# Preliminary Assessment of Potential Injection Strata for Carbon Dioxide Sequestration at New Haven, West Virginia

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# Preliminary Assessment of Potential Injection Strata for Carbon Dioxide Sequestration at New Haven, West Virginia

## INTRODUCTION

The Ohio Department of Natural Resources, Division of Geological Survey (DGS) was contracted by Battelle (Columbus, Ohio) to provide subsurface geologic information in support of Battelle's carbon dioxide sequestration project at New Haven, West Virginia. The area of review (AOR) is a 7,300 mile² area (about 83 miles by 88 miles) approximately centered on New Haven, and includes portions of West Virginia and southeastern Ohio (fig.1). The primary area of interest is the Ohio River corridor near the proposed site.

## OBJECTIVES

The objective of this investigation is to prepare a subsurface geologic assessment of the AOR to include: literature review/bibliography, all pertinent data (digital where possible), geologic cross sections, and structure and isopach maps of important and potential injection horizons with emphasis on the deep Cambrian geologic units. This information will be used as the basis for other tasks to be completed by Battelle including a field-work plan (well design), monitoring plan, risk assessment, and application for underground injection permit. General subsurface data targeted for review include: oil and gas plays, deep wells to the Cambrian, and public-domain seismic reflection data.

## METHODS

Standard procedures and geologic mapping techniques were used to compile and represent existing geologic information. Data collected included: formation depths, formation thickness, well-construction details, formation pressure, permeability, porosity, location and availability of core samples, location and availability of brine/formation fluid samples, and mineralogy for potential injection zones. Digital data were assembled from sources at the DGS and West Virginia Geological and Economic Survey (WVGES) into Microsoft Access and Geographix Explorer computer software. Table 1 lists digital data types and fields. Wells in the text and figures are referred to by both lease name and APINO. The APINO is a national standardized method for assigning unique identifiers to oil and gas wells. It is expressed as a 10-digit number with the first 2 digits representing the state code, the next 3 numbers representing the county code, and the next 5 numbers representing the permit number. No wells have been drilled to the Precambrian basement complex within 25 miles of the New Haven site, therefore interpretation of Cambrian geology in the AOR is based on data from wells located at distances more than 25 miles from the site (fig. 1).

Correct and consistent usage of stratigraphic nomenclature has been an ongoing difficulty for investigators conducting regional stratigraphic studies across state boundaries (Janssens, 1973; Riley and others, 1993). A stratigraphic framework for subsurface Cambrian and Ordovician geologic units in eastern Ohio has been established from previous (Janssens, 1973; Riley and others, 1993; Ryder, 1992; Ryder and others, 1996) and ongoing work at the DGS. The Middle Cambrian in particular has been problematic in the past because of sparse deep-well data and a lack of continuous core. Another difficulty has been a lack of Cambrian paleontological studies to adequately constrain lithostratigraphic correlations (Babcock, 1994). Recent investigations of continuous core, and lithostratigraphic correlation of that core to available geophysical logs from deep wells, have resulted in an updated Cambrian nomenclature and stratigraphy from that used by Janssens (1973). Figure 2 shows a preliminary stratigraphic chart for the Cambrian and lower part of the Ordovician, which compares Janssens (1973) nomenclature with the nomenclature used for this report. The Cambrian stratigraphy and nomenclature as used in this report is an ongoing project at the DGS and has not been finalized.

A network of three-dip and two-strike cross sections were constructed within the AOR using Geographix software (fig. 1). The cross sections illustrate the regional stratigraphy of the potential injection zones and confining units within the AOR. Two sets of cross sections were used for correlation (shallow and deep sections), with stratigraphic datums on the top of the Onondaga Limestone and Maryville Formation, respectively.

Computer mapping was done in Geographix Explorer software using minimum curvature algorithms. Structure maps were made on the top of the Cambrian Rose Run sandstone, and Maryville Formation. A digital structure map on the Precambrian unconformity surface (Baranoski, 2002) was utilized for the evaluation (fig. 3). Isopach maps were made of the Cambrian Rose Run sandstone, Maryville Formation, and "lower unit" of the Maryville Formation.

Computer mapping of bulk-density (RHOB) measurements from digital geophysical density logs was also performed for potential injection zones in the Cambrian Rose Run sandstone and the "lower unit" of the Maryville Formation. Multiple log suites (sonic, neutron, photo electric) from deep wells in the AOR were not available to calculate lithology models of the potential injection zones. As a result, RHOB was chosen as the best quantifiable rock-property measurement of potential injection zones within the AOR. The RHOB values were taken directly from the raw digital well-log data (Log ASCII Standard-LAS format) and were used to generate computer-contoured net footage maps for three bulk density cutoffs.

The RHOB values used for this report cannot be utilized for engineering calculations/estimations. Converting RHOB values into statistically accurate porosity values must take into account many en-

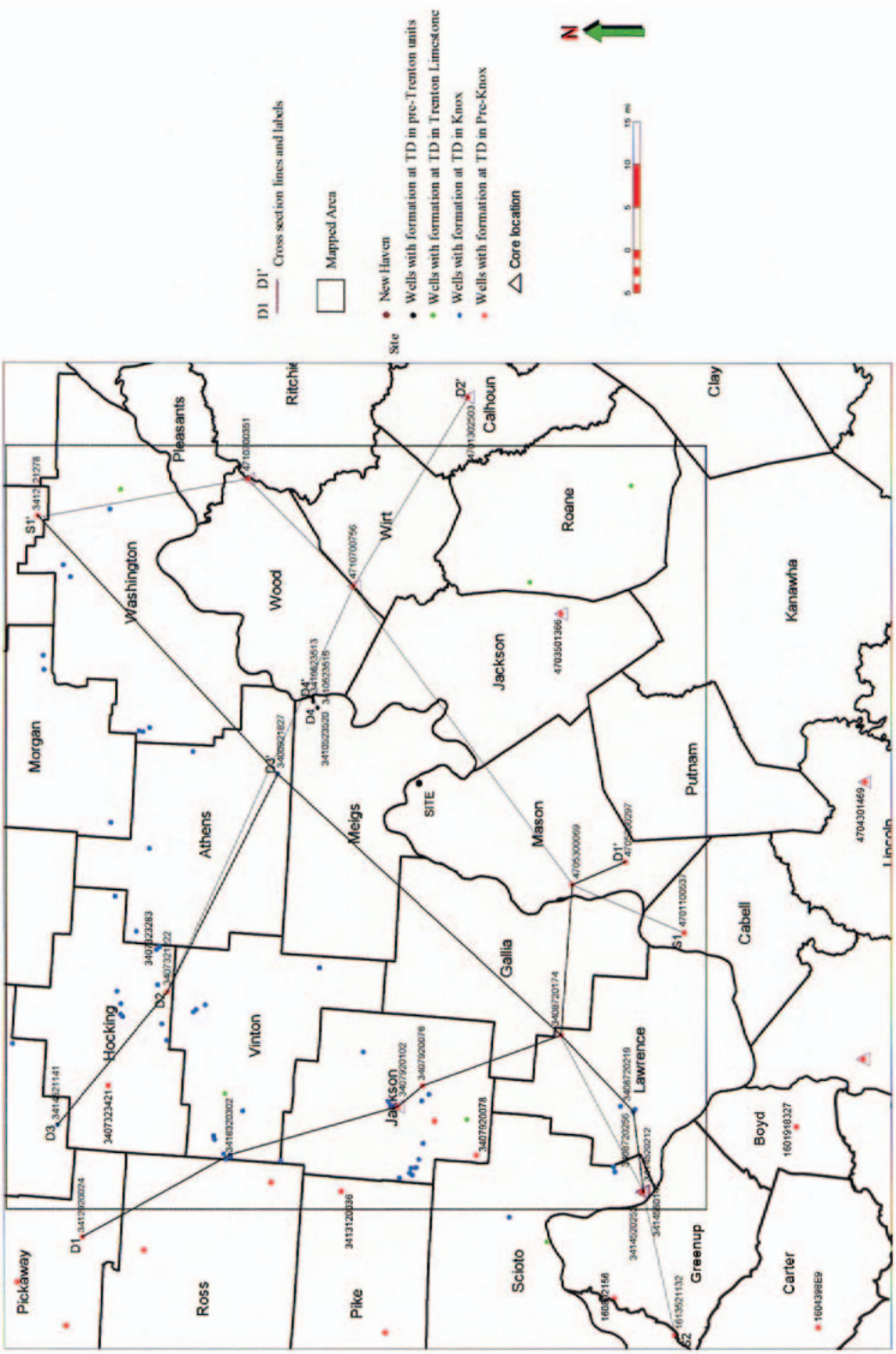



Figure 1.—Map of the New Haven AOR (Area of Review) showing location of oil and gas wells used in the study, cores, and lines of cross sections. Formations at total depth for oil and gas wells are indicated by color. Also shown are the mapped area and the location of the New Haven site.

Table 1. *List of data types/fields in ACCESS database*

| FieldName | Type | Size | Description |
|---|---|---|---|
| APINO | Text | 14 | 14 digit American Petroleum Institute well number |
| SHRT_APINO | Text | 10 | 10 digit American Petroleum Institute well number |
| PERMIT | Text | 8 | well permit |
| ST_PRV | Text | 12 | State or Province |
| MAPX83 | Long Integer | 4 | Ohio state plane X coordinate North American Datum 1983 feet |
| MAPY83 | Single | 4 | Ohio state plane Y coordinate North American Datum 1983 feet |
| LAT | Double | 8 | Latitude |
| LONG | Double | 8 | Longitude |
| CNTY | Text | 20 | County |
| TWP | Text | 20 | Township |
| LOCATION | Text | 255 | Footage location |
| QUAD | Text | 30 | USGS 7.5 minute quadrangle |
| COMPNAME | Text | 54 | company name |
| LEASE | Text | 54 | lease/farm name |
| WELL_NO | Text | 8 | well number |
| END_DATE | Date/Time | 8 | drilling end date |
| STATUS | Text | 8 | well status |
| ABANDONED | Date/Time | 8 | well abandoned |
| LOGCON | Text | 25 | logging contractor |
| LOGS | Text | 255 | geophysical logs |
| DIG_LOGS | Text | 2 | digital geophysical logs |
| SAMPLE_NO | Text | 8 | well cuttings sample number |
| SAMP_RNG | Text | 54 | well cuttings sample range in feet |
| CORE_NO | Text | 8 | well core number |
| CORE_RNG | Text | 155 | well core range in feet |
| SAMPDESC | Text | 2 | sample description Y/N |
| SAMPINTR | Text | 255 | sample description interval |
| ELEV | Long Integer | 5 | well reference elevation |
| SNBR | Long Integer | 5 | top Sunbury Sh |
| BERE | Long Integer | 5 | top Berea Ss |
| OHIO | Long Integer | 5 | top Ohio Sh |
| ONDG | Long Integer | 5 | top Onondaga Ls |
| ORSK | Long Integer | 5 | top Oriskany Ss |
| BASE_ORSK | Long Integer | 5 | base Oriskany Ss |
| SLIN | Long Integer | 5 | top Salina Gp |
| NWBGSS | Long Integer | 5 | top Newberg Ss |
| BASE_NWBGSS | Long Integer | 5 | base Newberg Ss |
| LCKP | Long Integer | 5 | top Lockport Dol |
| BASE_PCKS | Long Integer | 5 | base Packer shell |
| BRSF | Long Integer | 5 | top Brassfield |
| TUSC | Long Integer | 5 | top Tuscarora |
| OVUV | Long Integer | 5 | top Ordovician undifferentiated |
| TRNN | Long Integer | 5 | top Trenton Ls |
| BKRV | Long Integer | 5 | top Black River Gp |
| GLRV | Long Integer | 5 | top Gull River Ls |
| WLCK | Long Integer | 5 | top Wells Creek Fm. |
| WLCK2 | Long Integer | 5 | top Wells Creek Fm. lower unit |
| SNPR | Long Integer | 5 | top St. Peter Ss |
| KNOX | Long Integer | 5 | top Knox unconformity |
| BKMN | Long Integer | 5 | top Beekmantown Dol |
| RSRN | Long Integer | 5 | top Rose Run Sandstone |
| NET_RSRN | Long Integer | 5 | net thickness Rose Run Sandstone |
| CPRG | Long Integer | 5 | top Copper Ridge Dol |
| KNOXB | Long Integer | 5 | top Knox B-zone |
| BASE_KNOXB | Long Integer | 5 | base Knox B-zone |
| BASE_KNOX | Long Integer | 5 | base Knox Dol |
| CNSG_GP | Long Integer | 5 | top Conasauga Gp |
| MDVL | Long Integer | 5 | top Maynardville Ls |
| NCCK | Long Integer | 5 | top Nolichucky Sh |
| MRVL | Long Integer | 5 | top Maryville Fm. |
| ROME | Long Integer | 5 | top Rome Fm. |
| MNSM | Long Integer | 5 | top Mt. Simon Ss |
| NET_MRVL | Long Integer | 5 | net thickness Maryville Fm. |
| PCMB | Long Integer | 5 | top Precambrian unconformity |
| TD | Long Integer | 5 | well total depth |
| FMTD | Text | 8 | well formation at total depth |
| BATTELLE_PROJ | Yes/No | 1 | |
| CTYNUM | Long Integer | 4 | county identication number |
| PERF_INT | Text | 64 | well perforated interval |
| CSGREC | Text | 255 | well casing record |
| ROCKPRES | Double | 8 | well rock pressure |

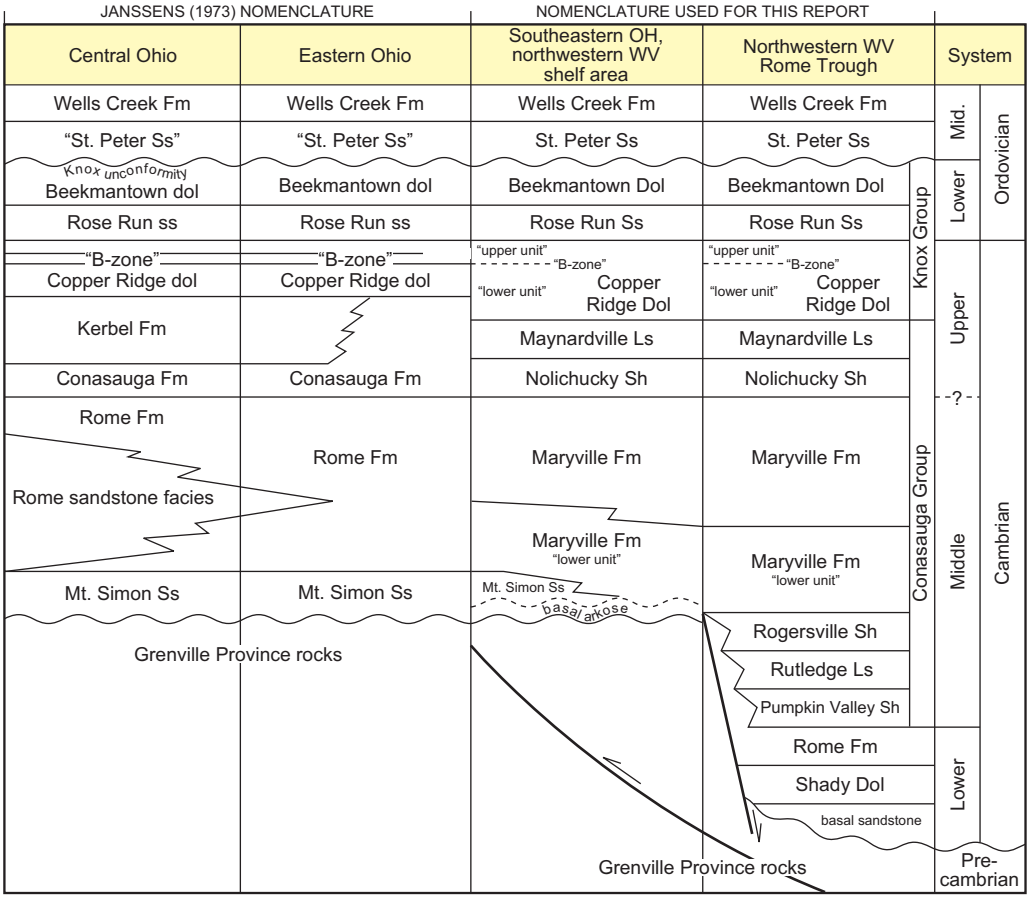



Figure 2.—Stratigraphic correlation chart for the AOR showing the Cambrian and lower part of the Ordovician (modified from Janssens, 1973; Ryder, 1992; and Harris and Baranoski, 1996). Figure by the ODNR, Division of Geological Survey.

gineering and geological variables that are not available for most wells in this study area: bore hole condition (rugosity, wash-out zones, mud cake buildup, etc.), drilling fluids, drilling muds, formation fluid density, formation fluid temperature, formation temperature, geophysical wireline logging tool calibration, geophysical wireline logging tool variations, etc. For example the single variable, formation temperature changes significantly across the AOR, thus affecting accurate modeling of RHOB across the AOR. Taking into account the numerous other variables, both geologic and engineering, yields an extremely complex relationship needed to model the porosity distribution across the AOR with a very incomplete data set. In addition, this report discusses the complex depositional, diagenetic and cementation history that affected the porosity and permeability of both the Rose Run Sandstone and Maryville Formation. These factors add significant heterogeneity to these units, which further complicates models using the RHOB data to calculate porosity across the AOR. Another difficulty with quantifying the RHOB data as porosity across the AOR is a lack of appropriate well logs available. To accurately model the potential injection intervals at the New Haven site, a stratigraphic test core should be acquired and calibrated to multiple modern geophysical wireline log suites (e. g. Density, Neutron, Photoelectric, Nuclear Magnetic Resonance, etc.).

Arbitrary RHOB cutoffs of 2,68, 2.55 and 2.40 grams per cubic centimeter (g/cc) were chosen in this investigation to illustrate an estimated net footage at different RHOB ranges. A porosity equivalency to each RHOB cutoff is assigned and shown in the legend for each of the net RHOB maps. These porosity equivalencies are derived from a RHOB versus porosity graph (Asquith, 1982) for a pure quartz sandstone. It is important to note that these porosity equivalencies assume the subject interval is of a uniform lithology (pure quartz arenite sandstone), which they are not. The complex depositional and diagenetic history of the Rose Run sandstone and Maryville Formation, which is based on deep wells more than 25 miles away, emphasize that arbitrary RHOB cutoffs can not be accurately assigned porosity and porosity-feet values. To accurately model the potential injection intervals at the New Haven site a stratigraphic test core must be acquired and calibrated to multiple modern geophysical wireline log suites (such as Density, Neutron, Photoelectric, etc.). Table 3 lists the RHOB and porosity equivalency values calculated for deep wells evaluated.

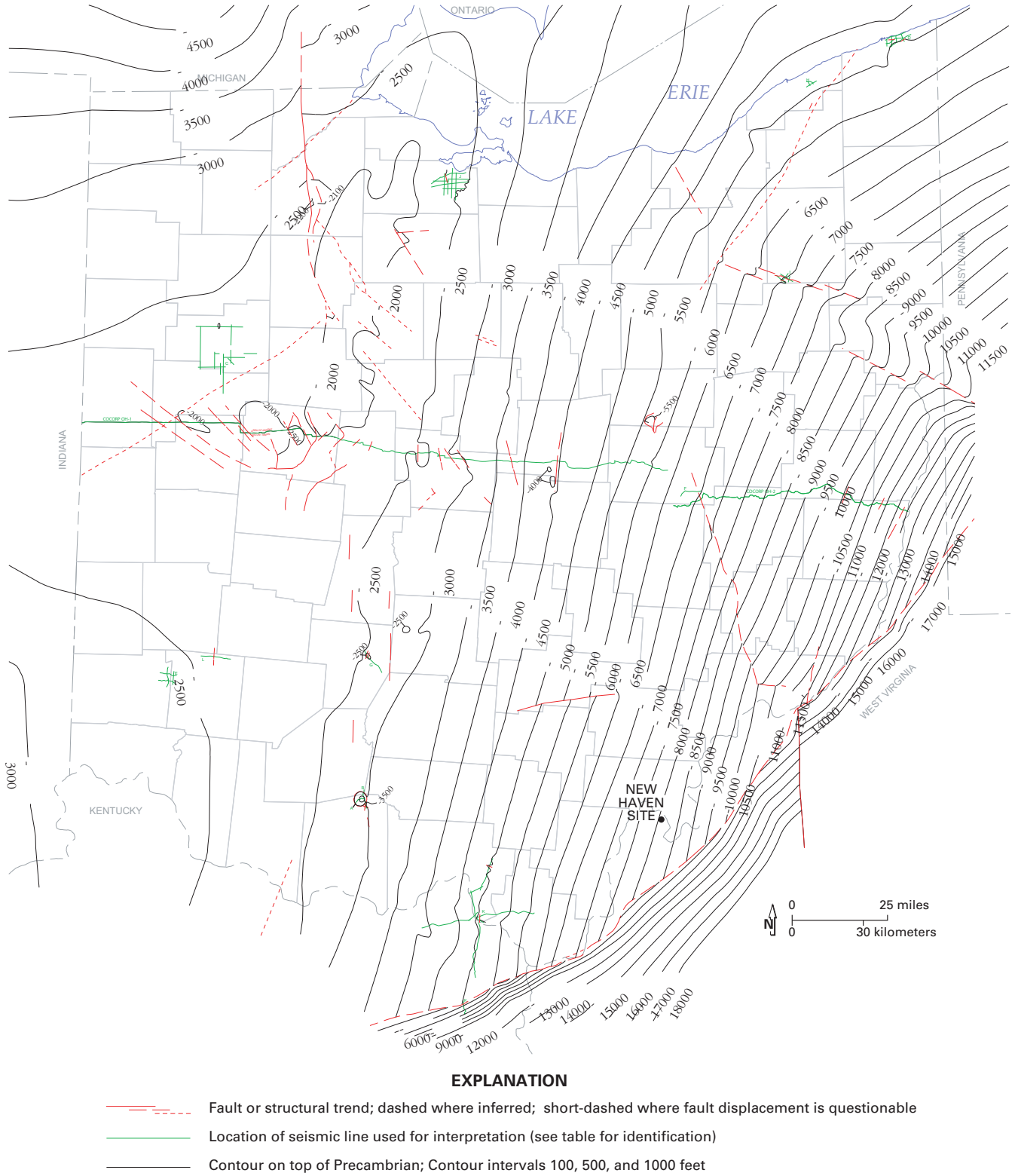



Figure 3.—Map showing structure on unconformity Precambrian surface in Ohio and surrounding region, and location of the New Haven site (modified from Baranoski, 2002). Contour interval = 500 feet. See figure 5 for the names of major features discussed in the text. Figure by the ODNR, Division of Geological Survey.

## PREVIOUS WORK

Aside from regional mapping investigations that included the AOR, no detailed deep-subsurface investigations of the Cambrian strata have been conducted for the New Haven area. Subsurface studies of shallow strata in the area were done for the U.S. Department of Energy and Gas Research Institute Gas Shales projects (Negus-de Wys and Shumaker, 1978; Gray and others, 1982; Ohio Division of Geological Survey, 1988). See Ohio Division of Geological Survey (1988) for an additional listing of shallow studies in Meigs County, Ohio and adjacent West Virginia. Seismic reflection investigations were done in the Cottageville oil and gas field 10 miles SE of the New Haven site (Sundheimer, 1979). References to previous work related directly to the objectives of this investigation can be found in the appropriate sections of this report. Indirectly related references are listed in the Appendix D.

## REGIONAL STRUCTURAL GEOLOGIC SETTING

### Precambrian Structure

The Precambrian Era basement complex is the foundation for overlying Paleozoic Era (and younger) rocks of eastern North America. In general terms, the Precambrian complex of the region includes all rocks older than 600 million years, and Paleozoic rocks include rocks less than 600 million years old. A thorough understanding of the geologic structure, character and history of the underlying Precambrian complex is necessary in order to understand the geologic framework of the Paleozoic strata. However, the paucity of physical rock samples and cores from the deep subsurface of the AOR prevents a thorough characterization of the basement complex. Therefore, a very general description is provided based on our interpretation of the limited data.

The Precambrian basement complex of the region consists of portions of the Grenville Province, East Continent Rift System and the Eastern Granite-Rhyolite Province (fig. 4). On magnetic anomaly maps, Grenville Province metamorphic and igneous rocks of high magnetic susceptibility east of the Grenville Front show pronounced positive anomalies against less magnetic rocks of the Eastern Granite-Rhyolite Province west of the Grenville Front (Bass, 1960; Lucius and von Frese, 1988). U/Pb age dates have not been determined for the Eastern Granite-Rhyolite Province or Grenville Province in Ohio. However, regional geochronological investigations outside Ohio indicate the Eastern Granite-Rhyolite Province is approximately 1.3 to 1.4 GA (Van Schmus et al., 1996), and the Grenville Province is approximately 1.0 to 1.2 GA (Culshaw and Dostal, 2002). The Eastern Granite-Rhyolite Province was down faulted and structurally deformed by continental rifting during the development of the East Continent Rift System. The rift is filled, in part, with Precambrian clastic sediments named the Middle Run Formation (Shrake, 1991; Shrake and others, 1990) and extends from northwest Ohio to central Kentucky and westward across Indiana. It is thought to be part of the Midcontinent Rift System (Drahovzal and others, 1992) (fig. 4).

The Grenville Province is an extension of the Grenville metamorphic and igneous terrane exposed in southern Canada, and consists of regionally metamorphosed igneous and sedimentary rocks formed during the Grenville Orogeny. Within two deep wells outside the AOR, the Grenville Province consists of meta-gabbro, orthogneiss, granite, and amphibolite ((#1 Aristech (APINO 3414520212, Scioto County) and #1 Power Oil Company (APINO 4710700351, Wood County)). The Grenville Province underlies eastern Ohio and adjacent West Virginia and forms the underpinning structure beneath Paleozoic sedimentary cover. Seismic reflection data suggests localized Precambrian sedimentary units beneath the Paleozoic in eastern Ohio and adjacent West Virginia, however the presence of these units has not been confirmed by drilling.

### Paleozoic Structure

During the Paleozoic Era, periodic structural adjustment occurred along pre-existing Precambrian faults and associated zones of weakness. This adjustment affected faulting, sedimentation and depositional patterns during the Paleozoic (Beardsley and Cable, 1983; Riley and others, 1993).

Two regional structural features developed on the eastern Laurentian craton, which was the deeply eroded Grenville Province: the Rome Trough (McGuire and Howell, 1963) and the Appalachian Basin (fig. 5). The Rome Trough, which was first described by Woodward (1961) as a "Cambrian coastal declivity," is considered an Early to Middle Cambrian age failed interior rift (Harris, 1978). The Rome Trough is a regional NE trending structure extending from southwestern Pennsylvania, where it is termed the Olin Basin (Wagner, 1976), to northern Tennessee (fig.6) and is very prominent on magnetic intensity maps (King and Zietz, 1978). Sparse deep-well data and seismic reflection data correlate to this magnetic trend and indicate the Rome Trough is an asymmetric failed-rift zone with the deepest portion on the NW side (Ryder and others, 1998; Gao and others, 2000). A thick accumulation of carbonate and clastic rocks in excess of 10,000 feet (Ryder, 1995) infilled the Rome Trough. Figure 7 is a simplified cross section of the Rome Trough from Ohio to West Virginia with datum on the Ordovician Gull River limestone.

The Appalachian Basin did not begin to take on its present configuration until after Middle Cambrian time following the major movement of the Rome Trough. Major structural features in the region that were active along basement faults during the Late Cambrian subsidence of the Appalachian Basin include: the Waverly Arch, the Cambridge Cross-Strike-Structural-Discontinuity, and the Burning Springs Cross-Strike-Structural-Discontinuity (fig. 5). The subsidence of the Appalachian Basin culminated with the Alleghenian Orogeny and development of the Appalachian structural front and lastly the Burning Springs Anticline and Cambridge Arch features (fig. 8). As the Appalachian Basin subsided, monoclinal flexures developed parallel to NNE strike, affecting localized structures throughout the region.

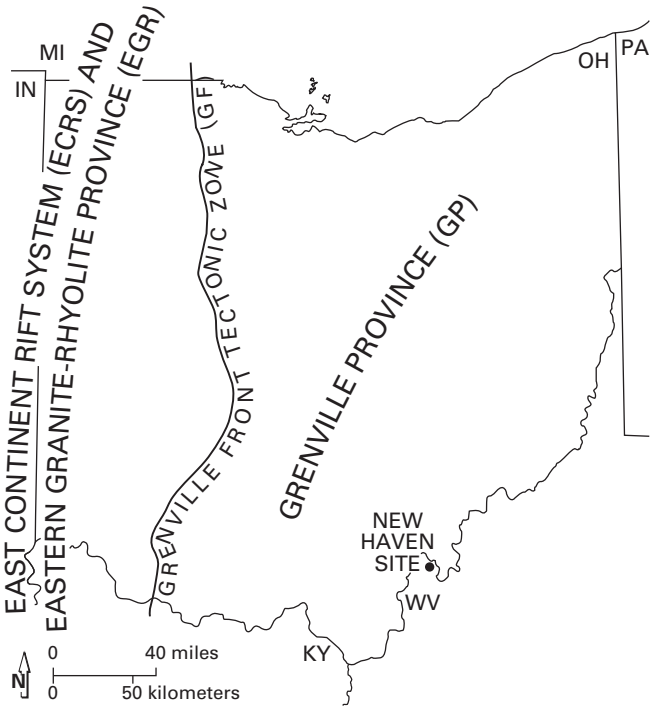



Figure 4.—Map showing Precmbrian Provinces and location of the New Haven site (modified from Baranoski, 2002). Figure by the ODNR, Division of Geological Survey.

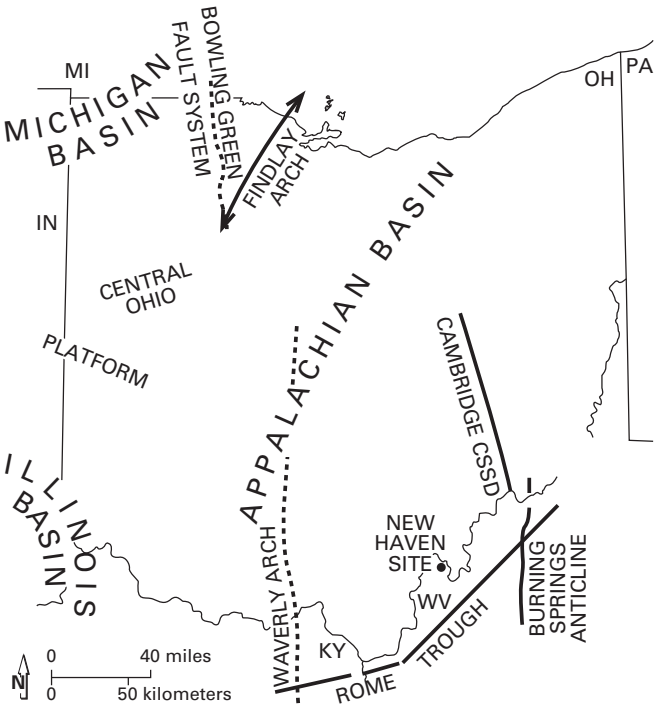



Figure 5.—Map showing major Cambrian structures and location of the New Haven site (modified from Baranoski, 2002). Figure by the ODNR, Division of Geological Survey.

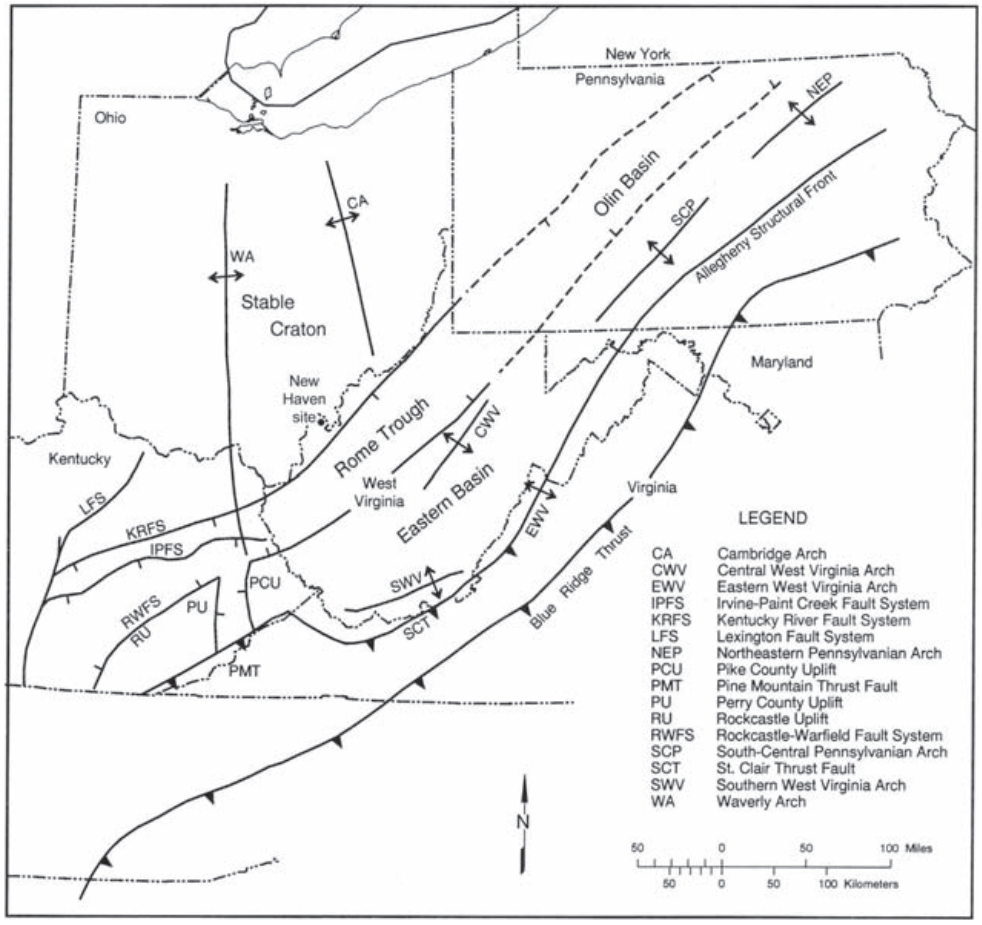



Figure 6.—Map showing regional extent of the Rome Trough, major Cambrian structures and location of the New Haven site (modified from Harris and Baranoski, 1996). Figure by the ODNR, Division of Geological Survey.

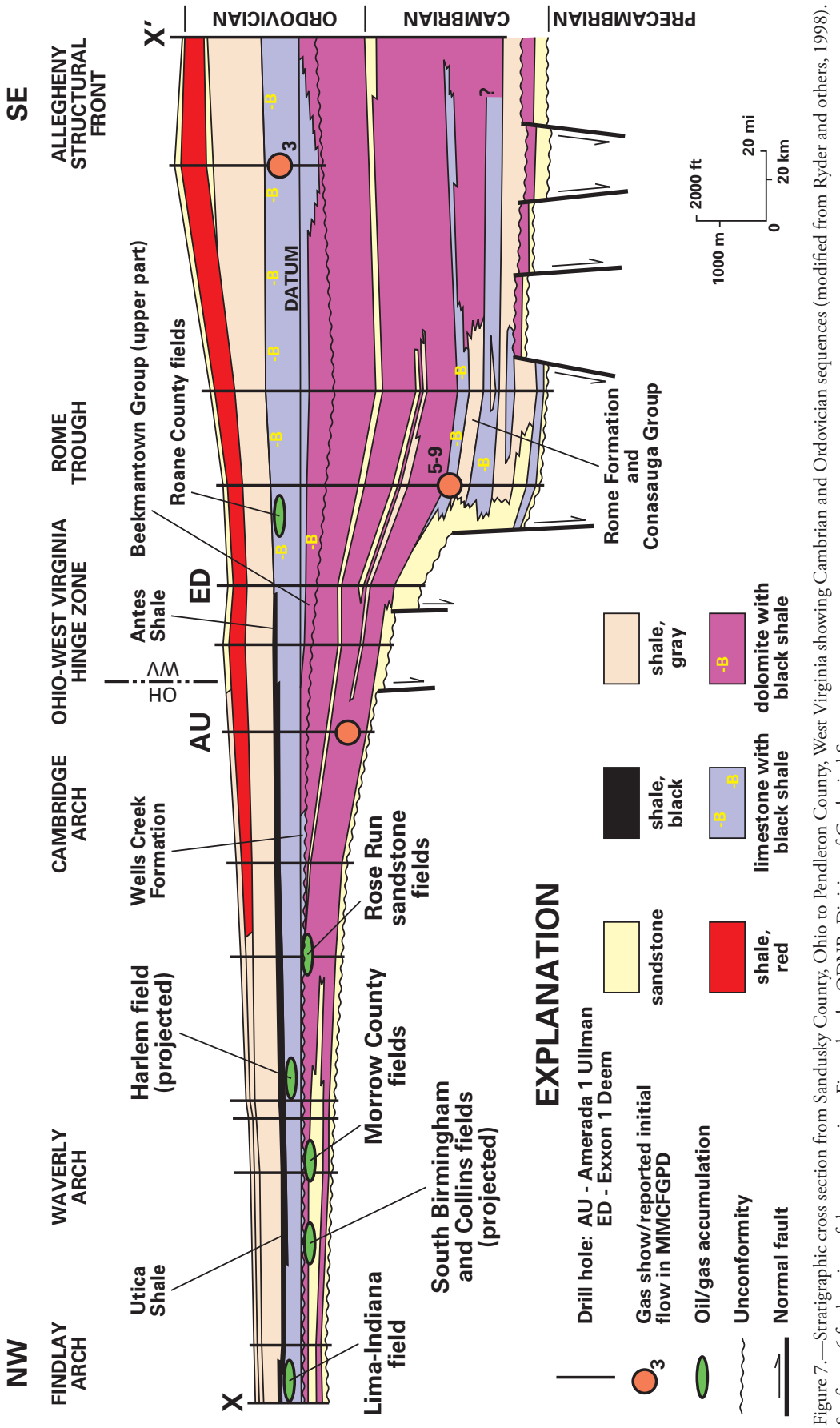



Figure 7.—Stratigraphic cross section from Sandusky County, Ohio to Pendleton County, West Virginia showing Cambrian and Ordovician sequences (modified from Ryder and others, 1998). See figure 6 for location of the cross section. Figure by the ODNR, Division of Geological Survey.

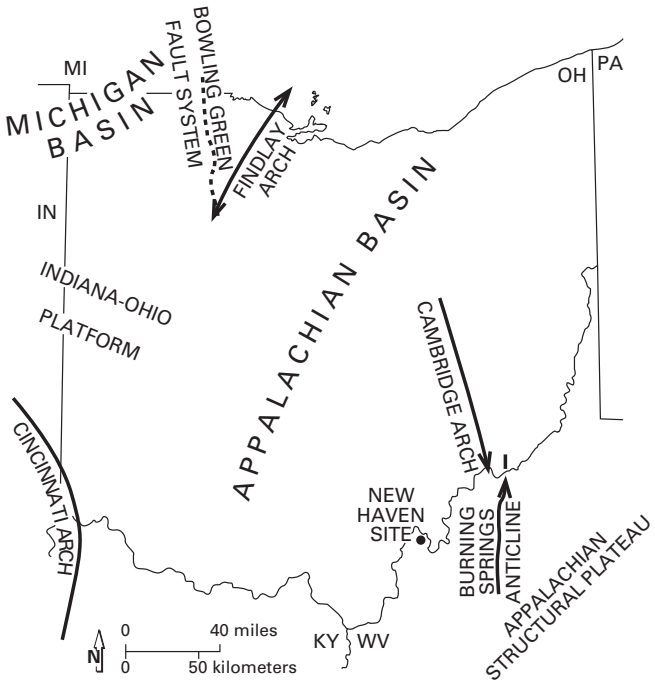



Figure 8.—Map showing major post-Cambrian structures and location of the New Haven site (modified from Baranoski, 2002). Figure by the ODNR, Division of Geological Survey.

## PALEOZOIC STRATIGRAPHY

Regional and localized areas of recurrent crustal movement of the Precambrian basement and later regional uplifts, subsidence, and compressional forces affected the distribution, character and thickness of Paleozoic rock units. Thickness of Paleozoic Appalachian Basin rock units in the region ranges from approximately 3,000 feet in central Ohio to an estimated 45,000 feet in central Pennsylvania (Milici, 1996). The Paleozoic stratigraphic column in the Appalachian Basin ranges in age from Lower Cambrian to Early Permian (fig. 9). A range of sedimentary units (carbonates, evaporites, shale, sandstone, siltstone, k-bentonites, chert, etc) are present throughout the region. Major unconformities mark the Middle Cambrian, Middle Ordovician, Lower Silurian, Middle Devonian, and Upper Mississippian. Pennsylvanian and Permian rock units are largely clastic rocks with minor carbonate units.

The emphasis of this report is an evaluation of potential injection zones within the Lower Ordovician-Cambrian rock sequence of NW West Virginia and adjacent SE Ohio. This interval is bounded at the bottom (base of the Maryville Formation/basal arkose) and top (top of the Beekmantown dolomite) by major unconformities (fig. 2). Sloss and others (1949) used the informal term Sauk sequence for this interval for facies analysis in the upper Mississippi Valley and regional subsurface correlation. Janssens (1973) recognized the importance of regional stratigraphic relationships to the Sauk Sequence in Ohio. His detailed regional study documented significant stratigraphic changes within the Cambrian that show variations from western Ohio, eastward into the Appalachian Basin. In a pre-Knox study of the Appalachian Basin, Harris and Baranoski (1997) divided the region into three sequences: stable cratonic sequence, Rome Trough sequence, and eastern basin sequence (fig. 6). The stable cratonic sequence is stratigraphically much thinner than the Rome Trough sequence, and both fall within the AOR. These terms will be used for the remaining discussion.

It should be noted that the stratigraphy and nomenclature presented in this report is preliminary and has not yet been published. Work in progress at the DGS indicates that significant changes from Janssens (1973) work are present in the Middle Cambrian (fig. 2). Specifically, the Mount Simon Sandstone pinches out in extreme southeastern Ohio, the Rome Formation is not present in southeastern Ohio, and the Conasauga Formation (Janssens, 1973) has been redefined to the Conasauga Group (Ryder, 1992; and Ryder and others, 1996). The Conasauga Group includes the Maryville Formation (including the "lower unit"), the Nolichucky Shale, and the Maynardville Limestone. The Pumpkin Valley Shale, Rutledge Limestone and Rodgersville Shale (Ryder, 1992; and Ryder and others, 1996), which form the lower portion of the Conasauga Group, are confined to the Rome Trough east of New Haven, based on present well control. Appendix A and B lists detailed core descriptions used in the evaluation.

The earliest record of sedimentation within the region is found within the Rome Trough sequence of rocks in West Virginia and Kentucky. Deposition of this sequence began with the lowermost Paleozoic basal sandstone (arkose) in the Latest Precambrian-Early Cambrian time. Rifting of the eastern Laurentian continent resulted in the opening of the Iapetus Ocean (Harris, 1978; Scotese, and McKerrow, 1991). Subsidence of the Rome Trough continued with deposition of the Shady Dolomite and Rome Formation during the Lower Cambrian and continued through Middle Cambrian with deposition of the Conasauga Group. The pre-Knox section of the Rome Trough is older and greatly thickened when compared to the same intervals of the stable cratonic sequence. As much as 10,000 feet of pre-Knox sediments accumulated in the Rome Trough (Webb, 1980; Ryder, 1992; Ryder and others, 1996). Dip sections D1-D1' deep (fig. 10) and D2-D2' deep (fig. 11) illustrate the variation in thickness of the Lower and Middle Cambrian units into the Rome Trough fault system. This is best illustrated between the #1 Arrington well (APINO 4705300069, Mason County) and the #1 Jividen well (APINO 4705300297, Mason County) (fig. 10). Regional cross sections S1-S1' deep (fig. 12) and S2-S2' deep (fig. 13) illustrate the stratigraphic changes along depositional strike for these units.

The basal arkosic sandstone is the lowermost unit within the Rome Trough sequence. The basal sandstone was deposited on the Precambrian unconformity surface and ranges in thickness from 20 to 650 feet (McGuire and Howell, 1963; Webb, 1980). Ryder shows thickness of approximately 150 feet for the basal sandstone in the Rome Trough in West Virginia (Ryder, 1992; Ryder and others, 1995). The Shady Dolomite, which is confined to the Rome Trough

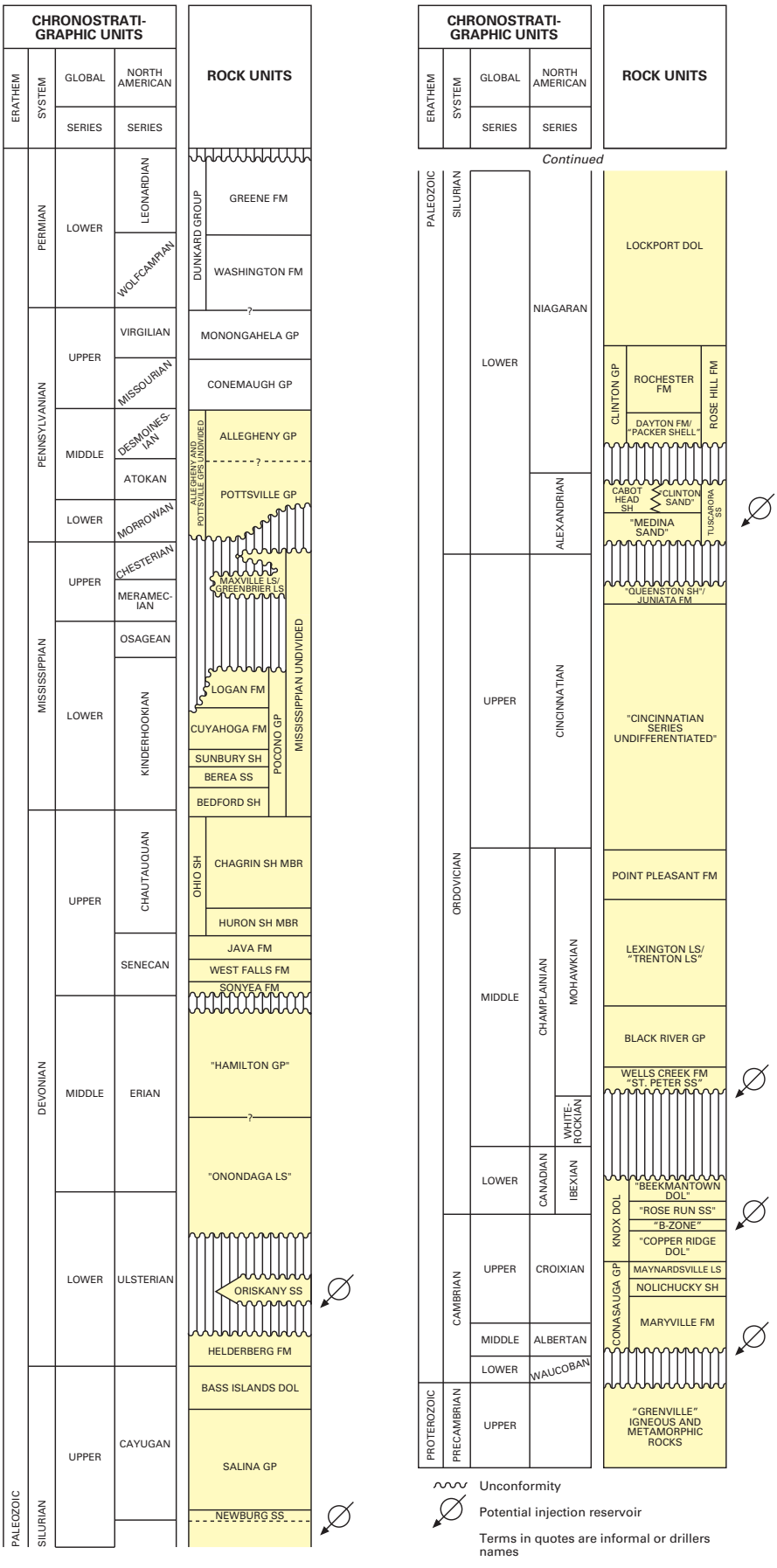



Figure 9.—Stratigraphi column for the New Haven site and potential injection zones (modified from Larsen, 1998). Figure by the ODNR, Division of Geological Survey.

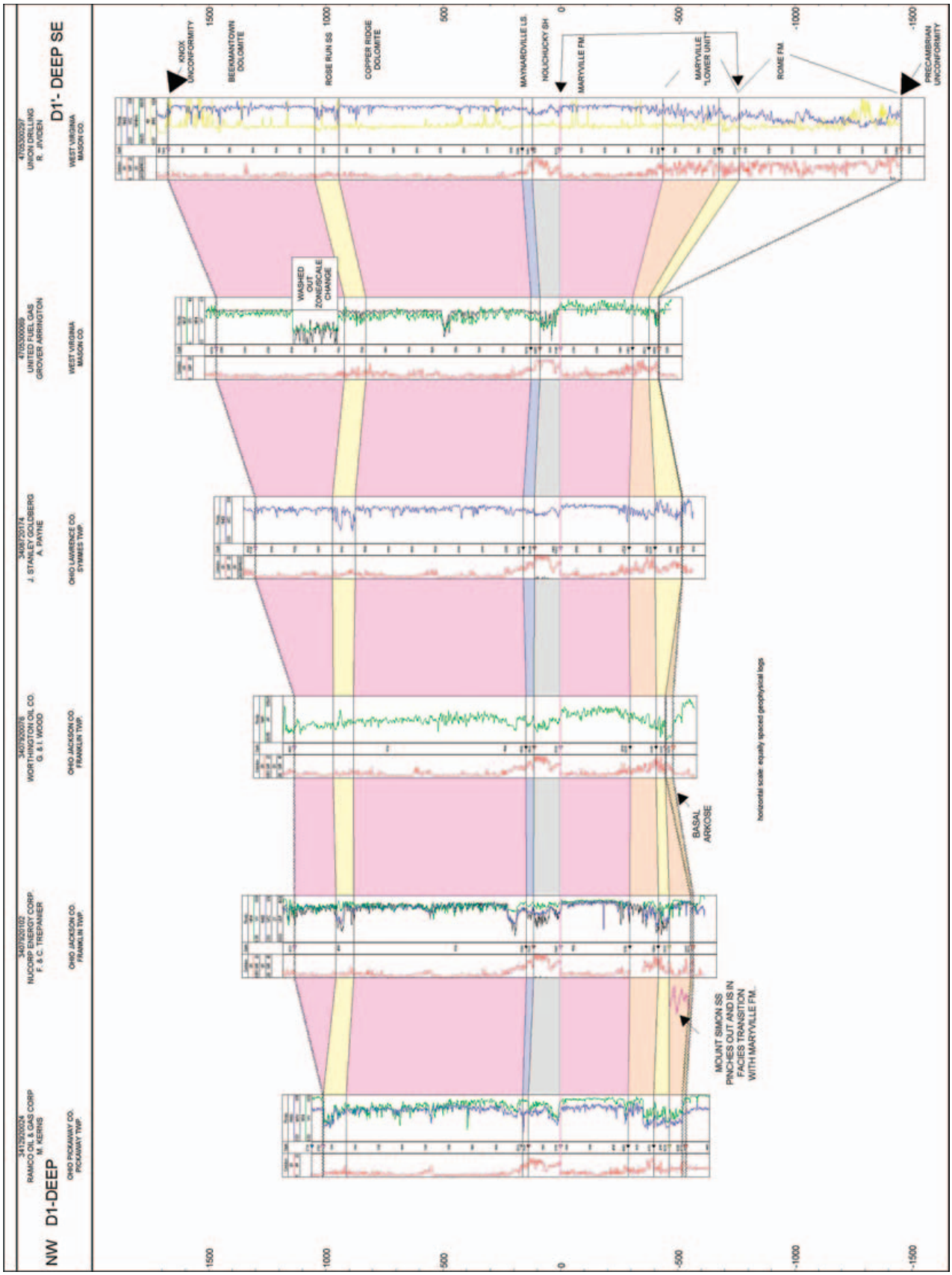



Figure 10.—Stratigraphic cross section (Knox unconformity to Precambrian unconformity interval) Dip D1-D1' deep. Datum on top of the Maryville Formation. Figure by the ODNR, Division of Geological Survey.

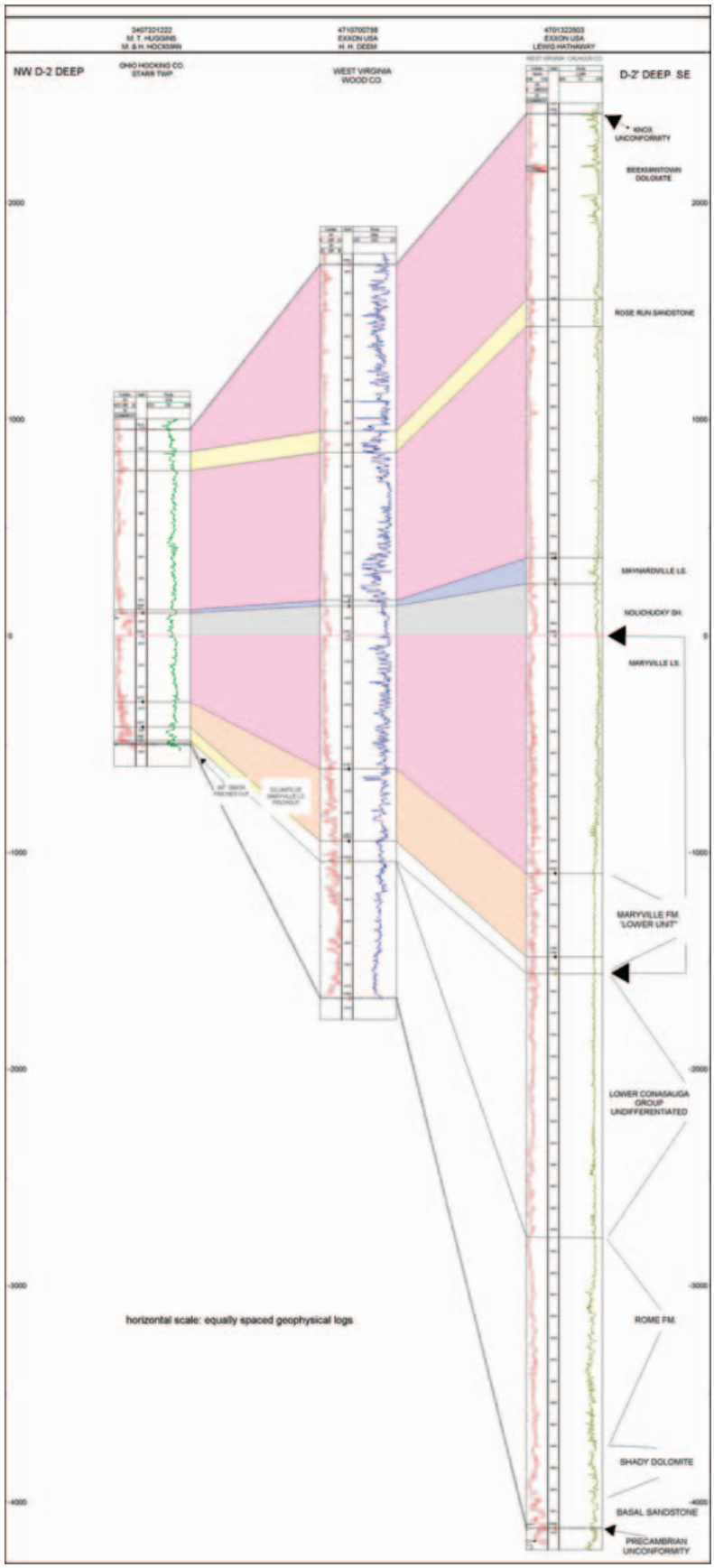



Figure 11.—Stratigraphic cross section (Knox unconformity to Precambrian unconformity interval) Dip D2-D2' deep. Datum on top of the Maryville Formation. Figure by the ODNR, Division of Geological Survey.

