigraphy in the interpretation of multicomponent seismic data. Elastic-wavefield seismic stratigraphy is based on the following principles:

1. S-wave sequences and facies differ from P-wave sequences and facies across many stratigraphic intervals,
2. Although P and S images are different, both images are correct because P-waves react to rock and fluid properties in a different way than do S-waves,
3. S-wave sequences and facies have as much weight and importance in interpretation as do P-wave sequences and facies.

Rock Physics

Little progress can be made in applying multicomponent seismic data to prospect evaluation unless rock-physics principles are emphasized in interpreting P and S seismic data. Rock physics explains why P and S images of some geologic targets look similar, and why P images of other targets are dramatically different from S images of the same target. EGL stresses rock-physics analysis of key geologic targets in all projects we pursue.

Depth Registration of P and S Data

S waves propagate with a slower velocity than P waves. Thus a geologic target appears at a later image time in S-wave image space than it does in P-wave image space. This principle, when coupled with the principle that P and S images of a target may not be similar, means that P and S seismic data must be depth registered before the data can be used to evaluate a prospect. EGL has developed several ways to depth register P and S data, with the most rigorous approach being to utilize vertical seismic profile (VSP) data inside P and S image space if an appropriate receiver well is available.

Example of Present-Day Research Project

One multicomponent seismic research project now underway at EGL is a study of shale-gas targets and water-disposal units in the Appalachian Basin. The following description of this study is lifted from the proposal that led to research funding to do the multicomponent seismic research.

Offeror: Bureau of Economic Geology, The University of Texas at Austin

Principal Investigator: Dr. Bob A. Hardage

Title: Evaluation of Fracture Systems and Stress Fields within the Marcellus Shale and Utica Shale and Characterization of Associated Water-Disposal Reservoirs: Appalachian Basin

The Bureau of Economic Geology, The University of Pittsburgh, Chesapeake Energy Corporation, Jeter Field Service, RARE Technology, AscendGeo, AOA Geophysics Inc., Austin Powder Company, and Seismic Source will form an industry-university team to show how multicomponent seismic data acquired with emerging cable-free data-acquisition technology and with new accelerated-weight impactors and vector-explosive seismic sources can be used to evaluate fracture systems that control production of shale-gas systems, quantify stress fields and elastic moduli that influence hydrofrac performance in shale reservoirs, and measure the capacity of porous sandstone units to accept flow-back water produced during hydrofrac operations. Industry cost sharing will be provided by each of the industry team members. The study will focus on the Marcellus Shale and Utica Shale of the Appalachian Basin and on younger Pennsylvanian and Mississippian sandstones and conglomerates that are potential water-disposal reservoirs. Rock physics concepts will be combined with compressional-wave (P-wave) and shear-wave (S-wave) seismic attributes to determine fracture and stress properties of producing shales and to characterize the capacity of targeted sandstone and conglomerate intervals to accept and retain produced waters. Multicomponent seismic data will be acquired using both cable-based and cable-free data-acquisition technologies to confirm that cable-free operations simplify seismic data acquisition and produce optimal-quality seismic data at reduced cost. Seismic data will be acquired with conventional vertical vibrators and with two new seismic source technologies: an accelerated-weight inclined impactor and a shot hole explosive that generates an oriented horizontal force vector. A key research objective will be to evaluate the quality of S-wave data produced by these new source concepts relative to the converted-shear mode produced by a vertical vibrator. One or more wells will be drilled to obtain subsurface calibration data and to confirm research findings. The key deliverable will be documentation of the value of multicomponent seismic technology for exploiting shale-gas systems.