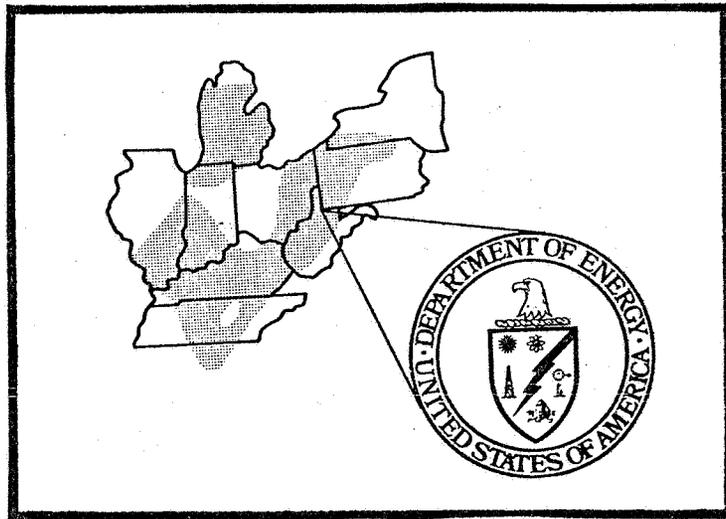


EGSP FACTS

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United States Department of Energy
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Eastern Gas Shales Project

by
Science Applications, Inc.

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INFORMATION MANAGEMENT

1. The "Second Eastern Gas Shale Symposium" was held in Morgantown in October 1978. Approximately 250 persons attended the 2½ day meeting and sixty technical papers were presented. The papers were published in a two volume preprint form totalling 617 pages.
2. A UGR File has been established at METC. Over 185 articles and 75 maps have been placed into the system for use by contractors, industry, independent drillers, and other interested individuals. A 70 page information book has been prepared, listing all materials available. In addition to EGSP documents, maps, and logs, this publication also contains lists of symposium papers, current contractors for EGSP and MRCP, and MRCP documents.
3. Technological Information Letters TI/79-1 through TI/79-11 have been distributed by METC beginning in December, 1978 to a mailing list of over 1000, including State energy officials, State oil and gas associations, the Gas Research Institute, AGA, and producers, operators and user organizations that have expressed interest in the project. These fliers will continue to be written as the need arises.
4. A 12½ minute, 16mm film was prepared outlining the objectives, goals, strategy, and accomplishments of the EGSP. The film has been shown at professional meetings, civic meetings, and at Universities and colleges.
5. In order to set up requirements for the EGSP report format, word processor capabilities and the structured matrix were reviewed and analyzed. Report documentation is being addressed in order to develop a standard format to facilitate storage, retrieval, and evaluation of cumulative project activity information. User requirements are being assessed and functional utility is being determined for management and technical personnel by project element and by contract summary.

GEOLOGIC EVALUATION

1. Preliminary investigations of slickensides and natural fracture trends from a Wise County, VA, core indicate that they trend in the same direction as the Pine Mountain Thrust sheet movement. If this relationship is subsequently proven, the occurrence of porous fractions associated with these features (slickensides and natural fractures) may be predicted. Natural porous fracture systems are primary exploration targets in maximizing gas production from the Devonian Shales.
2. Preliminary analysis of paleocurrent indicators in parts of the Appalachian Basin shows that the eastern two-thirds of the Upper Devonian Shale sequence has uniformly westward-oriented paleocurrents. This is an initial step in developing a depositional model of the Appalachian Basin to include directions of sediment transport, types of sediments being deposited, and location of the source area for these sediments.
3. The Chautauqua County, NY, area has been identified as potentially the most gas-productive of the black shale areas in New York.
4. Results of structural studies, such as those completed at the Cottageville Gas Field, indicate that the development of fracture facies, critical in gas production from the shales, may be related to fault movements in the basement (Rome Trough) structure.
5. An analysis of joints by USGS in the northwestern and western parts of the Appalachian Basin indicates that joint patterns are different for different lithologies at the same locality. This suggests that surface lineations resulting from the surface expression of joints from the hardest near-surface beds may not be indicative of joint patterns developed in the black shales at depth. This phenomena is discussed by De Sitter in Structural Geology, 1964.
6. In the Illinois Basin, a cross section extending from the deep basin in Crittenden County, KY, to west-central Illinois demonstrates that the base of the New Albany Shale is older in the deep basin than in marginal areas. The base of the New Albany Shale in western Illinois appears to be about the same age as the base of the Grassy Creek Shale in the deep basin.