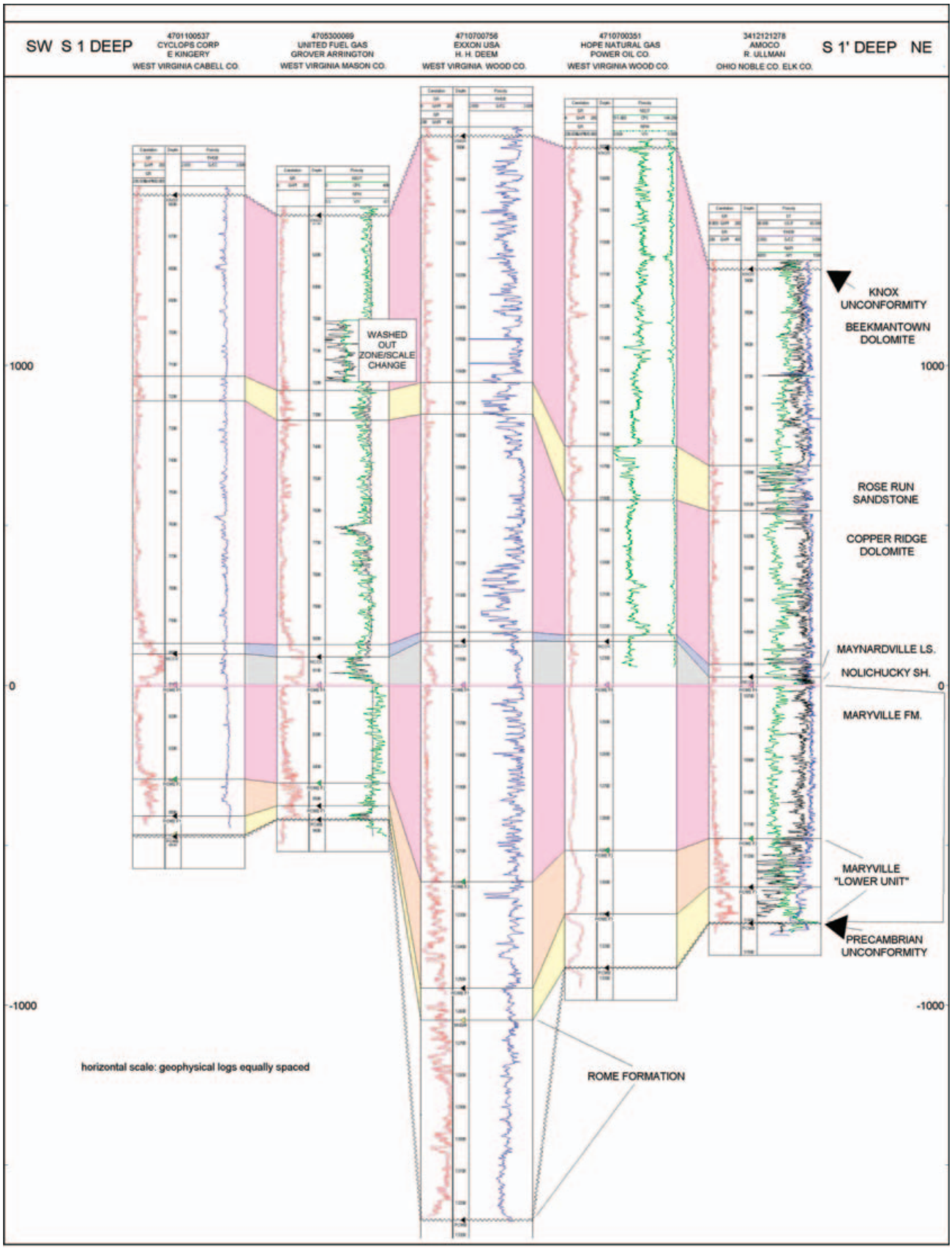



Figure 12.— Stratigraphic cross section (Knox unconformity to Precambrian unconformity interval) Strike S1-S1' deep. Datum on top of the Maryville Formation. Figure by the ODNR, Division of Geological Survey.

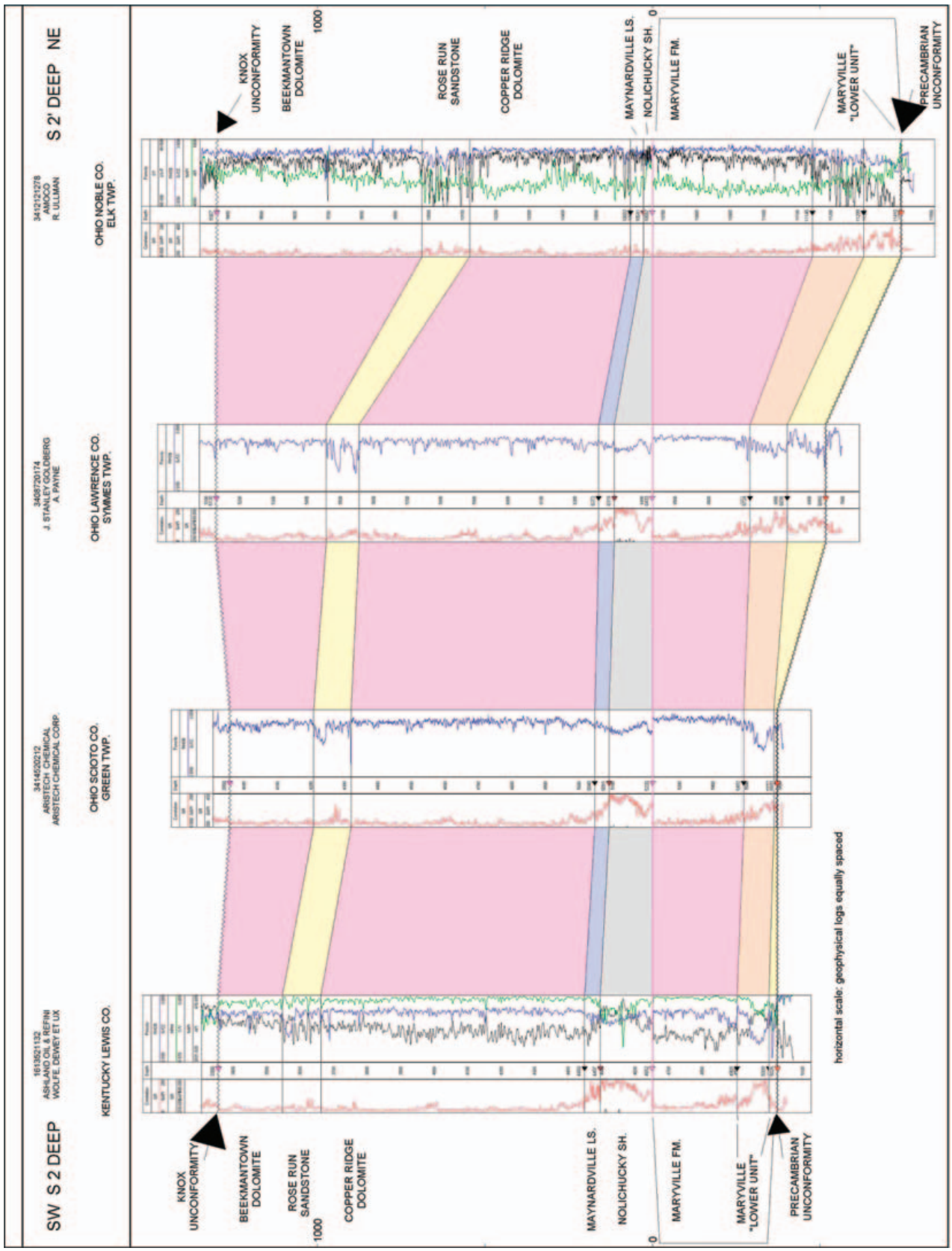



Figure 13.— Stratigraphic cross section (Knox unconformity to Precambrian unconformity interval) Strike S2-S2' deep. Datum on top of the Maryville Formation. Figure by the ODNR, Division of Geological Survey.

area, is a carbonate unit that directly overlies the basal sandstone. Cross sections by Ryder (1992) and Ryder and others (1995) show thickness of the Shady Dolomite at approximately 250 feet in the Rome Trough. The Rome Formation consists of sandstone, siltstone, shale, limestone, and dolomite and ranges in thickness from 1,000 to 2,900 feet (Ryder, 1992; Ryder and others, 1996). Depositional environments for the Rome and overlying Conasauga Group are interpreted as tidal-flat, tidal-channel, and shallow subtidal environments based on core (Donaldson and others, 1975, 1988). The Conasauga Group also consists of sandstone, siltstone, shale, limestone, and dolomite and ranges in thickness from 2,400 to 5,500 feet, which are subdivided into the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Formation, Nolichucky Shale, and Maynardville Limestone (Ryder, 1992; Ryder and others, 1996). Figures 7, 10, and 11 show dramatic thickness increase in Cambrian rock units and generalized stratigraphic relationships from Ohio into West Virginia.

Throughout latest Precambrian to most of Middle Cambrian time, eastern Ohio remained an emergent area as a stable cratonic platform. During this time the erosion of the exposed Grenville basement complex in Ohio and northwestern West Virginia supplied clastic sediment to the Rome Trough while carbonates dominated the eastern side of the structure. Seismic reflection data in southeastern Ohio indicates local areas of Cambrian sediments older than the Maryville Formation "lower unit" in structurally low areas following incised channels, which drained into the Rome Trough. Near the end of the Middle Cambrian, seas had completely transgressed the exposed Precambrian basement complex in Ohio resulting in near shore to marginal marine deposition of Mount Simon Sandstone in western Ohio to marginal marine and marine deposition of Maryville Formation (Conasauga Group) in eastern Ohio. The Mount Simon Sandstone, which is a 200 to 300 feet-thick, highly permeable, porous quartz sandstone in western Ohio, pinches out and/or is in facies transition with the lowermost part of the Maryville Formation in the western portion of the AOR. The Mount Simon had previously been considered a region-wide, areally extensive unit in Ohio (Janssens, 1973). The DGS is presently updating Janssens (1973) work using core and additional geophysical logs. This ongoing study indicates that the Mount Simon disappears eastward either at a pinch-out above the Precambrian unconformity surface or in facies transition from sandstone to dolomite with the lower-most portion of the Maryville "lower unit". The implication is that the Mount Simon Sandstone is not recognized as a regional stratigraphic "blanket" of sandstone.

The Maryville Formation consists dominantly of dolomite to feldspathic quartz dolomite and ranges in thickness within the AOR from 373 to 2,800 feet (fig. 14). The upper portion is light to medium gray, cryptocrystalline to fine and medium crystalline, laminated to irregular, massive bedded, slightly arenaceous dolomite. Glauconite, anhydrite-filled vugs, rip-up clasts, stylolites, shaley discontinuity surfaces, scour surfaces, and bioturbation are locally common (fig. 15). Depositional environments range from shallow subtidal to shallow marine and continental slope (appendix A). The "lower unit" of the Maryville is feldspathic quartz dolomite to feldspathic quartz sandstone, and ranges in thickness within the AOR from 100 to more than 650 feet (fig. 16). The "lower unit" is light pink to white and light brown, fine and medium grained, poorly to well sorted, rounded to subrounded, laminated to irregular, massive bedded, feldspathic dolomitic quartz arenite (fig. 17). Trough cross-bedding, fining upwards sequences, anhydrite replacement clasts, shaley discontinuity surfaces, scour surfaces, bioturbation, vertical burrows, trace fossils, and intraformational breccia are locally common. Depositional environments range from near shore and shallow subtidal to shallow marine environments (appendix A). The quartz sandstone content and geophysical log porosity of the "lower unit" increases in the western portion of the AOR. Dip sections D1-D1' deep (fig.10) and D2-D2' deep (fig.11) illustrate the variation in thickness of the Maryville from Ohio into West Virginia. The most notable aspect is the rapid increase in thickness across the Rome Trough fault system from the #1 Arrington well (APINO 4705300069, Mason County) to the #1 Jividen well (APINO 4705300297, Mason County). Also notable is the decrease in Maryville thickness in the #1 Arrington well, which may indicate a higher shelf area on the immediate NW footwall to the Rome Trough. The Maryville Formation grades upward into the overlying Nolichucky Shale. Appendix A describes the Maryville sedimentary lithofacies from core. Figure 17 is a photo of core from the Maryville "lower unit" showing quartz arenite beds from the #1 Aristech well (APINO 3414520212, Scioto County).

Deposition of the Conasauga Group continued into the Upper Cambrian with a minor marine regression represented by the Nolichucky Shale clastics and carbonates, followed by a transgression with deposition of the Maynardville Limestone. Open marine conditions continued with deposition of the Knox Dolomite. As used in this report, the Knox Dolomite is subdivided in ascending order into the Copper Ridge dolomite, the Rose Run sandstone, and the Beekmantown dolomite (figs. 2 and 9). Minor regressions took place with input of clastics in the "B-zone ", and to a greater degree, the Rose Run sandstone.

The Rose Run sandstone occurs within a thick sequence of predominantly shallow-water carbonates that comprise the Knox Dolomite. This sequence has been interpreted to consist of the vertical stacking of various peritidal facies resulting from cyclical sea-level changes on a broad carbonate shelf (Read, 1989; Osleger and Read, 1991; Riley and others, 1993). The Rose Run sands represent lowstand deposits, related to both third-order sea-level falls and short-term sea-level cycles (Read, 1989). Thin-section petrography indicates that the Rose Run sandstone has a continental block provenance with a source in the craton interior to the north and northwest of the project area (Riley and others, 1993). Thus, siliciclastic deposition in the Rose Run decreases to the south and southeast away from the stable craton.

The Rose Run sandstone is present throughout the entire AOR and can be correlated in the subsurface to where it subcrops in the extreme western portion of the mapped area (fig. 18). The gross thickness of the Rose Run sandstone ranges from 74 feet in Hocking County,

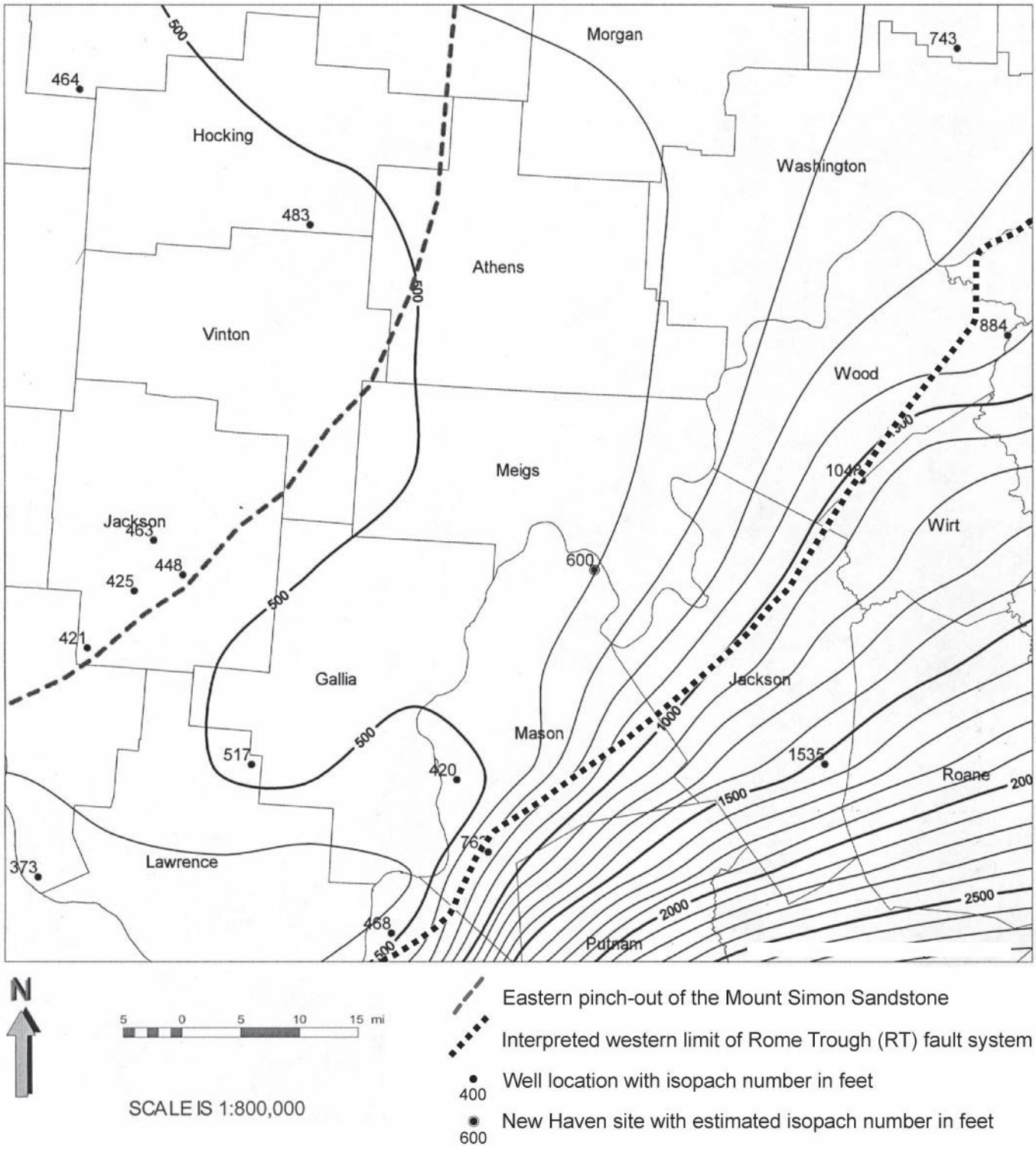



Figure 14.—Map showing isopach of the Maryville Formation within the AOR and location of the New Haven site. Contour interval = 100 feet. Computer generated contours from interpreted grid. Contours not interpreted across fault. Figure by the ODNR, Division of Geological Survey.

Figure 15.—Maryville Formation core interval 5205.5 to 5214.5 API-INO 3414560141 Aristech monitor well number 4. See Appendix A core interval description. Figure by the ODNR, Division of Geological Survey.

Ohio, to over 195 feet in Jackson County, West Virginia (fig 18). In the mapped area, the average gross thickness is approximately 100 feet. At the proposed project site, the mapped Rose Run gross thickness is estimated to be approximately 125 feet. Generally speaking, the Rose Run gross interval thickens to the east and southeast downdip towards the basin center. Regional thickening of this interval also is illustrated on the northwest-southeast trending stratigraphic cross sections (figs. 10 and 11). It is important to note that while the gross interval thickens to the southeast, the amount of siliciclastics or potential injection zone in this interval decreases in this direction. This supports previous ideas on Rose Run provenance work that the sandstone-to-carbonate ratio decreases to the east and southeast away from the depositional source (Riley and others, 1993; Baranoski and others, 1996). The nearest logged well with a complete Rose Run section is about 25 miles SE, #1 Arrington (API-NO 4705300069, Mason County) (fig.10). The neutron log indicates poor sandstone development in the Rose Run interval. Sample cuttings were not recovered from the upper 100 feet of this interval, which may indicate a washed out zone (Overby, 1961). The interval with a high neutron curve above the Rose Run in this well occurs within a cherty dolomite (Overby, 1961), and may represent a drilling-induced fracture zone (Schlumberger, personal communication). The geophysical log notes that the calibration was changed above this anomalous interval.

A major regression took place during the Middle Ordovician with the onset of the regional Knox unconformity. An extensive erosional surface developed on the emergent Knox carbonate platform (Riley and others, 1993). Paleotopography reached a maximum of 150 feet on the karstic terrain of the Knox Dolomite (Janssens, 1973). Tropical seas returned to the Ohio region and inundated the subsiding Knox platform in the Middle Ordovician. The St. Peter sandstone and Wells Creek Formation represent the next major marine transgression; these units were deposited on the regional Knox unconformity. The St. Peter is a very fine grained, well-sorted, quartz arenite that forms the basal part (where the unit is present) of the Wells Creek Formation. The St. Peter increases in thickness from stable craton into the Rome Trough (Humphreys and Watson, 1996). The Wells Creek Formation is a sandy, dolomitic shale that locally contains beds of limestone. Shallow marine sedimentation continued through the Middle and Upper Ordovician with deposition of the Black River Group, Trenton Limestone, and Cincinnatian Series undifferentiated. The clastic sediments of the Cincinnatian Group were associated with the Taconic Orogeny of eastern North America.

Marine sedimentation in the region temporarily ceased during Late Ordovician-Early Silurian time as another major regression began and a regional unconformity develops on top of the Cincinnatian Series undifferentiated. By the end of the Ordovician the western margin of the Appalachian Basin was delineated by the Indiana-Ohio Platform, and the Cincinnati and Findlay Arches. As Silurian time progressed, repeated fluctuations of sea level flooded and retreated from the coastal lowlands on the western flank of the Appalachian Basin. Silurian-age Tuscarora Sandstone and other clastic equivalents were deposited in near shore to marginal marine deposition on this unconformity surface at the onset another marine transgression. A mixture of clastics and carbonates followed with deposition of the Rose Hill Formation and its equivalents, and the overlying Lockport Dolomite, Newburg sandstone, Salina Group, Bass Islands Dolomite and Helderburg Formation. Another period of regression is marked by an unconformity within Lower Devonian strata, and is followed by a period of transgression and subsequent deposition of the Oriskany Sandstone, overlying Onondaga Limestone, and shales of the Hamilton Group (marking the onset of the Acadian Orogeny). Dip sections D1-D1' shallow (fig.19) and D2-D2' shallow (fig.20), and strike sections S1-S1' shallow (fig. 21) and S2-S2' shallow (fig. 22) illustrate the variation in thickness of the units deposited above the Knox unconformity to the top of the Berea Sandstone.

During the Late Devonian Acadian Orogeny, tropical seas again inundated the region with deposition of the Sonyea, West Falls, and Rhinestreet Formations, and Ohio Shale into a partially restricted marine basin. The overlying Bedford Shale and Berea Sandstone represent the progradation of gray shales and sandstones. The regional stratigraphy is shown in figures 19, 20, 21,and 22. An Early Mississippian marine transgression resulted in the deposition of the Sunbury Shale. Renewed mountain building in eastern North America with the Al-

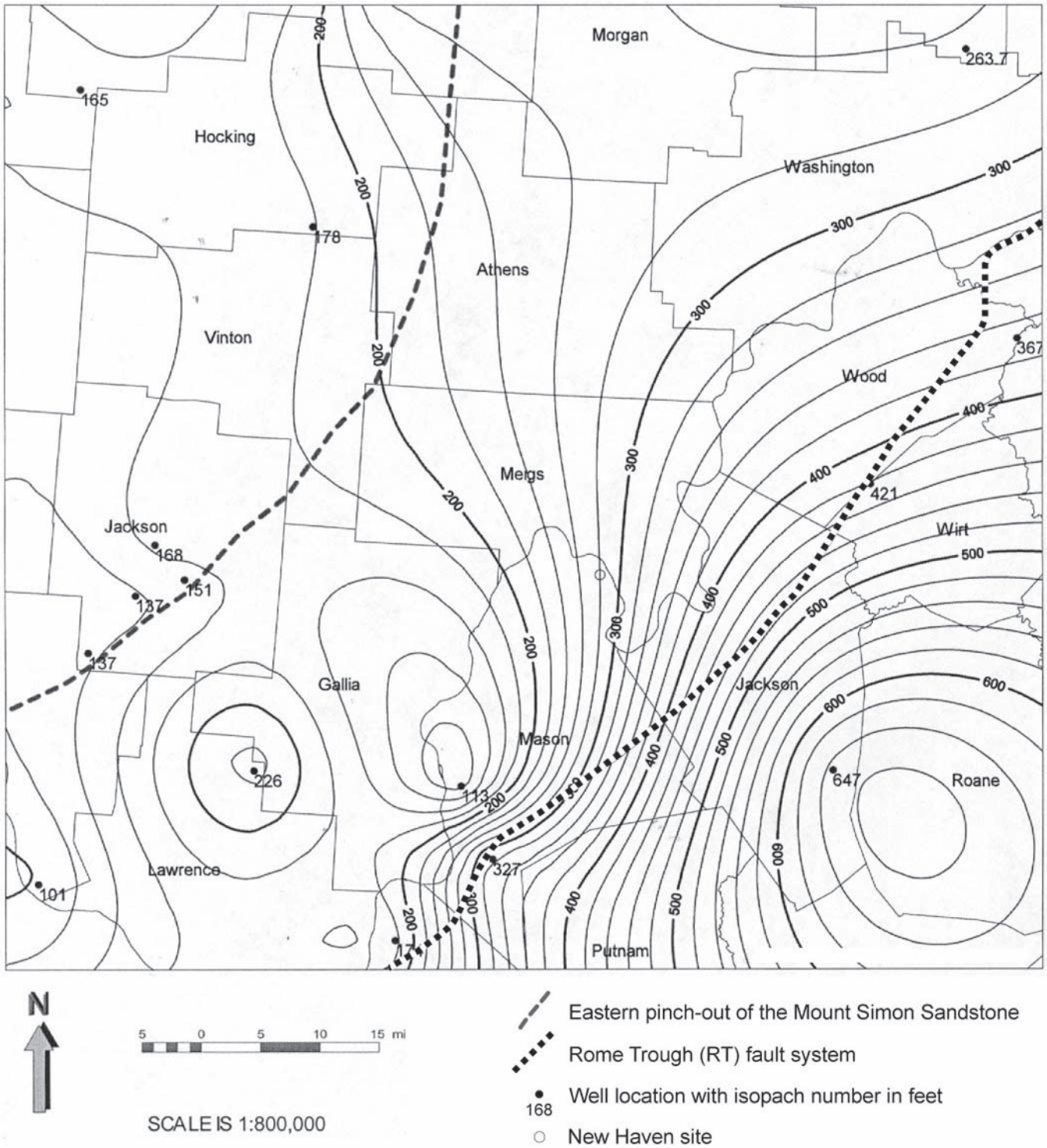



Figure 16.—Map showing isopach of the Maryville Limestone "lower unit" within the AOR and location of the New Haven site. Contour interval = 20 feet. Contours not interpreted across fault. Figure by the ODNR, Division of Geological Survey.

Figure 17.—Lower unit of the Maryville Formation core interval 5558.8 to 5572.3 APINO 3414520212 Aristech well number 1. See Appendix A core interval description. Figure by the ODNR, Division of Geological Survey.

leghenian Orogeny during the Early Mississippian resulted in delta progradation and the deposition of the Cuyahoga and Logan Formations, followed by a minor marine transgression with deposition of the Greenbrier Limestone and equivalents. Continued mountain building to the east resulted in extensive fluvial, clastic deposition including coals with minor limestone accumulations throughout the Pennsylvanian and Permian Systems.

## REVIEW OF OIL AND GAS PLAYS

### Introduction

While enhanced recovery of oil and gas from $CO_2$ injection is not a primary objective of the Battelle project at New Haven, the impact of injection on hydrocarbon deposits is a significant consideration. Especially since some formations with potential hydrocarbon reserves may be targeted for $CO_2$ injection. Updated maps (extracted from DGS oil and gas fields digital maps and WVGES digital data) of oil and gas plays in the AOR are provided to assist in understanding their potential to impact $CO_2$ sequestration. In the AOR, the following plays are discussed: the Cambrian Conasauga Group, the Cambrian-Ordovician Knox Group, the Middle Ordovician Lexington/Trenton and Black River group carbonates, the Lower Silurian "Clinton"/Tuscarora Sandstone, the Lower Devonian Oriskany Sandstone and the Upper Silurian Newburg Sandstone and Lockport Dolomite, the Upper Devonian Black Shales, the Upper Mississippian and Lower Devonian Berea Sandstone, the Upper and Lower Mississippian sandstones, and the Lower and Middle Pennsylvanian Allegheny and Pottsville Groups (figs. 23-31). A detailed description of these plays is present in the Atlas of Major Appalachian Gas Plays (Roen and Walker, 1996).

### Cambrian Conasauga Group

Drilling to Cambrian-Ordovician stratigraphic units in the AOR is very rare due to great depth and rare hydrocarbon production. About 25 miles SE of the New Haven site, the #1 McCoy well (APINO 4703501366, Jackson County) reported open-flow gas production of 9.2 million cubic feet of gas per day (MMcfd) from a Conasauga Group sandstone unit (Harris and Baranoski, 1996). The zone produced over 400 MMcf during a 5-month period and correlates to the lower part of the upper portion of the Maryville Formation of this report. Shows of gas have been reported from the Maryville within the AOR (Table 2). Thus, hydrocarbon production from the Maryville at the New Haven site is possible if good reservoir and trapping mechanisms are present.

### Cambrian-Ordovician Knox Group (including the Rose Run sandstone) and St. Peter sandstone

In Ohio, Knox hydrocarbon production occurs in the Beekmantown dolomite, Rose Run sandstone, and Copper Ridge dolomite. There is no historic Knox production in West Virginia. Nearest Knox hydrocarbon-producing fields to the proposed site are about 50 miles to the NW in Hocking County, Ohio (fig. 23). Production in this field is from the Beekmantown dolomite and Rose Run sand-

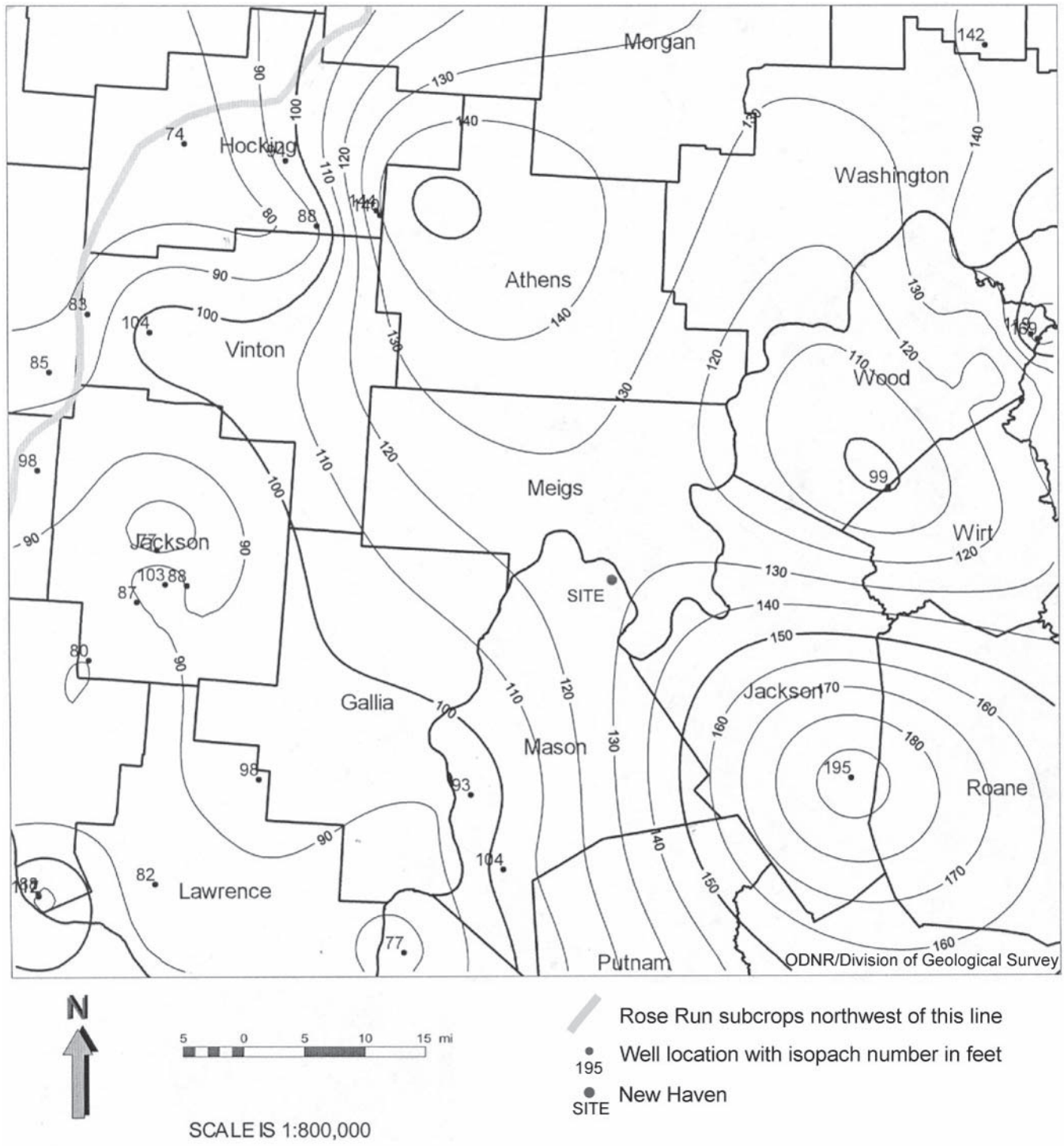



Figure 18.—Map showing isopach of the Rose Run within the AOR and location of the New Haven site. Contour interval = 10 feet. Figure by the ODNR, Division of Geological Survey.

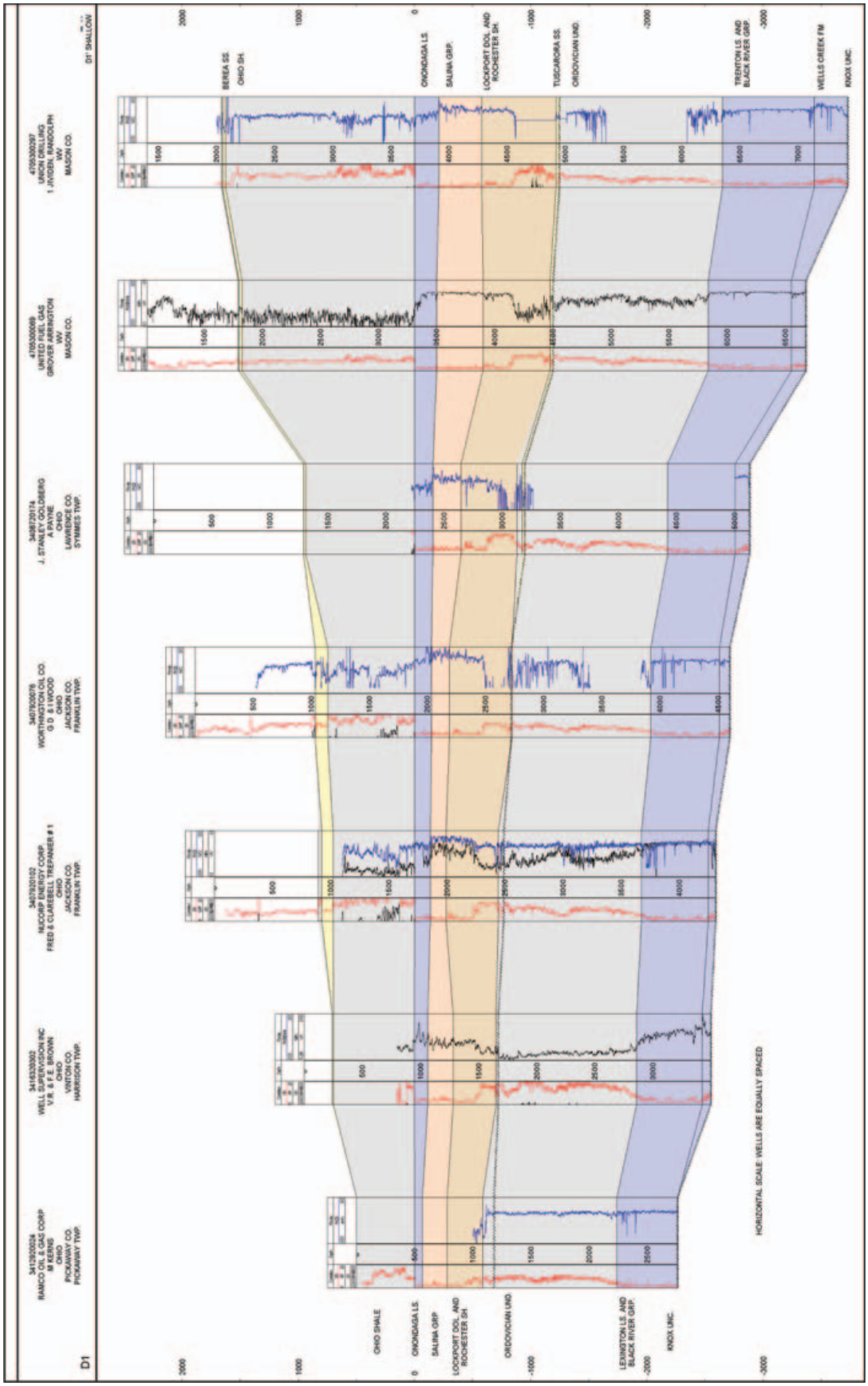



Figure 19.—Stratigraphic cross section (shallow geologic units to Knox unconformity interval) Dip D1-D1' shallow. Datum on top of the Onondaga Limestone. Figure by the ODNR, Division of Geological Survey.

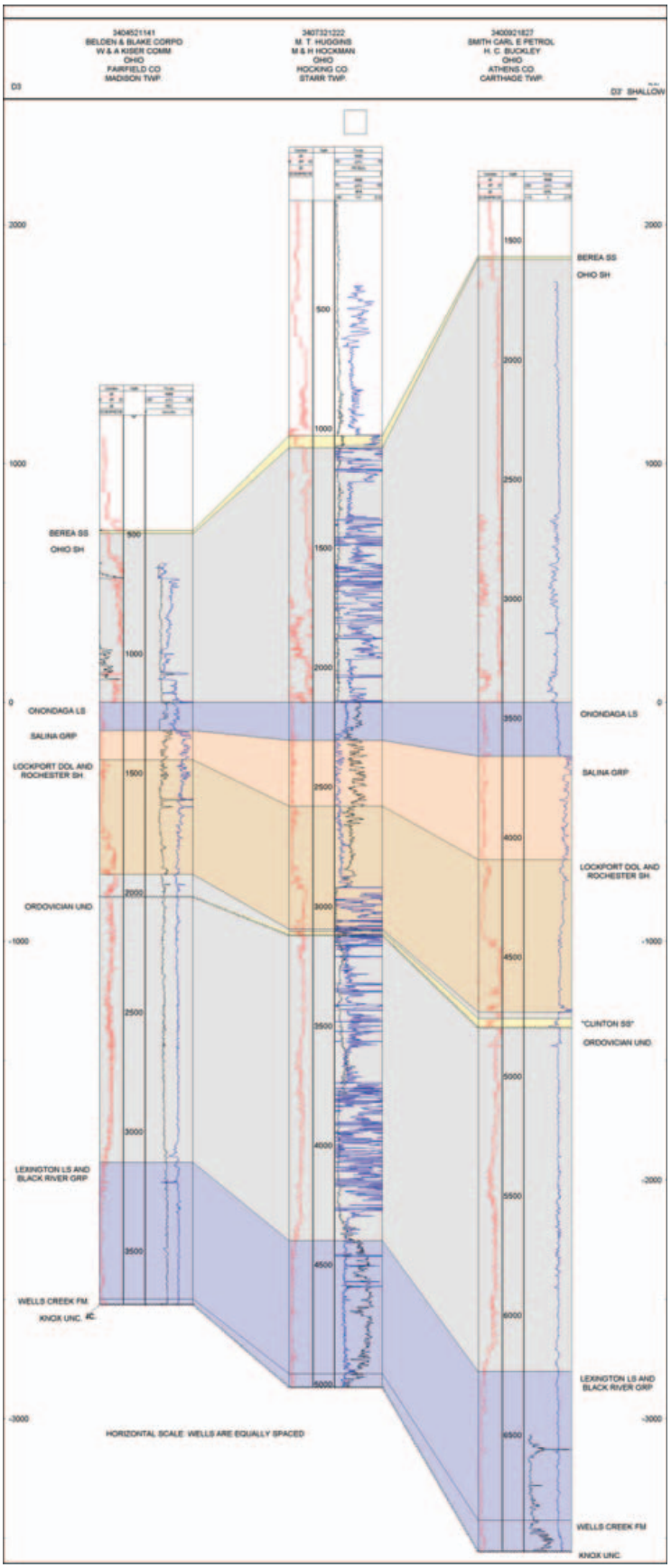



Figure 20.—Stratigraphic cross section (shallow geologic units to Knox unconformity interval) Dip D3-D3' shallow. Datum on top of the Onondaga Limestone. Figure by the ODNR, Division of Geological Survey.

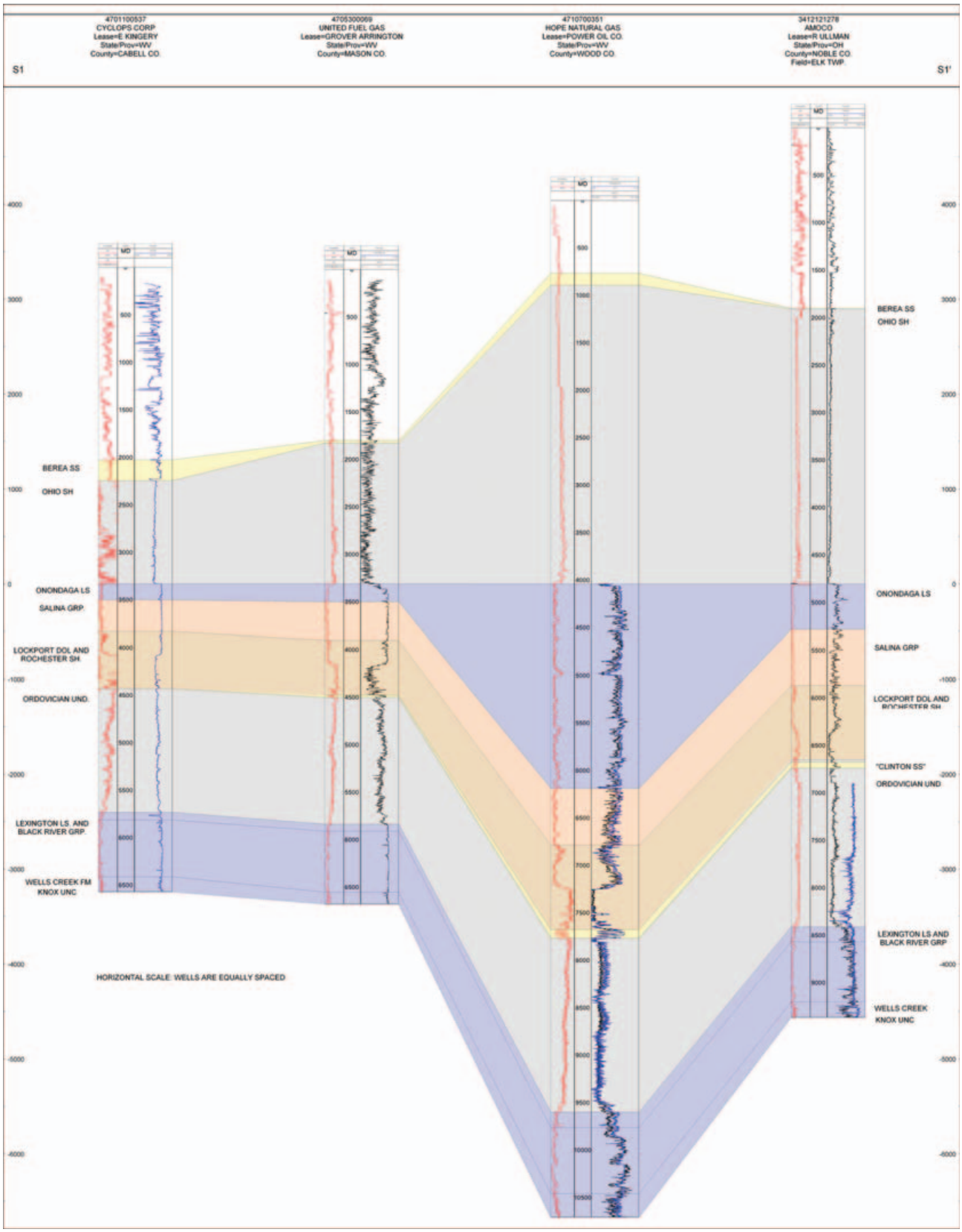



Figure 21.—Stratigraphic cross section (shallow geologic units to Knox unconformity interval) Strike S1-S1' shallow. Datum on top of the Onondaga Limestone. Figure by the ODNR, Division of Geological Survey.

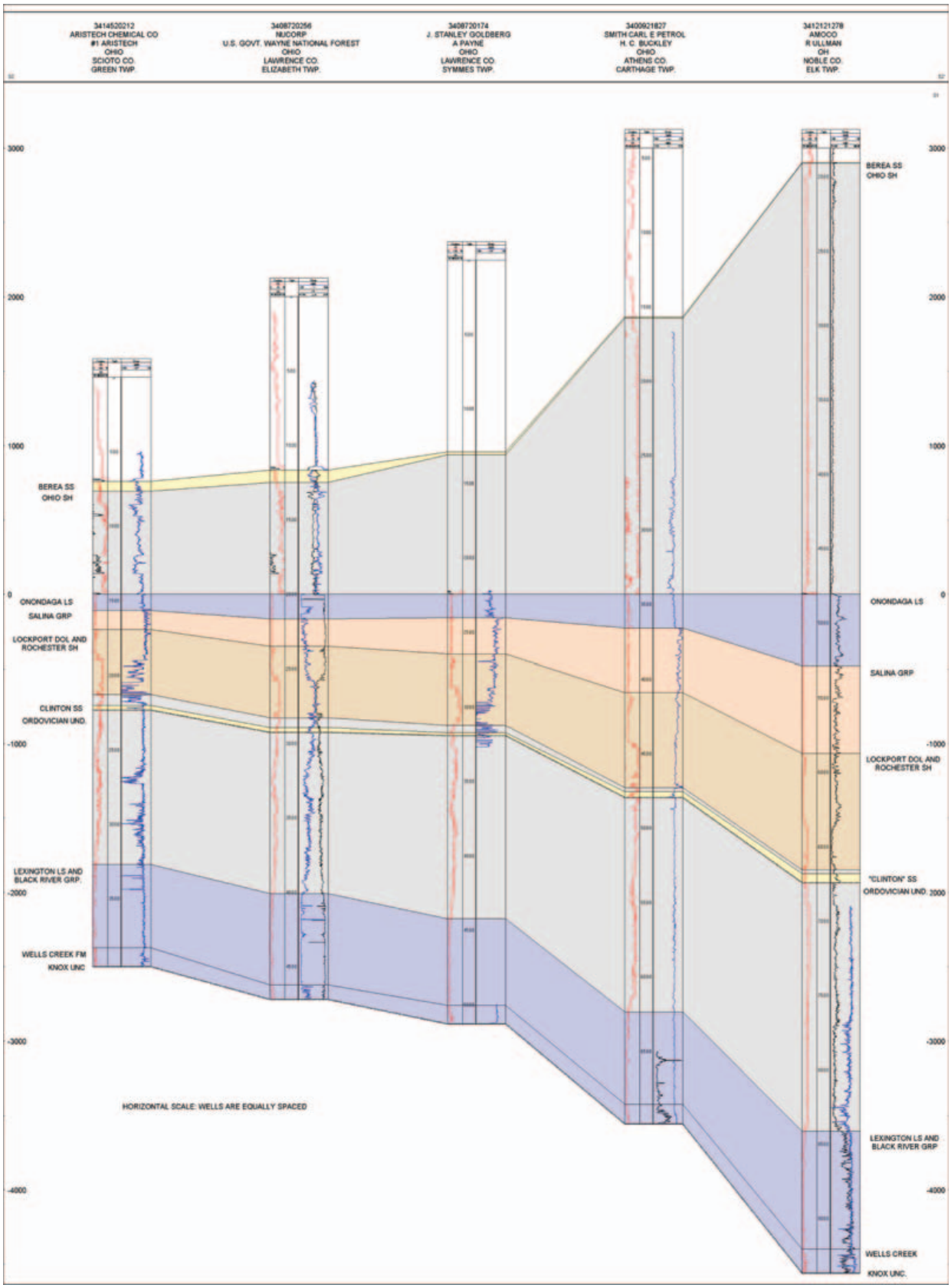



Figure 22.—Stratigraphic cross section (shallow geologic units to Knox unconformity interval) Dip S2-S2' shallow. Datum on top of the Onondaga Limestone. Figure by the ODNR, Division of Geological Survey.

Table 2. *List of wells in the AOR with preKnox oil and gas production and shows*

| API No. | State | County | Company | Lease | Total depth (feet) | Formation at total depth | GAS | | | OIL | | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | MCF | Formation | Depth/ interval | BO | Formation | Depth/ interval | |
| **6 wells** | | | | | | | | | | | | | |
| 3407920078 | OH | Jackson | Ralph C.Halbert | Slavens | 5,681 | PCMB | | Conasauga Gp. | 4960; 5120-5150 | | | | gas show; gas cut saltwater |
| 3412121278 | OH | Noble | AMOCO | R. Ullman | 11,442 | PCMB | | Conasauga Gp. | 10611 | | | | gas cut water |
| 3412920003 | OH | Pickaway | Mcmahon-Bullington Drlg. | J. Dunlap | 3,525 | ROME | | | | | Conasauga Gp. | | small oil show |
| 3412920006 | OH | Pickaway | Midwest Oil & Gas Co. | C. Miller | 4,179 | PCMB | | | | | Conasauga Gp. | 3949-3958 | oil show |
| 3412920129 | OH | Pickaway | Redman Oil Co. | V. Thompson | 3,690 | MNSM | 25 | Conasauga Gp. | 3600-3606; 3690-3698 | | | | gas show |
| 3414560141 | OH | Scioto | Aristech Chemical Corp. | Aristech Chemical Corp. | 5,650 | MRVL | | Conasauga Gp. | 5188-5198 | | | | slight petroleum odor; fluor. in core; gas blow during drilling |
| **3 wells** | | | | | | | | | | | | | |
| 1601918327*† | KY | Boyd | Inland Gas Co, Inc. | L. O. White et al | 7,676 | ROME | 90 | Conasauga Gp. | 7445; 7516-7574 | 15 | Conasauga Gp. | 7516-7574 | well completion |
| 160435730† | KY | Carter | Inland Gas Co., Inc. | Everett & Myrtle McDavid | 9,980 | BASL | | Tomstown; basal sand | 7672; 8898 | | | | gas show |
| 1604398E9 | KY | Carter | United Fuel Gas Co. | Lloyd L. Stamper et al | 5,085 | PCMB | | ROME, basal ss | | | | | gas show |
| **5 wells** | | | | | | | | | | | | | |
| 4701100537 | WV | Cabell | Cyclops Corp. | E. Kingery | 8,552 | PCMB | | Pre-Knox | | | | | gas show |
| 4703501366* | WV | Jackson | EXXON USA | McCoy | 17,675 | PCMB | 9,100 | Conasauga Gp. | 14358 | | | | gas completion |
| 4704301469 | WV | Lincoln | EXXON USA | D. E. McCormick | 19,124 | PCMB | | Conasauga Gp. | 11608 | | | | gas show |
| 4705900805† | WV | Mingo | Columbia Gas Trns. | Columbia Gas | 19,537 | PCMB | | Conasauga Gp. | | | | | gas show |
| 4710700351 | WV | Wood | Hope Natural Gas | Power Oil | 13,331 | PCMB | | Conasauga Gp. | | | | | gas show |

*Completed
†Not on Figure 1
Compiled from information available from the Ohio Division of Geological Survey, the Kentucky Geological Survey, and Harris and Baranoski (1996)

Production Abbreviations:
MCF Thousands of cubic feet of gas per day
BO Barrels of oil per day

Geologic Unit Abbreviations:
MRVL Maryville Formation
MNSM Mount Simon Sandstone
ROME Rome Formation
BASL Basal sandstone
PCMB Precambrian undifferentiated

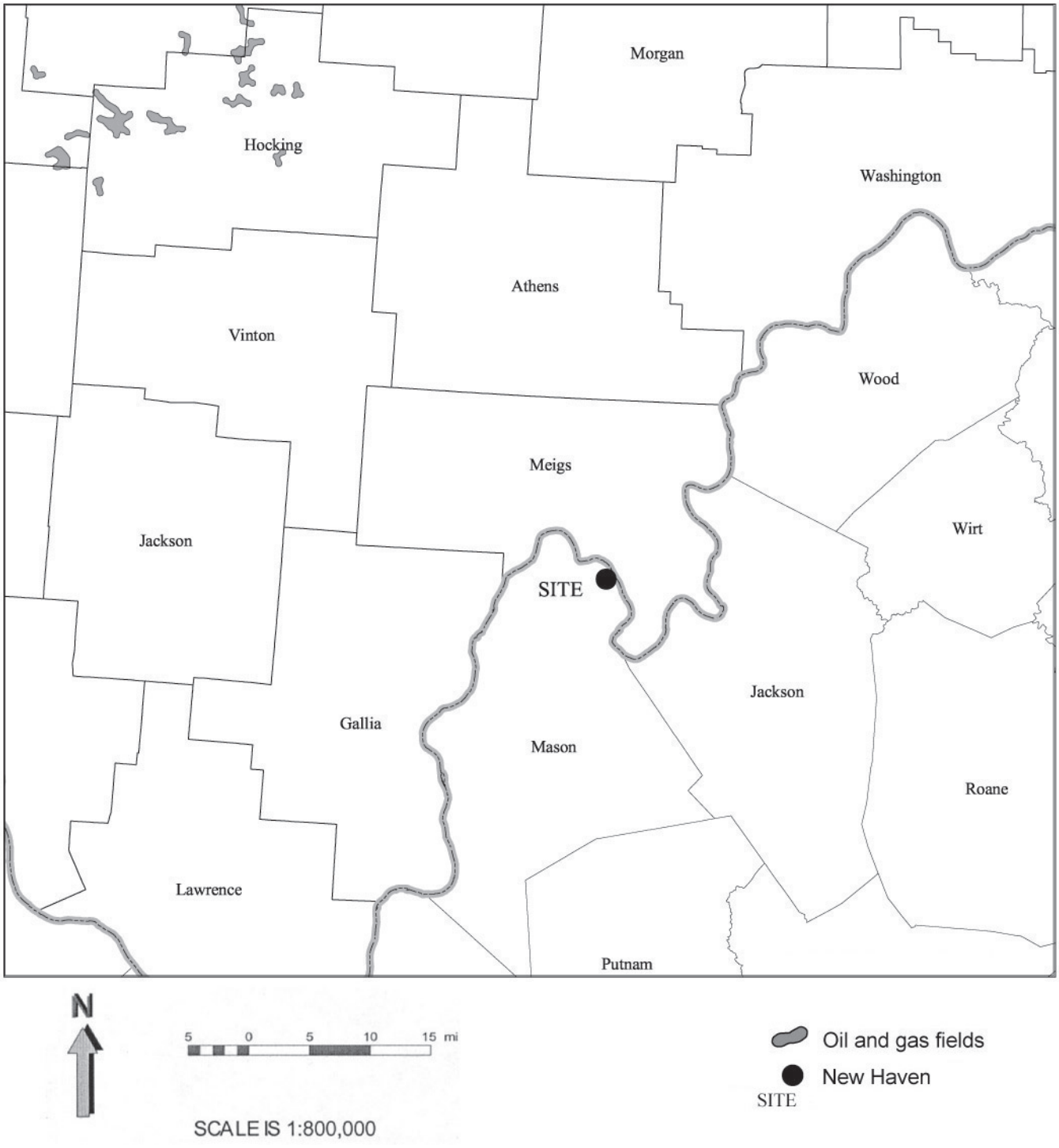



Figure 23.—Map showing the Cambrian-Ordovician Knox Dolomite and St. Peter sandstone oil and gas fields and location of the New Haven site. Figure by the ODNR, Division of Geological Survey.

stone. Isolated producing wells (not shown) are also present in Jackson and Vinton counties. The majority of active Knox drilling and production is from the Rose Run sandstone to the west and north along the Rose Run subcrop trend. Although there is currently no historic production near the proposed site, this may be a favorable area for future fractured Beekmantown, St. Peter sandstone and Rose Run production.

