Sandia National Laboratories

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HYDRAULIC FRACTURING

Sandia's role in shale gas production technologies

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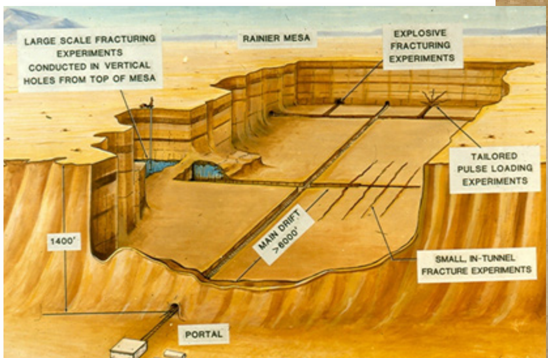
DOE Energy 100 Award for Synthetic Diamond Drill Bits (2000)

Oil and gas production directly from shale is a revolutionary change for the U.S. energy supply. In less than a decade, the nation has become the world's leading natural gas producer and has increased domestic oil production to levels not seen since 1990, due largely to shale production. The huge impact of shale gas and shale oil stems from game-changing technological advances in drilling and hydraulic fracturing stimulation ("fracking") that create access to gas and oil trapped in the "tight" shale formations. Since the early 2000s, the oil and gas industry, particularly independent producers led by Mitchell Energy, established shale production by assembling and implementing a suite of technologies including horizontal drilling, slickwater fracturing, and fracture mapping. The technological roots for several of these innovations are traceable to U.S. government investments in the 1970s and 1980s in research and development (R&D) on tight gas production and drilling technologies. R&D at Sandia National Laboratories has an enormous impact on current industry practice in two areas: polycrystalline diamond compact (PDC) drill bits and hydraulic fracture mapping.

Sandia's R&D activities in energy began in the 1970s, during the energy crisis. At that time, the Atomic Energy Commission asked its laboratories to apply capabilities developed for the nuclear weapons program to solving urgent energy issues. Sandia's world-class engineering focus and experience with large-scale field experiments, essential for the nuclear weapons mission, were particularly synergistic with developing technologies for extracting energy from the subsurface: fossil and geothermal. With support from the geothermal research program at the Department of Energy (DOE), in the 1980s Sandia engineers improved the General Electric's 1970s PDC cutter and made it durable enough for oilfield use. While the cutters had great potential for cost-effective drilling in difficult formations, the synthetic diamonds tended to detach from the bits. Through finite element modeling and analysis, fundamental tests of rock-cutter interactions, development of bit design codes, and field tests, Sandia worked with industry to create a new drilling technology. PDC bits had an immediate impact on the oil and gas industry, and by 1989, accounted for about one-fourth of all petroleum well footage. PDC bits are now a key technology enabling economic drilling of extended-reach horizontal wells, which is standard practice for shale production. As a result, the market share of PDC drill bits has increased dramatically since 2000 and now represents 75% of the well footage drilled annually, worldwide. DOE recognized Sandia's role in PDC bit development with a DOE Energy 100 Award in 2000. These awards honored the top 100 DOE scientific and technical accomplishments between 1977 and 2000. Clearly, the impact of the PDC drill bit development has significantly increased since that time.

G-tunnel, Nevada Test Site



Sandia's contributions to hydraulic fracturing mapping started in the 1970s with the ERDA (Energy Research and Development Administration) Enhanced Gas Recovery Program's Western Gas Sands Program. While hydraulic fracturing had long been successful in a number of conventional gas fields, success was elusive in western low-permeability reservoirs (tight gas sands) and

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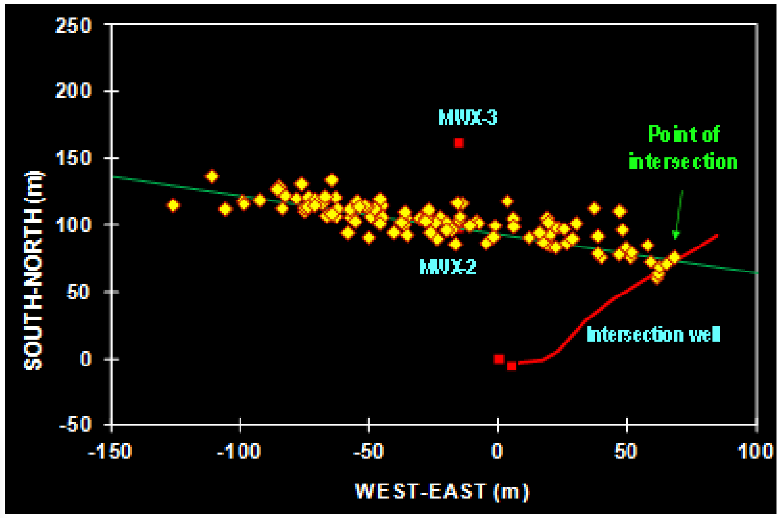
in shales. Almost nothing was known about how fractures interacted with the subsurface—from growth mechanisms to height, length, and direction. Working with industry, Sandia developed government funding to conduct mineback experiments and observe hydraulic fractures in the field. From 1977 to 1985, Sandia created an underground laboratory at the Nevada Test Site G-tunnel for hydraulic fracturing observations. Key insights included the level of complexity of the fractures in the subsurface and the importance of the subsurface *in situ* stress regime on the behavior and geometry of the fractures.



An early hydraulic fracture map from the M-site experiment

MWX Site, Colorado

Around 1980, DOE established a field laboratory for hydraulic fracturing in tight gas sands: the Multi-well Experiment (MWX), led by Sandia. At a location near Rifle, Colorado, three closely spaced vertical wells provided the opportunity to further develop monitoring technologies for hydraulic fracture mapping; Sandia had been working on microseismic and other mapping technologies since 1976. At the MWX site, Sandia built on early Los Alamos National Laboratory Hot Dry Rock geothermal work with small seismic events (“microseisms”) to develop a mapping method and system that used a single three-component borehole seismometer to determine direction and distance of small seismic events that occur during the fracturing process. Importantly, the multiyear MWX program also yielded significant scientific insights on measuring stress states in the subsurface, the importance of detailed geological reservoir characterization, and how the stress state controls the fracture-height growth. Sandia’s combination of experimental and field expertise with advanced computational modeling and geological knowledge was essential for developing the scientific basis for hydraulic fracturing mapping.

Detailed fracture mapping clearly required more seismic information than is available from one seismometer, so in the late 1980s, DOE asked Sandia and its industry partner OYO-Geospace to develop a multilevel downhole seismic receiver system using a fiber-optic wireline. This instrument was used in numerous Sandia field experiments to refine microseismic fracture mapping; the largest was the Multi-site (M-site) Hydraulic Fracture Diagnostics Project, funded by the Gas Research Institute, in the 1990s. The M-site project and others in the mid-1990s established that microseismic data yielded accurate information on fracture dimensions and served as a major basis for the development, by the year 2000, of a microseismic mapping service industry. Microseismic monitoring has now been established as the primary method for evaluating details of hydraulic fracture stimulations in shale reservoirs. Today, every major petroleum service company provides microseismic technology for fracture mapping in both shale and tight gas-sand reservoirs.

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This story was compiled by Marianne Walck with information from Doug Blankenship and retired Sandia employees Norm Warpinski and Dave Northrop.

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