The cross section also shows that black shale deposition began earlier and persisted later in the deep basin than in marginal areas. Only the most prominent black shale horizons of the deep basin can be traced with much assurance into the distant marginal areas. In the marginal areas they are much thinner and have less prominent geophysical characteristics. The base of the Hannibal-Saverton Shale sequence is older in western Illinois than in the deep basin, where its equivalents are largely black shales of the Upper Grassy Creek Shale.

Geologic Evaluation.....continued

7. It was reported that conodonts from a core sample from the basal Antrim Shale of the Dow Chemical Company's test site in Sanilac County, Michigan indicate an early Late Devonian age for the basal Antrim. In terms of Appalachian Basin stratigraphy this part of the Antrim is equivalent to strata between the Genundewa Limestone Member of the Genesee Formation and the basal part of the Rhinestreet Member of the West Falls formation. The conodonts have a Conodont Alteration Index value of 7, which indicates the rocks were not heated to a temperature greater than 60°C (108°F).
8. Recent work by the USGS has determined that the Rome Trough structure extends into west-central Pennsylvania.
9. Based on conodont identifications made from samples recovered from cores in Lincoln County, WV, all but the basal few feet of black shale above the Onondaga Limestone in Lincoln County are Late Devonian in age and probably are the Rhinestreet Member of the West Falls Formation. The absence of a fauna in the basal rich shale beds precludes their identification and assignment to a specific stratigraphic interval.
10. The Rhinestreet and Dunkirk Shales have been identified as possibly having the highest gas potential of the radioactive shales in northwestern Pennsylvania.
11. The final printing of nine cross sections and two maps has been completed. These products were submitted by the Pennsylvania Geological Survey and are available through the METC UGR File. The EGSP Series Numbers and titles are as follows:

Title: Preliminary Stratigraphic Cross Section () Showing Radioactive Black Shale Zones and Sandstones in the Middle and Upper Devonian, Western Pennsylvania (for first nine numbers only)

<u>EGSP Series Number</u>	<u>Cross Section</u>
1	(C ₁ -C ₃) E-W
2	(A ₃ -D ₃) N-S
3	(A ₂ -D ₂) N-S
4	(A ₁ -D ₁) N-S
5	(C ₄ -D ₄) E-W
6	(D ₃ -D ₄) E-W
7	(B ₁ -B ₄) E-W
8	(D ₁ -D ₃) E-W
9	(A ₁ -A ₄) E-W
10 (new Title)	Drilling Depth Map to the Top of the Middle Devonian Onondaga Group
11 (new Title)	Gas Show and Production Map from Middle and Upper Devonian Organic Rich Shales in Western and Northern Pennsylvania

Geologic Evaluation.....continued

12. A preliminary assessment of the shale characterization work being coordinated by Dow Chemical Company in the Michigan Basin has shown that the Antrim Shale is very similar in its lithology and physical and geochemical characteristics to the Devonian Shale of the Illinois and Appalachian Basins. However, additional core data and analytical tests are required before the gas resource potential of the Antrim Shale can be determined.
13. A contiguous nineteen county area of southeastern Illinois has been determined as having the greatest Devonian Shale gas potential in the State. Central and northwestern Illinois are not prospective gas sources as a result of (1) depositional facies lacking dark, organic rich shale, (2) minimum thickness of laminated black shale, (3) low thermal maturation values, and (4) little tectonic activity to produce natural fracture systems.