### Middle Ordovician Lexington/Trenton Limestone and Black River Group carbonates

In the Ohio portion of the AOR, the nearest Lexington/Trenton and Black River production (includes the Utica Shale) is approximately 35 miles to the north in Hocking and Washington counties (fig. 24). All Trenton or deeper well penetrations for West Virginia are also shown in Figure 24; however, it is difficult to determine the producing formation and well status for many of these wells because of the 2-year time period for holding permits. More detailed well-specific information can be obtained from the WVGES. Approximately 40 miles to the southeast of the proposed site (fig. 24) in Roane County, the discovery of large volumes of gas in the Trenton/Black River has led to a flurry of drilling activity. The discovery #20097 Parker well (APINO 4708704250, Roane County) had a reported natural open flow of 50 MMcfd, with a reported rock pressure of 5,750 pounds per square inch (psi) in an open-hole completion at 10,255 to 10,271 feet (Avary, 2002). Over 100 wells in 12 West Virginia counties have been permitted to the Trenton through March, 2001. The pay is from highly fractured carbonates in the Trenton/Black River interval, thought to be reactivated basement faults associated with the Rome Trough. Information on these wells is available on the WVGES website, <http://www.wvgs.wvnet.edu/>. The proximity of the New Haven site to the Rome Trough and possible deep structures make the AOR an area of potential Trenton/Black River hydrocarbon production.

### Lower Silurian "Clinton-Medina"/Tuscarora Sandstone

Scattered hydrocarbon production in the "Clinton-Medina"/Tuscarora sandstone is present in the AOR (fig. 25). In Ohio, the nearest "Clinton-Medina" fields are approximately 10 miles to the north of the proposed New Haven site. Ohio has 186 "Clinton-Medina" sandstone fields with approximately 60,000 wells that produced over 5 trillion cubic feet of gas (tcf) (McCormac and others, 1996). The major producing "Clinton-Medina" sandstone fields are located north and west of the AOR where porosity and permeability are higher. Reservoir rock is not as well developed in the "Clinton-Medina" sandstone in the AOR ((fig. 27; #1 Baker (APINO 3410523520, Meigs County)). In West Virginia, the nearest Tuscarora hydrocarbon field in the AOR is approximately 20 miles southeast of New Haven in Jackson County. Most of West Virginia Tuscarora hydrocarbon production is in Kanawha County, outside of the AOR. It is important to note that the Tuscarora sandstone reservoir is characterized as having a high carbon dioxide ($CO_2$) and nitrogen ($N_2$) content. The reported $CO_2$ content ranges from 4 to 83 percent and the reported nitrogen content ranges from 13.9 to 35 percent (Avary, 1996). Some of the $CO_2$ produced was subsequently used for repressuring and secondary recovery in nearby fields (Cardwell, 1977).

### Lower Devonian Oriskany Sandstone and Upper Silurian Newburg Sandstone and Lockport Dolomite

Significant Oriskany Sandstone production is present in the AOR (fig. 26). Production is concentrated in eastern Meigs County, Ohio, and in Jackson and Mason counties, West Virginia. The first commercial Oriskany production in the Appalachian Basin occurred in early 1900. Estimated cumulative production for the Oriskany in the Appalachian Basin is 82 billion cubic feet of gas (bcf) (Opritza, 1996). Recent drilling and production since 1995 has occurred in Olive Township of Meigs County. Cross section D4-D4' (fig. 27) illustrates the Oriskany sandstone development in this area. The Oriskany sandstone in this area has an average thickness of 6 to 8 feet, and average porosities of 6 to 8 percent. The updip pinchout for the Oriskany sandstone trends north-south through central Meigs and Mason counties near the proposed site. It is not certain whether or not Oriskany will be present at New Haven.

Newburg sandstone production is also present in Meigs County, Ohio, and Jackson County, West Virginia (fig. 26). Newburg sandstone production was first discovered in 1939 in West Virginia, but the Newburg play developed in 1964 in Kanawha County. Since then, seven gas fields including 300 productive wells have been discovered. Estimated cumulative production is 290 bcf in the Appalachian basin (Patchen, 1996). Only scattered Lockport production occurs within the AOR. One small field is located in Jackson County, West Virginia. However, a Lockport reef trend extending through Meigs (OH), Mason (WV) and Jackson (WV) Counties is interpreted to be present (Smosna and others, 1989) indicating hydrocarbon potential in these reservoirs near the proposed site.

### Upper Devonian Black Shales

Extensive Devonian shale production is present and is the most significant producing horizon within the AOR in terms of cumulative production and number of wells (fig. 28). The highest concentration of production and wells drilled occurs in eastern Meigs County. Historical Devonian shale production has occurred since the late 1800s, and development of these fields was revitalized in the 1970s and 80s in response to increasing gas prices and federal tax incentives. Cumulative production for the Devonian Shales in the Appalachian Basin is estimated at approximately 3 tcf from roughly 10,000 wells (Boswell, 1996).

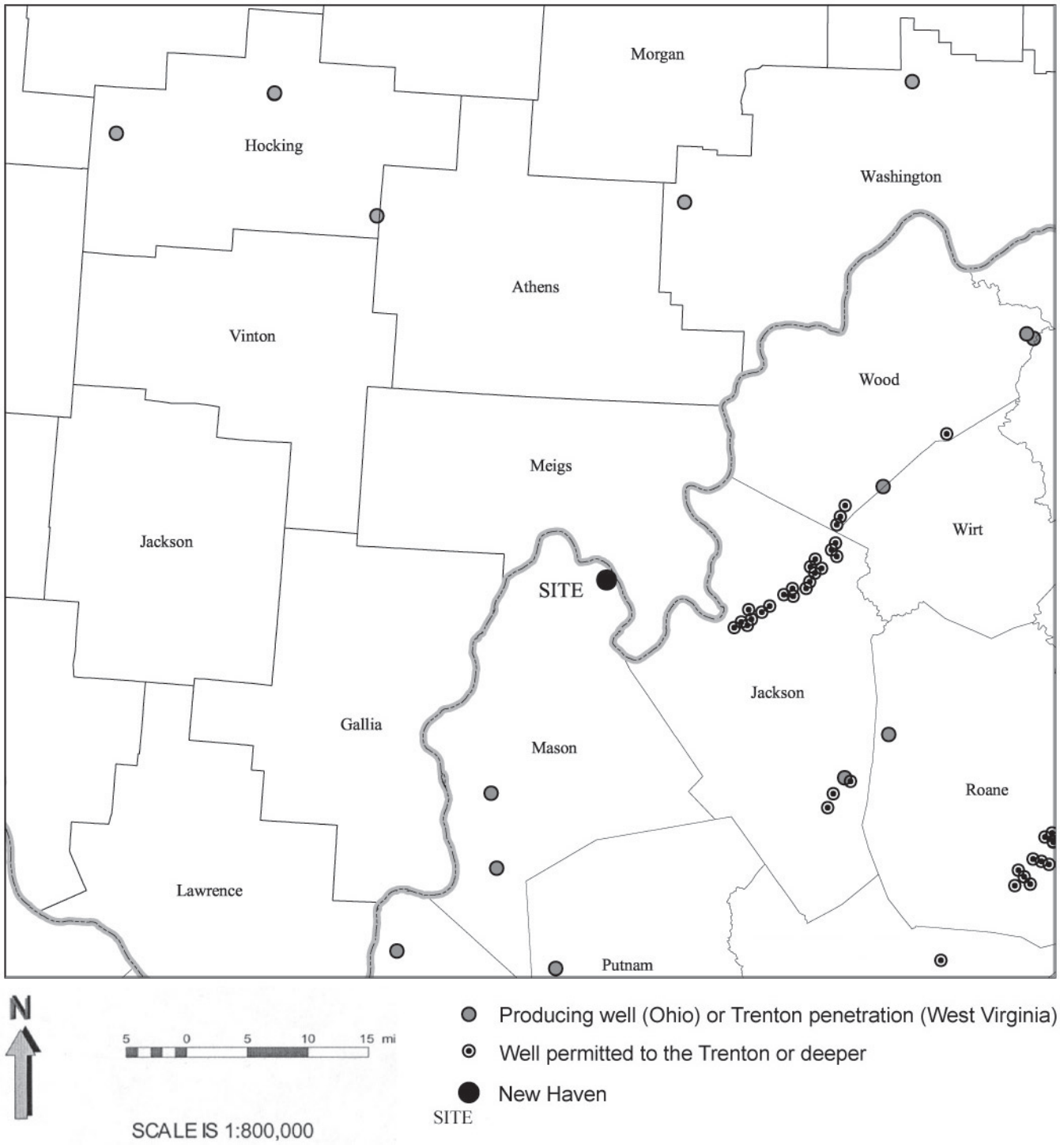



Figure 24.—Map showing the Middle Ordovician Lexington/Trenton Limestone, Black River Group carbonates, and Utica shale oil and gas fields in Ohio, and location of the New Haven site. Also shown are wells permitted to the Trenton in West Virginia. Figure by the ODNR, Division of Geological Survey.

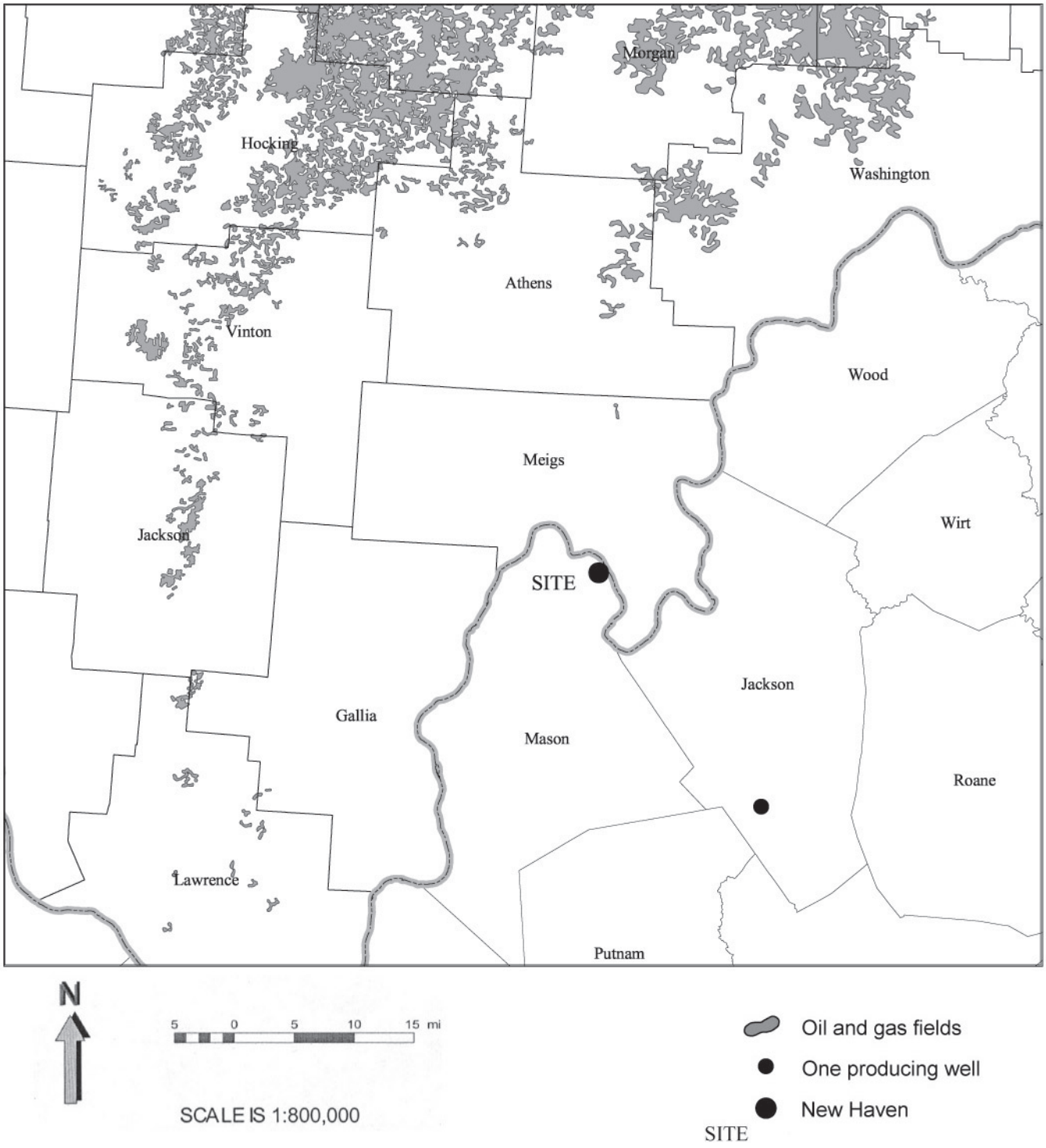



Figure 25.—Map showing the Lower Silurian "Clinton-Medina"/Tuscarora sandstone ol and gas fields and location of the New Haven site. Figure by the ODNR, Division of Geological Survey.

Figure 26.—Map showing the Lower Devonian Oriskany Sandstone and Upper Silurian Newburg Sandstone and Lockport Dolomite oil and gas fields and location of the New Haven site. Figure by the ODNR, Division of Geological Survey.

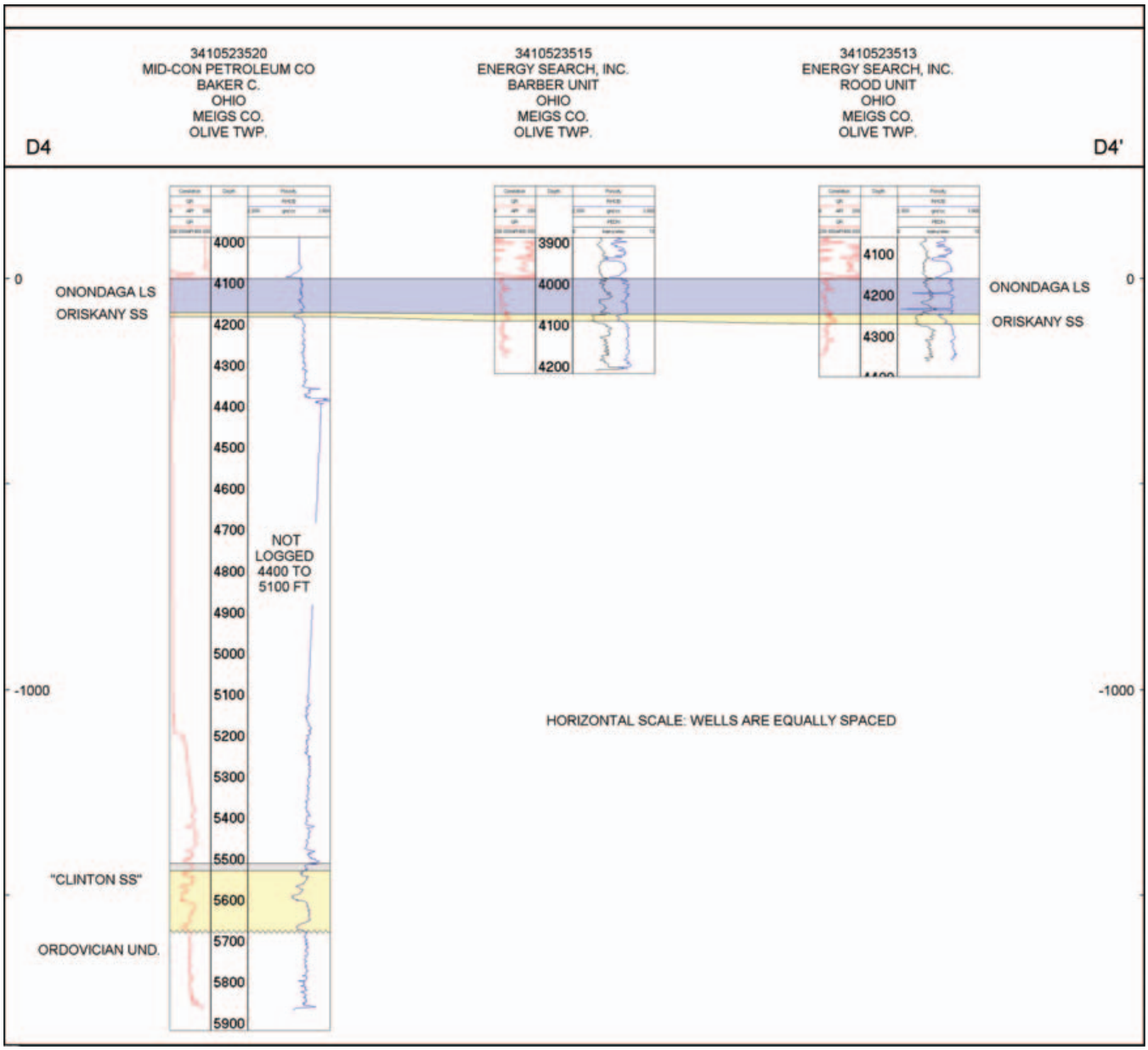



Figure 27.—Stratigraphic cross section (Devonian Oriskany Sandstone to Ordovician interval) Dip D4-D4'. Datum on top of the Onondaga Limestone. Figure by the ODNR, Division of Geological Survey.

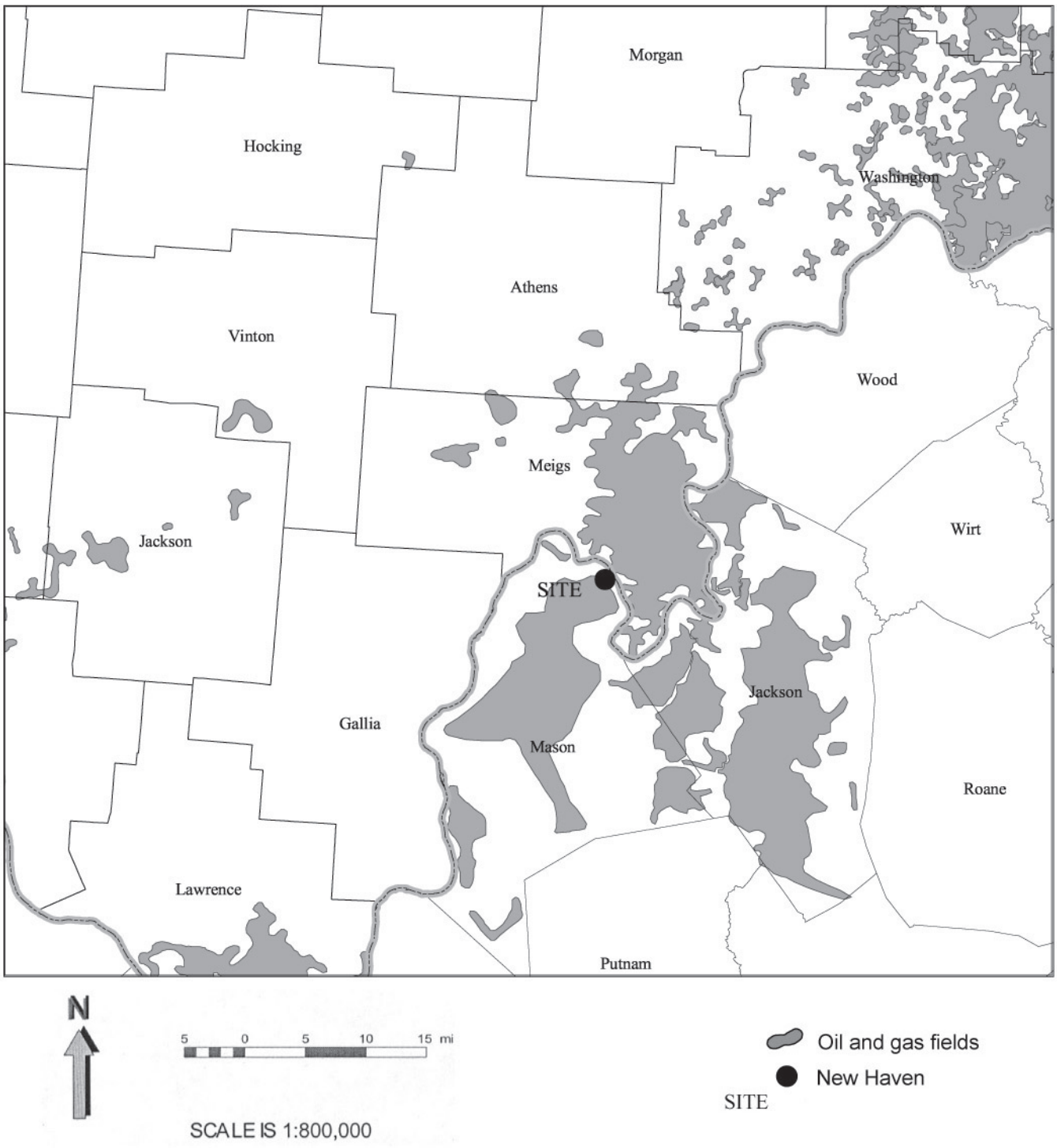



Figure 28.—Map showing the Upper Devonian Black Shales oil and gas fields and location of the New Haven site. Figure by the ODNR, Division of Geological Survey.

### Upper Mississippian and Lower Devonian Berea Sandstone

The Berea sandstone is a significant producing horizon within the AOR (fig. 30). The largest productive field is the Cheshire Consolidated field in Meigs County, which had an estimated cumulative production of 1.4 bcf and 5 million barrels of oil (MMbo) (Tomastik, 1996). Berea fields occur in broad linear trends from eastern Ohio to western West Virginia. In the Appalachian Basin, 15,834 Berea wells representing 151 fields have been drilled (Tomastik, 1996). Estimated cumulative production for Berea and equivalent wells is 1.9 tcf (Tomastik, 1996).

### Upper and Lower Mississippian Limestones and Sandstones

Limited historical production from the Lower and Upper Mississippian sandstones is present in the AOR (fig. 30). The Greenbrier/Newman Limestones are prolific producers of natural gas further to the east in West Virginia. Approximately 6,000 wells have hydrocarbon production from 183 fields in West Virginia and 54 wells from 3 fields in Ohio (Smosna, 1969). Production from the Big Injun sandstone is limited in the AOR. However, widespread and prolific hydrocarbon production occurs from the Big Injun in central West Virginia and eastern Ohio, east and north of the AOR. Cumulative production for fields in West Virginia is estimated to be 4 tcf (Vargo and others, 1996).

### Lower and Middle Pennsylvanian Allegheny and Pottsville Group

Production from the Allegheny Group was first discovered in 1860 (Hohn, 1996). Since then, isolated wells have produced gas in scattered fields in the AOR (fig. 31). Much of this production was encountered while drilling for deeper targets and was commingled. Using an average cumulative of 200 thousand cubic feet of gas (mcf), the estimated cumulative production for the Allegheny Group in the Appalachian basin is 181 bcf (Hohn, 1996). Pottsville sandstones have produced hydrocarbons since the late 1800s in the Appalachian Basin. Of 1,136 Pottsville wells on record at the DGS, 250 have a cumulative production of 20 bcf, averaging 8 MMcf per well (Hohn, 1996). Figure 31 show the current and historical production areas from both the Allegheny and Pottsville Group in the AOR.

## SEISMIC REFLECTION DATA

The nearest public domain seismic reflection data to the New Haven site were acquired in Lawrence and Scioto Counties, Ohio, and Carter County, Kentucky, for the Aristech Corporation Class -1 injection site (fig. 3). The injection site is approximately 60 miles SW of the New Haven site (fig. 3). The data was acquired as a requirement for a Class 1 well permit-to-operate. The Aristech data has been reprocessed by Stiegerwalt (2002). Sundheimer (1979) acquired and processed seismic reflection data over the Cottageville oil and gas field 10 miles SE of the New Haven site. Gao and others (2000) and Kulander (2001) are the most recent studies of the Rome Trough using seismic reflection data adjacent to the New Haven site. Gao and others (2000) used 8 seismic lines and shallow well control in NW West Virginia. Kulander (2001) reprocessed 28 lines of industry seismic reflection data and 15 synthetic seismograms within the Rome Trough and adjacent NW stable shelf. This single-fold reflection data was acquired by industry during the 1950s and recently assembled into pseudo 2D modern stacked data, which was reprocessed by Kulander (2001) with modern processing techniques. Total seismic line-miles are not published.

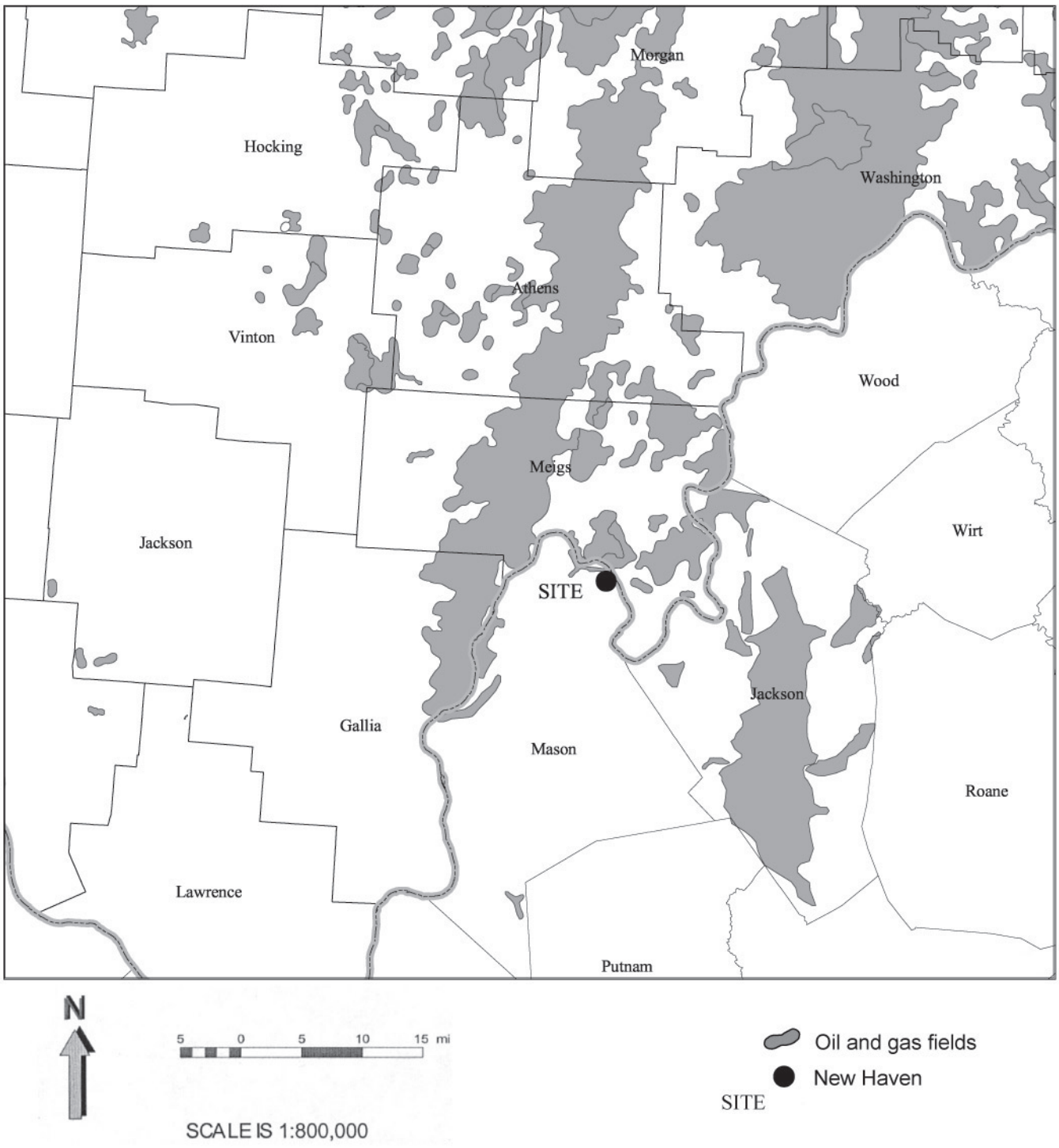
## SEISMICITY

Recent seismicity has been recorded by the Ohio Geological Survey Seismic Network near the New Haven site across the Ohio River. On May 6, 2002, a small earthquake with a magnitude of 2.8 mbLg (see web pages below for detailed discussions on the units) and estimated depth of 3 miles occurred near Antiquity, Ohio about 3 miles SE of New Haven (Hansen, 2002). A small-magnitude (3.6 ) (see web pages below for detailed discussions on the units) earthquake caused minor damage in the Pomeroy area of Meigs County in 1926 (http://www.ohiodnr.com/OhioSeis/earthquakes/020506/020506.htm). The May, 2002 event may relate to NW trending basement faulting, that appears to manifest itself by the straight line segment of the Ohio River at this location.

## STRUCTURAL GEOLOGY NEAR THE NEW HAVEN SITE

Depth to Precambrian basement at the New Haven site is estimated to be 8,600 feet below mean sea level (MSL), based on very sparse deep well and seismic reflection data (fig. 32). The site is located NW of the northern boundary fault of the Rome Trough in an area that was probably exposed Precambrian basement complex during most of the structural movement of the Rome Trough. The nearest documented basement fault to the New Haven site is in Jackson County, West Virginia, in the Cottageville area (Negus-de Wys and Shumaker, 1978). The fault segment trends NE-SW, subparallel to the Ohio River.

The structure map on the top of the Maryville Formation indicates regional dip to the east and southeast at a rate of approximately 100 feet per mile (fig. 33). Subsea values range from –3,000 feet MSL in the northwest to below –14,000 feet MSL in the southeast portion of the AOR. The top of the Maryville Formation surface at the New Haven site is estimated to be –8,100 MSL based on computer mapping within the AOR (fig. 33). The structure map on the top of the Rose Run sandstone indicates regional dip to the east and southeast at a rate of approximately 100 feet per mile (fig. 34). Subsea values




Ficure 29.—Map showing the Upper Mississippian and Lower Devonian Bearea Sandstone oil and gas fields and location of the New Haven site. Figure by the ODNR, Division of Geological Survey.

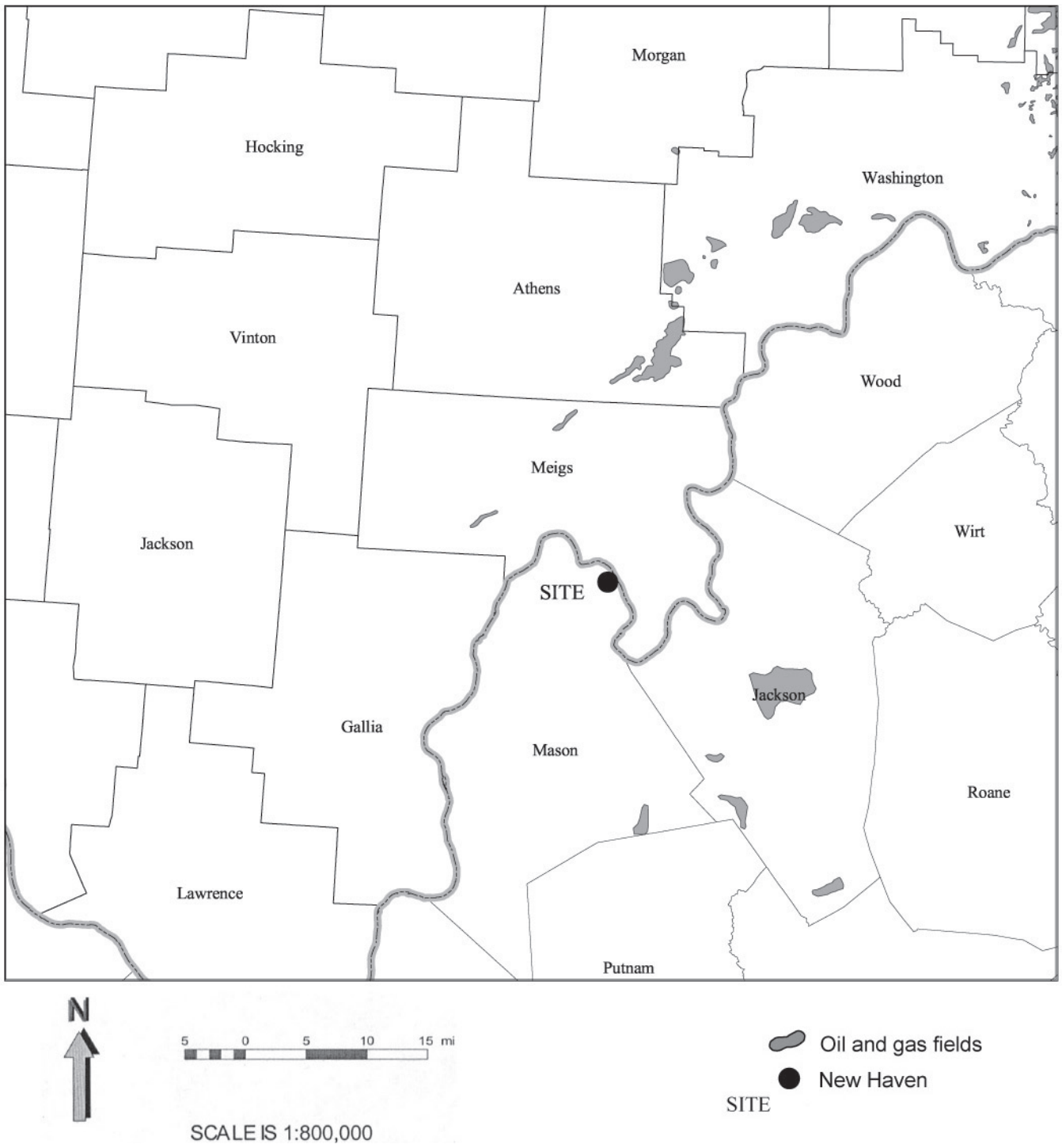



Figure 30.— Map showing the Upper and Lower Mississippian limestones and sandstones oil and gas fields and location of the New Haven site. Figure by the ODNR, Division of Geological Survey.

Figure 31.— Map showing the Lower and Middle Pennsylvanian Allegheny and Pottsville Group oil and gas fields and location of the New Haven site. Figure by the ODNR, Division of Geological Survey.

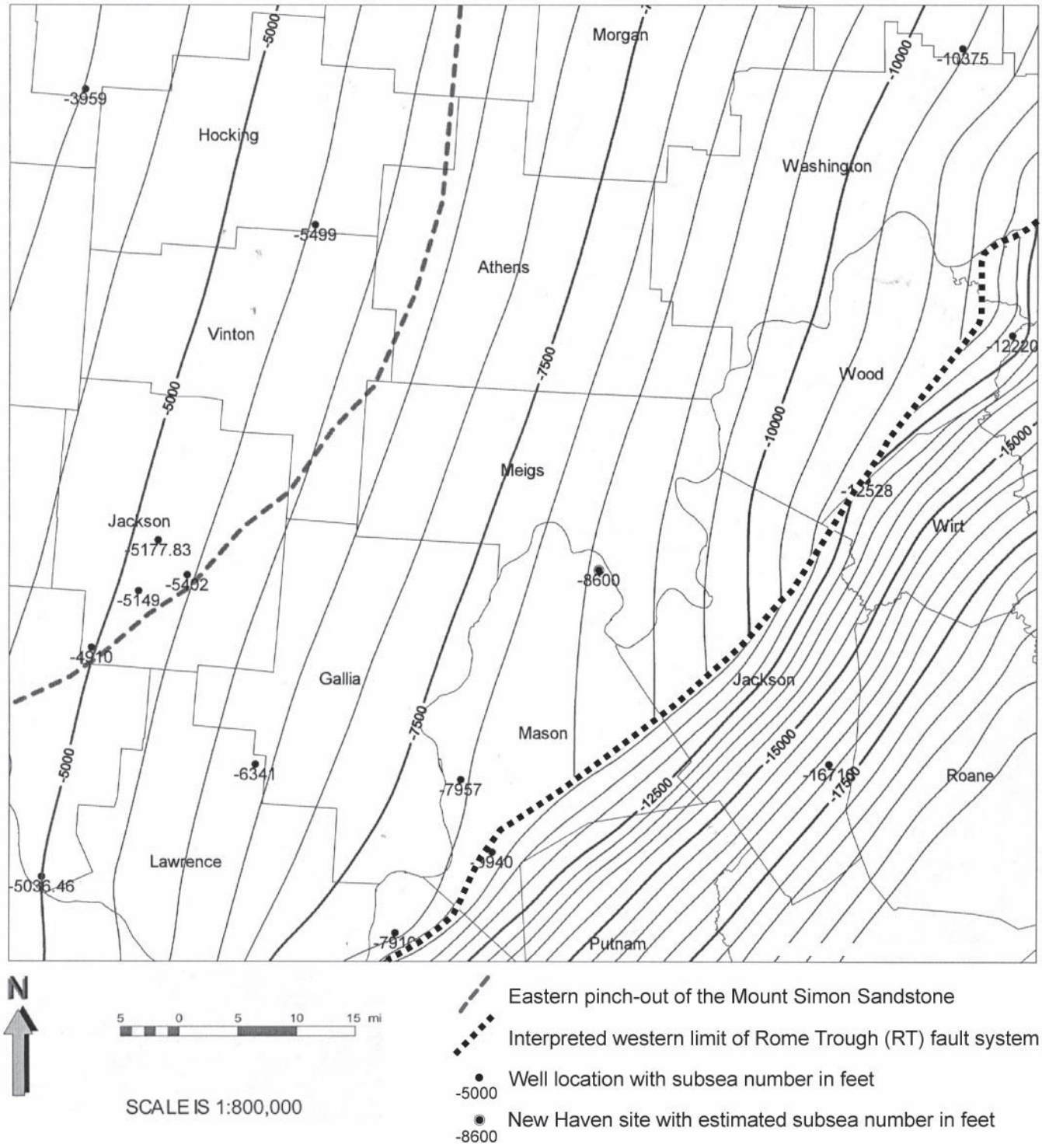



Figure 32.—Structire map on the top of the Precambrian unconformity surface in the AOR and location of the New Haven site. Contour interval = 500 feet. Figure by the ODNR, Division of Geological Survey.

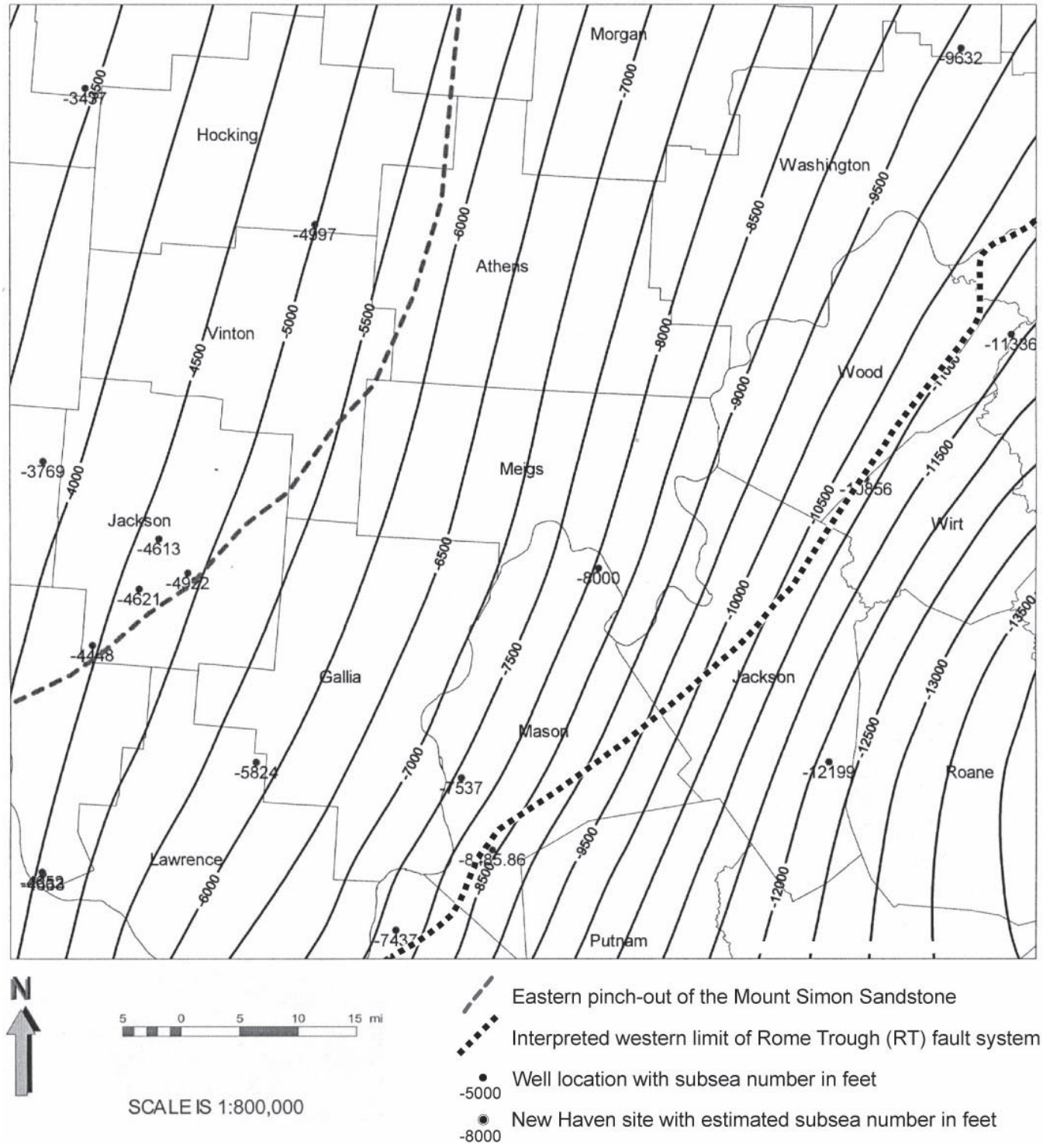



Figure 33.—Structire map on the top of the Maryville Formation in the AOR and location of the New Haven site. Contour interval = 500 feet. Contours not interpreted across fault. Figure by the ODNR, Division of Geological Survey.

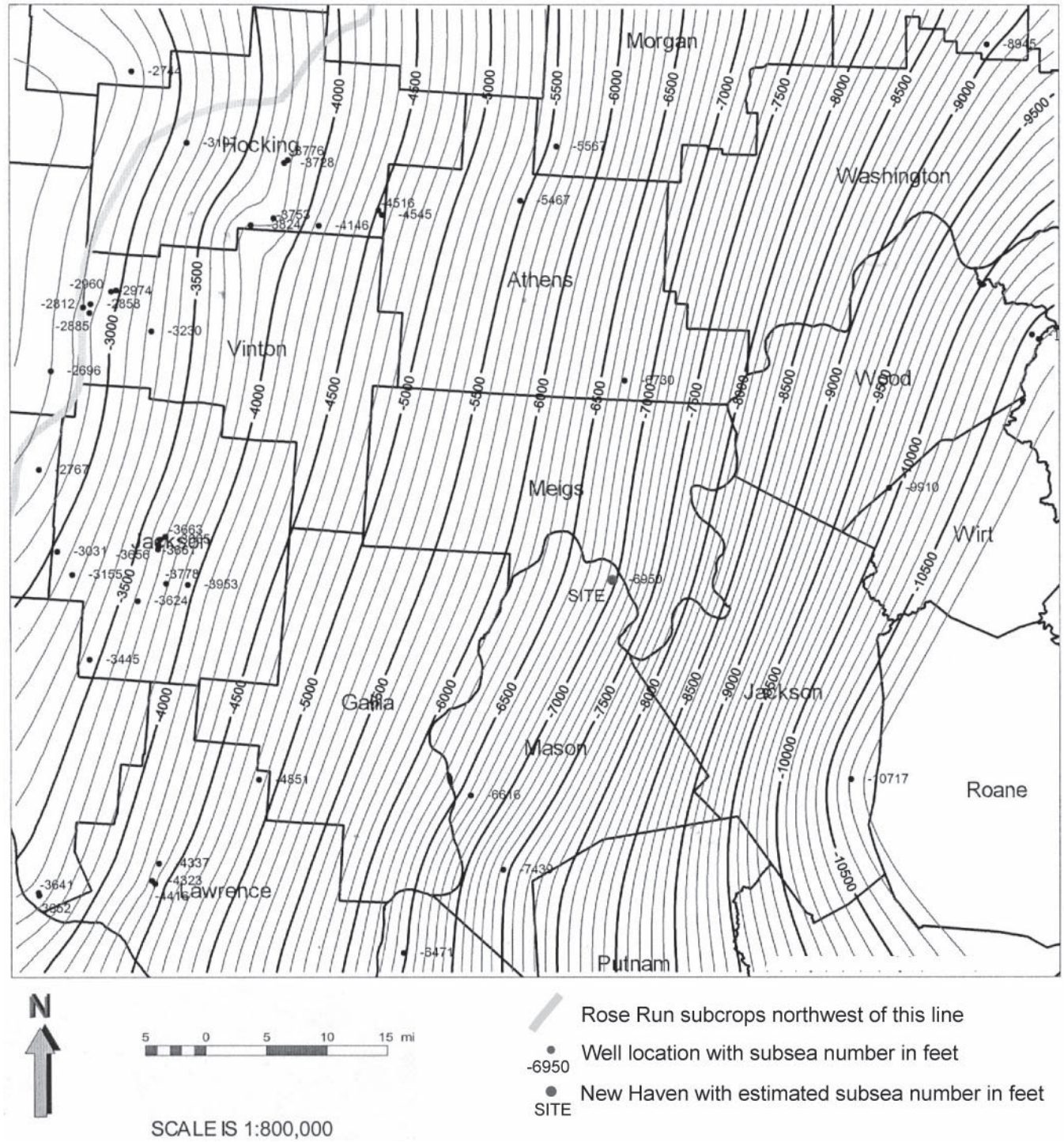



Figure 34.—Structire map on the top of the Rose Run Sandstone in the AOR and location of the New Haven site. Contour interval = 100 feet. Figure by the ODNR, Division of Geological Survey.

range from –2,600 feet MSL in the northwest to less than –10,800 feet MSL in the southeast portion of the AOR. At the proposed site, the top of the Rose Run is estimated to be at a subsea depth of approximately –6,950 feet MSL. The nearest wells to the proposed site for the Maryville Formation and Rose Run structure maps are the #1Arrington well (APINO 4705300069, Mason County) and the #2 Buckley well (APINO 3400921827, Athens County). The #2 Buckley well only penetrated the Rose Run sandstone.

In the vicinity of Meigs County, Ohio, across the river from the New Haven site, NW-SE-trending faults and SE-plunging structural noses and troughs have been mapped on Devonian and Mississippian surfaces based on shallow formation tops from geophysical logs (Ohio Division of Geological Survey, 1988; Baranoski and Riley, in review). Reactivated basement faulting in Meigs County during the Paleozoic was attributed to these mapped structures.

## POTENTIAL INJECTION ZONES, ISOPACH, NET SANDSTONE (DENSITY CUTOFF) MAPPING

Stratigraphic analyses of Cambrian units in the AOR based on subsurface mapping, geophysical well logs, and sample and core descriptions resulted in two potential injection zones: the "lower unit" of the Maryville Formation of the Conasauga Group and the Rose Run sandstone of the Knox Group. Also, the possibility exists for previously unknown porous and permeable zones beneath the Maryville within the AOR. Although highly speculative, the potential for these older potential zones is based on seismic reflection data in the region and is discussed below. Based on computer-generated isopach maps, the estimated gross thickness of the Maryville "lower unit" is 280 feet and the Rose Run is 125 feet at the New Haven site (figs. 16 and 18). The computer-generated map thickness of 280 feet for the Maryville "lower unit" is most likely optimistic, precluding a previously unknown tectonic subsidence of the Middle Cambrian at New Haven. Based on the #1Arrington well (APINO 4705300069, Mason County) a thickness of between 100 and 200 feet is expected for the Maryville "lower unit" at New Haven. Acquisition of reflection seismic data and drilling a test well will be required to arrive at an accurate value.

### Cambrian Maryville Formation

Based on cores within the AOR, both the Maryville Formation and the Rose Run sandstone consists of a sequence of quartz arenites and subarkoses interbedded with thin beds of nonporous dolomite (Appendix A and B, DGS cores 2898, 768, and 3049). Both of these units underwent a long and complicated burial and diagenetic history, which influenced the present day porosity and permeability. Cementation plays an important role in permeability and porosity variations, which affect reservoir character. Figures 35 and 36 are bulk density (RHOB) type-logs with arbitrary cutoff points used for the analyses for this study.

### Cambrian Maryville Formation "lower unit"

The Maryville Formation "lower unit" consists of a range of lithologies from dolomite to arkosic quartz arenite. Terratek, (1990) provides a detailed discussion of the petrography for the Maryville core from the Aristech site in Scioto County, Ohio. Ooids, stromatolites and fossil fragments are common and typically completely replaced with dolomite. Dolomite cement and voids filled with dolomite and anhydrite are common within carbonate-dominated intervals (Terratek, 1990). The quartz arenite is typically fine to medium grained arkose and subarkose with clay minerals common. Cement types vary from authigenic silica and feldspar overgrowths to dolomite, calcite, chlorite, ankerite, and anhydrite pore and fracture fillings (Terratek, 1990). Porosity types include: intergranular, intragranular, fracture, and clay microporosity with secondary intergranular and intragranular porosity also present (Terratek, 1990). Appendix E lists possible diagenetic sequence for the Maryville carbonate and quartz arenites at the Aristech site (Terratek, 1990).

The average porosity calculated from analyses of 29 feet of Maryville "lower unit" core from the #1 Aristech well (APINO 3414520212, Scioto County) was 12 percent with an average permeability of 27 millidarcies (md) and a calculated core bulk density (RHOB) ≤ 2.55 g/cc (Table 3). The methods used for ALL porosity calculations from cores and geophysical well logs should be standardized if possible with actual stratigraphic test well data from New Haven.

Net footage of RHOB using three arbitrary cutoff density points was calculated to isolate qualitative areas of lower bulk density, which hypothetically represent areas of higher porosity. The arbitrary cutoff values used were RHOB ≤ 2.68 g/cc (≥ 0% porosity), RHOB ≤ 2.55 g/cc (≥ 6% porosity), and RHOB ≤ 2.40 g/cc (≥ 15% porosity) (figs. 35 and 36). Maps for the arbitrary RHOB cutoffs were computer contoured at 5-foot intervals (figs. 37-43). For the Maryville "lower unit", a line representing the Rome Trough was added because three of the wells yielding contoured density data are located within the Rome Trough. Also, a dashed line depicting the eastern pinchout of the Cambrian Mount Simon is shown on the Maryville maps as this unit does not occur in the New Haven area. The maps were not interpreted beyond computer-generated contouring and show possible injection zone thickness at arbitrary density cutoffs. Table 3A shows total thickness and average RHOB of the Maryville Formation and "lower unit" and RHOB ≤ 2.68 g/cc (≥ 0% porosity), RHOB ≤ 2.55 g/cc (≥ 6% porosity), and RHOB ≤ 2.40 g/cc (≥ 15% porosity) for wells analyzed within the AOR. The #1 Kingery well (APINO 4701120537, Cabell County) was not used during the analyses because the data was suspect. Appendix C and E lists RHOB, porosity, and permeability calculations from core within the AOR. These data were used to qualitatively calibrate the RHOB data from their respective wells.

Net footage of Maryville" lower unit" with RHOB ≤ 2.68 g/cc (≥ 0% porosity) ranges from 54 to 226 feet of quartz sandstone (fig. 37). Net footage of RHOB ≤ 2.55 g/cc (≥ 6% porosity) for the Maryville"

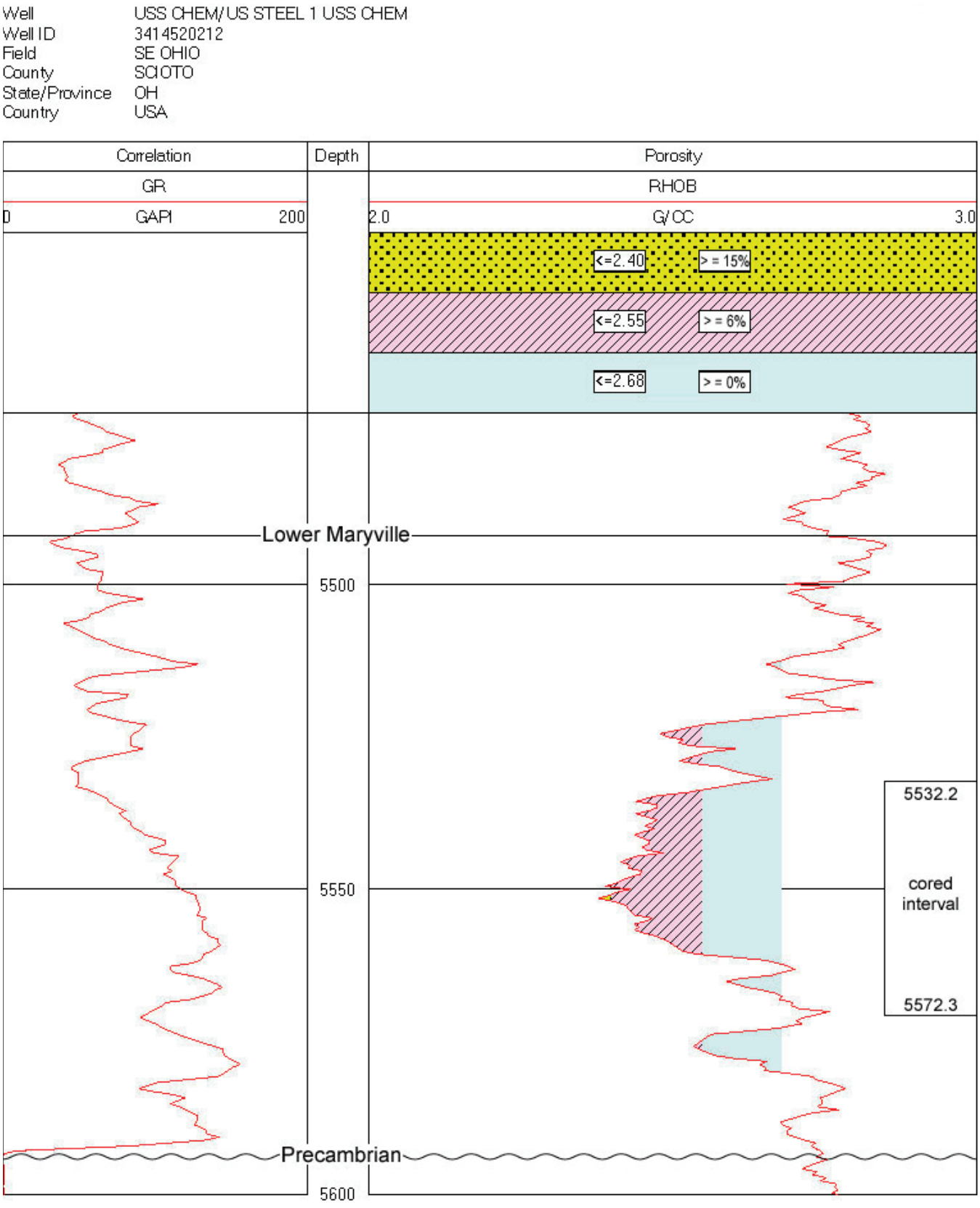



Figure 35.—Type density log showing arbitrary net RHOB from well APINO 3414520212 Aristech well number 1. Estimated porosity equivalent assuming 100% quartz arenite sandstone. Figure by the ODNR, Division of Geological Survey.

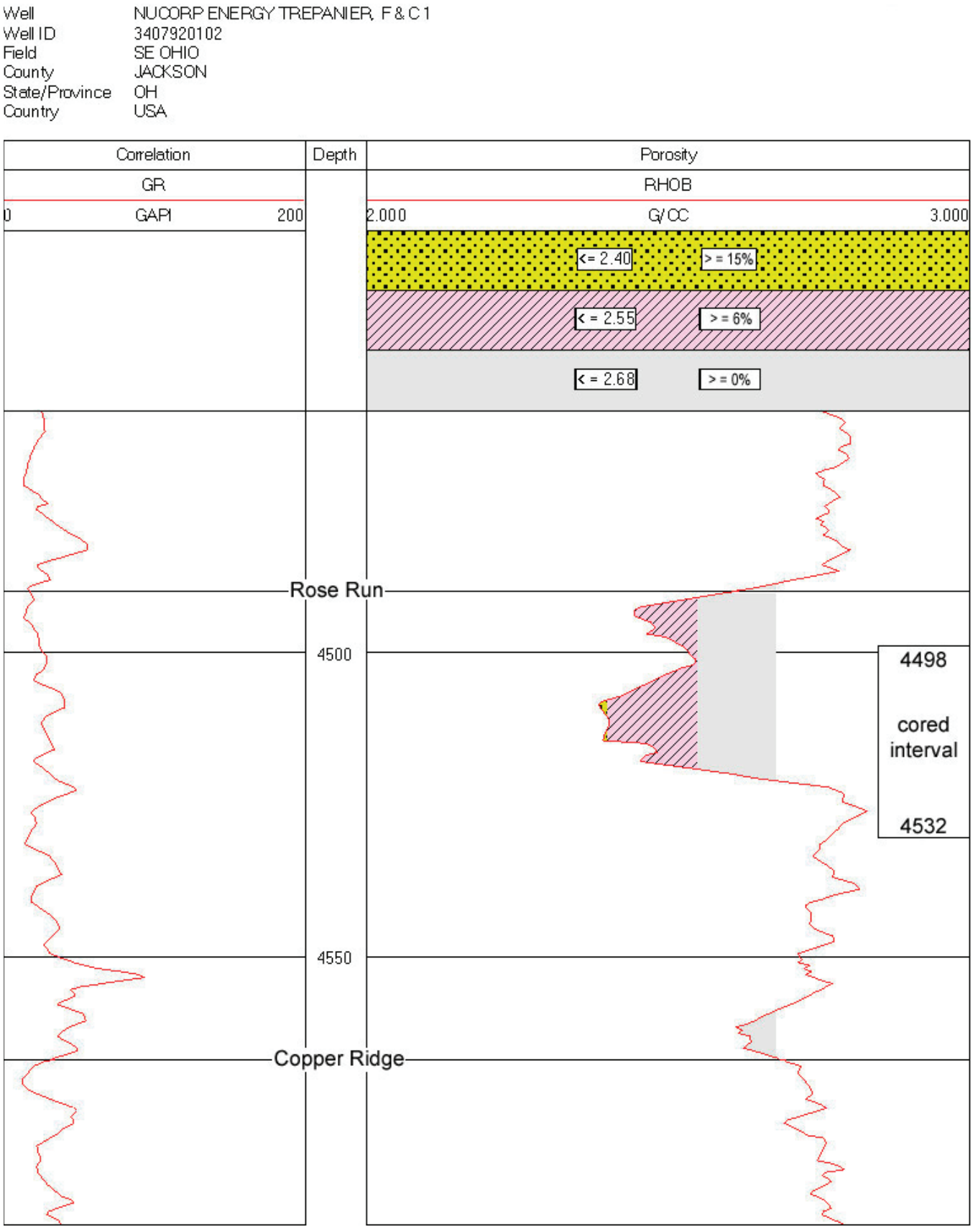



Figure 36.—Type density log showing arbitrary net RHOB from well APINO 3407920102 Nucorp Trepanier well. Estimated porosity equivalent assuming 100% quartz arenite sandstone. Figure by the ODNR, Division of Geological Survey.

Table 3. *List of wells in the AOR with thickness calculations and RHOB calculations for injection intervals*

3A—Maryville Formation thickness and RHOB calculations

| Well ID | MRVL total thickness | RHOB average MRVL | Lower MRVL thickness | RHOB average Lower MRVL | RHOB <= 2.68 net feet >= 0% porosity Lower MRVL thickness | RHOB <= 2.55 net feet >= 6% porosity Lower MRVL thickness | RHOB <= 2.40 net feet >= 15% porosity Lower MRVL thickness |
|---|---|---|---|---|---|---|---|
| 1608921256 | 363 | 2.71 | 100 | 2.57 | 66 | 54 | 14 |
| 1613521132 | 373 | 2.66 | 117 | 2.54 | 77 | 59 | 41 |
| 3400120005† | 398 | 2.56 | 135 | 2.54 | 102 | 64 | 25 |
| 3407920076 | 448 | 2.71 | 150 | 2.58 | 109 | 59 | 13 |
| 3407920102 | 463 | 2.75 | 114 | 2.58 | 94 | 44 | 8 |
| 3408720174 | 517 | 2.73 | 226 | 2.67 | 136 | 14 | 2 |
| 3412121278 | 743 | 2.80 | 263 | 2.71 | 105 | 13 | 0 |
| 3412726595† | 590 | 2.73 | 265 | 2.65 | 145 | 47 | 0 |
| 3412920020† | 524 | 2.58 | 236 | 2.48 | 208 | 182 | 71 |
| 3412920024 | 463 | 2.64 | 175 | 2.50 | 137 | 111 | 71 |
| 3414520212 | 373 | 2.63 | 102 | 2.63 | 54 | 35 | 2 |
| 3414520257† | 420 | 2.62 | 141 | 2.58 | 98 | 58 | 12 |
| 4703501366 | 1,535 | 2.65 | 303 | 2.65 | 193 | 1 | 0 |
| 4705300297 | 763 | 2.74 | 327 | 2.66 | 197 | 34 | 0 |
| 4710700756 | 1,048 | 2.71 | 421 | 2.67 | 226 | 37 | 8 |
| Average | 601 | 2.68 | 205 | 2.60 | 130 | 54 | 18 |

3B—Rose Run thickness and RHOB calculations

| APINO | RSRN total thickness | RHOB average RSRN | | RHOB <= 2.68 net feet >= 0% porosity RSRN thickness | RHOB <= 2.55 net feet >= 6% porosity RSRN thickness | RHOB <= 2.40 net feet >= 15% porosity RSRN thickness |
|---|---|---|---|---|---|---|
| 3407323283 | 140 | 2.70 | | 47 | 30 | 0 |
| 3407323421 | 74 | 2.55 | | 55 | 42 | 12 |
| 3407920076 | 88 | 2.62 | | 49 | 27 | 8 |
| 3407920078 | 80 | 2.56 | | 36 | 27 | 22 |
| 3407920102 | 77 | 2.63 | | 39 | 29 | 5 |
| 3408720174 | 98 | 2.57 | | 66 | 38 | 21 |
| 3408720219 | 82 | 2.65 | | 39 | 18 | 1 |
| 3412121278 | 142 | 2.73 | | 42 | 2 | 0 |
| 3413120036 | 98 | 2.64 | | 54 | 23 | 0 |
| 3414520212 | 112 | 2.70 | | 34 | 16 | 1 |
| 3414560141 | 88 | 2.67 | | 41 | 17 | 0 |
| 4705300297 | 104 | 2.71 | | 28 | 9 | 0 |
| Average | 99 | 2.64 | | 44 | 23 | 6 |

Not on Figure 1
MRVL = Maryville Formation
RSRN = Rose Run Sandstone
RHOB = Log bulk density in grams per cubic centimeter (estimated porosity equivalence assuming 100% quartz arenite sandstone)

lower unit" ranges from 1 to 182 feet (fig. 38). Net footage of RHOB ≤ 2.40 g/cc (≥ 15% porosity) for the Maryville" lower unit" ranges from 0 to 71 feet (fig. 39). The "raw uninterpreted" contoured RHOB maps suggest that net quartz sandstone footage of Maryville "lower unit" at New Haven is: 210 feet of RHOB ≤ 2.68 g/cc (≥ 0% porosity); 40 feet of RHOB ≤ 2.55 g/cc (≥ 6% porosity); and 10 feet of RHOB ≤ 2.40 g/cc (≥ 15% porosity). Overall, areas west of the AOR have the thickest development of Maryville" lower unit" sandstone porosity.

As seen on the Maryville "lower unit" RHOB maps, the thickest areas with RHOB ≤ 2.68 g/cc (≥ 0% porosity) are developed within the Rome Trough and the NW portion of the AOR. The increased net thickness of RHOB ≤ 2.68 g/cc (≥ 0% porosity) in the Rome Trough is attributed to rapid accumulation of sediments during structural movement. Net thickness decrease in the Rome Trough with RHOB ≤ 2.55 g/cc (≥ 6% porosity) and 2.40 g/cc (≥ 15% porosity) most likely is due to increased compaction and cementation during diagenesis and deep burial. The thick net RHOB areas in the western AOR are attributed to higher energy shelf environment, in closer proximity to the source of the quartz sandstone, which may have less compaction and cementation during burial and diagenesis. In general, areas west and southwest of the AOR have the best-developed net quartz sandstone. Other areas within the AOR have very low to no net feet of the lower RHOB cutoff developed. Comparing the core analyses with the net RHOB ≤ 2.55 g/cc (≥ 6% porosity) mapping values suggests that net sandstone footage of Maryville "lower unit" in the New Haven site area is an estimated 35 to 40 feet thick.

Based on core data and geophysical well log analyses, the regional stratigraphy trending SW-NE from Scioto County, Ohio to Wood County, West Virginia, supports a model of an extensive carbonate marine shelf environment decreasing in quartz sandstone eastward for the Maryville Formation (including the "lower unit"). Core and log analyses also indicate the quartz sandstone of the "lower unit" occurs in thin discontinuous beds, which are probably not connected as a reservoir (assuming vertical fractures are absent). However, contoured data RHOB ≤ 2.68 g/cc (≥ 0% porosity) suggest that the New Haven site may have between 100 and 130 net feet of quartz sandstone, based on an along-strike depositional model for the stable craton shelf between Noble (OH) and Wood Counties (WV); and Lawrence (OH) County. The greatest unknown at the New Haven site for the Maryville "lower unit" is the thickness and extent of effective reservoir porosity and permeability.

### Cambrian-Ordovician Rose Run sandstone

Based on cores within the AOR, the Rose Run sandstone consists of a sequence of quartz arenites and subarkoses interbedded with thin beds of nonporous dolomite (Appendix A and B, DGS cores 2898, 768, and 3049). The Rose Run sandstone underwent a long and complicated burial and diagenetic history, which influenced the present-day porosity and permeability. The most abundant cement in the Rose Run sandstones is dolomite, which formed during two or more periods of dolomitization and plays an important role in permeability and porosity variations. Other cements include quartz overgrowths, feldspar overgrowths, and clay minerals (Riley and others, 1993). Dominant pore textures in the Rose Run include: 1) intergranular pores, 2) oversized pores, 3) moldic pores, 4) intraconstituent pores, and 5) fractures. It is important to note that the Rose Run sandstone is not a blanket sandstone, but is heterogeneous with porosity and permeability variability within the individual sandstone beds interbedded with dolomite (Riley and others, 1993).

Core data also indicate that the Rose Run sandstone reservoir quality, similar to the Maryville, decreases to the east and southeast. The most detailed Rose Run core data within the AOR is from the #1 Trepanier well (APINO 3407920102, Jackson County), which is located approximately 40 miles west and updip of the proposed New Haven site (fig.1). Core porosities in this well range from 1.5 to 14.9 percent and average 9 percent. Maximum permeabilities range from 0.1 to 198 md and average 47 md. Rose Run grain density ranges from 2.62 to 2.77 gm/cc with an average of 2.66 gm/cc. Rose Run core samples were analyzed in the #1 Trepanier well and the #4 Aristech well (APINO 3414560141, Scioto County) (Appendix C). Permeabilities for these samples were 6 and 86 md (average of 46 md). Porosities range from 9.1 and 12.7 percent with an average of 10.9 percent. Grain density was 2.64 and 2.65 with an average of 2.65. The #1 Power Oil Company well (APINO 4710700351, Wood County), located approximately 40 miles northeast and downdip from the proposed site, contained the lowest core porosity values. Core porosities in this well for the Rose Run sandstone range from 0.45 to 0.50 percent and averaged 0.47 percent. Grain density ranged from 2.63 to 2.79 gm/cc and averages 2.67 gm/cc.

Rose Run net sandstone maps (figs. 40, 41, 42) also were constructed using density cutoffs of ≤ 2.40 g/cc (≥ 15% porosity), ≤ 2.55 g/cc (≥ 6% porosity), and ≤ 2.68 g/cc (≥ 15% porosity). These values are summarized in Table 3b along with the gross thickness and average density within the Rose Run sandstone interval. This table only includes those wells with bulk-density curves using a standard 2.0- to 3.0-gm/cc calibration. Average bulk-density measurements in the AOR range from 2.55 to 2.73 gm/cc (average 2.65 gm/cc) and increased generally to the east and southeast indicating more carbonate and less quartz sandstone content in the Rose Run interval in that direction (fig. 43). The #1 Jividen (APINO 4705300297, Mason County) is the nearest downdip well to the proposed New Haven site, and had the second highest average bulk density (2.71 gm/cc) in the AOR, which indicates a high percentage of carbonates in the Rose Run interval. Two Rose Run wells intervals in the western portion of the AOR had average bulk density values of 2.55 and 2.56 gm/cc indicating a much higher percentage of sandstone.

Calculated net footage Rose Run sandstone values for the bulk-density cutoff of ≤ 2.68 g/cc (≥ 15% porosity) range from 28 to 66 feet (average 43 feet) (Table 3, fig. 40). The net footage quartz sandstone map shows the greatest net sandstone footage to be in

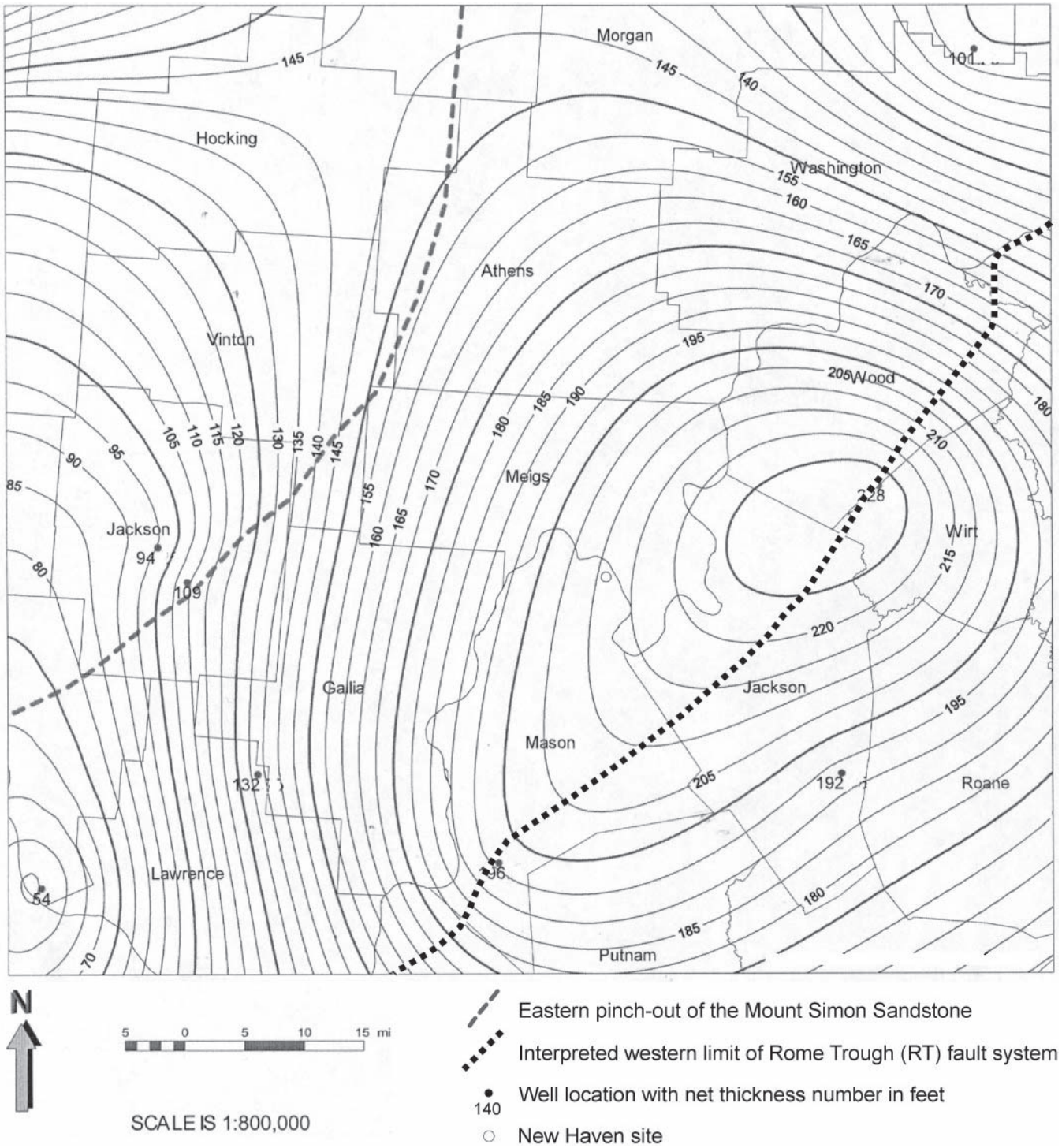



Figure 37.—Maryville "lower unit" net RHOB at ≤ 2.68 g/cc (equivalent to ≥ 0% porosity assuming 100% quartz arenite) cutoff and location of the New Haven site. Contour interval = 5 feet. Figure by the ODNR, Division of Geological Survey.

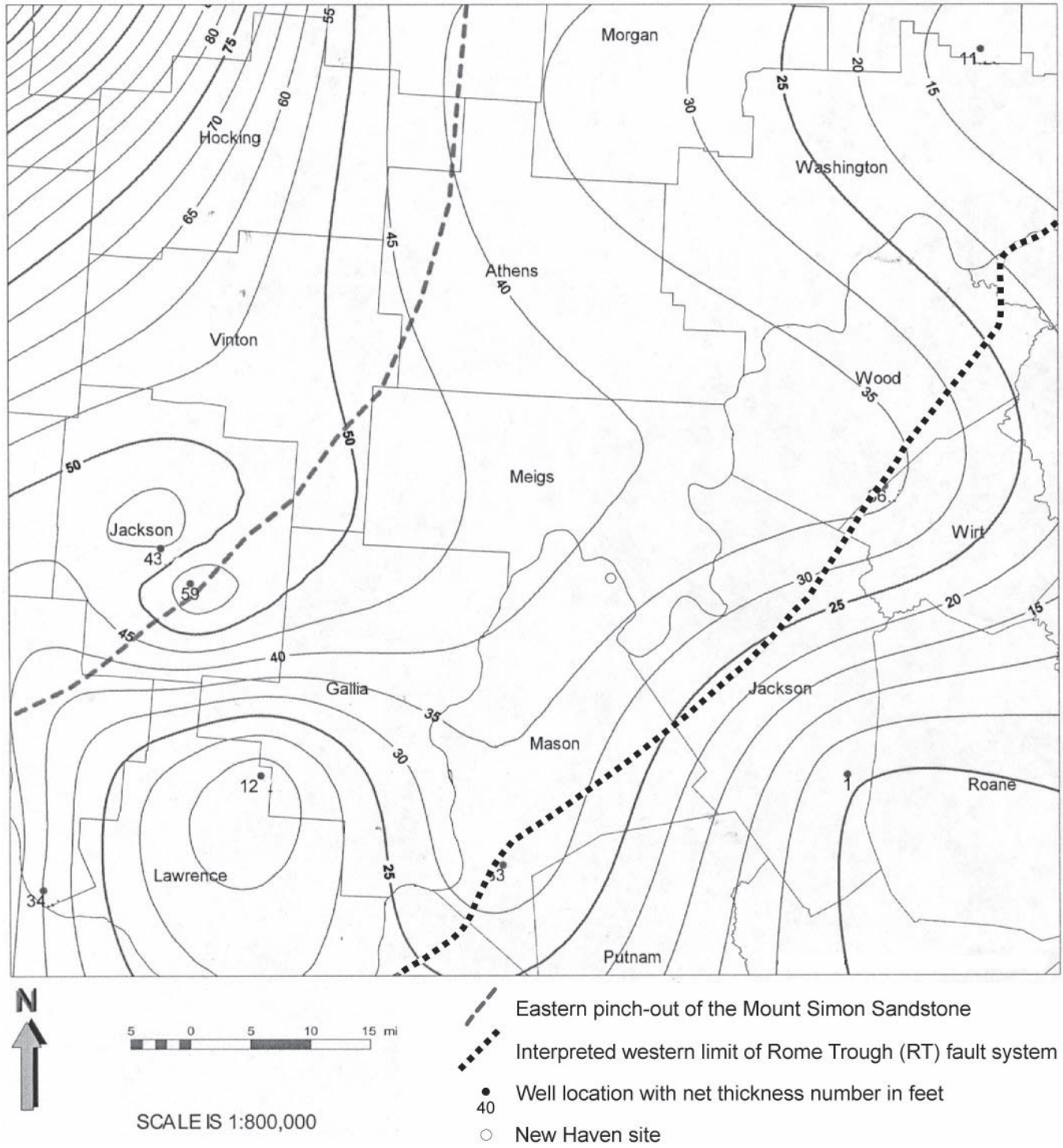



Figure 38.—Maryville "lower unit" net RHOB at ≤ 2.55 g/cc (equivalent to ≥ 6% porosity assuming 100% quartz arenite) cutoff and location of the New Haven site. Contour interval = 5 feet. Figure by the ODNR, Division of Geological Survey.

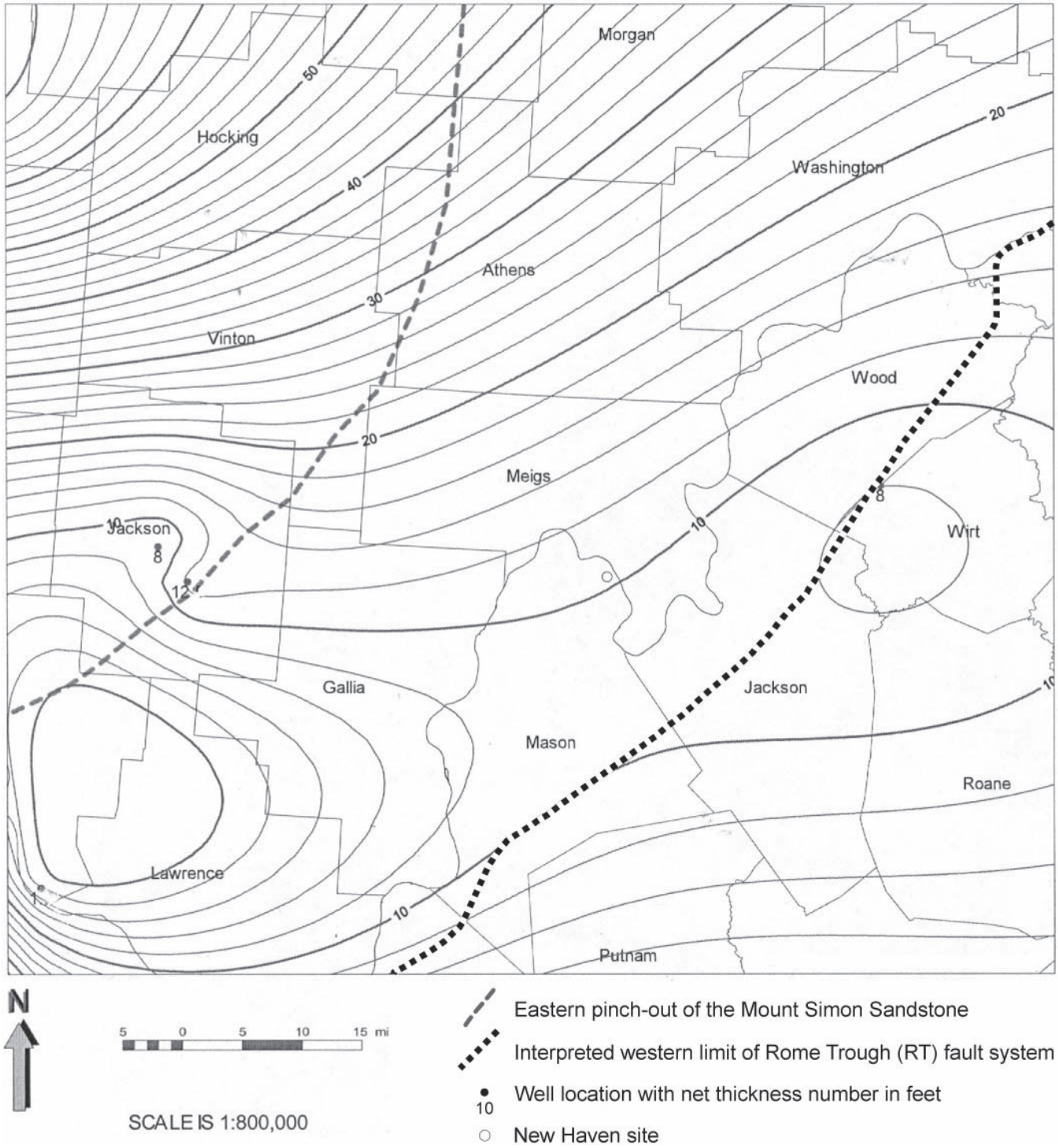



Figure 39.—Maryville "lower unit" net RHOB at ≤ 2.40 g/cc (equivalent to ≥ 15% porosity assuming 100% quartz arenite) cutoff and location of the New Haven site. Contour interval = 2 feet. Figure by the ODNR, Division of Geological Survey.

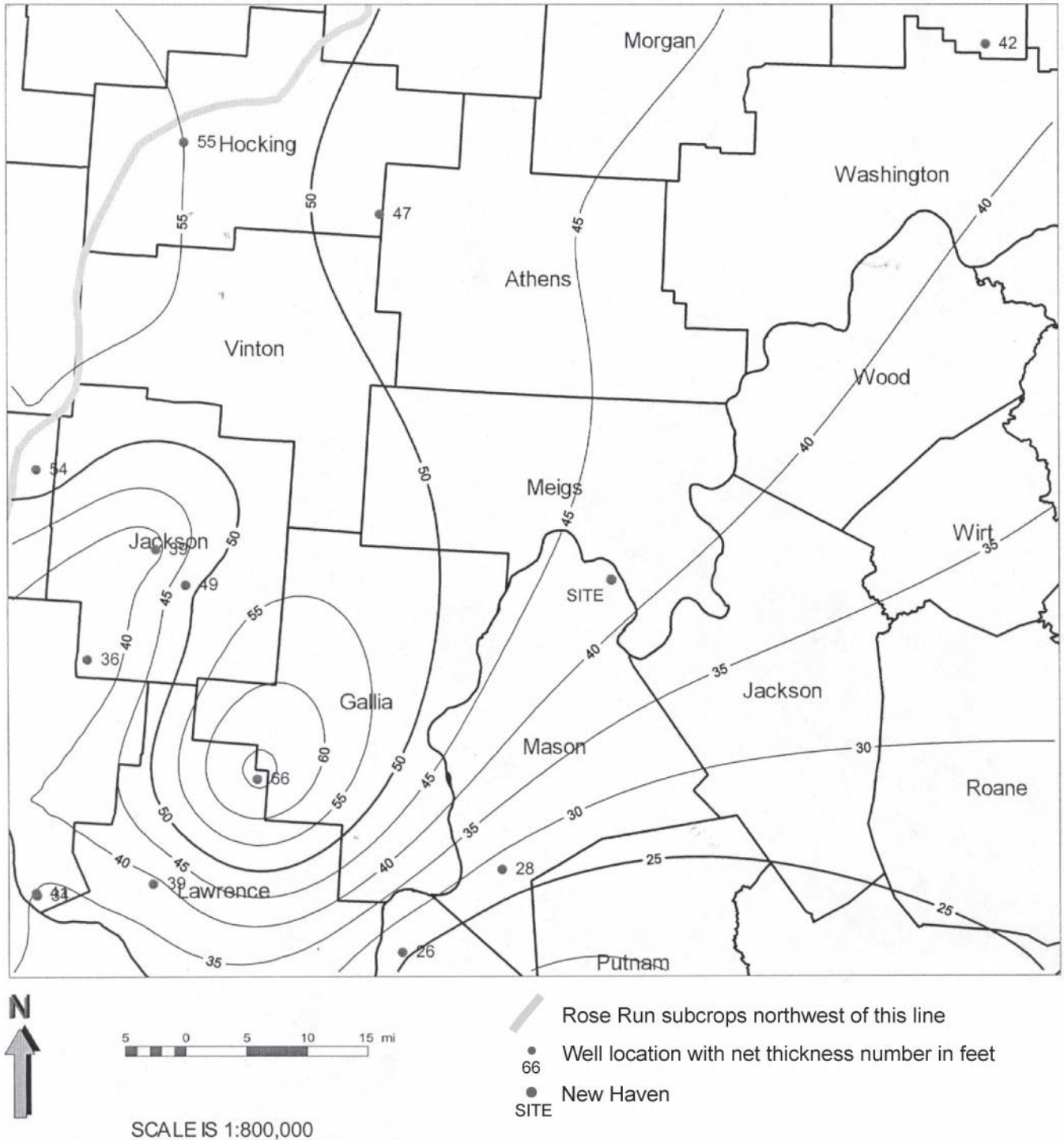



Figure 40.—Rose Run net RHOB at ≤ 2.68 g/cc (equivalent to ≥ 0% porosity assuming 100% quartz arenite) cutoff and location of the New Haven site. Contour interval = 5 feet. Figure by the ODNR, Division of Geological Survey.

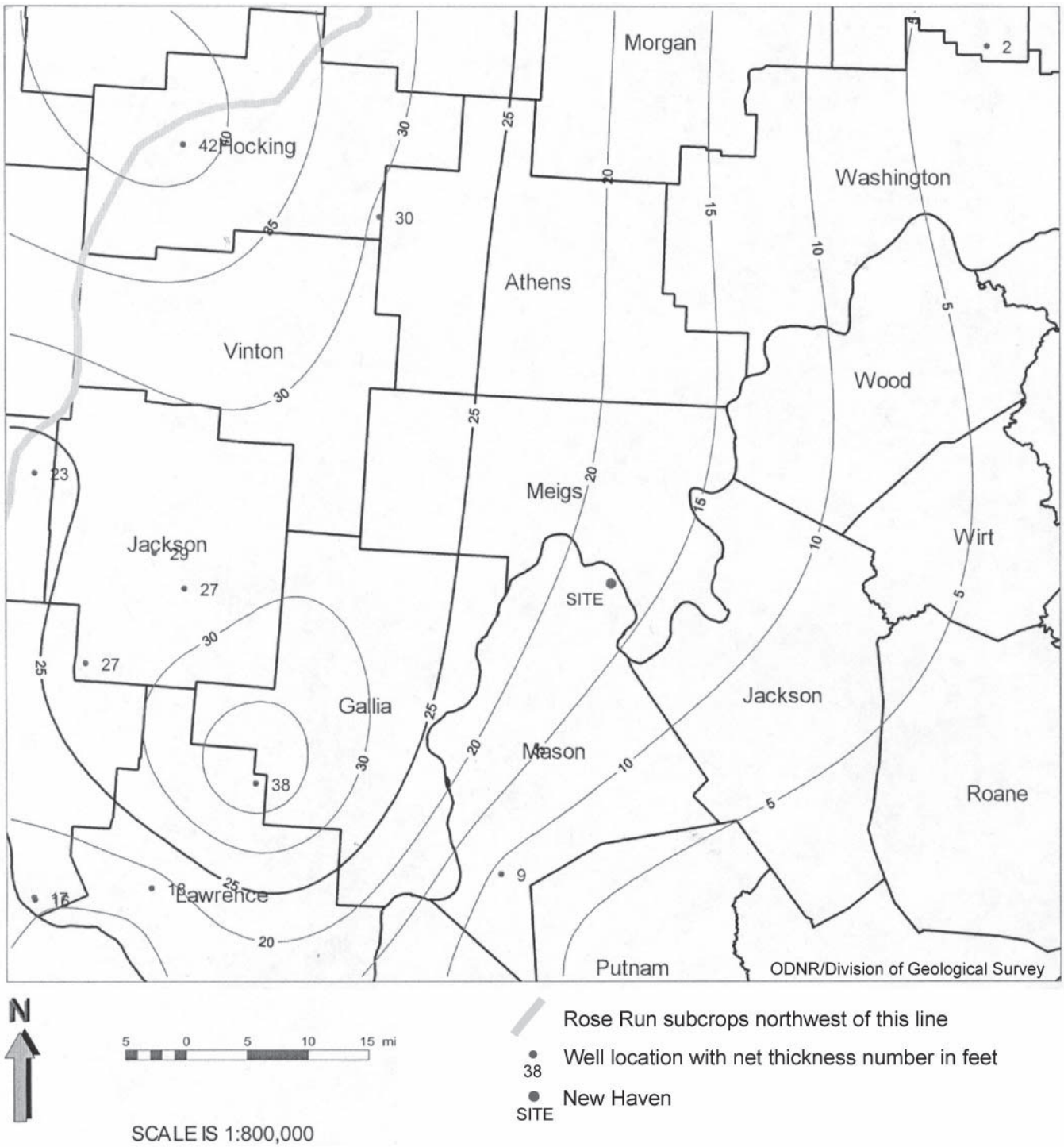



Figure 41.—Rose Run net RHOB at ≤ 2.55 g/cc (equivalent to ≥ 6% porosity assuming 100% quartz arenite) cutoff and location of the New Haven site. Contour interval = 5 feet. Figure by the ODNR, Division of Geological Survey.

Figure 42.—Rose Run net RHOB at ≤ 2.40 g/cc (equivalent to ≥ 15% porosity assuming 100% quartz arenite) cutoff and location of the New Haven site. Contour interval = 5 feet. Figure by the ODNR, Division of Geological Survey.

Figure 43.—Map showing average bulk density from geophysical logs for Rose Run Haven site. Figure by the ODNR, Division of Geological Survey.

northern Lawrence County, Ohio. The proposed New Haven site has an estimated net Rose Run sandstone footage of approximately 42 feet (at the 2.68 gm/cc cutoff). The nearest well with a density log is the #1 Jividen (APINO 4705300297, Mason County), which is approximately 25 miles to the south. Higher values of net Rose Run sandstone footage may be present in the Rome Trough to the east of the proposed site, where thicker accumulations of sand may have been deposited.

The amount of net Rose Run sandstone footage in the AOR decreases with a density cutoff of ≤ 2.55 gm/cc (≥ 6% porosity). Calculated values range from about 2 to 42 feet (average 21 feet)(Table 3, fig. 41). The highest net Rose Run sandstone footage value in the AOR at this cutoff is about 42 feet in Hocking County, Ohio. The New Haven site has a mapped net sandstone value at ≤ 2.55g/cc (≥ 6% porosity) of approximately 18 feet.

Using a bulk density cutoff of ≤ 2.40 g/cc (≥ 15%), the net Rose Run sandstone values look much worse for injection potential. Calculated values range from 0 to 22 feet (average 5 feet) (Table 3, Figure 42). The highest value is in Jackson County, Ohio. The New Haven site has approximately 16 feet of net quartz sandstone footage at this cutoff. As with the previous net Rose Run sandstone footage maps, the better sandstone development is to the north and west closer to the source. There may be thicker net Rose Run sandstone deposits accumulated in the Rome Trough to the east of the proposed site.

### Speculative deep-injection zones

Very little is known about the Precambrian basement complex and lowermost Cambrian strata in the AOR. Although very speculative, the possibility of porous and permeable pre-Maryville sediments within the AOR including the Rome Trough, which would enhance the Maryville "lower unit" injection-zone should be discussed. The presence of deep, layered seismic reflectors within the AOR and proximity to the Rome Trough increase the possibility that such sediments may be present. Published and unpublished seismic reflection data in Ohio indicates local areas of thicker basal Paleozoic/Precambrian sediments, which may represent the following depositional settings dominated by clastic sediments: Rome Formation of the Rome Trough, basal Paleozoic incised river systems, Middle Cambrian rift basins, Precambrian Neoproterozoic rift basins, Mesoproterozoic rift basins, and Grenville foreland basins. The acquisition of seismic reflection data at the New Haven site would assist in recognizing the presence of these speculative zones.

### Shallow Potential Injection Intervals

The Ordovician St. Peter sandstone, Silurian "Clinton"/Tuscarora sandstone, Newburg sandstone, and the Devonian Oriskany sandstone were also examined to evaluate their potential as injection zones. The nearest well to the New Haven site with St. Peter sandstone is the #1 Arrington well (APINO 4705300069, Mason County). At this well location, the St. Peter interval is at a depth of 6,646 to 6,682 feet, and consists of a white, very fine to medium-grained, glauconitic sandstone (Overbey, 1961). In the AOR, the St. Peter occurs locally on the Knox unconformity, and may not be present at the New Haven site. The nearest producing field is the Stephens field in Elliot County, Kentucky, where the average log porosity is 7 percent.

The "Clinton"/Tuscarora sandstone occurs as a sequence of interbedded sandstones, siltstones, and shales. Lithologically, the individual reservoir beds consist of a white to gray to red, medium- to very fine-grained, monocrystalline, quartzose sandstone (McCormac and others, 1996). Based on correlation to the #1 Baker well (APINO 3410523520, Meigs County), the "Clinton"/Tuscarora sandstone occurs at a depth of approximately 5,600 feet (fig. 27). This well is approximately 13 miles to the northeast of the New Haven site. Gross thickness for the interval is approximately 150 feet and net sandstone thickness is 38 feet. Log porosities range from 4 to 6 percent and average 5 percent in this well. There is no nearby core data available, but as mentioned earlier, the porosity and permeability of the "Clinton"/Tuscarora sandstone decreases to the east and southeast.

The Newburg sandstone consists of a thin, white to gray, very fine- to fine-grained, well-sorted sandstone (Patchen, 1996). Nearest wells which encountered the Newburg sandstone are in eastern Meigs County, approximately 7 miles to the east of the New Haven site. Here the Newburg sandstone occurs at a depth ranging from 4,800 to 5,100 feet. Net thickness is approximately 3 feet and the average log porosity is 11 percent (Patchen, 1996). It is not certain if the Newburg sandstone will be present at the New Haven site.

The Oriskany Sandstone is an unconformity sandstone overlying the Helderberg Formation and underlying the Onondaga Limestone. Lithologically, this unit consists of well-sorted, white to light gray, and gray-brown, quartzose sandstone (Opritza, 1996). The updip pinchout of the Oriskany sandstone trends north-south through eastern Meigs County and central Mason County (Opritza, 1996). Presence of this unit at the New Haven site is questionable because of its proximity to the updip pinchout. A cross section across northern Meigs County, approximately 15 miles to the northeast (fig. 27), illustrates the local stratigraphy of this unit. Here, the Oriskany occurs at depths ranging from 4,100 to 4,250 feet. Average net thickness is 15 feet and the average log porosity is 6 percent.

## CONFINING UNITS FOR POTENTIAL INJECTION INTERVALS

### Cambrian Maryville "lower unit"

At the New Haven site, the Maryville "lower unit" is unconformably confined below by the Precambrian basement complex and above by the remaining Conasauga Group (Maryville Formation, Nolichucky Shale, Maynardville Limestone) and Copper Ridge Dolomite. While little is known about the Precambrian basement in this area, a

general assumption is that it consists of Grenville igneous and metamorphic rocks, which will provide effective confinement in the absence of open fractures, faults and porous, permeable, fault gouge.

Approximately 1,100 feet of dolomite and shale act as the confining unit between the Maryville "lower unit" and Rose Run sandstone. Porosity in the Maryville Formation confining interval is generally less than 1 per cent; permeability is less than 1 md based on the #1 Aristech (APINO 3414520252, Scioto County) core analyses. Core analyses for the Copper Ridge shows similar low porosity and permeability values. (Appendix C, E)

### Cambrian-Ordovician Rose Run sandstone

At the proposed site, estimated thickness values for units confining and overlying the Rose Run sandstone are based on correlation to the nearest logged wells to the site and along strike for the Rose Run structure (fig. 34; #1 Arrington and #1 Jividen (APINOs 4705300069 and 47053000297, Mason County)). Actual thickness values encountered at the New Haven site may vary from those predicted depending on presence of faulting in the area and its effect on deposition. The immediate confining zone for the Rose Run sandstone consists of the Ordovician Wells Creek Formation, the Black River Group, and the Lexington Limestone (fig. 9). Estimated combined total thickness for this interval at the proposed site ranges from 840 to 1,070 feet.

In the vicinity of the proposed site, estimated thickness of the Wells Creek Formation is 130 feet. Thickness of the Wells Creek Formation can vary greatly depending on the Knox paleotopography, and may be locally absent because of nondeposition over paleotopographic highs. Estimated thickness of the Black River Group and Lexington Limestone ranges from 640 to 860 feet and 70 to 80 feet respectively.

The Wells Creek Formation unconformably overlies the Knox Dolomite. It is composed of very fine-grained dolomite interbedded with thin gray to green to black shale lenses. A sandstone unit informally called the St. Peter sandstone occurs locally on the Knox unconformity surface. Thickness of the Wells Creek ranges from 22 to 654 feet in the AOR. The Black River Group conformably overlies the Wells Creek Formation and consists of light brown to gray, slightly argillaceous, finely crystalline limestone.

Between the top of the confining zone (Lexington Limestone) and the base of the lowermost USDW (Pennsylvanian), the overlying rocks at New Haven have an estimated total thickness ranging from 3,955 to 4,180 feet. As discussed in the regional stratigraphy section, this section of rock strata includes the Upper Ordovician shale, the Silurian-Devonian carbonates, and the Upper and Middle Devonian shale (fig. 9). At the proposed site, the estimated thickness for these overlying units ranges from 1,335 to 1,400 feet (Upper Ordovician shale section), 1,140 to 1,150 feet (Silurian-Devonian carbonate section), and 1,480 to 1,630 feet (Upper and Middle Devonian shale section). Total thickness for this interval ranges from 520 to 2,109 feet in the AOR.

## SUMMARY

An evaluation of 128 wells deeper than the Ordovician Trenton Limestone within or adjacent to a 7,300 mile$^2$ area centered on New Haven, West Virginia indicates two potential $CO_2$ injections zones: Cambrian Maryville "lower unit" and Rose Run sandstone. The possibility also exists for previously unknown porous and permeable zones beneath the Maryville within the AOR. Although highly speculative, the potential for these older zones is based on seismic reflection data from Ohio and West Virginia.

Based on cores within the AOR, both the Maryville Formation and the Rose Run sandstone consists of a sequence of quartz arenites and subarkoses interbedded with thin beds of nonporous dolomite with very similar depositional environments, ranging from shallow marine to subtidal on an extensive shallow cratonic shelf. Within the AOR, the quartz sandstone facies for both units (the Maryville Formation "lower unit" and the Rose Run sandstone) occurs in thin discontinuous beds. Each of these units is a separate reservoir, separated by hundreds of feet of carbonates and shales. Within each unit, the individual beds are probably not connected as a reservoir (assuming fractures are absent). The source of quartz arenites appears to be generally from the north and west as dolomite predominates eastward and southeastward. Both of these units underwent a long and complicated burial and diagenetic history, which influenced the present day porosity and permeability.

The greatest unknown at the New Haven site for the potential injection zones is the thickness and extent of effective reservoir porosity and permeability. However, at the New Haven site, the two zones have a combined estimated thickness between 50 and 100 feet with average porosity greater than 8 per cent. Depths to the Maryville "lower unit" and Rose Run sandstone is estimated at –8,000 feet MSL and –6,950 feet MSL respectively at the site. Depth to Precambrian basement is estimated at –8,600 feet MSL. Other speculative injection zones may exist in the Cambrian and Precambrian units beneath the Maryville "lower unit" based on seismic reflection data in Ohio and West Virginia.

Confining units are regionally very impermeable with low porosity and should provide adequate confinement for the injection zones in the absence of open fractures, open faults, and fault gouge. The Maryville "lower unit" is confined by about 1,100 feet of dolomite and shale at New Haven. The Rose Run sandstone is confined by about 1,000 feet of limestone and shale at the site.

It is recommended that strike and dip seismic reflection data be acquired crossing the Ohio River at New Haven. The seismic evaluation would tie to existing seismic reflection data and the geologic evaluation from this report to determine the best geological location(s) for drilling a stratigraphic test well. A stratigraphic test well will be required to realistically characterize the stratigraphy, thickness, porosity, and permeability of the prospective injection intervals and the geology, composition, and character of the Precambrian complex. The methods used for ALL porosity calculations from cores and geophysical well logs

should be standardized if possible with actual stratigraphic test well data from New Haven. This well data, accompanied by seismic reflection data, will facilitate modeling of the subsurface geology at the New Haven site, and thus assist in the determination of realistic injectivity and storativity values necessary to evaluate the suitability of the site to sustain the volumes of $CO_2$ injection for the proposed project.

## BIBLIOGRAPHY


Asquith, G.B., 1982, Basic well log analysis for geologists: American Association of Petroleum Geologists, Methods in Exploration Series No. 3, 216 p.

Avary, K. L., 1996, Play Sts: The Lower Silurian Tuscarora Sandstone fractured anticlinal play: *in* Roen, J. B. and B. J. Walker, (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p 151-155.

Babcock, L., E., 1994, Biostratigraphic significance and paleogeographic implications of Cambrian fossils from a deep core, Warren County, Ohio: Journal of Paleontology, v. 68, p. 24-30.

Bass, M. N., 1960, Grenville boundary in Ohio: Journal of Geology, v. 68, p. 673-677.

Baranoski, M. T., Riley, R. A., and Wolfe, M. E., 1996, Cambrian-Ordovician Knox Group unconformity play: *in* Roen, J. B. and B. J. Walker, (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 181-188.

Baranoski, M. T., 2002, Structure contour map on the Precambrian unconformity surface in Ohio and related basement features: Ohio Division of Geological Survey Map PG-23, scale 1:500,000, and 18 p. text.

Beardsley, R.W., and Cable, M.S., 1983, Overview of the evolution of the Appalachian basin: Northeastern Geology, v. 5, nos. 3 and 4, p. 137-145.

Boswell, Ray, 1996, Play Uds: Upper Devonian black shales play: *in* Roen, J. B. and B. J. Walker, (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 93-99.

Cardwell, D.H.,1977, West Virginia gas development in the Tuscarora and deeper formations (with structural maps contoured on top of Ordovician and Precambrian): West Virginia Geological and Economic Survey, Mineral Resources Series MRS-8, 38 p.

Culshaw, Nicholas, and Dostal, Jaroslav, 2002, Amphibolites of the Shawanaga domain, Central Gneiss Belt, Grenville Province, Ontario: tectonic setting and implications for relations between the Central Gneiss Belt and Midcontinental USA: Precambrian Research, v. 113, p. 65-85.

Dean, S. L. and Baranoski, M. T. 2002, Precambrian hydrocarbon potential in Ohio: Oil & Gas Journal, v. 100.29, p. 34-37, and v. 100.30, p. 37-40.

Donaldson, A.C., Heald, M.T., Renton, J.J., and Warshauer, S.M., 1975, Depositional environment of Rome trough rocks, Mingo County well, West Virginia [abs.]: American Association of Petroleum Geologists Bulletin, v.59, p. 1735.

Donaldson, A.C., Heald, M.T., and Warshauer, S.M., 1988, Cambrian rocks of the Rome trough in West Virginia: Cores from Mingo and Wayne Counties: in Smosna, Richard, organizer, A walk through the Paleozoic of the Appalachian basin: American Association of Petroleum Geologists Eastern Section Meeting Core Workshop, Charleston, West Virginia: American Association of Petroleum Geologists, p. 6-18.

Drahovzal, J. A., Harris, D. C., Wickstrom L. H., Walker, Dan, Baranoski, M. T., Keith, Brian, and Furer, L. C., 1992, The East Continent Rift Basin: a new discovery: Kentucky Geological Survey, Special Publication 18, Series XI, 25 p.

Gao, D., Shumaker, R.C., and Wilson, T.H., 2000, Along-axis segmentation and growth history of the Rome Trough in the Central Appalachian Basin: AAPG Bull., v. 84, p. 75-99.

Gray, J.D., Struble, R. A., Carlton, R. W., Hodges, D. A., Honeycutt, F. M., Kingsbury, R. H., Knapp, N. F., Majchszak, F. L., and Stith, D. A.,1982, in Gray, J.D., ed., An integrated study of the Devonian-age black shales in eastern Ohio: U.S. Department of Energy, DOE/ET12131-1399, variously paged.

Hansen, M. C., 2002, Earthquake epicenters in Ohio and adjacent areas: Ohio Division of Geological Survey Map EG-2, scale 1:500,000.

Harris, L. D., 1978, The eastern interior aulacogen and its relation to Devonian shale gas production, *in* Preprints for Second Eastern Gas Shales Symposium: U.S. Department of Energy, Morgantown Energy Technology Center, METC/SP-78/6, v. 1, p. 55-72.

Harris, D.C. and Baranoski, M.T., 1996, Play Cpk: Cambrian Pre-Knox Group Play: *in* Roen, J.B. and Walker, B.J. (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 188-192.

Hohn, M. E., (eds.), Play Pps: Lower and Middle Pennsylvanian Pottsville, New River, and Lee Sandstone playThe Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 26-30.

Humphreys, M., and A. Watson, 1996, Play Osp: Middle Ordovician St. Peter Sandstone, *in* Roen, J. B. and B. J. Walker, (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 177-180.

Janssens, A., 1973, Stratigraphy of the Cambrian and Lower Ordovician rocks in Ohio: Ohio Division of Geological Survey, Bulletin 64, 197 p.

King, E.R., and Zietz, I., 1978, The New York-Alabama Lineament: Geophysical evidence for a major crustal break in the basement beneath the Appalachian basin: Geology, v. 6, no. 5, p. 312-318.

Kulander, C. S., 2001, Regional seismic lines in West Virginia—A preliminary look at the Rome trough and its implications for energy resources: U.S. Geological Survey Open-File Report 01-127, 28 p, CD-ROM.

Larsen, Glenn, E., 1998, Generalized correlation chart of bedrock units in Ohio, Ohio Division of Geological Survey Open-File Report 98-2, 1 plate.

Lucius, J. E., and von Frese, R. R. B., 1988, Aeromagnetic and gravity anomaly constraints on the crustal geology of Ohio: Geological Society of America Bulletin, v. 100, p. 104-116.

McCormac, M. P., Mychkovsky, G. O., Opritza, S. T., Ronald, R. A., Wolfe, M. E., Larsen, G. E., and Baranoski, 1996 Play Scm: Lower Silurian Cataract/Medina Group ("Clinton") Sandstone play: *in* Roen, J.B. and Walker, B.J. (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p.156-163.

McGuire, W. H., and Howell, P., 1963, Oil and gas possibilities of the Cambrian and Lower Ordovician in Kentucky: Lexington, Kentucky, Spindletop Research Center, 216 p.

Milici, R.C., 1996, Stratigraphic history of the Appalachian Basin:Southeastern Geology: *in* Roen, J.B. and Walker, B.J. (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 4-7.

Negus-de Wys, J., and Shumaker, R.C., 1978, Results of a pilot study of Cottageville field, Jackson and Mason counties, West Virginia: U.S. Department of Energy, Morgantown Energy Technology Center, METC/SP-180, 14 p.

Ohio Division of Geological Survey, 1988, Analysis of stratigraphic and production relationships of Devonian shale gas reservoirs in Meigs County, Ohio: report prepared for the Gas Research Institute, Contract No. 5085-213-1154, 58 p.

Opritza, S. T., 1996, Dop: Lower Devonian Oriskany updip permeability play: *in* Roen, J. B. and B. J. Walker, (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 126-129.

Osleger, D., and Read, J.F., 1991, Relation of eustasy to stacking patterns of meter-scale carbonate cycles, Late Cambrian, U.S.A.: Journal of Sedimentary Petrology, v. 61, no. 7, p. 1225-1252.

Overbey, W.K., Jr., 1961, Oil and gas report and map on Jackson, Mason, and Putnam counties, West Virginia: West Virginia Geological and Economic Survey, Bulletin B-23, 26 p.

Patchen, D. G., 1996, Sns: The Upper Silurian Newburg Sandstone play: : *in* Roen, J.B. and Walker, B.J. (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 139-144.