PHYSICAL AND GEOCHEMICAL CHARACTERIZATION FACTS

1. Approximately 16,906 feet of oriented and nonoriented core have been collected for physical and geochemical characterization.
2. 1848 samples were encapsulated at the well site to preserve the approximate "downhole" condition. This number does not include samples from Tennessee.
3. Seven wells were located in WV, two in IN, three in OH, four in KY, one in VA, four in IL, one in NY, and two in PA. (Eight wells have been cored in TN).
4. Shale lithology has shown little variation between wells except in the relative percentages of light and dark shale.
5. Carbon content of an individual sample shows a positive correlation to uranium and gas volume. Carbon content, however, shows an inverse correlation to Th/U ratio and bulk density. A more significant correlation is indicated by comparing the ratio of V/Ni:Th/U to the carbon content. Bulk density of an individual sample shows an inverse correlation to gas volume and gamma-ray intensity. Therefore, high gas zones in the shale should be indicated by a combination of gamma-ray intensity and bulk density logs.
6. Porosity data show a range of values from less than 0.1 percent to greater than 24.00 percent total porosity for individual samples. The mean of the total porosity for eleven wells ranged from 1.631 to 15.835 percent. The mean value for open porosity of the same wells ranged from 0.590 to 12.256 percent. Statistical analysis has shown no relationship between porosity and gas volume on a sample to sample basis (except for the Mason County, WV well), and two of the Illinois wells show extremely high porosity and little or no gas content.
7. Permeability, measured both perpendicular and parallel to the bedding planes, is low, ranging from zero to a few microdarcies. An abnormally high value of 2.8 darcy has been reported by Mound.
8. Most pore spaces in the shale are very small, generally less than 1.0 μ in diameter. Internal surface areas range from 0.40 to 24.01 m^2/g .
9. The mineralogy of the shales is relatively constant on samples and wells tested to date. The major components are quartz and the clay material illite. In well #20403 from Lincoln County, WV, the gas production zones were characterized by relatively greater amounts of quartz, pyrite, and dolomite and lesser amounts of illite.
10. The shale is extensively laminated and the laminae range from less than 2 mm to greater than 25 mm in thickness. Irregularities in the laminations in the Illinois Basin shales appear to control fracture direction.

Physical and Geochemical Characterization Facts.....continued

11. Mean gas content for the wells tested ranged from 0.003 to 1.110 and averaged 0.42 cu ft gas per cu ft shale in the Appalachian Basin and 0.36 in the Illinois Basin. The Illinois Basin wells have less gas and a lower percentage of lighter hydrocarbons than the Appalachian Basin wells. Gas is unevenly distributed through the core and most Appalachian Basin wells have zones of high gas content approaching or exceeding 1 cu ft gas per cu ft shale.
12. The maturity of the shale in the Appalachian Basin is higher than the Illinois Basin and therefore, should have a higher concentration of gaseous hydrocarbons.

RESOURCE/RESERVE ASSESSMENT
and
FIELD OPERATIONS

1. A total of 32 wells have been cored.
2. Approximately 16,906 feet of oriented and non-oriented Devonian Shale core been retrieved from these wells.
3. Seven wells were located in WV, two in IN, three in OH, four in KY, one in VA, four in IL, one in NY, and two in PA. (Eight wells have been cored in TN).
4. A dry hole sonic tool has been designed and manufactured for specific use in the Devonian Shales.
5. Updated resource calculations based on off-gassing measurements* of seven wells in the Appalachian Basin and five wells in the Illinois Basin indicated the following:
 - The average off-gassing value in the Appalachian Basin was 0.52 cu ft gas/cu ft shale.
 - The average off-gassing value in the Illinois Basin was 0.424 cu ft gas/cu ft shale.

Based on these studies, the following is an estimate of the gas resource**

Appalachian Basin-----	734	TCF
Illinois Basin-----	49	TCF
	<hr/>	
	783	TCF

In each of the wells tested by measuring the gas content of canned samples, a potential producing zone has been indicated at the base of the shale. The thickness of these zones has ranged from 80 to 300 feet. The one exception has been the Monongalia County, WV well in which no potential zone of high gas content is indicated.

6. Production Decline Curves were extrapolated to regions with similar geological characteristics. Preliminary calculations indicated an estimated 277 TCF for an area of 143,835 square miles, which includes the Illinois, Michigan, and Appalachian Basins.

* Based on analysis by Battelle & Mound Labs.

** Area of regions based on "EGR Strategy" document, MERC, November 1977.

EXPLORATION R&D

1. Lineaments have both a beneficial and detrimental effect on shale gas production, according to preliminary studies:
 - WVU (8040) found that maximum gas production was on wells drilled between rather than on lineaments. The P.I. attributed this to possible degassing of shale reservoirs by the lineament-indicated fracture system.
 - ERIM has determined that lineaments closely overlaid and extended beyond the line of high-production wells in the Cottageville, WV field, suggesting a positive correlation between lineaments and production.
 - Results of a WVU (5194) study to determine the influence of photolineaments on water and gas well yields in the Cottageville Gas Field show that short straight photolineaments have certain positive associations with both water well and gas well yields; whereas LANDSAT lineaments have neither positive nor negative associations with water and gas well yields. Short lineaments may represent near-surface zones of enhanced permeability that are about 400 feet wide, with permeability increasing as a photolineament's center line is approached.
2. Detailed geophysical well log suites are routinely run in DOE-sponsored wells. SAI has defined a suite of five dry-hole logs that is the current optimum in terms of information gained versus the cost of recording the logs. Work will continue to refine well log interpretation techniques for the Devonian Shale.
3. The USGS borehole gravimeter is not capable of detecting fracture porosity, and is presently being developed into an indicator of organic content. The commercially available Dresser-Atlas Spectralog is already more useful than the gravimeter. The results of a test of the Spectralog in a Devonian Shale well should be available in August, 1979.
4. WVU (8087) has determined that rocks within cross-strike structural discontinuities (CSDs) are more highly fractured than elsewhere in the detached Appalachian foreland. An exploration rationale for locating Devonian Shale gas in the area was developed and will be further investigated for potential well siting.