Patchen, D. G., 1982, Geometry, facies, and development of Middle Ordovician carbonate buildups, Virginia Appalachians: American Association of Petroleum Geologists Bulletin, v. 66, no. 2, p. 189-209.

Patchen, D. G., 1989a, Controls on evolution of Cambrian-Ordovician passive margin, U.S. Appalachians, in Crevello, P.S., ed., Controls on carbonate platform and basin development: Society of Economic Paleontologists and Mineralogists Special Publication 44, p. 147-165.

Read, J.F., 1989, Controls on evolution of Cambrian-Ordovician passive margin, U.S. Appalachians, in Crevello, P.S., ed., Controls on carbonate platform and basin development: Society of Economic Paleontologists and Mineralogists Special Publication 44, p. 147-165.

Riley, R.A., Harper, J.A., Baranoski, M.T., Laughrey, C.D., and Carlton, R.W., 1993, Measuring and predicting reservoir heterogeneity in complex deposystems: The late Cambrian Rose Run sandstone of eastern Ohio and western Pennsylvania: U.S. Department of Energy, contract no. DE-AC22-90BC14657, 257 p.

Roen, J. B. and B. J. Walke, editors, 1996, The Atlas of Major Appalachian Gas Plays: West Virginia Geological and Economic Survey, Publication V-25, 201 p.

Ryder, R.T., 1992, Stratigraphic framework of Cambrian and Ordovician rocks in the Central Appalachian basin from Morrow County, Ohio, to Pendleton County, West Virginia: U.S. Geological Survey Bulletin 1839-G, 25 p., 1 pl.

Ryder, R.T., Burruss, R.C., and Hatch, J.R., 1998, Black shale source rocks and oil generation in the Cambrian and Ordovician of the central Appalachian Basin, USA: AAPG Bull., v. 82, p. 412-441.

Ryder, R.T., Repetski, J.E., and Harris, A.G., 1995, Stratigraphic framework of Cambrian and Ordovician rocks in the central Appalachian basin from Fayette County, Ohio, to Botetourt County, Virginia: U.S. Geological Survey Miscellaneous Investigations Series Map I-2495.

Ryder, R.T., Repetski, J.E., and Harris, A.G., 1996, Stratigraphic framework of Cambrian and Ordovician rocks in the central Appalachian basin from Fayette County, Ohio, to Botetourt County, Virginia: U.S. Geological Survey Miscellaneous Investigations Series Map I-2495.

Scotese, C.R., and McKerrow, W.S., 1991, Ordovician plate tectonic reconstructions, *in* Barnes, C.R., and Williams, S.H., eds., Advances in Ordovician geology: Geological Survey of Canada, Paper 90-9, p. 271-282.

Shrake, D. L., 1991, The Middle Run Formation: a new stratigraphic unit in the subsurface of southwestern Ohio: The Ohio Journal of Science, v. 91, p. 49-55.

Shrake, D. L., Wolfe, P. J., Richard, B. H., Swinford, E. M., Wickstrom, L. H., Potter, P. E., and Sitler, G. W., 1990, Lithologic and geophysical description of a continuously cored hole in Warren County, Ohio, including description of the Middle Run Formation (Precambrian?) and a seismic profile across the core site: Ohio Division of Geological Survey Information Circular 56, 11 p.

Sloss, L. L., Krumbein, W. C., and Dapples, E. C., 1949, Integrated facies analysis, in Longwell, C. R., chairman, Sedimentary facies in geologic history: Geological Society of America Memoir 39, p. 91-123.

Smosna, R.A., Conrad, M.J., and Maxwell, T., 1989, Stratigraphic traps in Silurian Lockport Dolomite of Kentucky: American Association of Petroleum Geologists Bulletin, v. 73, no. 7, p. 876-886.

Smosna, Richard, 1996, Play Mgn: Upper Mississippian Greenbrier/Newman Limestones play : *in* Roen, J.B. and Walker, B.J. (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 37-40.

Stiegerwalt, R., 2002, New evidence for shallow lateral movement within the Grenville Province: implications for basin development: Univ. of Akron (unpub.) MS thesis, 26 p.

Sundheimer, G., 1978, Seismic analysis of the Cottageville field, in Preprints for Second Eastern Gas Shales Symposium: U.S. Department of Energy, Morgantown Energy Technology Center, METC/SP-78/6, v. 1, p. 111-120.

Terratek, 1990, Petrographic analyses of the Mount Simon Formation from Aristech Chemical Corporation's waste disposal well #3, Scioto County, Ohio: Report prepared for Aristech Chemical Corporation, Rose Run/Copper Ridge Report, Volume II, Appendices A (ODNR BLD. I: bar code 002636)

Tomastik, T. E., 1996, Play Mgn: Lower Mississippian-Upper Devonian Berea Sandstone and equivalents sandstones play: *in* Roen, J.B. and Walker, B.J. (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 56-62.

Van Schmus, W. R., Bickford, M., E., and Turek, A., 1996, Proterozoic geology of the east-central Midcontinent basement, *in* van der Pluijm, B. A., and Catacosinos, P. A., eds., Basement and basins of eastern North America: Geological Society of America Special Paper 308, p. 7-32.

Vargo, A. and Matchen, D. L., 1996, Play Mbi: Lower Mississippian Big Injun Sandstones: *in* Roen, J.B. and Walker, B.J. (eds.), The Atlas of Major Appalachian Gas Plays, W. Va. Geological and Economic Survey Publication V-25, p. 41-45.

Wagner, W.R., 1976, Growth faults in Cambrian and Lower Ordovician Rocks of western Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 60, no. 3, p. 414-427.

Woodward, H.P., 1961, Preliminary subsurface study of southeastern Appalachian interior plateau: AAPG Bulletin, v. 45, p. 1634-1655.

## APPENDIX A

*See attached PDF*

## APPENDIX B

*See attached PDF*

## APPENDIX C

Aristech
Well number 1
Scioto County, OH
Green Township
Permit no. 20212
DGS Core No. 2958 data sheets building I P8-68 002630 (see APPENDIX E this report)

| Depth (ft) | Kmax(md) | Perm K-90(md) vertical perm (md) | Vertical (md) | Porosity | Grain density (gm.cc) | FM |
|---|---|---|---|---|---|---|
| 4,242-4,246.5 | 0 | 0 | NA | 3.9 | 2.63 | RSRN |
| 4,250-4,261.2 | 83 | 33 | NA | 10.4 | 2.61 | RSRN |
| 5,532-5,561 | 94 | 26.8 | NA | 11.9 | 2.55 | MRVL |
| 5,563-5,573 | 3.9 | 0.4 | NA | 3.9 | NA | MRVL |

Aristech
Monitor well
Scioto County, OH
Green Township
Permit no. 60141
DGS Core No. 3409 data sheets building I P2-91 002637 (see APPENDIX E this report)

| Depth (ft) | Kmax(md) | Perm K-90(md) vertical perm (md) | Vertical (md) | Porosity | Grain density (gm.cc) | FM |
|---|---|---|---|---|---|---|
| 4,021-4,022 | 231 | 0.02 | 0.02 | 2.2 | 2.79 | BKMN |
| 4,193-4,194 | 6 | 3.3 | 0.07 | 9.1 | 2.65 | RSRN |
| 4,202-4,203 | 86 | 70 | 1.4 | 12.7 | 2.64 | RSRN |
| 4,592.5-4,593.1 | 0.1 | 0.06 | <.01 | 2.7 | 2.73 | CPRG |
| 5,196.5-5,197.0 | 1.8 | 0.04 | 1.7 | 3.6 | 2.84 | CPRG |

Aristech
Well number 3
Scioto County, OH
Green Township
Permit no. 60033
DGS Core No. 3248 data sheets building I P1-90 002632 (see APPENDIX E this report)

Hope Natural Gas
No. 9634 Power Oil Company
Wood County, WV
Permit No. 351
DGS Core No. 768
Source: 1959, West Virginia Geological Survey, Investigations No. 18, p. 126,127.
Interval: Wells Creek-Rome

| Depth (ft) | Density | Porosity | Thermal Cond. | Dielectric Constant | Magnetic Suscep. | Young's Modulus | Rigidity Modulus | Poisson's Ratio | Longit. Internal Friction | Shear Internal Friction | FM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10,670 | 2.79 | | 9.3 | 32 | 5 | | | | | | WLCK |
| 10,692 | 2.665 | 0.7 | 13.2 | 8.1 | | | | | | | WLCK |
| 10,710 | 2839 | 0.14 | 11.1 | 9.1 | | | | | | | BKMN |
| 10,730 | | | | | 6 | | | | | | BKMN |
| 10,750 | 2.749 | 0.5 | 10.8 | 8.5 | | | | | | | BKMN |
| 10,771 | 2.771 | 0.2 | 12 | 8.2 | | | | | | | BKMN |
| 10,791 | 2.813 | 0.45 | 12.2 | 7.7 | | | | | | | BKMN |
| 10,831 | | | | | | | | | | | BKMN |
| 10,851 | 2.783 | 0.15 | 9.7 | 11.5 | 1 | 9.5 | 3.75 | 0.26 | 0.019 | 0.008 | BKMN |
| 10,871 | 2.832 | 0.2 | 11.7 | 9.6 | 3 | 8.65 | 3.64 | 0.19 | 0.023 | 0.014 | BKMN |
| 10,891 | 2.817 | 0.1 | 11.5 | 8.1 | 1 | | | | | | BKMN |
| 10,911 | 2.797 | 0.45 | 10.4 | 12.9 | 2 | 8.55 | 2.95 | 0.44 | 0.04 | 0.04 | BKMN |
| 10,931 | 2.836 | 0.35 | 12.6 | 7.8 | 2 | | | | | | BKMN |
| 10,951 | 2.804 | 0.45 | 10.6 | 8.6 | 4 | | | | | | BKMN |
| 10,971 | 2.811 | 0.25 | 11.3 | | 4 | 7.5 | 3.45 | 0.11 | 0.026 | 0.023 | BKMN |
| 10,991 | 2.813 | 0.35 | 11.1 | 8.6 | 2 | 6.9 | 3.05 | 0.13 | 0.024 | 0.027 | BKMN |
| 11,011 | 2.841 | 0.2 | 11.8 | 7.7 | | | | | | | BKMN |
| 11,031 | 2.815 | 0.4 | 11.4 | 5.9 | | 6.15 | 2.8 | 0.1 | 0.023 | 0.057 | BKMN |
| 11,050 | 2.835 | 0.25 | 11.7 | 7.4 | 1 | | | | | | BKMN |
| 11,070 | 2.827 | 0.25 | 12.2 | 7.1 | 2 | 5.95 | 2.75 | 0.09 | 0.038 | 0.025 | BKMN |
| 11,090 | 2.824 | 0.45 | 13.2 | 10.5 | 1 | | | | | | BKMN |
| 11,101 | 2.825 | 0.4 | 13.2 | 10 | 1 | 7.45 | 3.25 | 0.14 | 0.032 | 0.029 | BKMN |
| 11,130 | 2.819 | 0.2 | 13.7 | 8.6 | 1 | 4.25 | 2.3 | -0.09 | 0.068 | 0.043 | BKMN |
| 11,150 | 2.818 | 0.35 | 12.6 | 8.4 | 1 | | | | | | BKMN |
| 11,170 | 2.756 | 0.15 | 11.2 | 7.4 | 1 | 8.55 | 3.7 | 0.16 | 0.031 | 0.015 | BKMN |
| 11,190 | 2.797 | 0.3 | 11.6 | 7.7 | 1 | 3.05 | 2.1 | -0.27 | 0.022 | 0.038 | BKMN |
| 11,211 | 2.79 | 0.6 | 12.1 | 9.3 | 1 | | | | | | BKMN |
| 11,230 | 2.814 | 0.4 | 11.6 | 10 | 2 | 3.55 | 2.2 | -0.21 | 0.114 | 0.038 | BKMN |
| 11,251 | 2.819 | 0.45 | 12.1 | 8.9 | 1 | 4.45 | 2.35 | -0.06 | 0.065 | 0.031 | BKMN |
| 11,267 | 2.819 | 0.3 | 11.5 | 8.1 | 1 | | | | | | BKMN |
| 11,291 | 2.817 | 0.45 | 11.9 | 9.6 | 1 | | | | | | BKMN |
| 11,330 | 2.676 | 0.55 | 9.7 | 11.1 | 1 | | | | | | BKMN |
| 11,349 | 2.805 | 0.65 | 11.6 | 7.5 | 1 | | | | | | BKMN |
| 11,371 | 2.825 | 0.35 | 11.6 | 8.5 | 3 | | | | | | BKMN |
| 11,391 | 2.792 | 1.05 | 11.2 | 7.6 | 1 | 6.6 | 2.9 | 0.13 | 0.078 | 0.044 | BKMN |
| 11,410 | 2.815 | 0.45 | 12.2 | 8 | | 6.85 | 2.9 | 0.18 | 0.036 | 0.041 | BKMN |
| 11,431 | 2.816 | 0.45 | 11.8 | 9.7 | 2 | | | | | | BKMN |
| 11,450 | 2.813 | 0.2 | 11.3 | 7.7 | | 6.45 | 2.9 | 0.12 | 0.03 | 0.02 | BKMN |
| 11,470 | 2.835 | 0.45 | 11.2 | 7.4 | | | | | | | BKMN |
| 11,491 | 2.803 | 0.4 | 12.2 | 9.2 | | | | | | | BKMN |
| 11,510 | 2.799 | 0.35 | 10.1 | 8.2 | 2 | | | | | | BKMN |
| 11,531 | 2.825 | 0.25 | 11.9 | 8.1 | | | | | | | BKMN |
| 11,551 | 2.819 | 0.45 | 13.1 | 8.4 | | | | | | | BKMN |
| 11,571 | 2.824 | 0.3 | 12.2 | 8.4 | 2 | | | | | | BKMN |
| 11,591 | 2.821 | 0.3 | 12.4 | 9.1 | | | | | | | BKMN |
| 11,611 | 2.806 | 0.3 | 11 | 10.1 | | | | | | | BKMN |
| 11,631 | 2.813 | 0.4 | 11.8 | 8 | | | | | | | BKMN |
| 11,650 | 2.651 | 0.45 | 14.7 | 4.6 | | 2.95 | 1.85 | -0.2 | 0.112 | 0.041 | RSRN |
| 11,671 | 2.729 | 0.45 | 14 | 6.8 | | 3.3 | 2 | -0.16 | 0.095 | 0.055 | RSRN |
| 11,684 | 2.63 | 0.5 | 15.2 | 4.5 | | 4.35 | 2.45 | -0.11 | 0.025 | 0.031 | RSRN |
| 11,924 | 2.824 | 0.75 | 12.4 | 5.6 | | 7.2 | 3.05 | 0.19 | 0.074 | 0.067 | CPRG |
| 11,945 | 2.819 | 0.3 | 13.4 | 8.6 | 1 | | | | | | CPRG |
| 13,005 | 2.819 | 0.25 | 9.2 | 7.8 | 4 | | | | | | MRVL |
| 13,026 | 2.678 | 0.65 | 10 | 6.2 | 6 | | | | | | MRVL |
| 13,045 | 2.832 | 0.2 | 10.4 | 7.6 | 8 | 7.1 | 2.95 | 0.19 | 0.024 | 0.01 | MRVL |
| 13,066 | 2.663 | 0.6 | 13.7 | 5.7 | 2 | | | | | | MRVL |
| 13,086 | 2.66 | 0.7 | 12.6 | 5.2 | 6 | | | | | | MRVL |
| 13,106 | 2.515 | 2.5 | 13.5 | 4.5 | 1 | | | | | | MRVL |
| 13,126 | 2.683 | 0.6 | 7 | 7 | 8 | | | | | | MRVL |
| 13,146 | 2.799 | 0.35 | 8 | 8.6 | 10 | 5.25 | 2.5 | 0.05 | 0.028 | 0.01 | MRVL |
| 13,165 | 2.675 | 0.85 | 7.4 | 6.9 | | | | | | | MRVL |
| 13,314 | 2.91 | 0.35 | 5 | 43.5 | 57 | | | | | | PCMB |
| 13,318 | 2.65 | 0.2 | 7.9 | 9.3 | 8 | | | | | | PCMB |

Nu Corp. Energy Company
#1 Trepanier
Jackson County, OH
Franklin Township
Section 8
Permit No. 102
OGS Core No. 2898
Source: Core Laboratories, Inc.; Note: Depths annotated on cores are 10 feet deeper than those on core descriptions.

| Sample No. | Depth | Perm. to air MD | | | Porosity | Fluid sats. | | Gr. Den. | Description | FM |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Max. | 90 deg. | Vert. | gex. fld. | Oil | Water | | | |
| 1 | 4,498-4,499 | 0.1 | 0.1 | 0.1 | 1.5 | 0 | 94.7 | 2.77 | DOL,SDY,SL/SHY,FOSS | RSRN |
| 2 | 4,499-4,500 | 3 | 2.5 | 0.2 | 3.1 | 0 | 56.5 | 2.68 | SD,SL/SHY | RSRN |
| 3 | 4,500-4,501 | 17 | 17 | 0.9 | 7.8 | 0 | 24.8 | 2.67 | SD,SL/SHY | RSRN |
| 4 | 4,501-4,502 | 33 | 32 | 1.9 | 9.6 | 0 | 62.3 | 2.64 | SD,SL/SHY | RSRN |
| 5 | 4,502-4,503 | 26 | 26 | 14 | 11.5 | 0 | 89.5 | 2.65 | SD,SL/SHY | RSRN |
| 6 | 4,503-4,504 | 156 | 152 | 11 | 12.8 | 0 | 94 | 2.63 | SD,SL/SHY | RSRN |
| 7 | 4,504-4,505 | 60 | 17 | 1.2 | 10.4 | 0 | 82.8 | 2.62 | SD,SL/SHY | RSRN |
| 8 | 4,505-4,506 | 17 | 15 | 0.6 | 8.6 | 0 | 71.3 | 2.64 | SD,SL/SHY | RSRN |
| 9 | 4,506-4,507 | 6.3 | 5.8 | 0.5 | 8.4 | 0 | 71.1 | 2.64 | SD,SL/SHY | RSRN |
| 10 | 4,507-4,508 | 6.7 | 6.6 | 1 | 9.1 | 0 | 72.9 | 2.66 | SD,SL/SHY | RSRN |
| 11 | 4,508-4,509 | 3.5 | 3.4 | 0.6 | 7.7 | 0 | 73.4 | 2.64 | SD,SL/SHY | RSRN |
| 12 | 4,509-4,510 | 0.3 | 0.2 | 0.1 | 5.2 | 0 | 85.4 | 2.63 | SD,SL/SHY,STY | RSRN |
| 13 | 4,510-4,511 | 0.1 | 0.1 | 0.1 | 2.9 | 0 | 85.3 | 2.7 | SD,SL/SHY | RSRN |
| 14 | 4,511-4,512 | 0.1 | 0.1 | 0.5 | 5.3 | 0 | 77.3 | 2.68 | SD,SL/SHY | RSRN |
| 15 | 4,512-4,513 | 0.2 | 0.1 | 0.3 | 5.6 | 0 | 75 | 2.68 | SD,SL/SHY | RSRN |
| 16 | 4,513-4,514 | 8.6 | 7 | 2 | 8 | 0 | 75.8 | 2.67 | SD | RSRN |
| 17 | 4,514-4,515 | 8.1 | 7.3 | 0.4 | 7.3 | 0 | 76.9 | 2.66 | SD | RSRN |
| 18 | 4,515-4,516 | 3.5 | 3.4 | 0.5 | 9.5 | 0 | 79.5 | 2.68 | SD,SL/SHY | RSRN |
| 19 | 4,516-4,517 | 0.9 | 0.8 | 0.1 | 9 | 0 | 86 | 2.65 | SD,SL/SHY | RSRN |
| 20 | 4,517-4,518 | 20 | 16 | 0.2 | 11.6 | 0 | 79.1 | 2.64 | SD,SL/SHY | RSRN |
| 21 | 4,518-4,519 | 18 | 16 | 1.7 | 12.5 | 0 | 84.7 | 2.68 | SD | RSRN |
| 22 | 4,519-4,520 | 159 | 144 | 35 | 14.9 | 0 | 73.1 | 2.68 | SD | RSRN |
| 23 | 4,520-4,521 | 28 | 26 | 46 | 10.8 | 0 | 90.7 | 2.68 | SD | RSRN |
| 24 | 4,521-4,522 | 63 | 59 | 41 | 13.2 | 0 | 86 | 2.68 | SD,SL/SHY | RSRN |
| 25 | 4,522-4,523 | 71 | 70 | 27 | 13.6 | 0 | 80.9 | 2.68 | SD,SL/SHY | RSRN |
| 26 | 4,523-4,524 | 198 | 194 | 98 | 14.8 | 0 | 89.3 | 2.68 | SD,SL/SHY | RSRN |
| 27 | 4,524-4,525 | 20 | 19 | 0.1 | 9.9 | 0 | 72 | 2.68 | SD,SL/SHY | RSRN |
| 28 | 4,525-4,526 | 184 | 152 | 22 | 13.2 | 0 | 95.3 | 2.67 | SD,SL/SHY | RSRN |
| 29 | 4,526-4,527 | 178 | 159 | 51 | 13 | 0 | 98.8 | 2.68 | SD | RSRN |
| 30 | 4,527-4,528 | 180 | 162 | 76 | 13.1 | 0 | 98.1 | 2.68 | SD,SL/SHY | RSRN |
| 31 | 4,528-4,529 | 109 | 103 | 41 | 12.1 | 0 | 97.8 | 2.68 | SD,SL/SHY | RSRN |
| 32 | 4,529-4,530 | 11 | 3.4 | 0.7 | 7 | 0 | 69.6 | 2.67 | SD,SL/SHY | RSRN |
| 33 | 4,530-4,531 | 0.1 | 0.1 | 0.1 | 4.3 | 0 | 75.6 | 2.68 | SD,SL/SHY | RSRN |
| 34 | 4,531-4,532 | 0.2 | 0.1 | 0.1 | 2 | 0 | 75 | 2.67 | SD | RSRN |

## APPENDIX D

Additional References


Aguilera, R., 1980, Naturally fractured reservoirs: Tulsa, OK, PennWell Publishing Company, 703 p.

Allen J.P., 1988, Stratigraphic analysis and syndepositional structural influence on Cambrian units of the Rome trough in West Virginia: Unpublished M.S. thesis, West Virginia University, 123 p.

Anderson, R.J., 1985, Southeastern Ohio, col. 7, North-central Ohio, col. 15, East-central Ohio, col. 16, in Patchen, D.G., Avary, K.L., and Erwin, R.B., Coordinators, Northern Appalachian region correlation chart: American Association of Petroleum Geologists, Correlation of Stratigraphic Units of North America (COSUNA) Project, 1 sheet.

Atha, T.M., 1981, A subsurface study of the Cambro Ordovician Rose Run sandstone in eastern Ohio: Unpublished M.S. thesis, Ohio University, 81 p.

Avila, J., 1976, Devonian shale as source of gas, in Natural gas from unconventional geologic sources: U.S. Energy Research and Development Administration Report FE-2271-1, p. 73-85.

Bagnall, W.D., and Ryan, W.M., 1976, The geology, reserves, and production characteristics of the Devonian shale in southwestern West Virginia, in Shumaker, R.C., and Overbey, W.K., Jr., eds., Devonian shale production and potential: Proceedings of the Seventh Appalachian Petroleum Geology Symposium, Morgantown Energy Research Center, MERC/SP-76/2, p. 41-53.

Baranoski, M.T., and Riley, R.A., 1988, Analysis of stratigraphic and production relationships of Devonian-shale gas reservoirs in Lawrence County, Ohio: Ohio Division of Geological Survey Open-file Report 88-2, 30 p.

Baranoski, M.T., and Wickstrom, L.H., 1991, Basement structures in Ohio: Ohio Division of Geological Survey, Digital Chart and Map Series DCMS-7.

Beardsley, R.W., and Cable, M.S., 1983, Overview of the evolution of the Appalachian basin: Northeastern Geology, v. 5, nos. 3 and 4, p. 137-145.

Boley, D.W., Johnson, H.B., and Overbey, W.K., Jr., 1965, Oil-reservoir characteristics and predicted recovery by water flooding, Clinton sand, Logan oilfield, Hocking County, Ohio: U.S. Bureau of Mines, Report of Investigation 6683, 43 p.

Boswell, R.M., 1985, Stratigraphy and sedimentation of the Acadian clastic wedge in northern West Virginia: Unpublished M.S. thesis, West Virginia University, 179 p.

Boswell, R.M., 1988a, Stratigraphic expression of basement fault zones in northern West Virginia: Geological Society of America Bulletin, v. 100, p. 1988-1998.

Boswell, R.M., 1988b, Basin analysis of the Acadian clastic wedge in northern West Virginia and adjacent areas: Unpublished Ph.D. dissertation, West Virginia University, 351 p.

Boswell, R.M., and Donaldson, A.C., 1988, Depositional architecture of the Catskill delta complex, central Appalachian basin, U.S., in McMillan, N.J., Embry, A.F., and Glass, D.J., eds., The Devonian of the world: Canadian Society of Petroleum Geologists, Memoir 14, v. 2, p. 65-84.

Boswell, R.M., Donaldson, A.C., and Lewis, J.S., 1987, Subsurface stratigraphy of the Upper Devonian and Lower Mississippian of northern West Virginia: Southeastern Geology, v. 28, no. 2, p. 105-131.

Boswell, R.M., and Jewell, G.A., 1988, Atlas of Upper Devonian/Lower Mississippian sandstones in the subsurface of West Virginia: West Virginia Geological and Economic Survey, Circular C-43, 144 p.

Boswell, R.M., Pool, S., Pratt, S., and Matchen, D.L., 1993, Appalachian basin low-permeability sandstone reservoir characterizations: Final contractor's report: Morgantown, WV, EG&G Washington Analytical Services, Inc. Morgantown Energy Techincal Center, U.S. Department of Energy contract no. DE-AC21-90MC26328, Report 94CC-R91-003, 73 p.

Brannock, M.C., 1993, The Starr fault system of southeastern Ohio: Presented at the Ohio Geological Society symposium "An update on Ohio's subsurface geology," Canton, Ohio, October 1993, p. 19.

Broadhead, R.F., 1993, Petrography and reservoir geology of Upper Devonian shales, northern Ohio, in Roen, J.B., and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shales of eastern North America: U.S. Geological Survey Bulletin 1909, p. H1-H15.

Broadhead, R.F., Kepferle, R.C., and Potter, P.E., 1982, Stratigraphic and sedimentologic controls on gas in shale—Example from Upper Devonian of northern Ohio: American Association of Petroleum Geologists Bulletin, v. 66, no. 1, p. 10-27.

Brown, P.J., 1976, Energy from shale—A little used natural resource, in Natural gas from unconventional geologic sources: U.S. Energy Research and Development Administration Report FE-2271-1, p. 86-99.

Bruner, K.R., 1983, Petrology and diagenesis of the Lower Silurian Tuscarora Sandstone, Kanawha County, West Virginia: Unpublished M.S. thesis, West Virginia University, 148 p.

Bruner, K.R., 1988, Sedimentary facies of the Lower Devonian Oriskany Sandstone, Greenbrier County, West Virginia, in Smosna, R.A., organizer, A walk through the Paleozoic of the Appalachian basin: Charleston, WV, American Association of Petroleum Geologist, Eastern Section Meeting, Core Workshop, p. 38-47.

Burford, A.E., and Frech, K.E., 1982, Nature and history of "Clinton" sandstone porosity: Presented at the Ohio Oil and Gas Association Technical Meeting, Columbus, Ohio, November 18, 1982.

Cable, M.S., 1984, Aspects of subsurface Cambrian and Early Ordovician lithostratigraphy and structure, eastern Kentucky, western West Virginia and Ohio: Unpublished Ph.D. dissertation, University of South Carolina, 90 p.

Cable, M.S., and Beardsley, R.W., 1984, Structural controls on Late Cambrian and Early Ordovician carbonate sedimentation in eastern Kentucky: American Journal of Science, v. 284, nos. 7-10, p. 797-823.

Calvert, W.L., 1962, Sub-Trenton rocks from Lee County, Virginia, to Fayette County, Ohio: Ohio Division of Geological Survey, Report of Investigations 45, 57 p.

Calvert, W.L., 1974, Sub-Trenton structure of Ohio, with views on isopach maps and stratigraphic sections as basis for structural myths in Ohio, Illinois, New York, Pennsylvania, West Virginia, and Michigan: American Association of Petroleum Geologists Bulletin, v. 58, p. 957-972.

Cardwell, D.H., 1971, The Newburg of West Virginia: West Virginia Geological and Economic Survey, Bulletin B-35, 54 p.

Cardwell, D.H., 1977, West Virginia gas development in the Tuscarora and deeper formations (with structural maps contoured on top of Ordovician and Precambrian): West Virginia Geological and Economic Survey, Mineral Resources Series MRS-8, 38 p.

Cardwell, D.H., and Avary, K.L., 1982, Oil and gas fields of West Virginia (and oil and gas fields map of West Virginia): West Virginia Geological and Economic Survey, Mineral Resource Series MRS-7B, 171 p., map scale 1:250,000.

Carter, B., Miller, P., and Smosna, R.A., 1988, Environmental aspects of Middle Ordovician limestones in the central Appalachians: Sedimentary Geology, v. 58, no. 1, p. 485-509.

Charpentier, R.R., de Witt, W., Jr., Claypool, G.E., Harris, L.D., Mast, R.F., Megeath, J.D., Roen, J.B., and Schmoker, J.W., 1982, Estimates of unconventional natural-gas resources of the Devonian shale of the Appalachian basin: U.S. Geological Survey Open-file Report 82-474, 43 p.

Charpentier, R.R., de Witt, W., Jr., Claypool, G.E., Harris, L.D., Mast, R.F., Megeath, J.D., Roen, J.B., and Schmoker, J.W., 1993, Estimates of unconventional natural gas resources of the Devonian shales of the Appalachian basin, in Roen, J.B., and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shale of eastern North America: U.S. Geological Survey Bulletin 1909, p. N1-N20.

Cheema, M.R., 1977, Sedimentation and gas production of the Upper Devonian Benson sand in north-central West Virginia: Unpublished Ph.D. dissertation, West Virginia University, 117 p.

Chen, P., 1977, Stratigraphic maps, lower Paleozoic stratigraphy, tectonics, paleography, and oil/gas possibilities in the central Appalachians (West Virginia and adjacent states), Part 1. Stratigraphic maps: West Virginia Geological and Economic Survey, Report of Investigation RI-26-1, 141 p.

Claypool, G.E., Threlkeld, C.N., and Bostick, N.H., 1978, Natural gas occurrence related to regional thermal rank of organic matter (maturity) in Devonian rocks of the Appalachian basin, in Preprints for Second Eastern Gas Shales Symposium: U.S. Department of Energy, Morgantown Energy Technology Center, METC/SP-78/6, v. 1, p. 54-65.

Clifford, M.J., and Collins, H.R., 1974, Structures of southeastern Ohio [abs.]: American Association of Petroleum Geologists Bulletin, v. 58, no. 9, p. 1891.

Cole, G.A., Drozd, R.J., Sedivy, R.A., and Halpern, H.I., 1987, Organic geochemistry and oil-source correlations, Paleozoic of Ohio: American Association of Petroleum Geologists Bulletin, v. 71, no. 7, p. 788-809.

Collins, H.R., and Smith, B.E., 1977, Geology and mineral resources of Washington County, Ohio: Ohio Division of Geological Survey, Bulletin 66, 134 p.

de Witt, W., Jr., and Roen, J.B., 1985, Correlation and geographic extent of some Middle and Upper Devonian and Lower Mississippian black shales in the Appalachian basin: U.S. Geological Survey Bulletin 1605-A, p. A45-A57.

de Witt, W., Jr., Roen, J.B., and Wallace, L.G., 1993, Stratigraphy of the Devonian black shales in the Appalachian basin, in Roen, J.B., and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shales of eastern North America: U.S. Geological Survey Bulletin 1909, p. B1-B57.

Diecchio, R.J., 1982, Tuscarora Sandstone stratigraphic summary and production trend: West Virginia Geological and Economic Survey, report to the Bureau of Economic Geology, University of Texas at Austin, Contract no. GRI-BEG-SC-111-81, 9 p.

Diecchio, R.J., Jones, S.E., and Dennison, J.M., 1983, Oriskany Sandstone—Regional stratigraphic relationships and production trends: West Virginia Geological and Economic Survey, Map-WV17.

Donaldson, A.C., Heald, M.T., Renton, J.J., and Warshauer, S.M., 1975, Depositional environment of Rome trough rocks, Mingo County well, West Virginia [abs.]: American Association of Petroleum Geologists Bulletin, v.59, p. 1735.

Donaldson, A.C., Heald, M.T., and Warshauer, S.M., 1988, Cambrian rocks of the Rome trough in West Virginia: Cores from Mingo and Wayne counties, in Smosna, R.A., Organizer, A walk through the Paleozoic of the Appalachian basin: American Association of Petroleum Geologists Eastern Section Meeting Core Workshop, Charleston, WV, p. 6-18.

Ferm, J.C., and Weisenfluh, G.A., 1989, Evolution of some depositional models in Late Carboniferous rocks of the Appalachian coal fields: International Journal of Coal Geology, v. 12, p. 259-292.

Filer, J.K., 1985, Oil and gas report and maps of Pleasants, Wood, and Ritchie counties, West Virginia: West Virginia Geological and Economic Survey, Bulletin B-11A, 87 p.

Filer, J.K., 1988, Chronostratigraphy and facies of the Upper Devonian clastic wedge, West Virginia, in Dennison, J.M., ed., Geologic field guide Devonian Delta in east-central West Virginia and adjacent Virginia: Charleston, WV, Appalachian Geological Society, p. 67-76.

Gray, J.D., 1982, Subsurface structure mapping in eastern Ohio, in Gray, J.D., ed., An integrated study of the Devonian-age black shales in eastern Ohio: U.S. Department of Energy, DOE/ET12131-1399, variously paged.

Kettering, C.L., 1984, Paleogeography and subsurface geometry of the "Sharon" conglomerate (Pennsylvanian) in Jackson and Gallia counties, Ohio: Unpublished M.S. thesis, Ohio State University, 101 p.

Krebs, C.E., 1911, Jackson, Mason, and Putnam counties: West Virginia Geological and Economic Survey, County Geologic Report CGR-9a, 387 p.

Kulander, B.R., and Dean, S.L., 1978, Gravity, magnetics, and structure of the Allegheny Plateau/western Valley and Ridges in West Virginia and adjacent states: West Virginia Geological and Economic Survey, Report of Investigations RI-27, 65 p.

Kulander, B.R., and Dean, S.L., 1986, Structure and tectonics of central and southern Appalachian Valley and Ridge and Plateau provinces, West Virginia and Virginia: American Association of Petroleum Geologists Bulletin, v. 70, no. 11, p. 1674-1684.

Lafferty, R.C., 1938, The Oriskany in West Virginia: American Association of Petroleum Geologists Bulletin, v. 22, p. 175-188.

Martin, P., and Nuckols, E.B., 1976, Geology and oil and gas occurrence in the Devonian shales: Northern West Virginia, in Shumaker, R.C., and Overbey, W.K., Jr., eds., Devonian shale production and potential: Proceedings of the Seventh Appalachian Petroleum Geology Symposium, Morgantown Energy Research Center, MERC/SP-76/2, p. 20-40.

Miller, B.M., Thomsen, H.L., Dolton, G.L., Coury, A.B., Hendricks, T.A., Lennartz, F.E., Powers, R.B., Sable, E.G., and Varnes, K.L., 1975, Geological estimates of undiscovered recoverable oil and gas resources in the United States: U.S. Geological Survey Circular 725, 78 p.

Mussman, W.J., Montanez, I.P., and Read J.F., 1988, Ordovician Knox paleokarst unconformity, Appalachians, in James, N.P., and Choquette, P.W., eds., Paleokarst: New York, Springer-Verlag, p. 211-229.

Neal, D.W., and Price, B.K., 1986, Oil and gas report and maps of Lincoln, Logan, and Mingo counties, West Virginia: West Virginia Geological and Economic Survey, Bulletin B-41, 68 p.

Negus-de Wys, J., 1979, The Eastern Kentucky gas field—A geological study of the relationships of oil shale gas occurrences to structure, stratigraphy, lithology, and inorganic geochemical parameters: Unpublished Ph.D. dissertation, West Virginia University, 199 p.

Negus-de Wys, J., and Shumaker, R.C., 1978, Results of a pilot study of Cottageville field, Jackson and Mason counties, West Virginia: U.S. Department of Energy, Morgantown Energy Technology Center, METC/SP-180, 14 p.

Nuckols, E.B., 1979, The Cottageville (Mount Alto) gas field, Jackson County West Virginia: A case study of Devonian shale gas production: U.S. Department of Energy, Morgantown Energy Technology Center, DOE/METC/12138-1359, 130 p.

Overbey, W.K., Jr., 1961, Oil and gas report and map on Jackson, Mason, and Putnam counties, West Virginia: West Virginia Geological and Economic Survey, Bulletin B-23, 26 p.

Overbey, W.K., Jr., 1967, Lithologies, environments, and reservoirs of the Middle Mississippian Greenbrier Group in West Virginia: Producers Monthly, v. 31, no. 2, p. 25-32.

Overbey, W.K., Jr., and Henniger, B.R., 1971, History, development, and geology of oil fields in Hocking and Perry counties, Ohio: American Association of Petroleum Geologists Bulletin, v. 55, no. 2, p. 183-203.

Overbey, W.K., Jr., Tucker, R.C., and Ruley, E.E., 1963, Recent developments in the Big Injun horizon in West Virginia: Producers Monthly, v. 27, no. 7, p. 18-22.

Owen, E.W., 1975, Trek of the oil finders—A history of exploration for petroleum: American Association of Petroleum Geologists, Memoir 6, 641 p.

Ozol, M.A., 1963, Alkali reactivity of cherts and stratigraphy and petrolgy of cherts and associated limestones of the Onondaga Formation of central and western New York: Unpublished Ph.D. dissertation, Rensselaer Polytechnic Institute, 228 p.

Patchen, D.G., 1967, Newburg gas development in West Virginia: West Virginia Geological and Economic Survey, Circular C-6, 46 p.

Patchen, D.G., 1968a, A summary of Tuscarora Sandstone (Clinton sand) and pre-Silurian test wells in West Virginia: West Virginia Geological and Economic Survey, Circular C-8, 34 p.

Patchen, D.G., 1971, Stratigraphy and petrology of the Williamsport Sandstone, West Virginia: Unpublished Ph.D. dissertation, Syracuse University, 109 p.

Patchen, D.G., 1977, Subsurface stratigraphy and gas production of the Devonian shales in West Virginia: U.S. Department of Energy, Morgantown Energy Research Center, MERC/CR-77/5, 35 p.

Patchen, D.G., and Avary, K.L., 1985, Southern coal basin, West Virginia, col. 1, Dunkard basin, West Virginia, col. 8, in Patchen, D.G., Avary, K.L., and Erwin, R.B., Coordinators, Northern Appalachian region correlation chart: American Association of Petroleum Geologists, Correlation of Stratigraphic Units of North America (COSUNA) Project, 1 sheet.

Patchen, D.G., Avary, K.L., and Erwin, R.B., Coordinators 1985a, Northern Appalachian region correlation chart: American Association of Petroleum Geologists, Correlation of Stratigraphic Units of North America (COSUNA) Project, 1 sheet.

Patchen, D.G., Avary, K.L., and Erwin, R.B., Coordinators, 1985b, Southern Appalachian region correlation chart: American Association of Petroleum Geologists, Correlation of Stratigraphic Units of North America (COSUNA) Project, 1 sheet.

Patchen, D.G., and Smosna, R.A., 1975, Stratigraphy and petrology of Middle Silurian McKenzie Formation in West Virginia: American Association of Petroleum Geologists Bulletin, v. 59, no. 12, p. 2266-2287.

Paska, M.A., 1981, Petroleum geology of the early Silurian Albion Group in Morgan, Athens, Hocking, and Vinton counties, Ohio: Unpublished M.S. thesis, Ohio University, 85 p.

Pepper, J.F., de Witt, W., Jr., and Demarest, D.F., 1954, Geology of the Bedford Shale and Berea Sandstone in the Appalachian basin: U.S. Geological Survey Professional Paper 259, 111 p.

Provo, L.J., 1977, Stratigraphy and sedimentology of radioactive Devonian-Mississippian shales of the central Appalachian basin: Unpublished Ph.D. dissertation, University of Cincinnati, 177 p.

Schwietering, J.F., 1970, Devonian shales of Ohio and their eastern equivalents: Unpublished Ph.D. dissertation, Ohio State University, Columbus, Ohio, 79 p.

Schwietering, J.F., and Roberts, P.A., 1988, Oil and gas report and maps of Cabell and Wayne counties, West Virginia: West Virginia Geological and Economic Survey, Bulletin B-42, 95 p.

Sundheimer, G., 1978, Seismic analysis of the Cottageville field, in Preprints for Second Eastern Gas Shales Symposium: U.S. Department of Energy, Morgantown Energy Technology Center, METC/SP-78/6, v. 1, p. 111-120.

Sweeney, J., 1986, Oil and gas report and maps of Wirt, Roane, and Calhoun counties, West Virginia: West Virginia Geological and Economic Survey, Bulletin B-40, 102 p.,12 pls.

Wallace, L.G., and Roen, J.B., 1989, Petroleum source rock potential of the Upper Ordovician black shale sequence, northern Appalachian basin: U.S. Geological Survey Open-File Report 89-488, 66 p.

Wallace, L.G., Roen, J.B., and de Witt, W., Jr., 1977, Preliminary stratigraphic cross section showing radioactive zones in the Devonian black shales in the western part of the Appalachian basin; U.S. Geological Survey Oil and Gas Investigations Chart OC-80.

Wallace, L.G., Roen, J.B., and de Witt, W., Jr., 1978, Preliminary stratigraphic cross section showing radioactive zones in the Devonian black shales in southeastern Ohio and west-central West Virginia: U.S. Geological Survey Oil and Gas Investigations Chart OC-83.

Webb, E.J., 1980, Cambrian sedimentation and structural evolution of the Rome trough in Kentucky: Unpublished Ph.D. dissertation, University of Cincinnati, 107 p.

West Virginia Tight Formation Committee, 1982, Areas recommended for tight formations in Jackson, Mason, and Wood counties, West Virginia: West Virginia Tight Formation Committee, 55 p.

Wilson, E.N., Zafar, J.S., and Ettensohn, F.R., 1981, Rome trough section: A stratigraphic section through the Devonian-Mississippian black-shale sequence in Tennessee, Kentucky, and West Virginia: Morgantown Energy Technology Center, EGSP Series No. 500.

## APPENDIX E

*(Also see attached PDF)*

Class 1 data/reports
All located in Building I

| Bar code Building I | Box no. | Dates | Company | General report contents | Description |
|---|---|---|---|---|---|
| 002630 | 28 | 12/20/67-4/1/88 | Aristech | Report P8-68 | Table 3: Fluid mobilities through core samples of MNSM, Well #1 |
| *002630 | 28 | | | Report P8-68 | Table 1: Core Analysis, Well #1: Berea; Newburg; St. Peter; Rose Run; Mt Simon (Maryville lower unit) |
| 002630 | 28 | | | Report P8-68 | Figure 3: Pressure transient tests, MNSM, Well #1 |
| 002630 | 28 | | | Report P2-88 | Annulus pressure test, Well #1 & #2, pages 86-88 |
| 002632 | 30 | 1/29/90-5/1/90 | Aristech | Report P1-90 | Appendix I: Chemical analyses formation fluids: BERE, CNSG/ROME, MNSM, RSRN, SNPR, Well #3 |
| *002632 | 30 | | | Report P1-90 | Core analysis and results for permeability and porosity, Well #3 |
| *002633 | 31 | 5/1/90-5/31/90 | Aristech | Report P2-90 | Appendix 4.3-H: Core Analysis, Well #3 |
| 002633 | 31 | | | Report P2-90 | Appendix 5.3-C: Chemical Analysis, BERE sample in Scioto County brine well |
| 002636 | 34 | 4/6/91-7/12/91 | Aristech | Report P1-91 vol. 4 | Appendix 9:1-A interference test analysis |
| 002636 | 34 | | | Report P1-91 vol. 4 | Page 9-2: Step-rate test analysis |
| 002636 | 34 | | | Report P1-91 vol. 4 | Page 9-2: In-situ stress test |
| 002636 | 34 | | | Report P1-91 vol. 4 | Appendix 9.0-A: About 200 pages; pressure fall-off, step rate and interference tests for WDW 1, 2, & 3 |
| 002636 | 34 | | | Report P1-91 vol. 4 | Appendix 7.3-B: Chemical analysis of samples of BERE and LOGN, Well #4 |
| 002636 | 34 | | | Report P1-91 vol. 4 | Appendix 7.3-C: Chemical analyses of water samples, Well #3 |
| 002636 | 34 | | | Report P1-91 vol. 4 | Appendix 7.3-D: Chemical analysis of formation samples in Scioto County brine wells |
| 002636 | 34 | | | Report P2-91 | Appendix C.1 to C.7: Drill stem and swab tests |
| *002636 | 34 | | | Report P1-91 vol. 4 | Appendix 6.3-L: Petrographic study of core interval 5,915'-6,109' (MNSM), Maryville this report, Well #3 |
| 002637 | 35 | 7/12/91-8/15/91 | Aristech | Report P4-91 | Appendix I: Description of formation testing procedures, Well #3 |
| 002637 | 35 | | | Report P4-91 | Appendix G-2: Summary of formation testing and logging procedures, Well #3 |
| 002637 | 35 | | | Report P4-91 | Appendix G-3: Summary of formation testing and logging procedures, Well #4 |
| 002637 | 35 | | | Report P2-91 | Appendix G: In-situ stress test |
| *002637 | 35 | | | Report P2-91 | Appendix H: Petrographic core analysis, Well #4, Samples from BKMN, RSRN, CPRG, ROME (Maryville this report) |
| 002637 | 35 | | | Report P4-91 | Appendix G-4: Step-rate testing, Well #3 |
| 002637 | 35 | | | Report P3-91 | Tables 1 through 5: In-situ stress test data |
| 002637 | 35 | | | Report P3-91 | Rose Run/Copper Ridge report V1 sections 3 & 5 analyses and data weels 1, 2, 3, 4 |
| 002639 | | 8/15/91-8/31/91 | Aristech | Report P4-91 | Appendix S-1: In-situ stress measurements |
| 002639 | | | | Report P4-91 | Appendix AA: DST data analysis |
| 002639 | | | | Report P4-91 | Appendix BB: Summary of studies performed and methodologies |
| 002639 | | | | Report P4-91 | Appendix M: Assessment of Haverhill fluid chemistry |
| 002640 | | 5/12/68-1/1/96 | Aristech | Report W1-68 | Inter-office memorandum, Well #1, June 15, 1968 |

*Cited this report

# Appendix A

Core descriptions

Conasauga Group well APINOs 3414520212, 3414560161, 4710700351

INDUSTRIAL WASTE DISPOSAL #1

**WELL NAME** ARISTECH CORP. **DEPTH** 5532.2 **TO** _____ **DATE** 3/7/01

**LOCATION** SCIOTO CO. GREEN TWP. ROME (JANSSENS) **CORE(S)** OHIO GEOL. SUR # 2958 **DESCRIBED BY** M. BARANOSKI

**STRATIGRAPHIC UNIT** MARYVILLE **SHEET** 1 **OF** 1 **VERTICAL SCALE** 1" = 10'

⊙ BTM CORE BOX

| CLASTIC FORMS: COBBLE, PEBBLE, GRANULE, V. COARSE, COARSE, MEDIUM, FINE, V.FINE, SILT, CLAY | CARB.: RUDSTONE, FLOATSTONE, BOUNDSTONE, GRAINSTONE, PACKSTONE, WACKESTONE, MUDSTONE, XLN | TEXTURE & SED. STRUCTURES | CORE DEPTH | GRAPHIC LITHOLOGY | GRAIN TYPE | POROSITY/ OIL STAIN | STYLOLITES | FRACTURES | SAMPLE LOCATION | SEDIMENTARY CYCLES | LITHOFACIES/ DEPOSITIONAL ENVIRONMENT | p = PYRITE<br>d = discontinuity<br>DESCRIPTIVE REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 5530 | | | TTE | | | | | SHALLOW MARINE | SS LT PINK TO LT. BRN, MASSIVE TO IRREGULAR AND WAVY BEDDED, MODERATELY TO POORLY BIOTURBATED, TROUGH X-BEDDING AND FINING UPWARD SEQUENCES, ANHYDRITE REPLACEMENT CLASTS, FELDSPATHIC, MODERATELY TO WELL CEMENTED W/ SILICA AND FELDSPAR, PYRITIC TR DOL'C AND CALCITE CEMENT, FINE TO MEDIUM GRAINED, POORLY TO WELL SORTED, ROUNDED TO SUBROUNDED MINOR DISCONTINUITIES |
| | | | 40 | | | IG ϕ | | | | | | |
| | | | | | | TTE | | | | | | |
| | | | 50 | | | | | | | | | |
| | | | 60 | | | IG TTE | | | | | | DOL. LT PINK TO WH, MASSIVE, IRREGULAR BEDDED, FN TO MED XLN, ARENACEOUS FELDSPATHIC, BIOTURBATED VERTICAL BURROWS, WSPY IRREGULAR LAMINATED DK GRY SHALE |
| | | | | | | IG TTE | | | | | | |
| | | | 70 | | | IG/TTE | | | | | | SS, MED - DK BRN, FN GR, MASSIVE - TO LAMINATED - ARGILLACEOUS BIOTURBATED, INTRAFORMATIONAL BRECCIA 5564.6 |
| | | | | | | | | | | | | SILTSTONE<br>SS, MED - DK BRN, ORANGE, PINK, V FN GRN, MASSIVE, LAMINATED, WSPY, IRREG. BEDDED, BIOTURBATED, VERTICAL BURROWS, TRACE FOSSILS (SCOLITHUS) ON BEDDING PLANE SURFACES, TRACE FOSSIL GHOSTS (BRACHIOPODS?) TR DOLO'C |

MONITOR WELL (NO.4)

**WELL NAME** ARISTECH CORP. GREEN TWP. **DEPTH** 4974.9 **TO** 5100 **DATE** 3/6/01

**LOCATION** SCIOTO CO, OHIO **CORE(S)** OHIO GEOL. SUR. #3409 **DESCRIBED BY** M. BARANOSKI

**STRATIGRAPHIC UNIT** COPPER RIDGE, MAYNARDVILLE, NOLICHUCKY (CONASAUGA OF JANSSENS) **SHEET** 1 **OF** 4 **VERTICAL SCALE** 1" = 10'

MISSING ✕ DEPTH BTM BOX

| CORE DEPTH | GRAPHIC LITHOLOGY | GRAIN TYPE | POROSITY/ OIL STAIN | STYLOLITES | FRACTURES | SAMPLE LOCATION | SEDIMENTARY CYCLES | LITHOFACIES/ DEPOSITIONAL ENVIRONMENT | DESCRIPTIVE REMARKS (↗ shallowing upward, ↗ fining upwards) |
|---|---|---|---|---|---|---|---|---|---|
| 4974 | | | | | | | | | COPPER RIDGE DOL. LOWER PART OF KNOX DOLOMITE |
| | | | IC TITE | | | | | SHALLOW SUBTIDAL | DOLOMITE, LT. TO MED. TO DARK BRN, LAMINATED, WISPY, ARGIL LAMINATED TO MASSIVE, RELICT BIOTURBATION, ICTO TITE, STYLOLITES, SOME STROMATOLITES, SOFT SEDIMENT DEFORMATION, ABUNDANT DISCONTINUITES |
| 5000 | | | | | | | | | DOLOMITE, LT. TO MED. TO DARK BRN, LAMINATED TO WAVY IRREGULAR BEDDED A/A |
| | | | | | | | | SLOPE (DEEPER WATER) | DOLOMITE A/A NODULAR BEDDED |
| | | | | | | | | | SHALE DK BRN-BRN; DOL. A/A SLI. CALCAREOUS |
| | | | | | | | | | DOLOMITE A/A TITE SLI CALCAREOUS – INCREASING DOWNWARD |
| COPPER RIDGE / MAYNARDVILLE | | | IC TITE IC TITE IC IC TITE IC TITE IC | | | | | SHALLOW SLOPE | DOLOMITE LT. TO MED. BRN, INCREASING CALCAREOUS NODULES; CONTACT PLACED AT TOP DOLO'IC SILTSTONE BED; SHALE-DK BRN, CALCAREOUS DECREASING CALCAREOUS NODULAR BEDDING & SHALE |
| | | | | | | | | | DOLOMITE & SHALE A/A ↳ RELICT BIOCLASTIC GRAINSTONE BEDS TRACE NODULAR BEDS |
| | | | | | | | | | POORLY DEV. CROSS BEDS |
| | | | | | | | | SHALLOW SUBTIDAL | DOL. A/A TRACE NODULAR BEDS |
| | | | | | | | | | DOL. A/A INTERBEDDED W/ SHALE INCREASING SHALE DOWNWARDS SHALE DK GRAY, LAMINATED, DOLO'IC |
| NOLICHUCKY | | | | | | | | SLOPE/DEEPER WATER | DOL. A/A INTERBEDDED RELICT BIOCLASTIC GRAINSTONE SHALE, DK GRY TO BLACK, LAMINATED, DOLO'IC, FOSSILIFEROUS; CONTACT GRADATIONAL |
| | | | | | | PAPER SLIPS INDICATE FOSSIL MATERIAL | | | DOL. A/A LAMINATED INTERBEDDED W/ SHALE |
| | | | | | | | | | SHALE A/A INTERBEDDED W/ DOL A/A |
| | | | TC IC TITE IC IC IC | | | | | SHALLOW SLOPE/DEEP | SHALE A/A INTERBEDDED W/ DOL. A/A GRADED FINING UPWARDS |
| | | | | | | | | | DOL A/A SILTSTONE W/ INTRA FORMATIONAL CLASTS ↖ RELICT BIOCLASTIC MATERIAL |
| | | | | | | | | | SHALE A/A INTERBEDDED W/ DOL A/A ↳ SLI. CALCAREOUS |
| 5100 | | | TITE IC | | | | | | |

EX-15-15-H-50

MONITOR WELL (NO.4)

WELL NAME ARISTECH CORP. DEPTH 5100 TO 5230 DATE 3/6/01

LOCATION GREEN TWP. SCIOTO CO., OHIO CORE(S) OHIO GEOL. SUR. #3409 DESCRIBED BY M. BARANOSKI

STRATIGRAPHIC UNIT NOLICHUCKY, MARYVILLE SHEET 2 OF 4 VERTICAL SCALE 1" = 10'

MISSING CORE ✕ DEPTH ⊙ BTM BOX

IC - intercry. ϕ
V - vuggy ϕ
d - discontinuity
br - brecciated
G - glauconite
gr - graded bedding
V = vuggy

| CLASTIC / CARB. | TEXTURE & SED. STRUCTURES | CORE DEPTH | GRAPHIC LITHOLOGY | GRAIN TYPE | POROSITY / OIL STAIN | STYLOLITES | FRACTURES | SAMPLE LOCATION | SEDIMENTARY CYCLES | LITHOFACIES / DEPOSITIONAL ENVIRONMENT | DESCRIPTIVE REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5100 | | | TITE IC IC IC | | / | PAPER SLIPS INDICATE FOSSIL MATERIAL | ↑ shallowing upwards ↗ fining upwards | SHALLOW SUBTIDAL / SLOPE / DEEP | DOL. LT. TO MED. BRN, LAMINATED, WISPY IRREGULAR BEDDED, RELICT BIOCLASTIC GRAINSTONE BEDS W/ INTRACLAST MED TO ~~LATTER~~ BEDDED W/ SHALE ↗ DK GRAY TO BLACK, LAMINATED, FOSSILIFEROUS |
| | | 10 | | | | | | | | | MED TO SHALE, A/A DK GRAY A/A, FOSSILIFEROUS |
| | | 20 | | | | | | | | | |
| | | 30 | | | TITE | | | | | | |
| | | 40 | | | | | | | | | INCREASING INTERLAMINATED AND BIOLIC SHALE DOWNWARD; INCREASING INTERCLASTS |
| | | 50 | | | TITE | | | | | | GLAUCONITE ZONE |
| | F6 | | | | | | | | | | F6 CONTACT MARKS LAST MAJOR SHALE BED; CONTACT WITH DOL. GRADATIONAL |
| | G G G gr G G G | 60 | | | | | | | | | GLAUCONITE AND GRADED BEDDING INCREASES DOWNWARDS |
| | | 70 | | | TITE | | | | | | |
| | gr G | 80 | | | | | | | | | |
| | gr | 90 | | | IC | | | | | | INTERBEDDED SHALE A/A & DOL, WHITE TO LT. GRAY, BIOTURBATED |
| | F5 d V MARYVILLE (RONE CANSELL) | | | | TITE V IC V V | | | | | | DOLOMITE, WHITE TO LT. GRY, MASSIVE, CRPT XLN, FINELY TO MED. XLN, VUGGY, GRADATIONAL W/ OVERLYING SHALE, AND BIOTURBATED DOL.; LOCALLY ARENACEOUS AND GLAUCONITIC; STYLOLITES ABUNDANT DOLOMITE FILLED FRACTURES, RARE PYRITE; SELENITE FILLED VUGS |
| | | 200 | | | TITE | | | | | | (Vugs and rip-up clasts beneath MARYSVILLE CONTACT) |
| | | 10 | | | | | | | | | |
| | V | 20 | | | V | | /DOL. | | | | DOL. A/A - LAMINATED TO MASSIVE BEDDED; LOW ANGLE BEDDING DIP? |
| | br br br v br | | | | | | /DOL. | | | | irregular fractures - dol. filled |
| | | 30 | | | V | | | | | | |

BOXED MIXED UP - RED ON LEFT

MONITOR WELL (NO.4)

WELL NAME ARISTECH CORP. DEPTH 5230 TO 5360 DATE 3/6/01

LOCATION GREEN TWP, SCIOTO CO., OH CORE(S) OHIO GEOL. SUR. #3409 DESCRIBED BY M. BARANOSKI

STRATIGRAPHIC UNIT MARYVILLE (ROME & JAUSSENS) SHEET 3 OF 4 VERTICAL SCALE 1" = 10'

© DEPTH BTM BOX

| CORE DEPTH | GRAPHIC LITHOLOGY | GRAIN TYPE | POROSITY/ OIL STAIN | STYLOLITES | FRACTURES | SAMPLE LOCATION | SEDIMENTARY CYCLES | LITHOFACIES/ DEPOSITIONAL ENVIRONMENT | DESCRIPTIVE REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 5230 | | | TITE | | | | | SHALLOW SUBTIDAL/SLOPE | WISPY, IRREG. DOL. - WH TO LT/MED GRY, LAMINATED TO MASSIVE BEDDED, CRPTYLN, FN TO MCA XLN, LOCALLY ARE/MACEOUS, POORLY DEVELOPED |
| | | | | | | | | | BIOTURBATION SLIGHTLY VUGGY, HIGH ANGLE DISCONTINUITIES / INTERLAMINATED MED TO DK GRY SHALE, |
| 40 | | | | | | | | | BRECCIATED SHALE CLASTS, ABUNDANT STYLOLITES, DISCONTINUITIES/SCOUR SURFACES COMMON |
| 50 | | | | | | | | | |
| 60 | | | TITE | | | | | | |
| 70 | | | | | | | | | |
| 80 | | | | | | | | | |
| 90 | | | | | | | | | |
| 5300 | | | TITE | | | | | | |
| 10 | | | | | | | | | |
| 20 | | | | | | | | | DOL A/A, SH A/A - INCREASING DOWNWARD LAMINATED/WISPY, IRREGULAR BEDDED SHALEY DISCONTINUITIES/SCOUR SURFACES COMMON |
| 30 | | | | | | | | | |
| 40 | | | | | | | | | ANHYDRITE BED/NODULE (SELENITE) |
| 50 | | | | | | | | | |
| 60 | | | | | | | | | |

DOL, & ANHY. FILLED

EX-15-10-H-50

WELL NAME ARISTECH CORP. DEPTH 5360 TO 5390.9 DATE 3/7/01

LOCATION SCIOTO CO., OHIO GREEN TWP. MARYVILLE (ROME OF JANSSENS) CORE(S) OHIO GEOL. SUR #3409 DESCRIBED BY M. BARANOSKI

STRATIGRAPHIC UNIT _____ SHEET 4 OF 4 VERTICAL SCALE 1" = 10'

⊙ BTM CORE BOX

| CORE DEPTH | GRAPHIC LITHOLOGY | GRAIN TYPE | POROSITY/ OIL STAIN | STYLOLITES | FRACTURES | SAMPLE LOCATION | SEDIMENTARY CYCLES | LITHOFACIES/ DEPOSITIONAL ENVIRONMENT | DESCRIPTIVE REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 5360 | | | TITE | | | | | | DOL - LT to MED GRY, CRYPT - FNXLN, LAMINATED, WAVY BEDDED; INTERBEDDED THIN LAMINATED WISPY IRREG MED TO |
| 70 | | | | | | | | | DK GRAY SHALE, DISCONTINUITIES/SCOUR SURFACES COMMON |
| | | | | | | | | | |
| | | | | | | | | | ANHYDRITE (SELENITE) FILLED VUGS |
| 80 | | | | | | | | | BRECCIA |
| | | | | | | | | | ANHYDRITE (SELENITE) |
| 90 | | | | | | | | | BRECCIA / W ANHYDRITE (SELENITE) FILL |

HOPE NAT. GAS — core images available

**WELL NAME** # 9634 POWER OIL CO. **DEPTH** 13,005 **TO** 13,060 **DATE** 5/10/01

**LOCATION** WOOD CO., WV **CORE(S)** 768 **DESCRIBED BY** MTB

**STRATIGRAPHIC UNIT** MARYVILLE LS. (JANSSENS MNSM) **SHEET** 1 **OF** 2 **VERTICAL SCALE** 1" = 10'

CONASAUGA GP.

⊙ BOTTOM CORE BOX (LOWER LEFT ON BOX)

| TEXTURE & SED. STRUCTURES (CLASTIC: COBBLE, PEBBLE, GRANULE, V. COARSE, COARSE, MEDIUM, FINE, V. FINE, SILT, CLAY; CARB.: RUDSTONE, FLOATSTONE, BOUNDSTONE, GRAINSTONE, PACKSTONE, WACKESTONE, MUDSTONE, XLN) | CORE DEPTH | GRAPHIC LITHOLOGY | GRAIN TYPE | POROSITY/ OIL STAIN | STYLOLITES | FRACTURES | SAMPLE LOCATION | SEDIMENTARY CYCLES | LITHOFACIES/ DEPOSITIONAL ENVIRONMENT | DESCRIPTIVE REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | ↑ coarsening upwards<br>↗ fining upwards<br>d - discontinuity<br>p - pyrite<br>● nodular<br>○ clasts |

5 10 20 30 40 13050

MUD CRACKS — WEAK FLOR. & DOL CLASTS @ 13025 — ANH — SHALLOW MARINE SUBTIDAL

DOL - MED GRAY, FN XLN - CRYPTOXLN, MASSIVE TO LAMINATED / IRREGULAR BEDDED ARENACEOUS, ARGILLACEOUS, RARE NODULAR

ss/siltstone/sh - lt brn, gry, red gry, green fn - med grn - poorly to mod sorted intraformational conglomerate, DOLOMIC mudcracks; numerous fining upward cycles; punctuated by coarse cycles; anhydrite nodules at bottom of sequence discontinuities in part angular. some X-bedding developed, irregular wispy bedded. contacts may be thin paleosols?

sh/silt - laminated, burrowed LT BRN

DOL - LT GRAY, FN XLN - ARENACEOUS AT TOP OF SEQ. - DOL MED-DK GRAY AS BELOW

DOL - med-dk gry, fn to cryptxln, oolith ghosts laminated to massive bedded, irregular fractures filled w/ DOL; ANHYD NODULES

ss/silt, lt br, med gray, fn grn, sl dolomic laminated to irregular, wispy bedded, poorly dev. bioturbation, argill[illegible]ous

T1010O351 HOPE NAT. GAS

**WELL NAME** #9634 POWER OIL CO. **DEPTH** 13,060 **TO** 13312 **DATE** 5/10/01

**LOCATION** WOOD CO. WV **CORE(S)** 768 **DESCRIBED BY** MTB

**STRATIGRAPHIC UNIT** MARYVILLE LS. JANSSENS MBSM OF COMB / CONASAUGA GP. **SHEET** 2 **OF** 2 **VERTICAL SCALE** 1"=10'

X MISSING

⊙ DEPTH BTM. BOX / LOWER LEFT ON BOX

| CORE DEPTH | GRAPHIC LITHOLOGY | GRAIN TYPE | POROSITY / OIL STAIN | STYLOLITES | FRACTURES | SAMPLE LOCATION | SEDIMENTARY CYCLES | LITHOFACIES / DEPOSITIONAL ENVIRONMENT | DESCRIPTIVE REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | ↗ coarsening ↘ fining<br>p - pyrite ○ clasts<br>d - discontinuity<br>● NODULAR |
| 13060 | | | | | | | | shallow marine subtidal | ss/silt, lt. brn, gray, med gry fn grn, irregular bedded to laminated, interbedded w/ sh - med to dark gray<br>→ poorly dev. X-bedding / bioturb.<br>anhydrite nodules @ 13,065.<br>trace calcite |
| 13070 | | | | | | | | | weathered paleosols? 13070 to 13077 |
| 13080 | | | | | | | | | interbedded with shale med gry, gry ↗ gry, reddish gray<br>ss, silt, wh - med gray, gra gry, red gry DOLO'C<br>mottled, fn grn, argillaceous, irregular bedded, to massive, poorly dev. X-bedding and bioturbation; intraform. conglom. |
| 13090 | | | | | | | | | dol. lt. to med gry, to lt brn, fn to med x'ln, crypto x'ln, arenaceous, bioturbated, laminated to wispy irr. bedded<br>silica |
| 13100 | | | | | | | | shallow marine shoreface | ss - wh. to lt./med. brn. to gray, fn to med grained, rnd to subang; poor lt. to mod. srtd., silica cement, massive, x-bedded, laminated, poorly dev. bioturbation, mottled |
| 13110 | | | | | | | | | |
| 13120 | | | | | | | | | |
| 13130 | | | | | | | | shallow marine subtidal | ss/silt - lt gray, lt brn gray, fn grn, irregular - wispy bedded to massive - bioturbated, poorly dev. X-bedding<br>micaceous<br>sh - black - dark gry, tr. dolo'c; interbedded w/ ss/silt as below. |
| 13140 | | | | | | | | | |
| 13150 | | | | | | | | | |
| 13160 | | | | | | | | | SS, SILT AS BELOW, BECOMING MORE ARGILLACEOUS UPWARD; SOFT SED. DEF. |
| 13170 | | | | | | | | | TO SILT.<br>SS/, LT. TO MED. GRAY, LT BRN LAMINATED, SOME MASSIVE BEDDING, BIOTURBATED WISPY IRREGULAR BEDDING, X-BEDDING, SLIGHTLY ARGILLACEOUS; INTRAFORMATION CLASTS / BRECCIA, ARGILLACEOUS FN TO MED. GRAINED, SUBANG TO ROUNDED, POORLY TO MOD. SORTED; MINOR DISCONTINUITIES |
| 13180 | | | | | | | | | Black to PINK TO ORANGE<br>N1-N2; 5R 8/2; 10R 6/6<br>DARK HORNBLENDE SCHIST; granite gneiss; sub horizontal schistocity. |

TITE NO UV FLUOR. — 13139 DOL FILLED IRREG. — FN TO MED X'LN. TIGHT — Ca FILLED ≈45° 13,310

MOTTLED

MISSING TO TD

TD 13,331

EX-15-15-H-50

## Appendix B

Miscellaneous test and analyses

APINO 3408720219 completion and DST data Knox dolomite

Arrington well DST results APINO 4705300069 Maryville Limestone DST (no pressures) brine analyses (Overbey, 1961).

OVERBY (1961)



## Cambrian System

### Upper Cambrian

**Trempealeau Formation**—This formation, composed mainly of brownish-gray dolomite in the Mason-69 deep well, may range in thickness from 400 to 600 feet in the area of the report. It is generally finely crystalline with scattered sand layers and small amounts of gray shale.

ARRINGTON

**Franconia-Dresbach Formation**—In the Mason-69 deep well, this formation is a white to light brownish gray, finely crystalline, sandy dolomite, 199 feet thick. The maximum thickness in this area is probably 400 feet.

**Eau Claire Formation**—This unit is composed of greenish gray and brown silty, dolomitic shales and dolomites. The estimated range in thickness is 460 to 600 feet. In the Mason-69 well the Eau Claire is 403 feet thick.

**Mt. Simon Sandstone**—A sandstone with shaly and dolomitic interbeds, the Mt. Simon is 116 feet thick in the Mason-69 well and may range to 250 feet thick in the area of this report.

**Basal Complex**—In the Mason-69 well, 77 feet of the basement complex, supposedly of pre-Cambrian age, was penetrated. The upper 22 feet or so consisted of a granite wash and the lower 55 feet was composed of a material resembling micaceous gneiss or a chlorite schist.

### EXAMINATION OF MASON COUNTY BASEMENT TEST

Only two wells have penetrated the entire thickness of sedimentary rocks in West Virginia: The Sandhill well in Wood County, which has been thoroughly covered in the Survey Report of Investigations No. 18, and the Grover Arrington No. 1 well in Mason County. The log of the Mason County well is included here.

The author wishes to acknowledge the aid of Dr. Ping-fan Chen, Petroleum Geologist, of the Survey, whose partial log of this well from 3,300 feet to total depth was consulted.

### Grover Arrington No. 1 Well (Permit Mason-69)

By United Fuel Gas Company, Clendenin District; elevation 597.22'; located 2.50 mi. S. of 38° 45'; 4.12 mi. W. of 82° 05'.

Drilling began June 7, 1959, and was completed on August 8, 1959. It was a dry hole. Four drill stem tests were attempted, the results of which were as follows:

Zone #1, from 7662 to 7672 feet showed salt water; total chloride, 112,500 ppm.

Zone #2, from 7643 to 7663 feet showed salt water; total chloride, 183,000 ppm.

Zone #3, from 6682 to 6687 feet, packer failed, no test.

Zone #4, 6669 feet, packer failed, no test.

# 3408720219

ANALYSES FILES

# JADO

SUBSURFACE ENGINEERING • OIL PROPERTY MANAGEMENT

P.O. Box 388
GRANVILLE, OHIO
344-6542

1105 GRANVILLE ROAD
NEWARK, OHIO
344-2427

see 27
p 219 Elizabeth Twp
Lawrence Co, OH

COMPLETION PROCEDURE

CAMBRIA CLAY # 1-A

2-20-71 Logged with Schlumberger utilizing Compensated Formation Density and Dual Induction Laterolog from 5873' to 5273' (depth of first logging program.)

2-21-71 Ran 5609.27' 4½" OD, 10.5#, K-55, API, smls, R-2, 8 rd thd casing to 5564'. Fitted casing with 6 centralizers and an automatic fillup shoe and float. Cemented with 240 sks Class A cement with 2256# D-53 and 600# D-33; followed top rubber plug with 500 ga. Dowell perforating acid.

3- 5-71 Moved service rig from Hanover to Pedro; unable to move onto location; cat did not meet rig as scheduled.

6-71 Rigged up service machine. Shelwell logged with Gamma Ray, Cement Density Survey and Collar Locator. Perforated at 5447' with a Single Plane Five-Way Jet.

Perforations at 5447' entered the most porous zone of the Copper Ridge and also that zone with the most favorable fluid saturations.

Dowell rigged up to displace that acid spotted during cementing of casing.

Pressured up to 1000 psi and let acid soak with no results. Increased pressure to 1500 psi with no results. Increased pressure incrementally to 2000 psi with slight pressure bleed-off. Permitted acid leak off to decrease pressure to 600 psi; displaced 450 gal. acid at 1000 psi and 0.5 BPM.

Following initial surge of displacement fluid, well flowed at an estimated rate of 15 BPH for three and one half hours. Shut well in over night.

3- 7-71 Flowed well at estimated rate of 15 BPH for six hours with slight gas bubble apparent in displacement fluid.

3- 8-71 Swabbed well to 1000 feet (estimate) with well flowing behind swabbed - show of gas (mostly acid gas) in fluid and behind swab. Continued swabbing - unable to lower fluid below 1000 feet.

3-10-71 Swabbed well to 1000 feet; lost acid gas and natural gas; swabbed salt water; unable to lower fluid below 1000 feet.

THE DIVISION OF GEOLOGICAL SURVEY MAKES NO AFFIRMATION CONCERNING THE COMPLETENESS AND ACCURACY OF THIS INFORMATION.

3-10-71 Set bridge plug at 5430'.

Perforated at 5373' with a Single Plane Four-Way Jet. These perforations opened the upper portion of the Copper Ridge Dolomite - a section with good porosity, good mud cake and favorable fluid saturations.

3-11-71 Swabbed well to 5300'; well producing some salt water with slight show of gas; able to light gas. Shut in over night.

3-12-71 No pressure build-up over night; fluid level at 3000'. Set bridge plug at 5310'. Perforated 5272' - 5275' with seven jets. These perforations opened the lower Rose Run section as requested by H. Atha.

Swabbed well; unable to lower fluid below 3000'.

3-15-71 Swabbed well; detected some gas in swabbed fluid and in front of swab; unable to lower fluid below 4000'.

Set bridge plug at 5010'; perforated at 4866'. Swabbed well dry.

Perforations at this point (4866') opened the upper portion of the Beekmantown Dolomite where gas was observed on the Baroid Gas Detector. Log analysis indicated fracture systems with little porosity, but slightly less than favorable fluid saturations.

3 -71 Checked well for fluid accumulation; swabbed only slight amount of salt water (less than 100 feet); most probably due to pipe runoff.

3-17-71 Shelwell perforated from 4837' to 4866' with 59 jets.

Dowell pumped 1000 gal. 15% H Cl acid at 4866' perforations. Perforations took acid easily at 1000 psi. Acid was displaced at less than 1 BPM at 400 psi (ave).

Swabbed displacing fluid and acid back. Well making gas throughout swabbing operations (est. 40 MCFPD).

3-22-71 Checked fluid in hole; found 2700'; swabbed well dry; gas flow estimated at 40 MCFPD.

3-24-71 Tried to swab well down; obstruction probably bridge plug at 2800' (floating).

3-25-71 Rigged up tools; drove plug to bottom of hole (5010').

3-26-71 Set bridge plug at 4986'; fluid level at 2500'; swabbed well down.

3-29-71 Checked fluid level at 1500'; swabbed well down; gas estimated at 40 MCFPD.

3-30-71 Checked fluid level at 1000'; swabbed well down; gas production estimate at 40 MCFPD.

Dowell pumped 5000 gal. 15% H Cl acid (10 gal. A130 + 10 gal. W-9 +80 gal. L-2) at 400 psi at 4 BPM. ISIP was 300 psi.

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/71 · Swabbed well down; detected slight increase in gas.

31-71 Swabbed well down from fluid level of 1500'.

4- 2-71 Checked fluid level at approximately 1500'. Swabbed well down. Estimated gas at approximately 50 MCFPD.

Remarks: Acid apparently did not stimulate Beekmantown Dolomite as is noted from above results. It is to be noted that acid swabbed back was not spent as well as it should have been.

It is also to be noted that the fluid level after acidization was approximately the same as that recovered during testing of the same horizon.

Apparently, this zone will produce water with gas in some quantities -- whether or not desirable.

There remains the possibility of re-stimulation by fracturing. I suggest we postpone any further stimulation to a later period following some hopeful and successful exploration of the area.

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NO AFFIRMATION CONCERNING THE COMPLETENESS
AND ACCURACY OF THIS INFORMATION.

## FLUID SAMPLE DATA

| | |
|---|---|
| Sampler Pressure | P.S.I.G. at Surface |
| Recovery: Cu. Ft. Gas | |
| cc. Oil | |
| cc. Water | |
| cc. Mud | |
| Tot. Liquid cc. | |
| Gravity | ° API @ °F. |
| Gas/Oil Ratio | cu. ft./bbl. |

| | RESISTIVITY | CHLORIDE CONTENT |
|---|---|---|
| Recovery Water | @ °F. | ppm |
| Recovery Mud | @ °F. | |
| Recovery Mud Filtrate | @ °F. | ppm |
| Mud Pit Sample | @ °F. | |
| Mud Pit Sample Filtrate | @ °F. | ppm |
| Mud Weight | 8.7 vis 37 | cp |

| | |
|---|---|
| Date | 2-14-71 |
| Ticket Number | 266008-B |
| Kind of Job | STRADDLE OPEN HOLE |
| Halliburton District | WOOSTER |
| Tester | MR. MULLINS MR. BENNETT |
| Witness | MR. VERNEW |
| Drilling Contractor | ATHA DRILLING COMPANY DR |

## EQUIPMENT & HOLE DATA

| | |
|---|---|
| Formation Tested | Knox |
| Elevation | 725' GL Ft. |
| Net Productive Interval | - Ft. |
| All Depths Measured From | Kelly Bushing |
| Total Depth | 5305' Ft. |
| Main Hole/Casing Size | 7 7/8" |
| Drill Collar Length | 465' I.D. 2.60 Anchor |
| Drill Pipe Length | 4668' I.D. 2.764" |
| Packer Depth(s) | 4700'-4850' Owc-Obk Ft. |
| Depth Tester Valve | 4673' Ft. |

Cushion — TYPE — AMOUNT — Ft. — Depth Back Pres. Valve — Surface Choke 3/8" — Bottom Choke 3/4"

Recovered 250 Feet of gas cut mud

Recovered Feet of

Recovered Feet of

Recovered Feet of

Recovered Feet of

Mea. From Tester Valve

Remarks SEE PRODUCTION TEST DATA SHEET

| TEMPERATURE | Gauge No. 455 Depth: 4675 Ft. | Gauge No. 276 Depth: 4727 Ft. | Gauge No. 260 Depth: 4855' Ft. | TIME |
|---|---|---|---|---|
| 109 °F. | 12 Hour Clock | 12 Hour Clock | Hour Clock | Tool Opened 16:40 A.M. P.M. |
| Actual °F. | Blanked Off No | Blanked Off Yes | Blanked Off | Tool Closed 17:55 A.M. P.M. |

| | Pressures Field | Pressures Office | Pressures Field | Pressures Office | Pressures Field | Pressures Office | Reported Minutes | Computed Minutes |
|---|---|---|---|---|---|---|---|---|
| Initial Hydrostatic | 2317.0 | 2309 | 2307.8 | 2320 | | 2510 | | |
| Flow Initial | 51.0 | 60 | 64.7 | 80 | | | — | — |
| Flow Final | 81.6 | 92 | 107.8 | 105 | | | 45 | |
| Closed in | 469.4 | 470 | 474.1 | 478 | | | 30 | |
| Flow Initial | 102.0 | 115 | 118.5 | 124 | | | — | — |
| Flow Final | 122.4 | 127 | 140.1 | 143 | | | — | — |
| Closed in | 326.5 | 327 | 323.3 | 334 | | | — | — |
| Flow Initial | | | | | | | | |
| Flow Final | | | | | | | | |
| Closed in | | | | | | | | |
| Final Hydrostatic | 2295.9 | 2309 | 2307.8 | 2320 | | 2510 | — | — |

HYDROSTATIC RELEASE: 2329

THE DIVISION OF GEOLOGICAL SURVEY MAKES NO AFFIRMATION CONCERNING THE COMPLETENESS AND ACCURACY OF THIS INFORMATION.

D IN U.S.A.

FORMATION TEST DATA

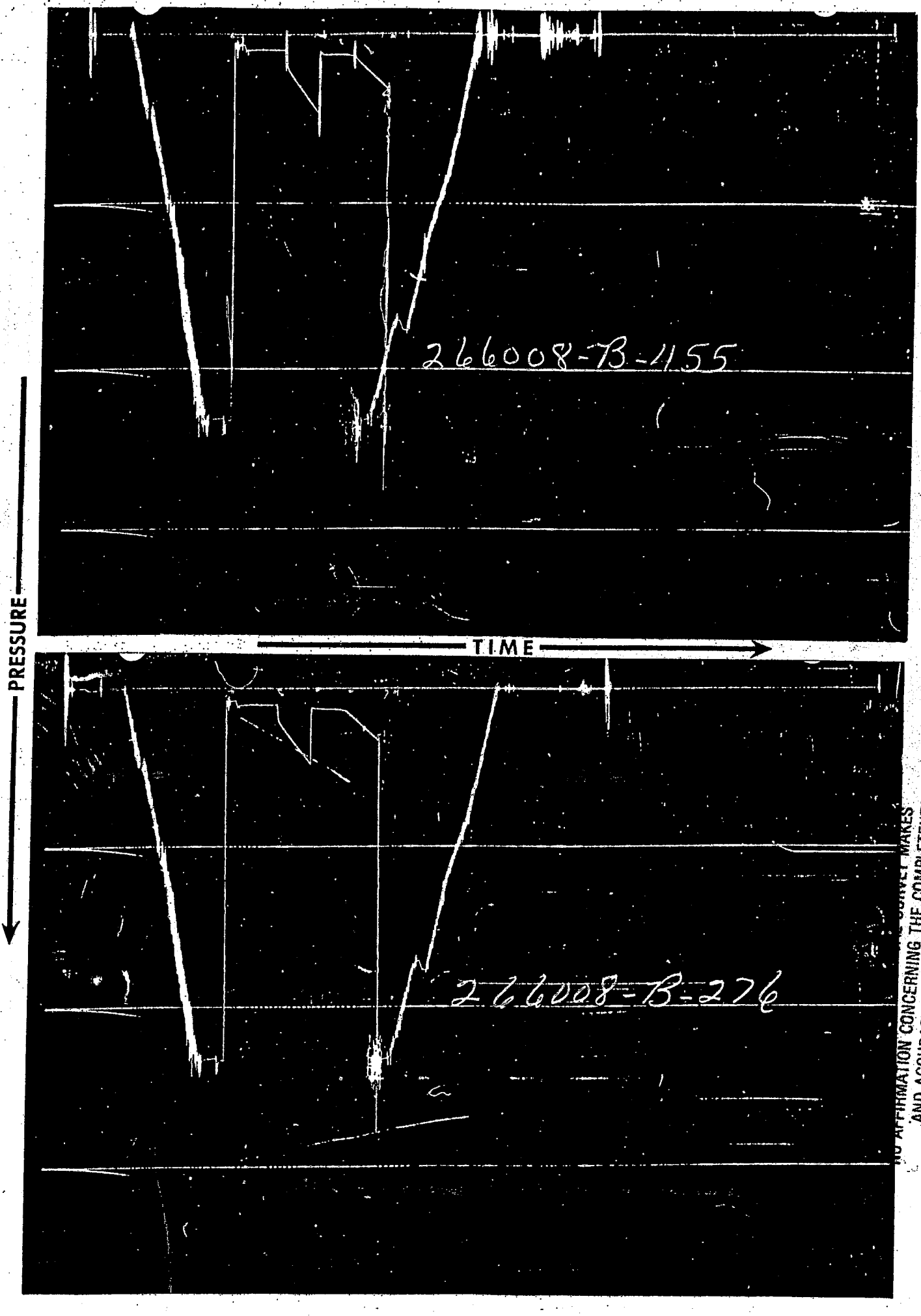
Legal Location Sec. - Twp. - Rng.

Lease Name 27 ELIZABETH Well No. 14

Test No. 3 Tested Interval

Field Area TRONTON County LAWRENCE State OHIO

Lease Owner/Company Name




NO AFFIRMATION CONCERNING THE COMPLETENESS AND ACCURACY OF THIS INFORMATION.

Casing perfs. _____ Bottom choke _____ Surf. temp _____ °F Ticket No. 266008-B

Gas gravity _____ Oil gravity _____ GOR _____

Spec. gravity _____ Chlorides _____ ppm Res. _____ @ _____ °F

| Date Time a.m. p.m. | Choke Size | Surface Pressure psi | Gas Rate MCF | Liquid Rate BPD | Remarks |
|---|---|---|---|---|---|
| 16:40 | 3/8" | | | | Opened tool for first flow with a good blow, off bottom 5 gallon bucket, stayed same throughout rest of flow. |
| 17:25 | 3/8" | | | | Closed tool for 30 minute first closed in pressure. |
| 17:55 | 3/8" | | | | Reopened tool for 30 minute first flow with a good blow. |
| 17:60 | | | | | Gas to surface, but very weak, 5" water on manometer, 3500 cu. ft. in 24 hours. |
| 18:25 | 3/8" | | | | Closed tool for 30 minute second closed in pressure. |
| 18:55 | | | | | Off bottom with test tool Job over. |

THE DIVISION OF GEOLOGICAL SURVEY MAKES NO AFFIRMATION CONCERNING THE COMPLETENESS AND ACCURACY OF THIS INFORMATION.



PRODUCTION TEST DATA

## FLUID SAMPLER DATA

ir Pressure _____ P.S.I.G. at Surface
ecovery: Cu. Ft. Gas _____
cc. Oil _____
cc. Water _____
cc. Mud _____
Tot. Liquid cc. _____
avity _____ ° API @ _____ °F.
s/Oil Ratio _____ cu. ft./bbl.

| | RESISTIVITY | CHLORIDE CONTENT |
|---|---|---|
| covery Water | ____ @ ____ °F. | ____ ppm |
| covery Mud | ____ @ ____ °F. | |
| covery Mud Filtrate | ____ @ ____ °F. | ____ ppm |
| ud Pit Sample | ____ @ ____ °F. | |
| ud Pit Sample Filtrate | ____ @ ____ °F. | ____ ppm |
| ud Weight | 8.8 vis 37 | cp |

| | |
|---|---|
| Date | 2-13-71 |
| Ticket Number | 266008 - A |
| Kind of Job | STRADDLE TEST OPEN HOLE |
| Halliburton District | WOOSTER, OHIO |
| Tester | BENNETT |
| Witness | VERNEW |
| Drilling Contractor | ATHA DRILLING COMPANY |

Legal Location Sec. - Twp. - Rng. 27

Lease Name ELIZABETH Well No. 4-B Test No. 2

Field Area TRONTON

County LAWRENCE State OHIO

Lease Owner/Company Name [illegible]

### EQUIPMENT & HOLE DATA

| | | | |
|---|---|---|---|
| Formation Tested | Knox | | |
| Elevation | 725' G.L. | | Ft. |
| Net Productive Interval | ? | | Ft. |
| All Depths Measured From | Kelly Bushing | | |
| Total Depth | 5305' | | Ft. |
| Main Hole/Casing Size | 7 7/8" | | |
| Drill Collar Length | 421' | I.D. 2.50" | ANCHOR |
| Drill Pipe Length | 4823' | I.D. 2.764" | |
| Packer Depth(s) | 4850' - 5000' | OPEN | Ft. |
| Depth Tester Valve | 4828' | | Ft. |

shion TYPE NONE AMOUNT ____ Ft. Depth Back Pres. Valve NONE Surface Choke 3/8" Bottom Choke 3/4"

Tested Interval [illegible]

| | | | |
|---|---|---|---|
| covered | 1000' | Feet of | gas cut mud |
| covered | 500' | Feet of | salt water and gas cut mud |
| covered | 1500' | Feet of | salt water - 9.3# |
| c[illegible]d | | Feet of | |
| covered | | Feet of | |

Meas. From Tester Valve

marks SEE PRODUCTION TEST DATA SHEET...

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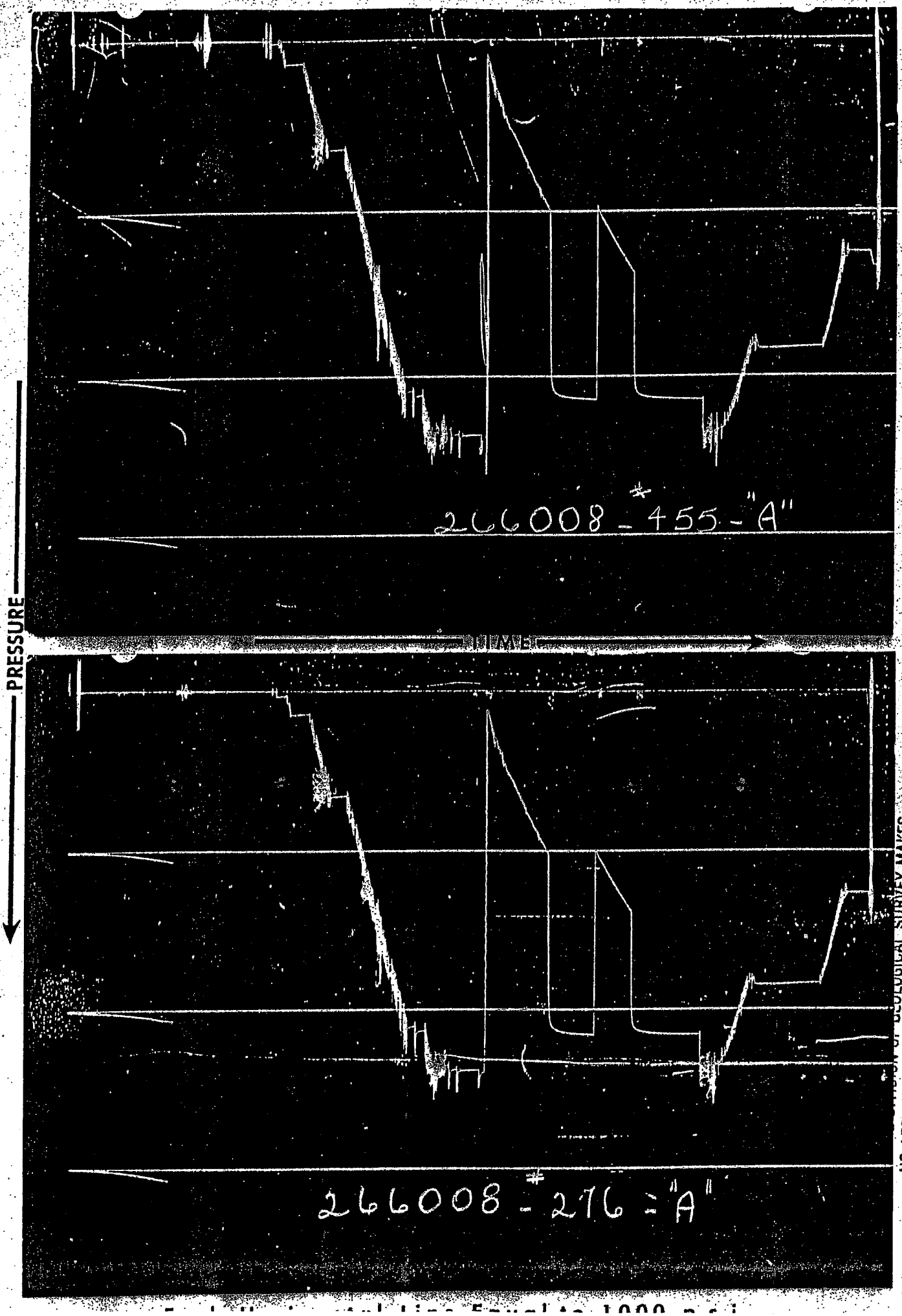
NO AFFIRMATION CONCERNING THE COMPLET[illegible]SS
AND ACCURACY OF THIS INFORMATION

| EMPERATURE | Gauge No. 455 | Gauge No. 276 | Gauge No. 260 | TIME |
|---|---|---|---|---|
| | Depth: 4833' Ft. | Depth: 4879' Ft. | Depth: 5004' Ft. | |
| | 12 Hour Clock | 12 Hour Clock | 12 Hour Clock | Tool Opened A.M. 02:45 P.M. |
| 109 °F. | Blanked Off NO | Blanked Off YES | Blanked Off YES | |
| ual °F. | Pressures | Pressures | Pressures | Tool Closed A.M. 05:50 P.M. |

| | Field | Office | Field | Office | Field | Office | Reported Minutes | Computed Minutes |
|---|---|---|---|---|---|---|---|---|
| ial Hydrostatic | 2359.3 | 2387 | 2374.1 | 2398 | - | 2462 | | |
| Flow Initial | 91.8 | 104 | 129.3 | 129 | - | - | —— | —— |
| Flow Final | 1001.0 | 1001 | 1004.3 | 1015 | - | - | 50 | 54 |
| Closed In | 2147.9 | 2148 | 2153.3 | 2160 | - | - | 45 | 40 |
| Flow Initial | 970.3 | 986 | 982.7 | 997 | - | - | —— | —— |
| Flow Final | 1363.3 | 1373 | 1374.7 | 1382 | - | - | 30 | 32 |
| Closed In | 2147.9 | 2150 | 2153.3 | 2161 | HYDROSTATIC | | 60 | 59 |
| Flow Initial | | | | | RELEASE: 2288 | | —— | —— |
| Flow Final | | | | | | | | |
| Closed In | | | | | | | | |
| al Hydrostatic | 2359.3 | 2370 | 2374.1 | 2383 | - | 2431 | —— | —— |

FORMATION TEST DATA

LITTLE B 63423 10M 4/69—39, 34-19




NO AFFIRMATION CONCERNING THE COMPLETENESS
AND ACCURACY OF THIS INFORMATION.

| Gauge No. | 455 | Depth | 4833' | Clock No. | 1719 | 12 hour | Ticket No. | 266008 - A |
|---|---|---|---|---|---|---|---|---|

| | First Flow Period | | First Closed In Pressure | | | Second Flow Period | | Second Closed In Pressure | | | Third Flow Period | | Third Closed In Pressure | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Time Defl. .000" | PSIG Temp. Corr. | Time Defl. .000" | $\text{Log}\frac{t+\theta}{\theta}$ | PSIG Temp. Corr. | Time Defl. .000" | PSIG Temp. Corr. | Time Defl. .000" | $\text{Log}\frac{t+\theta}{\theta}$ | PSIG Temp. Corr. | Time Defl. .000" | PSIG Temp. Corr. | Time Defl. .000" | $\text{Log}\frac{t+\theta}{\theta}$ | PSIG Temp. Corr. |
| 0 | .000 | 104 | .000 | | 1001 | .000 | 986 | .000 | | 1373 | | | | | |
| 1 | .0676 | 345 | .0274 | | 2100 | .0344 | 1041 | .0410 | | 2123 | | | | | |
| 2 | .1352 | 522 | .0548 | | 2122 | .0688 | 1110 | .0820 | | 2133 | | | | | |
| 3 | .2028 | 664 | .0822 | | 2129 | .1032 | 1174 | .1230 | | 2137 | | | | | |
| 4 | .2704 | 818 | .1096 | | 2135 | .1376 | 1235 | .1640 | | 2141 | | | | | |
| 5 | .365 | 1001* | .1370 | | 2138 | .1720 | 1294 | .2050 | | 2143 | | | | | |
| 6 | | | .1644 | | 2141 | .220 | 1373** | .2460 | | 2145 | | | | | |
| 7 | | | .1918 | | 2144 | | | .2870 | | 2146 | | | | | |
| 8 | | | .2192 | | 2145 | | | .3280 | | 2148 | | | | | |
| 9 | | | .2466 | | 2147 | | | .3690 | | 2149 | | | | | |
| 10 | | | .274 | | 2148 | | | .403 | | 2150*** | | | | | |
| 11 | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | | | | |

| Gauge No. | 276 | | Depth | 4879' | | Clock No. | 7521 | hour | 12 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | 129 | .000 | | 1015 | .000 | 997 | .000 | | 1382 | | | | | |
| 1 | .0678 | 359 | .0274 | | 2110 | .0339 | 1058 | .0411 | | 2135 | | | | | |
| 2 | .1356 | 529 | .0548 | | 2134 | .0678 | 1126 | .0822 | | 2146 | | | | | |
| 3 | .2034 | 674 | .0822 | | 2142 | .1017 | 1186 | .1233 | | 2151 | | | | | |
| 4 | .2712 | 830 | .1096 | | 2148 | .1356 | 1247 | .1644 | | 2155 | | | | | |
| 5 | .366 | 1015* | .1370 | | 2151 | .1695 | 1307 | .2055 | | 2157 | | | | | |
| 6 | | | .1644 | | 2155 | .217 | 1382** | .2466 | | 2158 | | | | | |
| 7 | | | .1918 | | 2156 | | | .2877 | | 2159 | | | | | |
| 8 | | | .2192 | | 2158 | | | .3288 | | 2160 | | | | | |
| 9 | | | .2466 | | 2159 | | | .3699 | | 2160 | | | | | |
| 10 | | | .274 | | 2160 | | | .404 | | 2161*** | | | | | |
| 11 | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | | | | |

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Reading Interval 10 | 4 | 5 | 6 | Minutes

REMARKS: * INTERVAL = 14 MINUTES. ** INTERVAL = 7 MINUTES. *** INTERVAL = 5 MINUTES.

Casing perfs. _____ Bottom choke 3/4" Surf. temp 18 °F Ticket No. 266008 - A

Gas gravity _____ Oil gravity _____ GOR _____

Spec. gravity _____ Chlorides _____ ppm Res. _____ @ _____ °F

| Date Time a.m. p.m. | Choke Size | Surface Pressure psi | Gas Rate MCF | Liquid Rate BPD | Remarks |
|---|---|---|---|---|---|
| 02:45 | 3/8" | NONE | | | Tool opened on first flow |
| | | | | | Good blow off bottom |
| | | | | | 5 gallon bucket - stayed same |
| | | | | | through first flow time |
| 03:35 | 3/8" | NONE | | | Closed for first closed in pressure |
| 04:20 | 3/8" | NONE | | | Opened to the second flow |
| | | | | | Good blow off bottom |
| | | | | | of 5 gallon bucket |
| 04:25 | 3/8" | NONE | | | Gas to the surface but very |
| | | | | | weak - stayed same through |
| | | | | | second flow |
| 04:50 | 3/8" | NONE | | | Closed for final closed in |
| 05:50 | 3/8" | NONE | | | Off bottom with tools |
| | | | | | Job over |
| | | | | | |
| | | | | | Bubble hose was trying to freeze off |
| | | | | | on first flow. |

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# PRODUCTION TEST DATA

LITTLE'S 83433 SM 6/63 40-18

## Appendix E

Tests and analyses from Aristech Class 1 well site, Scioto County, Ohio

P8-68
002630
Box 28
OGS CORE # 2958

TABLE 3

USS CHEMICALS
COMPARISON OF FLUID MOBILITIES
THROUGH CORE SAMPLES OF
MT. SIMON SANDSTONE
HAVERHILL, WASTE DISPOSAL WELL

| Core Sample No. | Depth, K.B. | % Por | Perm to Air Md. | Fluid Mobility Ratios Compared to Mt. Simon Brine 1/ | | | |
|---|---|---|---|---|---|---|---|
| | | | | Fresh Water | Mt. Simon Brine | Filtered Phenol Waste 9.7 pH | Filtered Phenol Waste 6.4 pH |
| 1 | 5540 | 13.7 | 55 | 2.06 | 1.00 | 1.22 | |
| 2 | 5544 | 13.7 | 30 | 3.26 | 1.00 | 1.27 | |
| 71X | 5545 | 15.3 | 41 | | 1.00 | | 1.43 |
| 3 | 5547 | 15.6 | 22 | 3.14 | 1.00 | 1.29 | |
| 75X | 5549 | 14.1 | 41 | | 1.00 | | 1.47 |
| 76X | 5550 | 15.5 | 50 | | 1.00 | | 1.56 |
| 4 | 5552 | 14.7 | 10 | 4.46 | 1.00 | 1.37 | |
| 82X | 5556 | 16.2 | 26 | | 1.00 | | 1.82 |
| Avg 9.7 pH waste | | 14.4 | 29 | 2.58 | 1.00 | 1.26 | |
| Avg 6.4 pH waste | | 15.3 | 40 | | 1.00 | | 1.47 |

1/ "Mobility" of a fluid is defined as the permeability of that fluid divided by the viscosity of the fluid. The mobility ratio is the ratio of the respective mobilities of the two fluids. (See pages 4 and 5 for discussion.)

10-17-68
mk

P8-68
002630
Box 28
CITED
OGS core #2958

EARLOUGHER ENGINEERING
TULSA, OKLAHOMA

TABLE 1

USS CHEMICALS
HAVERHILL DISPOSAL WELL NO. 1
SCIOTO COUNTY, OHIO

SUMMARY OF CORE ANALYSES

| Core No. | Formation | Depth, Feet From | Depth, Feet To | Feet Analyzed | Avg Perm Md | Average Porosity Per Cent | Average Grain Density | Average Bulk Density | % Soluble in 15% HCl |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Berea SS | 710 | 733.0 | 23. | 1.5 | 12.1 | 2.66 | 2.34 | |
| 2 | Newburg Ls, plug | 1805 | 1834.5 | 11. | 4.2 | 2.1 | 2.79 | 2.73 | 96 |
| | Newburg Ls, whole core | 1805 | 1833.0 | 5. | -- | 5.9 | 2.82 | 2.63 | |
| 3 | St. Peter Dolo | 3979 | 4007.0 | 6. | -0- | 2.5 | 2.74 | 2.67 | |
| 4 | Rose Run SS | 4242 | 4246.5 | 4.5 | -0- | 3.9 | 2.63 | 2.52 | |
| 5 | Rose Run SS | 4250 | 4261.8 | 11. | 33. | 10.4 | 2.61 | 2.34 | |
| 6 | Mt. Simon SS | 5532 | 5561.0 | 29. | 26.8 | 11.9 | 2.55 | 2.26 | |
| 7 | Mt. Simon SS, shaly | 5563 | 5573.0 | 10. | 0.4 | 3.9 | | | |
| 8 | Granite | 5595 | 5617.0 | Not Analyzed, Dense. | | | | | |

10-18-68 mk

TABLE 2

EARLOUGHER ENGINEERING

RESULTS OF CORE ANALYSES

COMPANY USS Chemicals WELL Haverhill Disposal Well No. 1

| Sample No. | Depth Feet | Air Perm. Md. | Porosity Per Cent | | Calc Grain Density | Meas Bulk Density | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | BEREA SAND | CORE NO. 1 (710-733 FEET) | | | | | | |
| 1 | 710.0 | 2.2 | 12.2 | | 2.70 | 2.37 | | Sand |
| 2 | 711.0 | 3.4 | 13.8 | | 2.64 | 2.27 | | Sand |
| 3 | 712.0 | 2.5 | 13.4 | | 2.64 | 2.29 | | Sand |
| 4 | 713.0 | 2.2 | 14.1 | | 2.69 | 2.31 | | Sand |
| 5 | 714.0 | 1.9 | 13.8 | | 2.67 | 2.31 | | Sand |
| 6 | 715.0 | 4.0 | 14.3 | | 2.66 | 2.28 | | Sand |
| 7 | 716.0 | 1.3 | 13.3 | | 2.69 | 2.33 | | Sand |
| 8 | 717.0 | 3.7 | 14.4 | | 2.64 | 2.26 | | Sand |
| 9 | 718.0 | 1.3 | 13.8 | | 2.68 | 2.31 | | Sand |
| 10 | 719.0 | 0.4 | 12.5 | | 2.62 | 2.29 | | Sand |
| 11 | 720.0 | -0- | 5.0 | | 2.58 | 2.45 | | Dense muddy sand |
| 12 | 721.0 | -0- | 2.4 | | 2.62 | 2.56 | | Dense muddy sand |
| 13 | 722.0 | 0.2 | 11.8 | | 2.64 | 2.33 | | Shaly sand |
| 14 | 723.0 | 0.3 | 11.8 | | 2.65 | 2.34 | | Shaly sand |
| 15 | 724.0 | 1.0 | 13.8 | | 2.68 | 2.31 | | Shaly sand |
| 16 | 725.0 | 0.8 | 14.9 | | 2.69 | 2.29 | | Shaly sand |
| 17 | 726.0 | 1.6 | 16.7 | | 2.70 | 2.25 | | Shaly sand |
| 18 | 727.0 | 3.1 | 15.4 | | 2.66 | 2.25 | | Shaly sand |
| 19 | 728.0 | 0.1 | 7.0 | | 2.65 | 2.46 | | Shaly sand |
| 20 | 729.0 | 0.4 | 11.2 | | 2.66 | 2.37 | | Shaly sand |
| 21 | 730.0 | 0.9 | 11.9 | | 2.66 | 2.34 | | Sand |
| 22 | 731.0 | 2.0 | 13.6 | | 2.63 | 2.27 | | Sand |
| 23 | 732.0 | 1.4 | 13.4 | | 2.63 | 2.28 | | Sand |
| 24 | 733.0 | 0.4 | 5.8 | | 2.64 | 2.49 | | Sd and shale lam |
| | Average | 1.5 | 12.1 | | 2.66 | 2.34 | | |

NOTE: Bulk density measured on dry core plug. Grain density calculated from bulk density and Washburn Bunting porosity.

mk

**SUMMARY**

(Continued following page)

| Sec. | Formation | Depth, Feet From | Depth, Feet To | Feet of Sand | Avg. Perm. | Avg. Por. | Avg. Oil Sat. | Avg. Water Sat. | Avg. Oil Content Bbl/A.Ft |
|---|---|---|---|---|---|---|---|---|---|

Table 2 (Cont'd)

COMPANY USS Chemicals WELL Haverhill Disposal Well No. 1

| Sample No. | Depth Feet | Air Perm. Md. | Porosity Per Cent | | Calc Grain Density | Meas Bulk Density | % Sol in 15% HCl | Remarks |
|---|---|---|---|---|---|---|---|---|
| | NEWBURG LIMESTONE | | CORE NO. 2 (1805 - 1835 FEET) | | | | | 3/4"Plugs |
| 25 | 1805.0 | -0- | 2.6 | | 2.83 | 2.76 | 98 | Dol, grey, V.vugular |
| 26 | 1806.0 | -0- | 1.6 | | 2.80 | 2.76 | 98 | Dol, grey, V vugular |
| 27 | 1807.0 | 44. | 3.5 | | 2.84 | 2.74 | 97 | Dol, grey, V vugular |
| 28 | 1808.0 | -0- | 0.5 | | 2.81 | 2.80 | 98 | Dol, grey |
| 29 | 1809.0 | -0- | 0.6 | | 2.79 | 2.77 | 95 | Dol, grey |
| 30 | 1830.0 | -0- | 0.7 | | 2.80 | 2.78 | 98 | Dol, grey |
| 31 | 1831.0 | -0- | 1.2 | | 2.76 | 2.73 | 89 | Dol, grey |
| 32 | 1832.0 | -0- | 3.5 | | 2.76 | 2.66 | 97 | Dol, brn vugular |
| 33 | 1832.5 | 2.6 | 6.8 | | 2.78 | 2.59 | 96 | Dol, brn V vugular |
| 34 | 1833.5 | -0- | 0.9 | | 2.76 | 2.74 | -- | Dol, grey |
| 35 | 1834.5 | -0- | 1.0 | | 2.78 | 2.75 | 93 | Dol, grey |
| Average | | 4.2 | 2.1 | | 2.79 | 2.73 | 96 | |
| The following porosities were measured on 4" long whole core vugular sections using grain densities from above & calipered bulk volumes. | | | | | | | | |
| 103 | 1805.0-06.0 | -- | 6.0 | | 2.82 | 2.65 | -- | V vugular, grey dol |
| 104 | 1806.0-07.0 | -- | 8.5 | | 2.82 | 2.58 | -- | V vug, gr dol, cracks |
| 105 | 1807.0-08.0 | -- | 6.4 | | 2.82 | 2.64 | -- | V vugular, grey dol |
| 106 | 1831.0-32.0 | -- | 5.1 | | 2.76 | 2.62 | -- | Sli vug, brn dol |
| 107 | 1832.0-33.0 | -- | 3.3 | | 2.76 | 2.67 | -- | V vugular brn dol |
| Average | | | 5.9 | | 2.80 | 2.63 | | |

NOTE: Vugular zones vary from 1/8" to 1-1/4" vugs with large amount of secondary crystal deposition in vugs. Chemical analysis of white crystals indicate dolomite with Ca/mg ratio of 1.91:1. Chemical analysis of grey rock indicates dolomite with Ca/mg ratio of 1.73:1.

bw

**SUMMARY**

(Continued following page)

| Sec. | Formation | Depth, Feet From | Depth, Feet To | Feet of Sand | Avg. Perm. | Avg. Por. | Avg. Oil Sat. | Avg. Water Sat. | Avg. Oil Content Bbl/A.Ft |
|---|---|---|---|---|---|---|---|---|---|

COMPANY USS Chemicals WELL Haverhill Disposal Well No. 1

| Sample No. | Depth Feet | Air Perm. Md. | Porosity Per Cent | | Calc Grain Density | Meas Bulk Density | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | ST. PETER | CORE NO. 3 (3979 - 4009.3 FEET) | | | | | | |
| 36 | 3979.0 | -0- | 6.0 | | 2.74 | 2.58 | | Shaly dol, grey |
| 37 | 3984.0 | -0- | 0.6 | | 2.69 | 2.67 | | Limy dol, white |
| 38 | 3989.0 | -0- | 1.8 | | 2.74 | 2.71 | | Limy dol, white |
| 39 | 3990.5 | -0- | 2.9 | | 2.75 | 2.67 | | V shaly dol, limy |
| 40 | 4002.0 | -0- | 0.4 | | 2.73 | 2.72 | | Dol, grey, V.F. |
| 41 | 4007.0 | -0- | 3.4 | | 2.78 | 2.69 | | Dol, grey |
| Average | | -0- | 2.5 | | 2.74 | 2.67 | | |
| | ROSE RUN | CORE NO. 4 (4242.0 - 4246.5 FEET) | | | | | | |
| 42 | 4242.0 | -0- | 0.9 | | 2.65 | 2.62 | | Grey dol sand |
| 43 | 4243.0 | -0- | 1.2 | | 2.65 | 2.62 | | Grey dol sand |
| 44 | 4244.0 | -0- | 4.1 | | 2.65 | 2.54 | | Sl shly, sl gr dol chert nodules. |
| 45 | 4245.0 | -0- | 6.1 | | 2.59 | 2.44 | | White sand |
| 46 | 4246.0 | -0- | 7.2 | | 2.59 | 2.40 | | White sand |
| Average | | -0- | 3.9 | | 2.63 | 2.52 | | |
| | ROSE RUN | CORE NO. 5 (4250.0 - 4261.8 FEET) | | | | | | |
| 47 | 4250.0 | 83. | 11.1 | | 2.60 | 2.30 | | Sand |
| 48 | 4251.3 | 53. | 10.7 | | 2.62 | 2.34 | | Sand |
| 49 | 4252.5 | 62. | 11.4 | | 2.60 | 2.31 | | Sand, sl dol, F |
| 50 | 4253.8 | 18. | 11.8 | | 2.62 | 2.31 | | Sand |
| 51 | 4255.0 | 2.1 | 10.7 | | 2.60 | 2.32 | | Shaly sand |
| 52 | 4256.3 | 0.3 | 8.0 | | 2.56 | 2.36 | | Shaly sand |
| 53 | 4257.0 | 48. | 14.9 | | 2.62 | 2.23 | | Sand |
| 54 | 4258.0 | 52. | 14.1 | | 2.58 | 2.21 | | Sand |
| 55 | 4258.8 | 1.8 | 10.3 | | 2.58 | 2.32 | | Shaly |
| 56 | 4259.7 | 1.0 | 8.5 | | 2.66 | 2.41 | | Shaly |
| 57 | 4261.2 | 0.3 | 2.6 | | 2.61 | 2.55 | | Sl dol sd w/sh strks |
| Average | | 33. | 10.4 | | 2.61 | 2.34 | | |

bw

**SUMMARY**

(Continued following page)

| Sec. | Formation | Depth, Feet From | Depth, Feet To | Feet of Sand | Avg. Perm. | Avg. Por. | Avg. Oil Sat. | Avg. Water Sat. | Avg. Oil Content Bbl/A.Ft |
|---|---|---|---|---|---|---|---|---|---|

COMPANY USS Chemicals WELL Haverhill Disposal Well No. 1

| Sample No. | Depth Feet | Air Perm. Md. | Porosity Per Cent | Kw | Calc Grain Density | Meas Bulk Density | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | MT. SIMON | CORE NO. 6 (5532.0-5560.8 FEET) | | | | | | |
| 58 | 5532.2 | 4.9 | 7.3 | | 2.65 | 2.47 | | Sand, shaly |
| 59 | 5533.0 | -0- | 1.2 | | 2.46 | 2.43 | | Sand |
| 60 | 5534.0 | 0.4 | 3.5 | | 2.62 | 2.53 | | Sand |
| 61 | 5535.0 | 11. | 4.4 | | 2.71 | 2.59 | | Sand, shaly |
| 62 | 5535.8 | 27. | 11.9 | | 2.61 | 2.30 | | Sand |
| 63 | 5537.2 | 94. | 14.1 | | 2.64 | 2.22 | | Sand |
| 64 | 5538.0 | 71. | 14.1 | | 2.57 | 2.21 | | Sand |
| 65 | 5539.0 | 21. | 13.9 | | 2.60 | 2.24 | | Sand |
| 66 | 5540.0 | 18. | 10.6 | 21.5 | 2.56 | 2.29 | | Sand |
| 67 | 5541.0 | 65. | 13.6 | | 2.59 | 2.24 | | Sand, VF |
| 68 | 5542.0 | 60. | 14.6 | | 2.55 | 2.18 | | Sand |
| 69 | 5543.0 | 6.7 | 11.1 | | 2.63 | 2.34 | | Sand |
| 70 | 5544.0 | 48. | 13.4 | 10.2 | 2.53 | 2.19 | | Sand |
| 71 | 5545.0 | 55. | 14.2 | | 2.58 | 2.21 | | Sand |
| 72 | 5546.0 | 22. | 12.9 | | 2.58 | 2.25 | | Sand |
| 73 | 5547.0 | 21. | 14.9 | 7.2 | 2.53 | 2.15 | | Sand |
| 74 | 5548.0 | 75. | 13.7 | | 2.57 | 2.22 | | Sand |
| 75 | 5549.0 | 42. | 14.4 | | 2.55 | 2.18 | | Sand |
| 76 | 5550.0 | 48. | 15.7 | | 2.55 | 2.15 | | Sand |
| 77 | 5551.0 | 39. | 15.6 | | 2.52 | 2.13 | | Sand |
| 78 | 5551.9 | 7.6 | 14.0 | 3.7 | 2.56 | 2.20 | | Sand |
| 79 | 5553.0 | 43. | 15.7 | | 2.55 | 2.15 | | Sand |
| 80 | 5554.0 | 2.7 | 10.7 | | 2.54 | 2.27 | | Sand |
| 81 | 5555.0 | 1.1 | 14.0 | | 2.56 | 2.20 | | Sand |
| 82 | 5556.0 | 14. | 15.9 | | 2.54 | 2.14 | | Sand |
| 83 | 5557.0 | 5.1 | 13.1 | | 2.52 | 2.19 | | Sand |
| 84 | 5558.0 | 1.0 | 10.8 | | 2.58 | 2.30 | | Sand |
| 85 | 5558.9 | 0.6 | 10.0 | | 2.57 | 2.31 | | Sand, shaly |
| 86 | 5559.9 | 0.5 | 10.8 | | 2.53 | 2.26 | | Sand, shaly |
| 87 | 5560.7 | 0.1 | 7.8 | | 2.51 | 2.31 | | Sand, shaly |
| Average | | 26.8 | 11.9 | | 2.55 | 2.26 | | |

Kw = Permeability to distilled water of 1-1/2" plug.