SHALE MATRIX STUDIES

1. Initial studies indicate that clay swelling caused by water adsorption may not be as serious a problem in the Devonian Shales as it is in the Gulf Coast oil- and gas-producing region. This has far reaching effects on the design of logging suites and stimulation treatments.

STIMULATION R&D

1. Fifty one stimulation tests have been performed to date in shales and sandstones. Forty one of the tests were conducted in the Devonian Shale. Of the forty one tests, twenty have resulted in substantially increased open flow (from 0-2 MCFD pre-frac to 80-620 MCFD post-frac), fourteen were failures, and seven are still being evaluated.
2. Complete evaluations of the stimulation techniques tested have not been possible because the wells haven't been producing for a long enough time period.
3. The following techniques have been tested in the project:
 - Massive Hydraulic Fracturing - MHF (gelled water principal fluid)
 - Massive Hydraulic Foam Fracturing - MHFF (foam principal fluid)
 - Modified Massive Hydraulic Fracturing - MMHF (alternating stages of gelled water and foam)
 - Cryogenic Fracturing - CF (approximately 80% gelled water, 20% liquid carbon dioxide)
 - Dendritic Fracturing - DF (Kiel Process) (alternating cycles of fracturing and pressure bleed-off with gelled water and nitrogen)
 - Foam Fracturing - FF (conventional size, approximately 50,000 gallons, with foam as the principal fluid)
 - Chemical Explosive Fracturing - CEF (liquid explosive displaced away from wellbore and detonated)

Dendritic Fracturing has not been tested in the Devonian Shale for the EGSP, but was tested in sandstone.

4. Methanol has been eliminated as a viable fluid to use in CF stimulation treatments due to the safety hazard.
5. Adding nitrogen or carbon dioxide as an energy assist mechanism improves well clean-up after stimulation.
6. A 500,000 gal. gelled H₂O frac was conducted in the Devonian Shale on Columbia well #20401. The fracture operation was successfully completed, but a 116-day clean-up period was required to remove the fracturing fluid from the wellbore. Therefore, the remaining scheduled MHF treatments were modified to include stages of foam to provide energy assistance for cleanup operations.
7. The first CEF treatment resulted in significantly increased open flow after fracture. However, it was discovered that the treatment badly damaged the casing due to the packer setting. Therefore, subsequent treatments have been conducted with the packer set in the open hole, which has prevented casing damage.

Stimulation R&D.....continued

8. Seismic monitoring on the surface during a CEF treatment indicated that approximately 100 percent of the liquid explosive was detonated.
9. Low fluid recovery from MHF treatments of the Columbia Gas test well (on the order of 30-50 percent) did not seem to affect in situ permeability measurements in the Devonian Shale.
10. For successful MHF treatments in the Middle Brown Shale, (Lincoln County, WV) the bottom hole pressure necessary to extend the fracture should not be greater than 400 psi above the minimum in situ stress in order to prevent deep excursion of the fracture into the barrier layers.
11. Shut-in pressure appears to provide an accurate estimate of the minimum principal stress.
12. Experiments show that the maximum stress (in Rome Trough only) aligned with the axis of the Appalachian Mountain Belt. This corresponds fairly well with the direction indicated by field experiment data (N45°E to N50°) in Lincoln County, WV.
13. Jet penetrators have been used to penetrate grout blocks. Approximately 8.2 feet of penetration have been achieved in the tests.
14. Stimulation and mineback experiments in welded tuff at the Nevada test site have shown the following:
 - The in situ fracture proppant distribution experiment showed the proppant distribution to be random.
 - The mineback operations into an area of chemical explosive tests revealed a cavern, a thin zone of compression that was impermeable, and an area of relieved stress that was subject to much lower hydraulic breakdown pressure than was normally expected.