**SUMMARY**

(Continued following page)

| Sec. | Formation | Depth, Feet From | Depth, Feet To | Feet of Sand | Avg. Perm. | Avg. Por. | Avg. Oil Sat. | Avg. Water Sat. | Avg. Oil Content Bbl/A.Ft |
|---|---|---|---|---|---|---|---|---|---|

COMPANY USS Chemicals WELL Haverhill Disposal Well No. 1

| Sample No. | Depth Feet | Air Perm. Md. | Porosity Per Cent | | | | Avg. Oil Content Bbl./A. Ft. | Remarks |
|---|---|---|---|---|---|---|---|---|
| | MT. SIMON | CORE NO. 7 (5563-5573 FEET) | | | | | | |
| 88 | 5563.4 | -0- | 3.5 | | | | | Shaly sand |
| 89 | 5564.3 | -0- | 1.3 | | | | | Shaly sand |
| 90 | 5565.4 | -0- | 6.4 | | | | | Shaly sand |
| 91 | 5566.6 | 3.9 | 8.6 | | | | | Shaly sand |
| 92 | 5567.5 | -0- | 6.2 | | | | | Shaly sand |
| 93 | 5568.4 | 0.1 | 6.1 | | | | | Shaly sand |
| 94 | 5569.5 | -0- | 1.8 | | | | | Shaly sand |
| 95 | 5570.4 | -0- | 1.8 | | | | | Shaly sand |
| 96 | 5571.4 | -0- | 2.4 | | | | | Limy sand |
| 97 | 5572.4 | -0- | 0.7 | | | | | Limy sand |
| Average | | 0.4 | 3.9 | | | | | |
| | CORE NO. 8 (5595-5617 FEET) GRANITE, NOT ANALYZED | | | | | | | |

mk

**SUMMARY**

| Sec. | Formation | Depth, Feet From | Depth, Feet To | Feet of Sand | Avg. Perm. | Avg. Por. | Avg. Oil Sat. | Avg. Water Sat. | Avg. Oil Content Bbl/A.Ft |
|---|---|---|---|---|---|---|---|---|---|

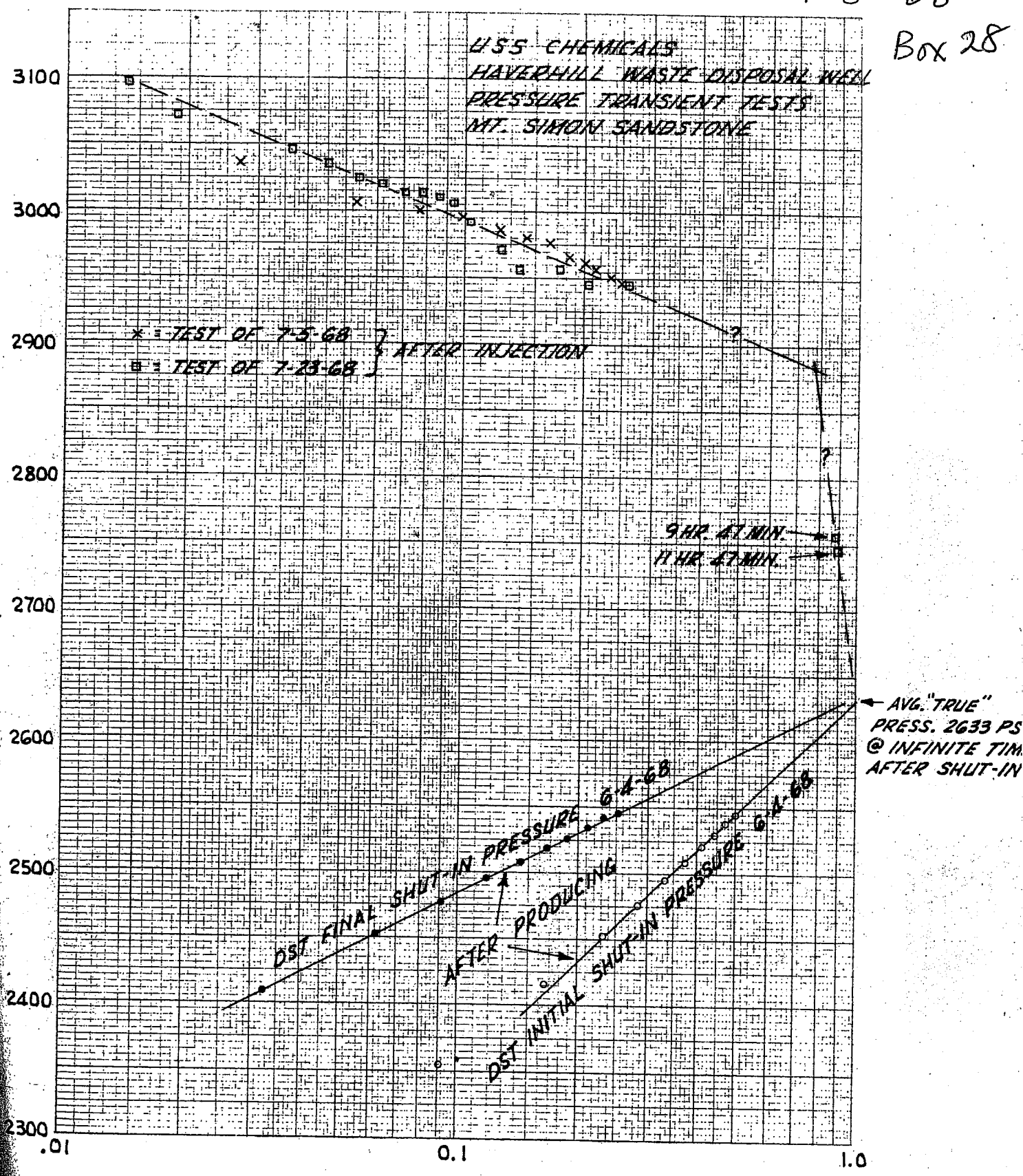
FIGURES

APPENDI

Barcode 002630

P8-68

Box 28




$\frac{\Delta t}{t + \Delta t}$

$\Delta t$ = TIME AFTER SHUT-IN
$t$ = TOTAL FLOW TIME BEFORE SHUT-IN

FIG. 3

Barcode 002630

## 8.1 Annulus Pressure Test Well No. 1

Waste Disposal Well No. 1 was shut-in and prepared for testing at 6:00 a.m. on Sunday November 8, 1987. A high pressure pneumatic pump was used to pressurize the annulus to 2240 psi the following Monday morning. Approximately 100 psi was bled off the annulus to allow any entrained air to escape. The well was repressurized to 2250 psig and the official mechanical integrity test was started at 10:00 a.m. After 1 hour, the pressure had fallen 50 psi; this was within the 3% limit imposed by the OEPA. After an additional 30 minutes, only 10 psi was lost indicating that the well was reaching stable equilibrium. The initial pressure loss was therefore due to thermal effects and the introduction of trapped air into the annulus.

Mike Moschell, OEPA communicated with Ernie Rotering, after witnessing the annulus pressure test. Approval was granted to commence injection and the well was put back into service. A copy of the pressure test report is presented in Table 8.1.0-I.

## 8.2 Annulus Pressure Test Well No. 2

Waste Disposal Well No. 2 was shut-in and prepared for testing on Wednesday, October 28, 1987. The official pressure test was performed at 10:30 a.m. and was witnessed by Mike Moschell (OEPA). The test was conducted at 2245 psig. No loss was recorded after 1 hour. A copy of the pressure test report is presented in Table 8.2.0-I.

TABLE 8.1.0-I

ANNULAR PRESSURE TEST

OPERATOR/OWNER Arastech Chem. STATE PERMIT NO. _____

ADDRESS Box 127 EPA PERMIT NO. _____

Ironton DATE OF TEST 10/28/87

WELL NAME/NUMBER WDW #2 CLASS I

LOCATION Plant TOWNSHIP Green COUNTY Scioto

CORRECTIVE ACTION _____ MECHANICAL INTEGRITY Pressure Test

COMPANY REPRESENTATIVE L. McCain FIELD INSPECTOR M. Mosciuk

TYPE PRESSURE GAUGE Ashcroft INCH FACE ____ PSI FULL SCALE, 10 PSI INCREMENTS

NEW GAUGE YES __ NO ✓ IF NO, DATE OF TEST CALIBRATION _____

CALIBRATION CERTIFICATION SUBMITTED: YES ✓ NO __

RESULTS:

| | PRESSURE (PSIG) | |
|---|---|---|
| TIME | ANNULUS | TUBING |
| 10:30 | 2245 | |
| 10:40 | 2245 | |
| 10:50 | 2245 | |
| 11:00 | 2245 | |
| 11:10 | 2245 | |
| 11:20 | 2245 | |
| 11:30 | 2245 | |
| | | |
| | | |
| | | |

TEST PRESSURE:

MAX. ALLOWABLE PRESSURE CHANGE: TEST PRESSURE X .03 (1739) 2173 → 2245 PSI

ONE HOUR PRESSURE CHANGE 67 PSI

TEST PASSED ✓ TEST FAILED / (CHECK ONE)

IF FAILED, NO INJECTION MAY OCCUR UNTIL CORRECTIONS HAVE BEEN MADE AND WELL PASSES.

Larry S McCain — 10/28/87

SIGNATURE OF COMPANY REPRESENTATIVE — DATE

Michael Mosciuk — 10/28/87

SIGNATURE OF OEPA REPRESENTATIVE — DATE

OEPA-1987
1524U

## Table 8.2.0-I

ANNULAR PRESSURE TEST

OPERATOR/OWNER Aristech Chem. | STATE PERMIT NO. _____
ADDRESS Box 127 | EPA PERMIT NO. _____
Ironton, Ohio 45638 | DATE OF TEST 11/9/87
WELL NAME/NUMBER WDW #1 | CLASS I
LOCATION Plant | TOWNSHIP Green | COUNTY Scioto
CORRECTIVE ACTION _____ | MECHANICAL INTEGRITY Pressure Test
COMPANY REPRESENTATIVE L. McCain | FIELD INSPECTOR M. Mosche11
TYPE PRESSURE GAUGE ~~Ashcroft~~ INCH FACE _____ PSI FULL SCALE, 10 PSI INCREMENTS

NEW GAUGE YES __ NO ✓ IF NO, DATE OF TEST CALIBRATION _____
CALIBRATION CERTIFICATION SUBMITTED: YES ✓ NO __

RESULTS:

| | PRESSURE (PSIG) | |
|---|---|---|
| TIME | ANNULUS | TUBING |
| 10:00 | 2250 | 1188 |
| 10:10 | 2240 | |
| 10:20 | 2230 | |
| 10:30 | 2220 | |
| 10:40 | 2210 | |
| 10:50 | 2210 | |
| 11:00 | 2200 | 1185 |
| 11:30 | 2190 | 1181 |
| | | |
| | | |

TEST PRESSURE: 2250

MAX. ALLOWABLE PRESSURE CHANGE: TEST PRESSURE X .03 67.5 PSI
ONE HOUR PRESSURE CHANGE 50.0 PSI

TEST PASSED ✓ TEST FAILED __ (CHECK ONE)
IF FAILED, NO INJECTION MAY OCCUR UNTIL CORRECTIONS HAVE BEEN MADE AND WELL PASSES.

Larry S McCain — SIGNATURE OF COMPANY REPRESENTATIVE — 11/9/87 — DATE

Michael Mosehill — SIGNATURE OF OEPA REPRESENTATIVE — 11/9/87 — DATE

OEPA-1987
1524U

P1-90

Barcode 002632

Box 30

## APPENDIX I

### CHEMICAL ANALYSES OF FORMATION FLUIDS

1. FORMATION TEST #1, BEREA (REFERENCE APPENDIX C-1)
2. FORMATION TEST #2, ROSE RUN (#1) (REFERENCE APPENDIX C-2)
3. FORMATION TEST #3, ROME/CONASAUGA (NO RECOVERY, NO ANALYSIS) (REFERENCE APPENDIX C-3)
4. FORMATION TEST #4, ROSE RUN (#2) (REFERENCE APPENDIX C-4)
5. FORMATION TEST #5, ST. PETER (NO RECOVERY, NO ANALYSIS) (REFERENCE APPENDIX C-5)
6. FORMATION TEST #6, NEWBERG (REFERENCE APPENDIX C-6)
7. FORMATION TEST #7, BASS ISLANDS ("NIAGARAN") (REFERENCE APPENDIX C-7)
8. FORMATION TEST #9, MT. SIMON (REFERENCE APPENDIX C-9)

Technical Testing Laboratories Inc.

# LABORATORY ANALYSIS REPORT

ARISTECH CHEMICAL CORPORATION

WDW #3 ICD LAB GRAB WATER
707 FT DEPTH

Date Sampled 04/14/89

Laboratory Number J0457

Sampled by CLIENT
Date Received 04/17/89

Respectfully Submitted:

ANALYSIS FOR REQUESTED METALS

| PARAMETER | RESULT | MDL | UNITS | METHOD | ANALYZED DATE/TIME/ANALYST |
|---|---|---|---|---|---|
| BARIUM(Total) | 9.2 | 0.01 | MG/L | E200.7 | 05/04/89 18:00 MS |
| CHROMIUM(Total) | ND | 0.025 | MG/L | E200.7 | 05/04/89 18:00 MS |
| LEAD(Total) | ND | 0.08 | MG/L | E200.7 | 05/04/89 18:00 MS |
| IRON(Total) | 2.7 | 0.015 | MG/L | E200.7 | 05/05/89 18:00 MS |
| MANGANESE(Total) | 0.5 | 0.004 | MG/L | E200.7 | 05/05/89 18:00 MS |
| ALUMINUM(Total) | ND | 0.1 | MG/L | E200.7 | 05/05/89 18:00 MS |
| CALCIUM(Total) | 3000 | 0.2 | MG/L | E200.7 | 05/05/89 18:00 MS |
| MAGNESIUM(Total) | 730 | 0.2 | MG/L | E200.7 | 05/05/89 18:00 MS |
| POTASSIUM(Total) | 96 | 0.1 | MG/L | E258.1 | 05/05/89 12:00 DK |
| IUM(Total) | 9900 | 0.02 | MG/L | E273.1 | 05/05/89 12:00 DK |

ND: Not detected at a concentration greater than or equal to the MDL - Method Detection Limit

REF: USEPA; Test Methods For Evaluating Solid Waste; SW-846,3rd Ed.;Nov,1986.

REF: USEPA; Methods For Chemical Analysis Of Water And Wastes; March,1983.

Technical Testing Laboratories Inc.

# LABORATORY ANALYSIS REPORT

ARISTECH CHEMICAL CORPORATION

WDW #3 4503/4587 #6

Laboratory Number J1752

Sampled by CLIENT
Date Received 05/18/89

Respectfully Submitted:

Date Sampled 05/17/89

ANALYSIS FOR REQUESTED METALS

| PARAMETER | RESULT | MDL | UNITS | METHOD | ANALYZED DATE/TIME/ANALYST |
|---|---|---|---|---|---|
| BARIUM(Total) | 1.7 | 0.3 | MG/L | E200.7 | 05/26/89 12:00 MS |
| CHROMIUM(Total) | ND | 2.5 | MG/L | E200.7 | 05/26/89 12:00 MS |
| LEAD(Total) | ND | 1.0 | MG/L | E239.1 | 05/31/89 16:00 DK |
| COPPER(Total) | ND | 1.0 | MG/L | E200.7 | 05/26/89 12:00 MS |
| IRON(Total) | 120 | 1.0 | MG/L | E236.1 | 05/31/89 16:00 DK |
| MANGANESE(Total) | 4.5 | 1.0 | MG/L | E243.1 | 05/31/89 16:00 DK |
| ALUMINUM(Total) | ND | 20 | MG/L | E202.1 | 05/31/89 16:00 MS |
| MAGNESIUM(Total) | 4800 | 0.02 | MG/L | E242.1 | 05/30/89 16:00 DK |
| POTASSIUM(Total) | 3700 | 0.1 | MG/L | E258.1 | 05/23/89 15:00 DK |
| SODIUM(Total) | 47,000 | 0.02 | MG/L | E273.1 | 05/30/89 16:00 DK |

ND: Not detected at a concentration greater than or equal to the MDL - Method Detection Limit

REF: USEPA; Methods For Chemical Analysis Of Water And Wastes; March, 1983.

Technical Testing Laboratories Inc.

# LABORATORY ANALYSIS REPORT

ARISTECH CHEMICAL CORPORATION

WDW #3 4503/4587 #5

Laboratory Number J1751

Sampled by CLIENT
Date Received 05/18/89

Respectfully Submitted:

Date Sampled 05/17/89

ANALYSIS FOR REQUESTED METALS

JUL 05 1989

| PARAMETER | RESULT | MDL | UNITS | METHOD | ANALYZED DATE/TIME/ANALYST |
|---|---|---|---|---|---|
| BARIUM(Total) | 3.3 | 0.3 | MG/L | E200.7 | 05/26/89 12:00 MS |
| CHROMIUM(Total) | ND | 2.5 | MG/L | E200.7 | 05/26/89 12:00 MS |
| LEAD(Total) | 35 | 1.0 | MG/L | E239.1 | 05/31/89 16:00 DK |
| COPPER(Total) | 24 | 1.0 | MG/L | E200.7 | 05/26/89 12:00 DK |
| IRON(Total) | 140 | 1.0 | MG/L | E236.1 | 05/31/89 16:00 DK |
| MANGANESE(Total) | 7.1 | 0.5 | MG/L | E243.1 | 05/31/89 16:00 DK |
| ALUMINUM(Total) | ND | 20 | MG/L | E202.1 | 05/31/89 16:00 MS |
| MAGNESIUM(Total) | 5000 | 5.0 | MG/L | E242.1 | 05/30/89 16:00 DK |
| POTASSIUM(Total) | 3700 | 10 | MG/L | E258.1 | 05/23/89 15:00 DK |
| SODIUM(Total) | 46,000 | 5.0 | MG/L | E273.1 | 05/23/89 12:00 DK |

ND: Not detected at a concentration greater than or equal to the MDL - Method Detection Limit

REF: USEPA; Methods For Chemical Analysis Of Water And Wastes; March, 1983.

Technical Testing Laboratories Inc.

# LABORATORY ANALYSIS REPORT

ARISTECH CHEMICAL CORPORATION

WDW #3 4503/4587 #6

Laboratory Number J1752

Sampled by CLIENT
Date Received 05/18/89

Respectfully Submitted:

Date Sampled 05/17/89

ANALYSIS FOR REQUESTED METALS

| PARAMETER | RESULT | MDL | UNITS | METHOD | ANALYZED DATE/TIME/ANALYST |
|---|---|---|---|---|---|
| BARIUM(Total) | 1.7 | 0.3 | MG/L | E200.7 | 05/26/89 12:00 MS |
| CHROMIUM(Total) | ND | 2.5 | MG/L | E200.7 | 05/26/89 12:00 MS |
| LEAD(Total) | ND | 1.0 | MG/L | E239.1 | 05/31/89 16:00 DK |
| COPPER(Total) | ND | 1.0 | MG/L | E200.7 | 05/26/89 12:00 MS |
| IRON(Total) | 120 | 1.0 | MG/L | E236.1 | 05/31/89 16:00 DK |
| MANGANESE(Total) | 4.5 | 1.0 | MG/L | E243.1 | 05/31/89 16:00 DK |
| ALUMINUM(Total) | ND | 20 | MG/L | E202.1 | 05/31/89 16:00 MS |
| MAGNESIUM(Total) | 4800 | 0.02 | MG/L | E242.1 | 05/30/89 16:00 DK |
| POTASSIUM(Total) | 3700 | 0.1 | MG/L | E258.1 | 05/23/89 15:00 DK |
| SODIUM(Total) | 47,000 | 0.02 | MG/L | E273.1 | 05/30/89 16:00 DK |

ND: Not detected at a concentration greater than or equal to the MDL - Method Detection Limit

REF: USEPA; Methods For Chemical Analysis Of Water And Wastes; March, 1983.

# LABORATORY RESULTS

**Environmental Resources Management, inc.**

855 Springdale Drive • Exton, Pennsylvania 19341 • (215) 524-3500 • Telex 4900009249

15 November 1989

Mr. George Chada
Aristech Chemical Corporation
Room 2156
600 Grant Street
Pittsburgh, PA 15230-0250

FILE: 881-04-00-01

Dear George:

Please find enclosed with this letter the Mt. Simon Formation permit analysis report and a corrected copy of the Rose Run Formation permit analysis report.

While preparing the Mt. Simon report, Environmental Resources Management, Inc. (ERM) discovered a misinterpretation regarding the formic acid analysis on the original Rose Run permit analysis report submitted to you. The quantitative results for the two trials indicated on Lancaster Laboratories, Inc.'s (LLI) analysis report are actual sample values and are not spiked sample results. ERM has reported the formic acid results for the Rose Run and Mt. Simon samples by averaging the two trials reported by LLI. The formic acid results for the other formation samples were reported correctly.

If you need any further clarification, please do not hesitate to call me. I apologize for any inconvenience this may have caused you.

Sincerely,

David R. Blye

David R. Blye
Quality Assurance Manager

DRB/stb

Enclosures
cc: Tim Prothero-Aristech
Susan Barry-ERM

Aristech Rose Run Well #3 Brine Water Sample
Lancaster Laboratory Incorporated No.: WW 1400857
Date Submitted: 6/15/89

| ANALYSIS | RESULT AS RECEIVED | | LIMIT OF QUANTITATION | |
|---|---|---|---|---|
| Sodium | 44,600. | mg/L | 0.5 | mg/L |
| Potassium | 3,330. | mg/L | 0.5 | mg/L |
| Calcium | 38,500. | mg/L | 0.05 | mg/L |
| Magnesium | 6,070. | mg/L | 0.05 | mg/L |
| Temperature (Measured in the field, value reported separately) | | | | |
| Barium | 1.8 | mg/L | 0.1 | mg/L |
| Alkalinity to pH 8.3 | <1. | mg/L | 1. | mg/L |
| Alkalinity to pH 4.5 | 129 | mg/L | 1. | mg/L |
| Aluminum | <1. | mg/L | 1. | mg/L |
| pH | 5.76 | | 0.01 | mg/L |
| Specific Gravity | 1.19 | | | |
| Specific Conductance | 607,000. | µmhos/cm | 1. | µmhos/cm |
| Total Dissolved Solids | 287,000. | mg/L | 100. | mg/L |
| Dimethyl Benzyl Alcohol | 44. | mg/L | 0.1 | mg/L |
| Phenol | 400. | mg/L | 0.1 | mg/L |
| Diphenylamine | N.D. | | 0.1 | mg/L |
| Alpha-Picoline | N.D. | | 0.1 | mg/L |
| Total Suspended Solids | 220. | mg/L | 20. | mg/L |
| Sulfate | 330. | mg/L | 50. | mg/L |
| Chloride | 170,000. | mg/L | 20. | mg/L |
| Nitrate Nitrogen | 220. | mg/L | 10. | mg/L |
| Carbonate | <1. | mg/L | 1. | mg/L |
| Bicarbonate | 129. | mg/L | 1. | mg/L |
| Dissolved Oxygen | <0.5 | mg/L | 0.5 | mg/L |
| Iron | 60.8 | mg/L | 0.05 | mg/L |
| Manganese | 2.35 | mg/L | 0.01 | mg/L |
| Viscosity | 3. | cps | 1. | cps |
| Acetone | 210. | mg/L | 1. | mg/L |
| Cumene Hydroperoxide* | | | | |
| Acetophenone | 6. | mg/L | 0.1 | mg/L |
| Ammonia Nitrogen | 80.5 | mg/L | 0.1 | mg/L |
| Aniline | N.D. | | 0.1 | mg/L |
| Total Chromium | <0.1 | mg/L | 0.1 | mg/L |
| Formic Acid ** | 169. | mg/L | 5.0 | mg/L |
| Toluene | N.D. | | 0.5 | mg/L |
| Lead | <0.3 | mg/L | 0.3 | mg/L |

* - Cumene hydroperoxide could not be determined due to impure reference material, as well as what appeared to be degradation in the chromatographic system.



I-4

The ERM

** - The reported formic acid result of 169. mg/L is an average of two trials which yielded the following results: 168. mg/L Trial #1
170. mg/L Trial #2
Additionally, the sample was spiked with 200 mg/L of formic acid and provided a recovery of 83.8%.

< - Indicates the result is less than the smallest amount which can be accurately quantitated.

N.D. - Indicates none detected.

Note: These results have been transcribed by ERM, Inc. from the Lancaster Laboratories Inc. analysis report for the Rose Run Well #3 Brine Water Sample (LLI# WW 1400857).



I-4

The ERM

# Environmental Resources Management, inc.

855 Springdale Drive • Exton, Pennsylvania 19341 • (215) 524-3500

# Letter of Transmittal

| DATE 7-12-89 | W.O. No. 88104000/ |
|---|---|
| ATTENTION Mr. Timothy Prothero | |
| RE: Rose Run Well #3 Brine Water Sample Analysis Report | |

TO Aristech Chemical Co.
Ironton, Ohio 45638

GENTLEMEN:

WE ARE SENDING YOU ☑ Attached ☐ Under separate cover via _____ the following items:

☐ Shop drawings ☐ Prints ☐ Plans ☐ Samples ☐ Specifications

☐ Copy of letter ☐ Change order ☐ _____

| COPIES | DATE | NO. | DESCRIPTION |
|---|---|---|---|
| 1 | 7-12-89 | 1 | Rose Run Well #3 Brine Water Sample Analysis Report |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

THESE ARE TRANSMITTED as checked below:

☑ For approval ☐ Approved as submitted ☐ Resubmit ____ copies for approval

☑ For your use ☐ Approved as noted ☐ Submit ____ copies for distribution

☑ As requested ☐ Returned for corrections ☐ Return ____ corrected prints

☐ For review and comment ☐ _____

☐ FOR BIDS DUE _____ 19____ ☐ PRINTS RETURNED AFTER LOAN TO US

REMARKS

Tim,

The Temperature entry is blank, I assume this was performed in the field. Please call me with the value and I will modify and resubmitt.

Also I did not see duly results for Hexavalent Chromium, was this cancelled. I only see results for Total Chromium. Please call.

COPY TO Fite, Sue Barry

SIGNED: David R. Blye

*If enclosures are not as noted, kindly notify us at once.*

I-4

Aristech WDW #3 Newburg Formation Sample
Lancaster Laboratory Incorporated No.: WW 1413820
Date Submitted: 7/18/89

| ANALYSIS | RESULT AS RECEIVED | | LIMIT OF QUANTITATION | |
|---|---|---|---|---|
| Sodium | 42,700. | mg/L | 0.5 | mg/L |
| Potassium | 1,430. | mg/L | 0.5 | mg/L |
| Calcium | 38,700. | mg/L | 0.05 | mg/L |
| Magnesium | 9,150. | mg/L | 0.05 | mg/L |
| Temperature (Measured in the field, value reported separately) | | | | |
| Barium | 1. | mg/L | 0.5 | mg/L |
| Alkalinity to pH 8.3 | <1. | mg/L | 1. | mg/L |
| Alkalinity to pH 4.5 | 640. | mg/L | 1. | mg/L |
| Aluminum | 5.4 | mg/L | 0.1 | mg/L |
| pH (Measured in the field, value reported separately) | | | | |
| Specific Gravity | 1.2 | | | |
| Specific Conductance | 551,000. | µmhos/cm | 1. | µmhos/cm |
| Total Dissolved Solids | 327,000. | mg/L | 40. | mg/L |
| Dimethyl Benzyl Alcohol | N.D. | | 0.02 | mg/L |
| Phenol | N.D. | | 0.02 | mg/L |
| Diphenylamine | N.D. | | 0.02 | mg/L |
| Alpha-Picoline | N.D. | | 0.02 | mg/L |
| Total Suspended Solids | 64. | mg/L | 7. | mg/L |
| Sulfate | 130. | mg/L | 50. | mg/L |
| Chloride | 179,000. | mg/L | 20. | mg/L |
| Nitrate Nitrogen | <10. | mg/L | 10. | mg/L |
| Carbonate | <1. | mg/L | 1. | mg/L |
| Bicarbonate | 640. | mg/L | 1. | mg/L |
| Dissolved Oxygen | <0.5 | mg/L | 0.5 | mg/L |
| Iron | 64. | mg/L | 0.05 | mg/L |
| Manganese | 2.9 | mg/L | 0.2 | mg/L |
| Viscosity | 3. | cps | 1. | cps |
| Acetone | 0.024 | mg/L | 0.01 | mg/L |
| Cumene Hydroperoxide* | | | | |
| Acetophenone | N.D. | | 0.02 | mg/L |
| Ammonia Nitrogen | 129. | mg/L | 0.5 | mg/L |
| Aniline | N.D. | | 0.02 | mg/L |
| Total Chromium | 0.15 | mg/L | 0.05 | mg/L |
| Formic Acid | <5. | mg/L | 5.0 | mg/L |
| Toluene | 0.12 | mg/L | 0.005 | mg/L |
| Lead | <0.2 | mg/L | 0.2 | mg/L |

* - Cumene hydroperoxide could not be determined due to impure reference material, as well as what appeared to be degradation in the chromatographic system.



The TERM

< - Indicates the result is less than the smallest amount which can be accurately quantitated.

N.D. - Indicates none detected.

Note: These results have been transcribed by ERM, Inc. from the Lancaster Laboratories Inc. analysis report for the Newburg Formation sample (LLI# WW 1413820).

Aristech WDW #3 Newburg Formation Sample
Lancaster Laboratory Incorporated No.: WW 1413820
Date Submitted: 7/18/89

| ANALYSIS | RESULT AS RECEIVED | | LIMIT OF QUANTITATION | |
|---|---|---|---|---|
| Sodium | 42,700. | mg/L | 0.5 | mg/L |
| Potassium | 1,430. | mg/L | 0.5 | mg/L |
| Calcium | 38,700. | mg/L | 0.05 | mg/L |
| Magnesium | 9,150. | mg/L | 0.05 | mg/L |
| Temperature (Measured in the field, value reported separately) | | | | |
| Barium | 1. | mg/L | 0.5 | mg/L |
| Alkalinity to pH 8.3 | <1. | mg/L | 1. | mg/L |
| Alkalinity to pH 4.5 | 640. | mg/L | 1. | mg/L |
| Aluminum | 5.4 | mg/L | 0.1 | mg/L |
| pH (Measured in the field, value reported separately) | | | | |
| Specific Gravity | 1.2 | | | |
| Specific Conductance | 551,000. | µmhos/cm | 1. | µmhos/cm |
| Total Dissolved Solids | 327,000. | mg/L | 40. | mg/L |
| Dimethyl Benzyl Alcohol | N.D. | | 0.02 | mg/L |
| Phenol | N.D. | | 0.02 | mg/L |
| Diphenylamine | N.D. | | 0.02 | mg/L |
| Alpha-Picoline | N.D. | | 0.02 | mg/L |
| Total Suspended Solids | 64. | mg/L | 7. | mg/L |
| Sulfate | 130. | mg/L | 50. | mg/L |
| Chloride | 179,000. | mg/L | 20. | mg/L |
| Nitrate Nitrogen | <10. | mg/L | 10. | mg/L |
| Carbonate | <1. | mg/L | 1. | mg/L |
| Bicarbonate | 640. | mg/L | 1. | mg/L |
| Dissolved Oxygen | <0.5 | mg/L | 0.5 | mg/L |
| Iron | 64. | mg/L | 0.05 | mg/L |
| Manganese | 2.9 | mg/L | 0.2 | mg/L |
| Viscosity | 3. | cps | 1. | cps |
| Acetone | 0.024 | mg/L | 0.01 | mg/L |
| Cumene Hydroperoxide* | | | | |
| Acetophenone | N.D. | | 0.02 | mg/L |
| Ammonia Nitrogen | 129. | mg/L | 0.5 | mg/L |
| Aniline | N.D. | | 0.02 | mg/L |
| Total Chromium | 0.15 | mg/L | 0.05 | mg/L |
| Formic Acid | <5. | mg/L | 5.0 | mg/L |
| Toluene | 0.12 | mg/L | 0.005 | mg/L |
| Lead | <0.2 | mg/L | 0.2 | mg/L |

* - Cumene hydroperoxide could not be determined due to impure reference material, as well as what appeared to be degradation in the chromatographic system.



The ERM

< - Indicates the result is less than the smallest amount which can be accurately quantitated.

N.D. - Indicates none detected.

Note: These results have been transcribed by ERM, Inc. from the Lancaster Laboratories Inc. analysis report for the Newburg Formation sample (LLI# WW 1413820).

Aristech Rose Run Well #3 Brine Water Sample
Lancaster Laboratory Incorporated No.: WW 1400857
Date Submitted: 6/15/89

| ANALYSIS | RESULT AS RECEIVED | | LIMIT OF QUANTITATION | |
|---|---|---|---|---|
| Sodium | 44,600. | mg/L | 0.5 | mg/L |
| Potassium | 3,330. | mg/L | 0.5 | mg/L |
| Calcium | 38,500. | mg/L | 0.05 | mg/L |
| Magnesium | 6,070. | mg/L | 0.05 | mg/L |
| Temperature (Measured in the field, value reported separately) | | | | |
| Barium | 1.8 | mg/L | 0.1 | mg/L |
| Alkalinity to pH 8.3 | <1. | mg/L | 1. | mg/L |
| Alkalinity to pH 4.5 | 129 | mg/L | 1. | mg/L |
| Aluminum | <1. | mg/L | 1. | mg/L |
| pH | 5.76 | | 0.01 | mg/L |
| Specific Gravity | 1.19 | | | |
| Specific Conductance | 607,000. | µmhos/cm | 1. | µmhos/cm |
| Total Dissolved Solids | 287,000. | mg/L | 100. | mg/L |
| Dimethyl Benzyl Alcohol | 44. | mg/L | 0.1 | mg/L |
| Phenol | 400. | mg/L | 0.1 | mg/L |
| Diphenylamine | N.D. | | 0.1 | mg/L |
| Alpha-Picoline | N.D. | | 0.1 | mg/L |
| Total Suspended Solids | 220. | mg/L | 20. | mg/L |
| Sulfate | 330. | mg/L | 50. | mg/L |
| Chloride | 170,000. | mg/L | 20. | mg/L |
| Nitrate Nitrogen | 220. | mg/L | 10. | mg/L |
| Carbonate | <1. | mg/L | 1. | mg/L |
| Bicarbonate | 129. | mg/L | 1. | mg/L |
| Dissolved Oxygen | <0.5 | mg/L | 0.5 | mg/L |
| Iron | 60.8 | mg/L | 0.05 | mg/L |
| Manganese | 2.35 | mg/L | 0.01 | mg/L |
| Viscosity | 3. | cps | 1. | cps |
| Acetone | 210. | mg/L | 1. | mg/L |
| Cumene Hydroperoxide* | | | | |
| Acetophenone | 6. | mg/L | 0.1 | mg/L |
| Ammonia Nitrogen | 80.5 | mg/L | 0.1 | mg/L |
| Aniline | N.D. | | 0.1 | mg/L |
| Total Chromium | <0.1 | mg/L | 0.1 | mg/L |
| Formic Acid ** | | | | |
| Toluene | N.D. | | 0.5 | mg/L |
| Lead | <0.3 | mg/L | 0.3 | mg/L |

* - Cumene hydroperoxide could not be determined due to impure reference material, as well as what appeared to be degradation in the chromatographic system.

** - Formic Acid (Sample was spiked with 200 mg/L of Formic Acid and provided the following results:) 168. mg/L Trial #1
170. mg/L Trial #2
83.8 % Spike Recovery

< - Indicates the result is less than the smallest amount which can be accurately quantitated.

N.D. - Indicates none detected.

Note: These results have been transcribed by ERM, Inc. from the Lancaster Laboratories Inc. analysis report for the Rose Run Well #3 Brine Water Sample (LLI# WW 1400857).

Aristech WDW #3 Niagaran Formation Sample
Lancaster Laboratory Incorporated No.: WW 1414238
Date Submitted: 7/20/89

| ANALYSIS | RESULT AS RECEIVED | LIMIT OF QUANTITATION |
|---|---|---|
| Sodium | 42,500. mg/L | 0.5 mg/L |
| Potassium | 1,210. mg/L | 0.5 mg/L |
| Calcium | 36,400. mg/L | 0.05 mg/L |
| Magnesium | 8,970. mg/L | 0.05 mg/L |
| Temperature (Measured in the field, value reported separately) | | |
| Barium | 1.1 mg/L | 0.5 mg/L |
| Alkalinity to pH 8.3 | <1. mg/L | 1. mg/L |
| Alkalinity to pH 4.5 | 68. mg/L | 1. mg/L |
| Aluminum | 12.9 mg/L | 0.1 mg/L |
| pH (Measured in the field, value reported separately) | | |
| Specific Gravity | 1.17 | |
| Specific Conductance | 445,000. µmhos/cm | 1. µmhos/cm |
| Total Dissolved Solids | 277,000. mg/L | 100. mg/L |
| Dimethyl Benzyl Alcohol | 0.19 J mg/L | 0.02 mg/L |
| Phenol | 0.14 mg/L | 0.02 mg/L |
| Diphenylamine | N.D. | 0.02 mg/L |
| Alpha-Picoline | N.D. | 0.02 mg/L |
| Total Suspended Solids | 337. mg/L | 7. mg/L |
| Sulfate | 180. mg/L | 50. mg/L |
| Chloride | 139,000. mg/L | 20. mg/L |
| Nitrate Nitrogen | <10. mg/L | 10. mg/L |
| Carbonate | <1. mg/L | 1. mg/L |
| Bicarbonate | 68. mg/L | 1. mg/L |
| Dissolved Oxygen | 5.9 mg/L | 0.5 mg/L |
| Iron | 122. mg/L | 0.05 mg/L |
| Manganese | 2.3 mg/L | 0.2 mg/L |
| Viscosity | 2. cps | 1. cps |
| Acetone | 0.11 mg/L | 0.01 mg/L |
| Cumene Hydroperoxide* | | |
| Acetophenone | N.D. | 0.02 mg/L |
| Ammonia Nitrogen | 133. mg/L | 0.5 mg/L |
| Aniline | <0.02 mg/L | 0.02 mg/L |
| Total Chromium | 0.25 mg/L | 0.05 mg/L |
| Formic Acid | <5. mg/L | |
| Toluene | 0.26 mg/L | 0.005 mg/L |
| Lead | <0.3 mg/L | 0.3 mg/L |

* - Cumene hydroperoxide could not be determined due to impure reference material, as well as what appeared to be degradation in the chromatographic system.

< - Indicates the result is less than the smallest amount which can be accurately quantitated.

N.D. - Indicates none detected.

J - Indicates this value is an estimate.

Note: These results have been transcribed by ERM, Inc. from the Lancaster Laboratories Inc. analysis report for the Niagaran Formation sample (LLI# WW 1414238).

Aristech WDW #3 Niagaran Formation Sample
Lancaster Laboratory Incorporated No.: WW 1414238
Date Submitted: 7/20/89

| ANALYSIS | RESULT AS RECEIVED | | LIMIT OF QUANTITATION | |
|---|---|---|---|---|
| Sodium | 42,500. | mg/L | 0.5 | mg/L |
| Potassium | 1,210. | mg/L | 0.5 | mg/L |
| Calcium | 36,400. | mg/L | 0.05 | mg/L |
| Magnesium | 8,970. | mg/L | 0.05 | mg/L |
| Temperature (Measured in the field, value reported separately) | | | | |
| Barium | 1.1 | mg/L | 0.5 | mg/L |
| Alkalinity to pH 8.3 | <1. | mg/L | 1. | mg/L |
| Alkalinity to pH 4.5 | 68. | mg/L | 1. | mg/L |
| Aluminum | 12.9 | mg/L | 0.1 | mg/L |
| pH (Measured in the field, value reported separately) | | | | |
| Specific Gravity | 1.17 | | | |
| Specific Conductance | 445,000. | µmhos/cm | 1. | µmhos/cm |
| Total Dissolved Solids | 277,000. | mg/L | 100. | mg/L |
| Dimethyl Benzyl Alcohol | 0.19 J | mg/L | 0.02 | mg/L |
| Phenol | 0.14 | mg/L | 0.02 | mg/L |
| Diphenylamine | N.D. | | 0.02 | mg/L |
| Alpha-Picoline | N.D. | | 0.02 | mg/L |
| Total Suspended Solids | 337. | mg/L | 7. | mg/L |
| Sulfate | 180. | mg/L | 50. | mg/L |
| Chloride | 139,000. | mg/L | 20. | mg/L |
| Nitrate Nitrogen | <10. | mg/L | 10. | mg/L |
| Carbonate | <1. | mg/L | 1. | mg/L |
| Bicarbonate | 68. | mg/L | 1. | mg/L |
| Dissolved Oxygen | 5.9 | mg/L | 0.5 | mg/L |
| Iron | 122. | mg/L | 0.05 | mg/L |
| Manganese | 2.3 | mg/L | 0.2 | mg/L |
| Viscosity | 2. | cps | 1. | cps |
| Acetone | 0.11 | mg/L | 0.01 | mg/L |
| Cumene Hydroperoxide* | | | | |
| Acetophenone | N.D. | | 0.02 | mg/L |
| Ammonia Nitrogen | 133. | mg/L | 0.5 | mg/L |
| Aniline | <0.02 | mg/L | 0.02 | mg/L |
| Total Chromium | 0.25 | mg/L | 0.05 | mg/L |
| Formic Acid | <5. | mg/L | | |
| Toluene | 0.26 | mg/L | 0.005 | mg/L |
| Lead | <0.3 | mg/L | 0.3 | mg/L |

* - Cumene hydroperoxide could not be determined due to impure reference material, as well as what appeared to be degradation in the chromatographic system.

< - Indicates the result is less than the smallest amount which can be accurately quantitated.

N.D. - Indicates none detected.

J - Indicates this value is an estimate.

Note: These results have been transcribed by ERM, Inc. from the Lancaster Laboratories Inc. analysis report for the Niagaran Formation sample (LLI# WW 1414238).

p1-90 002632
BOX30
CITED

# C O R E  A N A L Y S I S  R E S U L T S

ARISTECH CHEMICAL CORPORATION
Waste Disposal Well No.3
Scioto County, Ohio

OGS CORE # 3248

Formation: Conasauga/Rome/Mt.Simon
Coring Fluid: Water Based Mud
File No.: Envirocorp 50-1277

Date: 6-JULY-1989
Analysts: Davis

| SMPLE NUMBER | DEPTH ft | PERMEABILITY FULL DIAMETER Kmax md | K90 md | Vert. md | PLUG Horiz md | Vert md | POROSITY Full Diam. % | Plug Horiz. % | Plug Vert % | GRAIN DENSITY Full Diam. gms/cc | Plug Horiz. | Plug Vert | LITHOLOGICAL DESCRIPTION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5600-01 | 5.30 | 4.30 | 0.44 | | | 2.4 | | | 2.76 | | | Sh dk gry dolc scalc lam dns frac v/frac | |
| 2 | 5601-02 | 0.95 | 0.21 | <0.01 | | | 1.3 | | | 2.84 | | | Dol gry vfxln vsh scalc lam dns | |
| 3 | 5602-03 | # | # | 2.00 | | | 2.5 | | | 2.71 | | | Sh blk/dk gry vdolc scalc foss lam dns frac v/frac | |
| 4 | 5603-04 | | | | | | | | | | | | Sh blk/dk gry dolc scalc lam dns frac v/frac TBFA | |
| 5 | 5604-05 | | | | | | | | | | | | Sh blk/dk gry dol scalc lam dns frac v/frac TBFA | |
| 6 | 5605-06 | | | | | | | | 0.9 | | 2.84 | | Dol dk gry vfxln frac v/frac | PET.SMPLE |
| 7 | 5606-07 | | | | | | | | | | | | Sh blk dolc lam dns frac TBFA | |
| 8 | 5607-08 | | | | | | | | | | | | Sh blk dolc lam dns frac TBFA | |
| 9 | 5608-09 | 5.70 | 5.10 | 0.19 | | | 1.8 | | | 2.74 | | | Sh blk vdolc dns frac v/frac | |
| 10 | 5609-10 | | | | | | | | | | | | Sh blk dolc dns frac v/frac TBFA | |
| 11 | 5610-11 | | | | | | | | | | | | Sh blk dolc dns frac v/frac TBFA | |
| 12 | 5611-12 | 0.13 | 0.04 | <0.01 | | | 0.7 | | | 2.76 | | | Dol dk gry vfxln vsh dns frac | |
| 13 | 5612-13 | | | | | | | | | | | | Sh dk gry dolc dns frac TBFA | |
| 14 | 5613-14 | | | | | | | | | | | | Sh dk gry dolc dns frac TBFA | |
| 15 | 5614-15 | | | | | | | | | | | | Sh dk gry dolc dns frac TBFA | |
| 16 | 5615-16 | | | | | | | | | | | | Sh dk gry dolc dns frac TBFA | |
| 17 | 5616-17 | | | | | | | | 2.0 | | 2.72 | | Sh blk dolc dns frac | |
| 18 | 5617-18 | | | | | | | | | | | | Sh dk gry dolc dns frac TBFA | |
| 19 | 5618-19 | | | | | | | | | | | | Sh dk gry dolc dns frac TBFA | |
| 20 | 5619-20 | | | | | | | | | | | | Sh dk gry dolc dns frac TBFA | |
| 21 | 5620-21 | *705 | 3.10 | *647 | | | | | 1.3 | | 2.69 | | Sh blk dolc dns frac | |
| 22 | 5621-22 | | | | | | 1.8 | | | 2.86 | | | Dol dk gry vfxln scalc vsh lam dns v/frac | |
| 23 | 5622-23 | | | | | | | | | | | | Sh dk gry dolc lam v/frac TBFA | |
| 24 | 5623-24 | | | | | | | | 1.9 | | 2.74 | | Sh blk dolc dns | |
| 25 | 5624-25 | | | | | | | | | | | | Sh blk dolc dns TBFA | PET.SMPLE |
| 26 | 5625-26 | 4.00 | 1.50 | 0.20 | | | | | 0.9 | | 2.72 | | Sh blk dolc dns | |
| | | | | | | | 1.8 | | | 2.80 | | | Dol gry vfxln vsh calc lam sh lam dns v/frac | |

# C O R E  A N A L Y S I S  R E S U L T S

ARISTECH CHEMICAL CORPORATION
Waste Disposal Well No.3
Scioto County, Ohio

Formation: Conasauga/Rome/Mt.Simon
Coring Fluid: Water Based Mud
File No.: Envirocorp 50-1277

Date: 6-JULY-1989
Analysts: Davis

| SMPLE NUMBER | DEPTH ft | PERMEABILITY FULL DIAMETER Kmax md | K90 md | Vert. md | PLUG Horiz md | Vert md | POROSITY Full Diam. % | Plug Horiz. % | Plug Vert % | GRAIN DENSITY Full Diam. gms/cc | Plug Horiz. | Plug Vert | LITHOLOGICAL DESCRIPTION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 5626-27 | | | | | | | | | | | | | |
| 28 | 5627-28 | 1.30 | 0.79 | 0.34 | | | 1.1 | | | 2.86 | | | Dol gry fxln vshy scalc lam dns v/frac TBFA | |
| 29 | 5628-29 | | | | | | | | | | | | Dol dk gry fxln shy calc lam dns v/frac | |
| 30 | 5629-30 | | | | | | | | | | | | Dol dk gry fxln shy calc lam dns v/frac (Rubble) TBFA | |
| 31 | 5630-31 | | | | | | | | 0.5 | | 2.86 | | Dol dk gry fxln sshy dns v/frac | |
| 32 | 5631-32 | | | | | | | | | | | | Sh gry dolc lam dns v/frac TBFA | |
| 33 | 5632-33 | 4.30 | 1.60 | 1.15 | | | | | | | | | Sh gry dolc lam dns v/frac TBFA | |
| 34 | 5633-34 | | | | | | 1.6 | | | 2.74 | | | Sh blk dolc slty lam dns v/frac | |
| 35 | 5634-35 | 1.00 | 0.58 | <0.01 | | | | | | | | | Sh blk dolc slty lam dns v/frac TBFA | PET.SMPLE |
| 36 | 5635-36 | | | | | | 1.5 | | | 2.79 | | | Dol dk gry fxln vshy scalc lam dns v/frac | |
| 37 | 5636-37 | | | | | | | | 0.6 | | 2.72 | | Sh blk sdolc dns | |
| 38 | 5637-38 | | | | | | | | | | | | Sh blk sdolc dns TBFA | |
| 39 | 5638-39 | | | | | | | | | | | | Sh blk sdolc dns TBFA | |
| 40 | 5639-40 | 1.30 | 1.20 | 0.38 | | | | | | | | | Sh dk gry vdolc scalc v/frac TBFA | |
| 41 | 5640-41 | 1.30 | 0.85 | 1.80 | | | 1.6 | | | 2.82 | | | Dol gry fxln shy calc veins lam dns v/frac | |
| 42 | 5641-42 | 0.28 | 0.27 | <0.01 | | | 1.4 | | | 2.86 | | | Dol gry fxln shy calc veins lam dns v/frac | PET.SMPLE |
| 43 | 5642-43 | | | | | | 1.3 | | | 2.86 | | | Dol gry fxln scalc lam sh lam dns v/frac | |
| 44 | 5643-44 | | | | | | | | 1.0 | | 2.68 | | Dol gry fxln shy lam frac | |
| 45 | 5644-45 | | | | | | | | 0.8 | | 2.85 | | Dol lt gry lam dns | |
| 46 | 5645-46 | | | | | | | | | | | | Dol lt gry sdy lam v/frac TBFA | |
| 47 | 5646-47 | | | | | | | | 0.6 | | 2.73 | | Dol dk gry vfxln vshy lam dns | |
| 48 | 5647-48 | | | | | | | | 0.6 | | 2.83 | | Dol lt gry vfxln lam dns | |
| 49 | 5648-49 | | | | | | | | | | | | Sh dk gry vdolc dns frac | |
| 50 | 5649-50 | | | | | | | | 1.1 | | 2.67 | | Sh dk gry dolc dns | |
| 51 | 5650-51 | 2.70 | 1.20 | 0.06 | | | | | 1.7 | | 2.75 | | Sh dk gry dolc dns | PET.SMPLE |
| 52 | 5651-52 | 0.15 | 0.11 | 0.10 | | | 1.5 | | | 2.72 | | | Dol gry/dk gry vfxln vshy scalc sh lam v/frac | |
| | | | | | | | 1.2 | | | 2.85 | | | Dol gry fxln sh scalc lam dns v/frac | PET.SMPLE |

# C O R E  A N A L Y S I S  R E S U L T S

ARISTECH CHEMICAL CORPORATION
Waste Disposal Well No.3
Scioto County, Ohio

Formation: Conasauga/Rome/Mt.Simon
Coring Fluid: Water Based Mud
File No.: Envirocorp 50-1277

Date: 6-JULY-1989
Analysts: Davis

| SMPLE NUMBER | DEPTH ft | PERMEABILITY FULL DIAMETER Kmax md | K90 md | Vert. md | PLUG Horiz md | Vert md | POROSITY Full Diam. % | Plug Horiz. % | Plug Vert % | GRAIN DENSITY Full Diam. gms/cc | Plug Horiz. | Plug Vert | LITHOLOGICAL DESCRIPTION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53 | 5652-53 | 0.22 | 0.05 | <0.01 | | | 1.1 | | | 2.82 | | | Dol gry fxln scalc lam sh lam dns v/frac | |
| 54 | 5653-54 | | | | | | | | | | | | Sh dk gry dolc scalc lam dns frac TBFA | |
| 55 | 5654-55 | | | | | | | | | | | | Sh dk gry dolc scalc lam dns frac TBFA | |
| 56 | 5655-56 | | | | | | | | 0.7 | | 2.73 | | Sh dk gry dolc dns | |
| 57 | 5656-57 | | | | | | | | 2.6 | | 2.86 | | Dol gry fxln pp dns | |
| 58 | 5657-58 | | | | | | | | 0.6 | | 2.80 | | Dol gry vfxln lam sh lam dns v/frac | |
| 59 | 5658-59 | | | | | | | | | | | | Dol dk gry vfxln lam vshy dns v/frac | |
| 60 | 5659-60 | | | | | | | | | | | | Dol dk gry vfxln lam vshy dns v/frac TBFA | |
| 61 | 5660-61 | | | | | | | | 1.6 | | 2.82 | | Dol gry fxln shy dns | PET.SMPLE |
| 62 | 5661-62 | | | | | | | | 1.7 | | 2.87 | | Dol gry fxln dns | |
| 63 | 5662-63 | | | | | | | | | | | | Dol gry fxln lam dns v/frac | |
| 64 | 5663-64 | | | | | | | | 1.3 | | 2.79 | | Dol gry fxln shy dns | |
| 65 | 5664-65 | | | | | | | | 0.8 | | 2.80 | | Dol gry vfxln lam dns | |
| 66 | 5665-66 | 5.90 | 0.14 | <0.01 | | | 1.1 | | | 2.79 | | | Dol lt gry vfxln sshy scalc sh lam dns | |
| 67 | 5666-67 | 0.96 | 0.28 | <0.01 | | | 1.0 | | | 2.81 | | | Dol lt gry vfxln scalc sh lam dns | |
| 68 | 5667-68 | *880 | <0.01 | *155 | | | 1.0 | | | 2.83 | | | Dol gry vfxln calcnod sh lam v/frac | |
| 69 | 5668-69 | 0.41 | 0.09 | 0.24 | | | 1.4 | | | 2.86 | | | Sst mott gry fg scalc lam sh lam v/frac | |
| 70 | 5669-70 | | | | | | | | | | | | Dol gry cxln lam v/frac | |
| 71 | 5670-71 | 2.10 | 1.40 | 5.99 | | | 1.2 | | | 2.78 | | | Dol lt gry vfxln scalc lam sh lam dns v/frac | PET.SMPLE |
| 72 | 5671-72 | | | | | | | | | | | | Dol lt gry vfxln scalc lam sh lam dns v/frac | |
| 73 | 5672-73 | | | | | | | | | | | | Dol lt gry vfxln scalc lam sh lam dns v/frac | |
| 74 | 5673-74 | 0.99 | 0.15 | <0.01 | | | 1.0 | | | 2.77 | | | Dol gry scalc lam dns | |
| 75 | 5674-75 | 6.70 | 0.49 | <0.01 | | | 3.2 | | | 2.75 | | | Sst mott gry/brn fg scalc dolc lam | |
| 76 | 5675-76 | 0.58 | 0.03 | <0.01 | | | 2.8 | | | 2.77 | | | Dol mott gry/brn mxln vsdy scalc | |
| 77 | 5676-77 | 0.34 | 0.06 | 0.22 | | | 1.4 | | | 2.77 | | | Dol gry mxln vsdy lam sh lam dns v/frac (5677.3-78.2 Acous.Vel.) | |
| 78 | 5677-78 | 0.17 | 0.04 | 3.45 | | | 2.8 | | | 2.79 | | | Sst gry vfg dolc scalc lam sh lam v/frac | PET.SMPLE |

# C O R E  A N A L Y S I S  R E S U L T S

ARISTECH CHEMICAL CORPORATION
Waste Disposal Well No.3
Scioto County, Ohio

Formation: Conasauga/Rome/Mt.Simon
Coring Fluid: Water Based Mud
File No.: Envirocorp 50-1277

Date: 6-JULY-1989
Analysts: Davis

| SMPLE NUMBER | DEPTH ft | PERMEABILITY FULL DIAMETER Kmax md | K90 md | Vert. md | PLUG Horiz md | Vert md | POROSITY Full Diam. % | Plug Horiz. % | Plug Vert % | GRAIN DENSITY Full Diam. gms/cc | Plug Horiz. | Plug Vert | LITHOLOGICAL DESCRIPTION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 79 | 5678-79 | 3.00 | <0.01 | 6.42 | | | 2.9 | | | 2.77 | | | Sst gry fg vdolc scalc lam sh lam dns v/frac | |
| 80 | 5679-80 | 0.08 | 0.07 | <0.01 | | | 5.5 | | | 2.76 | | | Sst mott gry/brn fg dolc scalc lam sh lam v/frac | |
| 81 | 5680-81 | 0.17 | 0.12 | 0.14 | | | 4.4 | | | 2.73 | | | Sst mott gry/brn fg dolc scalc lam sh lam | |
| 82 | 5681-82 | 0.28 | 0.17 | <0.01 | | | 4.9 | | | 2.73 | | | Sst mott gry/brn fg dolc vscalc lam sh lam v/frac | |
| 83 | 5682-83 | 0.07 | 0.05 | <0.01 | | | 4.1 | | | 2.75 | | | Sst mott brn vfg vdolc scalc lam | |
| 84 | 5683-84 | 0.68 | 0.05 | <0.01 | | | 2.5 | | | 2.73 | | | Sst mott brn vfg dol vscalc lam (5683.9-85 Rock Mechanics) | |
| 85 | 5684-85 | | | | | | | | | | | | Sst mott brn vfg dol vscalc lam | |
| 86 | 5685-86 | 2.40 | 0.44 | <0.01 | | | 4.7 | | | 2.71 | | | Sst mott brn vfg vdolc lam | |
| 87 | 5686-87 | | | 0.03 | | | 5.0 | | | 2.71 | | | Sst mott brn vfg vdolc lam | |
| 88 | 5687-88 | | | | | | | | | | | | Sst mott brn vfg vdolc lam frac | |
| 89 | 5688-89 | | | | | | | | | | | | Sst mott brn vfg vdolc lam frac | |
| 90 | 5689-90 | 0.66 | 0.19 | <0.01 | | | 0.9 | | | 2.64 | | | Sst mott brn fg sdolc calc lam | |
| 91 | 5690-91 | 1.50 | 0.57 | <0.01 | | | 1.8 | | | 2.75 | | | Dol mott gry fxln sdy scalc lam sh lam | |
| 92 | 5691-92 | 2.30 | 0.03 | 0.83 | | | 1.0 | | | 2.85 | | | Dol wh/mott gry vfxln scalc sh lam dns v/frac | |
| 93 | 5692-93 | 5.30 | 3.30 | <0.01 | | | 1.0 | | | 2.83 | | | Dol gry vfxln calc lam dns v/frac | |
| 94 | 5693-94 | 2.00 | 0.87 | 2.41 | | | 6.6 | | | 2.90 | | | Dol wh vfxln vug pp v/frac | |
| 95 | 5694-95 | 0.14 | 0.07 | <0.01 | | | 3.3 | | | 2.88 | | | Dol wh vfxln calc styl vug pp v/frac | PET.SMPLE |
| 96 | 5695-96 | | | | | | | | | | | | Dol wh vfxln scalc styl sh lam vug pp v/frac | |
| 97 | 5696-97 | 1.60 | 0.19 | 1.38 | | | 4.5 | | | 2.89 | | | Dol wh vfxln scalc vug pp v/frac | |
| 98 | 5697-98 | 0.13 | <0.01 | <0.01 | | | 1.8 | | | 2.87 | | | Dol wh/mott wh/gry scalc svug dns | |
| 99 | 5698-99 | 0.06 | 0.05 | <0.01 | | | 1.8 | | | 2.82 | | | Dol wh/mott wh/gry scalc dns v/frac | |
| 5700 | 5699-5700 | 0.42 | 0.34 | 0.05 | | | 1.7 | | | 2.87 | | | Dol wh vfxln calc sh lam dns v/frac | |
| 01 | 5700-01 | 0.48 | 0.14 | <0.01 | | | 1.4 | | | 2.88 | | | Dol lt gry fxln scalc lam shlam styl dns | |
| 02 | 5701-02 | 0.57 | 0.27 | 0.58 | | | 2.3 | | | 2.87 | | | Dol mott wh/gry scalc vug dns v/frac | |
| 03 | 5702-03 | | | | | | | | | | | | Dol lt gry fxln scalc dns v/frac (5701.9-03 Rock Mechanics) | PET.SMPLE |
| 04 | 5703-04 | | | | | | | | | | | | Dol lt gry fxln scalc dns v/frac | |

# C O R E  A N A L Y S I S  R E S U L T S

ARISTECH CHEMICAL CORPORATION
Waste Disposal Well No.3
Scioto County, Ohio

Formation: Conasauga/Rome/Mt.Simon
Coring Fluid: Water Based Mud
File No.: Envirocorp 50-1277

Date: 6-JULY-1989
Analysts: Davis

| SMPLE NUMBER | DEPTH ft | PERMEABILITY FULL DIAMETER Kmax md | K90 md | Vert. md | PLUG Horiz md | Vert md | POROSITY Full Diam. % | Plug Horiz. % | Plug Vert % | GRAIN DENSITY Full Diam. gms/cc | Plug Horiz. | Plug Vert | LITHOLOGICAL DESCRIPTION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 105 | 5704-05 | 3.10 | 2.30 | 0.22 | | | 1.7 | | | 2.87 | | | Dol lt gry vfxln calc lam dns frac v/frac | |
| 106 | 5705-06 | 1.30 | 0.25 | 0.13 | | | 1.5 | | | 2.88 | | | Dol lt gry vfxln calc lam dns frac v/frac | |
| 107 | 5706-07 | | | | | | | | | | | | Dol lt gry vfxln calc lam sty dns frac v/frac | |
| 108 | 5707-08 | | | | | | | | 1.8 | | | 2.85 | Dol wh vfxln sh lam dns | |
| 109 | 5708-09 | | | | | | | | | | | | Dol lt gry vfxln lam dns (5708.0-09.3 Acoustic Velocity) | |
| 110 | 5709-10 | | | | | | | | 1.7 | | | 2.84 | Dol lt gry vfxln lam dns v/frac | |
| 111 | 5710-11 | 0.52 | 0.23 | 1.99 | | | 1.4 | | | 2.86 | | | Dol lt gry vfxln calc lam sh lam dns v/frac | |
| 112 | 5711-12 | 0.03 | 0.02 | <0.01 | | | 1.6 | | | 2.87 | | | Dol lt gry vfxln anhy calc lam sh alm dns v/frac | |
| 113 | 5712-13 | 0.36 | 0.24 | 0.38 | | | 1.5 | | | 2.86 | | | Dol lt gry vfxln scalc lam sh lam pp dns v/frac | |
| 114 | 5713-14 | 0.06 | 0.03 | <0.01 | | | 1.3 | | | 2.86 | | | Dol lt gry vfxln calc lam sh lam dns v/frac | |
| 115 | 5714-15 | 0.72 | 0.49 | <0.01 | | | 1.6 | | | 2.87 | | | Dol lt gry vfxln calc lam sh lam dns v/frac | PET.SMPLE |
| 116 | 5715-16 | | | | | | | | | | | | Dol lt gry vfxln calc lam dns v/frac TRFA | |
| 117 | 5716-17 | 0.03 | 0.03 | <0.01 | | | 0.5 | | | 2.82 | | | Dol lt gry vfxln calc lam styl dns v/frac | |
| 118 | 5717-18 | 0.30 | 0.12 | <0.01 | | | 0.8 | | | 2.84 | | | Dol lt gry vfxln scalc lam styl dns v/frac | |
| 19 | 5718-19 | 0.87 | 0.06 | <0.01 | | | 2.3 | | | 2.86 | | | Dol mott gry vfxln scalc sd inclu lam vug pp v/frac | |
| 20 | 5719-20 | 1.70 | 0.04 | 2.54 | | | 1.4 | | | 2.87 | | | Dol lt gry vfxln calc lam styl v/frac | |
| 21 | 5720-21 | 0.16 | 0.11 | 0.34 | | | 1.7 | | | 2.89 | | | Dol lt gry vfxln calc styl svug v/frac | |
| 22 | 5721-22 | | | | | | | | | | | | Dol lt gry vfxln v/frac TRFA | |
| 23 | 5722-23 | 0.02 | <0.01 | <0.01 | | | 0.5 | | | 2.86 | | | Dol lt gry vfxln calc lam sh lam/sty dns v/frac | |
| 24 | 5723-24 | 0.27 | 0.23 | 0.44 | | | 0.8 | | | 2.86 | | | Dol lt gry vfxln scalc lam sh lam styl dns v/frac | PET.SMPLE |
| 5 | 5724-25 | 0.20 | 0.19 | 0.22 | | | 1.0 | | | 2.82 | | | Dol mott lt gry fxln sdy lam sh lam dns | |
| 6 | 5725-26 | 0.15 | 0.06 | <0.01 | | | 1.1 | | | 2.82 | | | Dol mott gry vfxln scalc foss lam dns v/frac | |
| 7 | 5726-27 | 0.27 | 0.12 | 0.08 | | | 1.4 | | | 2.86 | | | Dol lt gry vfxln scalc sh lam svug dns v/frac | |
| 3 | 5727-28 | 7.00 | 0.36 | 0.21 | | | 1.3 | | | 2.86 | | | Dol lt gry vfxln calc styl svug dns v/frac | |
| 9 | 5728-29 | *442 | 0.12 | * 475 | | | 1.3 | | | 2.87 | | | Dol lt gry vfxln scalc svug dns v/frac | |
| 0 | 5729-30 | 0.13 | 0.12 | 0.22 | | | 1.8 | | | 2.87 | | | Dol mott gry vfxln scalc sh lam styl vug v/frac | |

# C O R E  A N A L Y S I S  R E S U L T S

ARISTECH CHEMICAL CORPORATION
Waste Disposal Well No.3
Scioto County, Ohio

Formation: Conasauga/Rome/Mt.Simon
Coring Fluid: Water Based Mud
File No.: Envirocorp 50-1277

Date: 6-JULY-1989
Analysts: Davis

| SAMPLE NUMBER | DEPTH ft | PERMEABILITY FULL DIAMETER Kmax md | K90 md | Vert. md | PLUG Horiz md | Vert md | POROSITY Full Diam. % | Plug Horiz. % | Plug Vert % | GRAIN DENSITY Full Diam. | Plug Horiz. gms/cc | Plug Vert | LITHOLOGICAL DESCRIPTION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 5730-31 | 7.80 | 2.70 | 0.02 | | | 2.5 | | | 2.87 | | | Dol mott gry vfxln scalc sh lam styl vug v/frac | |
| 32 | 5731-32 | 0.21 | 0.10 | 0.09 | | | 1.2 | | | 2.86 | | | Dol gry vfxln scalc lam sh lam dns v/frac | PET.SMPLE |

* - Open Vertical Fracture
\# - Sample failed during analysis
TBFA - To Broken For Analysis
PET.SMPLE - Sample Selected for X-Ray Diffraction, SEM, & Thin Section analyses.

P2-90 002633 Box 31

CITED

DGS CORE # 3248

APPENDIX 4.3-H

WDW NO. 3 - ENVIROCORP CORE ANALYSES

# TerraTek Core Services, Inc.®

University Research Park - 360 Wakara Way - Salt Lake City, Utah 84108 - (801) 584-2480 - TWX 910-925-5284

ENVIROCORP SERVICES & TECHNOLOGY, INC.

Well: Aristech Chemical WDW #3
Field: NA
Drilling fluid: NA

State: Ohio
County: Scioto
Location: NA

Date: 7-DEC-1989
TTCS File #: 5398
Elevation: NA

## FULL DIAMETER PERMEABILITY AND POROSITY

| Sample Number | Depth (feet) | Permeability Horz (md) | Horz-90 (md) | Vert (md) | Porosity % | Grain Density (gm/cc) | | Lithology |
|---|---|---|---|---|---|---|---|---|
| 1 | 5915.0-16.0 | .16 | .09 | .19 | 0.6 | 2.86 | | Dol,sl/anhy,fis |
| 2 | 5916.0-17.0 | .02 | .01 | .01 | 1.0 | 2.84 | | Dol |
| 3 | 5917.0-18.0 | .24 | <.01 | .25 | 0.7 | 2.85 | VF | Dol,fis |
| 4 | 5918.0-19.0 | .04 | .02 | .02 | 0.9 | 2.86 | | Dol,sl/anhy |
| 5 | 5919.0-20.0 | .45 | .08 | .09 | 0.6 | 2.81 | VF | Dol,few fis |
| 6 | 5920.0-21.0 | 1.1 | .01 | .46 | 1.3 | 2.81 | VF | Dol fis |
| 7 | 5921.0-22.0 | 1.6 | <.01 | .64 | 0.7 | 2.84 | VF | Dol,sh lam |
| 8 | 5922.0-23.0 | 209. | .04 | 139. | 0.7 | 2.86 | VF | Dol,sl/anhy |
| 9 | 5923.0-24.0 | .05 | .04 | .05 | 1.0 | 2.77 | | Dol,sdy,sh stks |
| 10 | 5924.0-25.0 | 1.3 | .65 | .70 | 1.3 | 2.78 | VF | Dol,sdy,chty,fis |
| 11 | 5925.0-26.0 | .28+ | .10 | .14 | 0.8 | 2.86 | | Dol,sl/anhy,fis |
| 12 | 5926.0-27.0 | .27 | .03 | .19 | 0.8 | 2.85 | VF | Dol,fis |
| 13@ | 5927.0-28.0 | .01 | NA | .01 | 0.6 | 2.83 | | Dol,few fis |
| 14 | 5928.0-29.0 | 5.9 | .11 | 5.5 | 1.5 | 2.84 | VF | Dol,fis |
| 15 | 5929.0-30.0 | 10. | .05 | 21. | 0.7 | 2.81 | VF | Dol,sl/shy |
| 16@ | 5930.0-31.0 | .01 | NA | .01 | 0.9 | 2.85 | | Dol,sl/anhy |
| 17 | 5931.0-32.0 | .03 | .01 | <.01 | 1.3 | 2.77 | VF | Dol,sl/shy,chty |

+ - Dehydration crack affecting permeability
VF - Vertical fracture present
@ - Plug Dean-Stark analysis - Not suitable for full diameter sampling

# TerraTek Core Services, Inc.

University Research Park - 360 Wakara Way - Salt Lake City, Utah 84108 - (801) 584-2480 - TWX 910-925-5284

ENVIROCORP SERVICES & TECHNOLOGY, INC. Date: 7-DEC-1989 TTCS File #: 5398

Well: Aristech Chemical WDW #3

## FULL DIAMETER PERMEABILITY AND POROSITY

| Sample Number | Depth (feet) | Permeability Horz (md) | Horz-90 (md) | Vert (md) | Porosity % | Grain Density (gm/cc) | | Lithology |
|---|---|---|---|---|---|---|---|---|
| 18 | 5932.0-33.0 | .24+ | .16+ | .02 | 1.3 | 2.73 | | Sd,dol,slty |
| 19 | 5933.0-34.0 | .26+ | .12+ | 1.6 | 0.8 | 2.83 | VF | Dol,anhy |
| 20 | 5934.0-35.0 | .11 | <.01 | <.01 | 0.6 | 2.82 | VF | Dol,sl/shy |
| 21 | 5935.0-36.0 | .04 | .02 | <.01 | 1.3 | 2.81 | | Dol,sdy,few fis |
| 22 | 5936.0-37.0 | <.01 | <.01 | <.01 | 0.3 | 2.92 | | Dol,v/anhy |
| 23 | 5937.0-38.0 | .02 | .01 | <.01 | 0.3 | 2.91 | | Dol,v/anhy |
| 24 | 5938.0-39.0 | .05 | .02 | .05 | 0.4 | 2.85 | | Dol,sl/anhy,few fis |
| 25 | 5939.0-40.0 | 1.9 | .43 | .06 | 0.8 | 2.87 | VF | Dol,anhy,fis |
| 26 | 5940.0-41.0 | .06 | .06 | .21 | 0.4 | 2.86 | | Dol,sl/anhy,few fis |
| 27 | 5941.0-42.0 | .04 | .01 | NA | 0.4 | 2.83 | | Dol,few fis |
| 28 | 5942.0-43.0 | .07 | <.01 | .01 | 0.7 | 2.83 | VF | Dol,few fis |
| 5965' Top of unit | 5943.0-73.0 | | | | | | | Core Not Received |
| 29 | 5973.0-74.0 | .40 | .06 | 1.1 | 1.1 | 2.82 | VF | Dol,sty,fis |
| 30 | 5974.0-75.0 | .12+ | .03 | <.01 | 1.3 | 2.78 | | Dol,sh lam,chty |
| 31 | 5975.0-76.0 | 10.+ | 3.3+ | 1.6 | 0.9 | 2.82 | VF | Dol,sl/anhy,chty |
| 32 | 5976.0-77.0 | 1.0 | .10 | .12 | 1.5 | 2.81 | VF | Dol,sh lam,chty |
| | 5977.0-82.0 | | | | | | | Core Not Received |
| 33 | 5982.0-83.0 | <.01 | <.01 | <.01 | 0.4 | 2.84 | | Dol,sty |
| 34 | 5983.0-84.0 | .81+ | <.01 | <.01 | 0.4 | 2.83 | | Dol,sh lam |
| 35 | 5984.0-85.0 | .24+ | .17+ | .42 | 0.6 | 2.84 | VF | Dol,sh lam |
| ✓36 | 5985.0-86.0 | .03 | .02 | .02 | 3.6 | 2.65 ✓ | | Sd,sh lam |

+ - Dehydration crack affecting permeability
VF - Vertical fracture present

# TerraTek Core Services, Inc.®

University Research Park - 360 Wakara Way - Salt Lake City, Utah 84108 - (801) 584-2480 - TWX 910-925-5284

ENVIROCORP SERVICES & TECHNOLOGY, INC. Date: 7-DEC-1989 TTCS File #: 5398
Well: Aristech Chemical WDW #3

## FULL DIAMETER PERMEABILITY AND POROSITY

| Sample Number | Depth (feet) | Permeability Horz (md) | Horz-90 (md) | Vert (md) | Porosity % | Grain Density (gm/cc) | | Lithology |
|---|---|---|---|---|---|---|---|---|
| 37 | 5986.0-87.0 | <.01 | <.01 | NA | 0.2 | 2.80 | | Dol,sl/chty |
| 38 | 5987.0-88.0 | .02 | .02 | <.01 | 0.7 | 2.80 | | Dol,sl/sdy |
| 39 | 5988.0-89.0 | .45 | <.01 | 2.1 | 0.3 | 2.78 | VF | Dol,chty |
| 40 | 5989.0-90.0 | .05 | <.01 | .16 | 0.1 | 2.79 | | Dol,sh lam,chty |
| 41 | 5990.0-91.0 | <.01 | .01 | <.01 | 1.9 | 2.76 | | Sd,dol,sh lam |
| 42 | 5991.0-92.0 | 7.1 | .25 | .94 | 2.0 | 2.77 | VF | Sd,dol |
| 43 | 5992.0-93.0 | .01 | .01 | <.01 | 0.7 | 2.81 | | Dol,sdy |
| 44 | 5993.0-94.0 | .17+ | .02 | .04 | 0.9 | 2.75 | | Dol,sdy,shy |
| 45 | 5994.0-95.0 | .64+ | .33+ | <.01 | 1.5 | 2.76 | | Sd,dol |
| 46 | 5995.0-96.0 | .99+ | .03 | <.01 | 0.3 | 2.80 | | Dol,sh stks |
| 47 | 5996.0-97.0 | <.01 | <.01 | <.01 | 0.7 | 2.83 | | Dol,sl/sdy |
| 48 | 5997.0-98.0 | .02 | <.01 | .01 | 0.7 | 2.84 | | Dol |
| 49 | 5998.0-99.0 | <.01 | <.01 | <.01 | 1.4 | 2.76 | | Sd,dol,sh lam |
| 50 | 5999.0-00.0 | .01 | <.01 | .01 | 2.0 | 2.70 | | Sd,sl/dol,sh lam |
| 51 | 6000.0-01.0 | .05+ | <.01 | <.01 | 0.5 | 2.79 | | Dol,sdy,sh lam |
| 52 | 6001.0-02.0 | .93+ | .01 | <.01 | 1.3 | 2.76 | | Sd,dol,sh lam |
| 53 | 6002.0-03.0 | .54+ | .38+ | .03 | 2.6 | 2.66 | | Sd,shy,sh lam |
| 54 | 6003.0-04.0 | .02 | .02 | <.01 | 1.1 | 2.75 | | Sd,dol,sh stks |
| 55 | 6004.0-05.0 | <.01 | <.01 | <.01 | 1.8 | 2.78 | | Sd,dol,sh lam |
| 56 | 6005.0-06.0 | <.01 | <.01 | <.01 | 1.3 | 2.82 | | Dol |
| 57 | 6006.0-07.0 | .06 | .02 | .16 | 2.3 | 2.82 | | Dol,sh lam |

+ - Dehydration crack affecting permeability
VF - Vertical fracture present
@ - Plug Dean-Stark analysis - Not suitable for full diameter sampling

# TerraTek Core Services, Inc.®

University Research Park - 360 Wakara Way - Salt Lake City, Utah 84108 - (801) 584-2480 - TWX 910-925-5284

ENVIROCORP SERVICES & TECHNOLOGY, INC. Date: 7-DEC-1989 TTCS File #: 5398

Well: Aristech Chemical WDW #3

## FULL DIAMETER PERMEABILITY AND POROSITY

| Sample Number | Depth (feet) | Permeability Horz (md) | Horz-90 (md) | Vert (md) | Porosity % | Grain Density (gm/cc) | Lithology |
|---|---|---|---|---|---|---|---|
| 58@ | 6007.0-08.0 | .02 | NA | .01 | 3.1 | 2.74 | Dol,sdy,chty |
| 59@ | 6008.0-09.0 | .01 | NA | <.01 | 0.4 | 2.82 | Dol,sl/sdy |
| 60 | 6009.0-10.0 | 602. | <.01 | .02 | 1.4 | 2.85 VF | Dol,sl/anhy |
| 61 | 6010.0-11.0 | .03 | .02 | .02 | 3.1 | 2.67 ✓ | Sd,sl/dol,sh lam |
| 62 | 6011.0-12.0 | .61 | .22 | .05 | 6.5 | 2.65 ✓ | Sd,sh lam |
| 63 | 6012.0-13.0 | .88 | .79 | .33 | 11.1 | 2.61 ✓ | Sd,few sh lam |
| 64 | 6013.0-14.0 | .04 | .03 | NA | 6.1 | 2.67 ✓ | Sd,sl/dol,sh lam |
| 65 | 6014.0-15.0 | .04 | .01 | NA | 4.8 | 2.71 | Sd,sl/dol,sh lam |
| 66 | 6015.0-16.0 | .68+ | .27+ | .39 | 2.6 | 2.69 | Sd,sl/dol,sh lam |
| 67 | 6016.0-17.0 | 88.+ | 48.+ | .14 | 6.1 | 2.65 ✓ | Sd,sh lam |
| 68 | 6017.0-18.0 | .02 | .02 | .03 | 3.2 | 2.71 | Sd,sl/dol,sh lam |
| 69 | 6018.0-19.0 | 2.9 | .37 | 2.4 | 6.5 | 2.66 ✓ | Sd |
| 70 | 6019.0-20.0 | .27 | .05 | .16 | 3.0 | 2.70 VF | Sd |
| 71 | 6020.0-21.0 | .03 | .02 | .02 | 1.3 | 2.72 | Sd |
| 72 | 6021.0-22.0 | 1.6 | 1.4 | .07 | 3.8 | 2.68 ✓ | Sd |
| 73 | 6022.0-23.0 | 496. | 1.6 | 226. | 6.1 | 2.68 ✓VF | Sd |
| 74@ | 6023.0-24.0 | 7.2 | NA | .09 | 10.0 | 2.63 ✓ | Sd |
| 75 | 6024.0-25.0 | 11. | 3.0 | .69 | 9.0 | 2.66 ✓VF | Sd |
| 76 | 6025.0-26.0 | 7.6 | 1.7 | 1.9 | 9.4 | 2.65 ✓ | Sd |
| | 6026.0-27.0 | | | | | | Core Not Received |

+ - Dehydration crack affecting permeability
VF - Vertical fracture present
@ - Plug Dean-Stark analysis - Not suitable for full diameter sampling

# TerraTek Core Services, Inc.®

University Research Park - 360 Wakara Way - Salt Lake City, Utah 84108 - (801) 584-2480 - TWX 910-925-5284

ENVIROCORP SERVICES & TECHNOLOGY, INC. Date: 7-DEC-1989 TTCS File #: 5398

Well: Aristech Chemical WDW #3

## FULL DIAMETER PERMEABILITY AND POROSITY

| Sample Number | Depth (feet) | Permeability Horz (md) | Horz-90 (md) | Vert (md) | Porosity % | Grain Density (gm/cc) | Lithology |
|---|---|---|---|---|---|---|---|
| 77 | 6027.0-28.0 | 6.8 | 6.6 | 7.6 | 10.3 | 2.63 ✓ | Sd |
| 78 | 6028.0-29.0 | 30. | 2.1 | 13. | 6.6 | 2.67 ✓ VF | Sd |
| 79 | 6029.0-30.0 | 11. | 5.2 | 13. | 8.5 | 2.65 ✓ VF | Sd |
| 80@ | 6030.0-31.0 | 5.7 | NA | 18.+ | 12.1 | 2.64 ✓ | Sd |
| 81 | 6031.0-32.0 | 4.4 | 2.6 | NA | 11.0 | 2.65 ✓ | Sd |
| 82 | 6032.0-33.0 | 5.2 | 5.2 | NA | 9.0 | 2.65 ✓ | Sd |
| 83 | 6033.0-34.0 | 5.7 | 5.5 | NA | 9.6 | 2.63 ✓ | Sd |
| 84 | 6034.0-35.0 | 5.6 | 3.8 | NA | 12.6 | 2.60 ✓ | Sd |
| 85 | 6035.0-36.0 | 2.7 | 2.0 | NA | 13.3 | 2.60 ✓ | Sd |
| 86 | 6036.0-37.0 | 2.1 | 1.3 | 3.9 | 14.6 | 2.59 ✓ | Sd |
| 87 | 6037.0-38.0 | 2.8 | 2.1 | 2.2 | 13.0 | 2.61 ✓ | Sd |
| 88@ | 6038.0-39.0 | 3.7 | NA | 3.7 | 14.7 | 2.58 ✓ | Sd |
| 89@ | 6039.0-40.0 | 3.1 | NA | 8.7 | 15.5 | 2.58 ✓ | Sd |
| 90@ | 6040.0-41.0 | 1.2 | NA | 5.7 | 13.3 | 2.59 ✓ | Sd |
| 91 | 6041.0-42.0 | 3.8 | 2.0 | 4.2 | 13.9 | 2.57 ✓ VF | Sd |
| 92 | 6042.0-43.0 | 3.9 | 1.3 | 3.4 | 15.3 | 2.63 ✓ VF | Sd,few sh lam |
| 93 | 6043.0-44.0 | 6.3 | 1.6 | 8.9 | 14.5 | 2.60 ✓ VF | Sd,few sh lam |
| 94 | 6044.0-45.0 | .60 | .27 | .39 | 10.8 | 2.65 ✓ VF | Sd,sl/lmy |
| 95 | 6045.0-46.0 | .04 | .02 | .05 | 6.0 | 2.66 ✓ VF | Sd,sl/shy |
| 96 | 6046.0-47.0 | 279. | .10 | 489. | 8.8 | 2.65 ✓ VF | Sd,sl/shy,sh lam |

+ - Dehydration crack affecting permeability
VF - Vertical fracture present
@ - Plug Dean-Stark analysis - Not suitable for full diameter sampling

# TerraTek Core Services, Inc.®

University Research Park - 360 Wakara Way - Salt Lake City, Utah 84108 - (801) 584-2480 - TWX 910-925-5284

ENVIROCORP SERVICES & TECHNOLOGY, INC. Date: 7-DEC-1989 TTCS File #: 5398

Well: Aristech Chemical WDW #3

## FULL DIAMETER PERMEABILITY AND POROSITY

| Sample Number | Depth (feet) | Permeability Horz (md) | Horz-90 (md) | Vert (md) | Porosity % | Grain Density (gm/cc) | Lithology |
|---|---|---|---|---|---|---|---|
| 97 | 6047.0-48.0 | 15. | .02 | 15. | 5.2 | 2.71 VF | Sd,sl/dol,sl/shy |
| 98 | 6048.0-49.0 | .03 | .01 | .02 | 1.6 | 2.70 | Sd,sl/dol,sh lam |
| 99 | 6049.0-50.0 | <.01 | <.01 | <.01 | 1.0 | 2.74 | Sd,dol,sh lam |
| 100 | 6050.0-51.0 | .02 | .02 | <.01 | 2.2 | 2.74 | Sd,dol,sh lam |
| 101 | 6051.0-52.0 | <.01 | <.01 | <.01 | 2.4 | 2.69 | Sd,sl/dol,sh lam |
| 102 | 6052.0-53.0 | <.01 | <.01 | <.01 | 1.7 | 2.68 | Sd,sl/dol,sh lam |
| 103 | 6053.0-54.0 | .02 | .01 | <.01 | 2.7 | 2.72 | Sd,dol,sh lam |
| 104 | 6054.0-55.0 | .06 | .05 | <.01 | 5.5 | 2.70 | Sd,dol,sh lam |
| 105 | 6055.0-56.0 | .24+ | .09 | .02 | 6.6 | 2.69 | Sd,dol,few sh lam |
| 106 | 6056.0-57.0 | .28+ | .13 | .03 | 7.4 | 2.69 | Sd,dol,few sh lam |
| 107 | 6057.0-58.0 | .09 | .09 | NA | 8.2 | 2.70 | Sd,dol |
| 108 | 6058.0-59.0 | .25 | .25 | NA | 7.2 | 2.65 | Sd |
| 109 | 6059.0-60.0 | .16 | .08 | .01 | 5.3 | 2.69 | Sd,sl/dol |
| 110 | 6060.0-61.0 | .01 | .01 | <.01 | 4.8 | 2.69 | Sd,sl/dol,few sh lam |
| 111 | 6061.0-62.0 | 1.3 | .21 | .36 | 7.8 | 2.71 VF | Sd,sl/dol |
| 112 | 6062.0-63.0 | .03 | .03 | .03 | 5.8 | 2.70 | Sd,sl/dol,few sh lam |
| 113 | 6063.0-64.0 | .87+ | .05 | .85 | 6.1 | 2.70 | Sd,dol,sh lam |
| 114 | 6064.0-65.0 | .09 | .08 | .02 | 6.2 | 2.66 | Sd,sl/dol,sh lam |
| 115 | 6065.0-66.0 | .08 | .02 | .04 | 4.7 | 2.68 | Sd,sl/dol,few sh lam |
| 116 | 6066.0-67.0 | .01 | .01 | .01 | 4.8 | 2.69 | Sd,sl/dol,sh lam |
| 117 | 6067.0-68.0 | 15. | .02 | 3.8 | 5.2 | 2.69 VF | Sd,sl/dol,sh lam |

+ - Dehydration crack affecting permeability
VF - Vertical fracture present

# TerraTek Core Services, Inc.®

University Research Park - 360 Wakara Way - Salt Lake City, Utah 84108 - (801) 584-2480 - TWX 910-925-5284

ENVIROCORP SERVICES & TECHNOLOGY, INC. Date: 7-DEC-1989 TTCS File #: 5398

Well: Aristech Chemical WDW #3

## FULL DIAMETER PERMEABILITY AND POROSITY

| Sample Number | Depth (feet) | Permeability Horz (md) | Horz-90 (md) | Vert (md) | Porosity % | Grain Density (gm/cc) | | Lithology |
|---|---|---|---|---|---|---|---|---|
| 118 | 6068.0-69.0 | .02 | .01 | .01 | 3.6 | 2.70 | | Sd,sl/dol,sh lam |
| 119 | 6069.0-70.0 | .04 | .03 | .02 | 4.4 | 2.61 | | Sd,sl/lmy,sh lam |
| 120 | 6070.0-71.0 | .02 | .01 | <.01 | 3.4 | 2.63 | | Sd,sh lam |
| 121 | 6071.0-72.0 | .05 | .05 | .01 | 2.4 | 2.67 | | Sd,sl/lmy,sh lam |
| 122 | 6072.0-73.0 | .07+ | .02 | <.01 | 0.9 | 2.70 | | Sd,sl/dol,sh stks |
| 123 | 6073.0-74.0 | .03 | <.01 | .02 | 0.7 | 2.76 | | Sd,dol,sh stks |
| 124 | 6074.0-75.0 | .06 | .02 | .06 | 0.9 | 2.82 | | Dol,sdy,sh stks |
| 125 | 6075.0-76.0 | <.01 | <.01 | NA | 2.8 | 2.75 | | Sd,dol |
| 126 | 6076.0-77.0 | 1.3+ | .18+ | .02 | 4.5 | 2.76 | | Sd,dol,sl/shy |
| 127 | 6077.0-78.0 | .63+ | .04 | NA | 2.9 | 2.71 | | Sd,dol,sl/shy |
| 128@ | 6078.0-79.0 | <.01 | NA | .92+ | 2.0 | 2.73 | | Sd,dol,sl/shy |
| | **Granite Basement** | | | | | | | |
| 129 | 6079.0-80.0 | 20. | .05 | 6.7 | 3.4 | 2.63 | VF | Ign |
| 130@ | 6080.0-81.0 | .13+ | NA | .01 | 1.9 | 2.71 | | Ign,pyr |
| 131 | 6081.0-82.0 | .03 | .02 | .02 | 2.2 | 2.62 | | Ign |
| 132 | 6082.0-83.0 | .01 | .01 | .03 | 1.8 | 2.61 | | Ign |
| 133 | 6083.0-84.0 | .02 | .02 | .03 | 1.1 | 2.65 | | Ign |
| 134 | 6084.0-85.0 | .07 | .05 | .09 | 1.5 | 2.64 | | Ign |
| 135 | 6085.0-86.0 | .44+ | .02 | .03 | 2.5 | 2.66 | | Ign |
| 136 | 6086.0-87.0 | 2.2+ | .07 | .41 | 2.4 | 2.66 | | Ign |
| 137 | 6087.0-88.0 | .06 | .02 | .03 | 1.5 | 2.65 | | Ign |

+ - Dehydration crack affecting permeability
VF - Vertical fracture present
@ - Plug Dean-Stark analysis - Not suitable for full diameter sampling

40' ≤ 2.65

# TerraTek Core Services, Inc.®

University Research Park - 360 Wakara Way - Salt Lake City, Utah 84108 - (801) 584-2480 - TWX 910-925-5284

ENVIROCORP SERVICES & TECHNOLOGY, INC. Date: 7-DEC-1989 TTCS File #: 5398

Well: Aristech Chemical WDW #3

## FULL DIAMETER PERMEABILITY AND POROSITY

| Sample Number | Depth (feet) | Permeability Horz (md) | Permeability Horz-90 (md) | Permeability Vert (md) | Porosity % | Grain Density (gm/cc) | Lithology |
|---|---|---|---|---|---|---|---|
| 138 | 6088.0-89.0 | .02 | .02 | .03 | 2.3 | 2.67 | Ign |
| 139 | 6089.0-90.0 | .02 | .01 | .02 | 2.3 | 2.66 | Ign |
| 140 | 6090.0-91.0 | .13+ | .11+ | .02 | 1.5 | 2.69 | Ign |
| 141 | 6091.0-92.0 | .27+ | .16+ | .04 | 2.5 | 2.68 | Ign |
| 142 | 6092.0-93.0 | .01 | .01 | .02 | 1.0 | 2.65 | Ign |
| 143 | 6093.0-94.0 | .03 | .03 | .04 | 0.9 | 2.66 | Ign |
| 144 | 6094.0-95.0 | .02 | <.01 | .02 | 1.3 | 2.69 | Ign |
| 145 | 6095.0-96.0 | 6.3+ | 3.6+ | .02 | 0.5 | 2.71 | Ign |
| 146 | 6096.0-97.0 | .01 | .01 | .02 | 0.8 | 2.76 | Ign |
| 147 | 6097.0-98.0 | .01 | <.01 | .02 | 0.3 | 2.73 | Ign |
| 148 | 6098.0-99.0 | .01 | .01 | .02 | 0.3 | 2.76 | Ign |
| 149 | 6099.0-00.0 | <.01 | <.01 | .01 | 0.3 | 2.77 | Ign |
| 150 | 6100.0-01.0 | .01 | .01 | .06 | 0.2 | 2.74 | Ign |
| 151 | 6101.0-02.0 | <.01 | <.01 | .05 | 0.8 | 2.82 | Ign |
| 152 | 6102.0-03.0 | .01 | .01 | .03 | 0.7 | 2.84 | Ign |
| 153 | 6103.0-04.0 | .03 | .02 | .06 | 0.6 | 2.74 | Ign |
| 154 | 6104.0-05.0 | .01 | .01 | .01 | 0.3 | 2.76 | Ign |
| 155 | 6105.0-06.0 | <.01 | <.01 | .01 | 0.4 | 2.77 | Ign |
| 156 | 6106.0-07.0 | .01 | .01 | .01 | 0.3 | 2.72 | Ign |
| 157 | 6107.0-08.0 | .51+ | .40+ | .04 | 1.3 | 2.72 | Ign |
| 158 | 6108.0-09.0 | 1.5+ | 1.1+ | .06 | 1.1 | 2.69 | Ign |

+ - Dehydration crack affecting permeability

P2-90 002633 Box 31

# APPENDIX 5.3-C

## CHEMICAL ANALYSIS, BEREA SAMPLE IN SCIOTO COUNTY BRINE WELL

No. 20

Brine Sample No. 20
U. S Lab No 182

GEOLOGICAL SURVEY OF OHIO
WILBER STOUT, State Geologist
COLUMBUS

BULLETIN 37

# TESTS ON SAMPLES

Material sampled Brine
Name of bed Berea sand

Sampled by W. M. Knight, Portsmouth
Date of sampling March, 1931
Tests made by Downs Schaaf, analyst

County Scioto
Township Jefferson
Section 9 (Houston Hollow)
Property owner Chas. Ziegler lease #2
Operator Local company, Edward Kleffner, president, W. M. Knight, secretary, 502 Union St Portsmouth

1.0770 @ 20°C

Specific gravity, 1.078 at 15°C. Mineral sediment, none.

| | Composition of saline matter | |
|---|---|---|
| Cl | 62.78 | — 68.98 Gr/Liter |
| Br | 0.47 | — .5170 Gr/Liter |
| $SO_4$ | 0.05 | |
| $CO_3$ | none | |
| $HCO_3$ | 0.02 | |
| Na | 22.86 | — 25.13 Gr/Liter |
| K | 0.20 | — .220 |
| Ca | 10.80 | |
| Mg | 2.65 | |
| $(Al.Fe)_2O_3$ | 0.15 | |
| $SiO_2$ | 0.02 | |
| Sr | ---- | |
| | 100.00 | |

Total dissolved solids 110.0 grams per liter
109.86 gm/L @ 1.0770
102.0 " " kilogram

Driller's record

Elevation of well head, 655 ft.

| | Top | Bottom |
|---|---|---|
| Berea sand | 256 | 315 |
| Total depth | | 339 |

Pumps about one-inch stream of brine regularly.
Water 8 feet in sand or at 264 feet.

Brine Sample No. 46
DS Lab. No. 263

No. 46

GEOLOGICAL SURVEY OF OHIO
WILBER STOUT, State Geologist
COLUMBUS

BULLETIN 37

# TESTS ON SAMPLES

Material sampled Brine
Name of bed Second Water of Big Lime

Sampled by W. R. Maxey
Date of sampling Oct., 1931
Tests made by Downs Schaaf

County Lawrence
Township Elizabeth
Section 25
Property owner Ceramic Clay Co. No. 1
Operator Ohio Fuel Gas Co.

1.159 @ 20°C

Specific gravity, 1.16 at 15°C. Mineral sediment, none

Composition of saline matter

| | | | |
|---|---|---|---|
| Cl | 152,218 | 62.69 | — 1.52.20 Gr/Liter |
| Br | 1,967 | 0.81 | 1.96-10 Gr/Liter |
| $SO_4$ | 291 | 0.12 | .29 |
| $CO_3$ | | none | |
| $HCO_3$ | 486 | 0.02 | |
| Na | 45,211 | 18.62 | 1.720 gr/Liter |
| K | 1,627 | 0.67 | — 1.628 Gr/Liter |
| Ca | 31,857 | 13.12 | |
| Mg | 8,110 | 3.34 | |
| $(Al.Fe)_2O_3$ | 85 | 0.035 | |
| $SiO_2$ | 12 | 0.005 | |
| Sr | 1,334 | 0.57 | |
| | | 100.000 | |

Total dissolved solids 243.02 grams per liter
242.81 g/l
209.5 grams per kilogram

Drillers record

Brine from a depth of about 2,800 ft.

| | Top | Bottom | |
|---|---|---|---|
| Sand | 520 | 540 | No water |
| Sand | 585 | 597 | 25,500 cu.ft. at 592 |
| Salt sand | 665 | 710 | ½ bbl. water 675-680 |
| Sand | 720 | 760 | 3 " " 740 |
| Maxton sand | 760 | 770 | |
| Big Injun sand | 865 | 1078 | |
| Hamden sand | 1340 | 1350 | |
| Berea grit sand | 1480 | 1528 | Hole full water. No oil or gas |
| Niagara lime | 2340 | 2948 | Brine sample about 2800 : |
| Clinton sand | 3199 | 3207 | 94,560 cu.ft. No oil or water |
| Total depth | | 3252 | |

No shale, etc.

Sample #121

82751

# GEOLOGICAL SURVEY OF OHIO

JOHN H. MELVIN, State Geologist
COLUMBUS

## TESTS ON SAMPLES

**Material sampled** Brine
**Name of bed** Trempealeau
Depth 3840' Bailer sample
**Sampled by**
**Date of sampling** Nov. 1964
**Tests made by** Dow Chemical
W7-512

Quad. Sciotoville
**County** Scioto
**Township** Harrison
**Section** SE 17
**Property owner** Albert R. Will #1
**Operator** Young & Henneberger
Well permit #202

Brine Bottle No. 93

1.1725 @ 20/20°C

| | |
|---|---|
| Sp. Gr. at 25/25°C | 1.1771 |
| °Be' | 21.8 |
| % $CaCl_2$ | 6.04 |
| % $MgCl_2$ | 2.17 |
| Ratio %$CaCl_2$/%$MgCl_2$ | 2.78 |
| % NaCl | 12.76 |
| % KCl | 0.53 |
| | 21.50 |

215.0 gm/liter

253.38 gm/l.

FORM PB 7-62

PAN AMERICAN PETROLEUM CORPORATION

RESEARCH DEPARTMENT

WATER ANALYSIS

Note – This is Old Blank Sample #121

W-398-D

Lease Albert R. Will Well No. 1 Lab. No. T-16758

Field County Scioto State Ohio

Quarter or Survey Twp. Harrison 1/4 SE Blk. Section 17 T. R.

Exact Location Sample Series No.

Producing Stratum PBTD Total Depth

Stratum Yielding Sample Trempealeau From To

Condition of Well Method Used Bailer Cable Tool

Sample Collected From Date Collected Date Received

Collected by Date File

Transmittal Letter by

(Central Division)

| Radicle | Per Cent by Analysis | (a) P. P. M. | (b) | (a) X (b) | Per Cent Reacting Value | Calculated Compound | P. P. M. |
|---|---|---|---|---|---|---|---|
| Na | 23.19 | 55,397 | .0435 | 2,409.85 | 28.27 | $Na_2SO_4$ | |
| Ca | 10.50 | 25,100 | .0499 | 1,252.49 | 14.69 | NaCl | 140,828 |
| Mg | 3.05 | 7,300 | .0822 | 600.06 | 7.04 | $Na_2CO_3$ | |
| Fe | | | | | | $NaHCO_3$ | 47 |
| | | | | | | $CaSO_4$ | 248 |
| | | | | | | $CaCl_2$ | 69,311 |
| $SO_4$ | .07 | 175 | .0208 | 3.64 | .04 | $CaCO_3$ | |
| Cl | 63.18 | 151,000 | .0282 | 4,258.20 | 49.95 | $Ca(HCO_3)_2$ | |
| $CO_3$ | 0 | 0 | .0333 | 0 | 0 | $MgSO_4$ | |
| $HCO_3$ | .01 | 34 | .0164 | .56 | .01 | $MgCl_2$ | 28,572 |
| $H_2S$ | | | | | | $MgCO_3$ | |
| | | | | | | $Mg(HCO_3)_2$ | |

Total solids as a summation of radicles 239,006 P.P.M.

Total solids by evaporation and ignition of residue at low red heat 259,760 P.P.M.

Sample as received: Resistivity: ohms/MM .046 at 77°F. | pH Value 5.4 | Specific Gravity 60°/60°F. 1.178

## PROPERTIES OF REACTION IN PER CENT

PRIMARY SALINITY: $SO_4 + Cl$ = ..... with equal value Na (K) ..... = 56.54 %

SECONDARY SALINITY: If $SO_4 + Cl$ is greater than Na (K) ..... = ..... %

Then $SO_4 + Cl$ = ..... with equal value of Ca + Mg ..... = 43.44 %

PRIMARY ALKALINITY: Excess Na (K) over $SO_4 + Cl$ = ..... with equal value of $CO_3 + S$ ..... = ..... %

SECONDARY ALKALINITY: Excess Ca + Mg over $SO_4 + Cl$ = ..... with equal value of $CO_3 +$ ..... = .02 %

CHLORIDE SALINITY: $Cl + (SO_4 + Cl)$ = ..... X 100% ..... = 99.92

SULPHATE SALINITY: $SO_4 + (SO_4 + Cl)$ = ..... X 100% ..... = .08

NOTE: Multiply Parts per Million by .0583 to obtain Grains per Gallon.

REMARKS:

K. W. Bolt
R. S. Tremaine
G. W. Schmidt (4)

mg/l (ppm)

Iodide 0
Bromide 520

Analyst James J. Elliott Date 12-15-64

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

File No. 308

County Scioto

Township Bloom

Section 35

15' Quad. Oak Hill

7½' Quad.

# TESTS ON SAMPLES

Material sampled Brine

Name of bed depths of 1000', 1500' and 1900'

Sampled by

Date of sampling 1-4-53

Tests made by Dow Chemical

Laboratory number SSR 184-613

Property owner Dow Ironton #3 T.D. 2030

Operator

Samples taken at completion of bailing

First Day 1910-1940 Second Day 1950-1972

| Sample No. | 2 | 2 | 1 |
|---|---|---|---|
| Depth from top of well | 1900 | 1500 | 1000 |
| Sp. Gr. at 20°C | 1.1967 | 1.1967 | 1.1967 |
| °Be' | 23.83 | 23.83 | 23.83 |
| % $CaCl_2$ | 9.30 | | |
| % $MgCl_2$ | 3.09 | | |
| $\frac{\%CaCl_2}{\% MgCl_2}$ | 3.0 | | |
| %KCl | 0.26 | | |
| % NaCl | 10.3 | | |
| % Br | .1521 | | |
| % $I_2$ | .0012 | | |

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

File No. 305

County Scioto

Township Green

Section Lot 29

15' Quad. Greenup

7½' Quad.

# TESTS ON SAMPLES

Material sampled Brine

Name of bed

Sampled by

Date of sampling 3/12/53

Tests made by Dow Chemical

Laboratory number SSR 186-831

Property owner Dow Ironton Well 5 T.D. 1631

Operator

Located 4 miles south of Wheelersburg on U. S. 52

| | | |
|---|---|---|
| Sample depth from surface | 200 | 1500 |
| Sp. Gr. at 20°C | 1.1817 | 1.1817 |
| °Be' | 22.30 | 22.30 |
| % $CaCl_2$ | 8.67 | 8.64 |
| % $MgCl_2$ | 2.98 | 3.00 |
| Ratio $\frac{\%CaCl_2}{\%MgCl_2}$ | 2.9 | 2.9 |
| % NaCl | 9.4 | 9.4 |
| % KCl | 0.22 | 0.24 |
| % $Br_2$ | 0.1372 | 0.1371 |
| % $I_2$ | 0.0010 | 0.0010 |

Samples taken at completion of bailing.

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

File No. 306
County Lawrence
Township Hamilton
Section 5
15' Quad. Greenup
7½' Quad.

# TESTS ON SAMPLES

Material sampled Brine
Name of bed Depth
Sampled by
Date of sampling 12-4-62

Tests made by Dow Chemical
Laboratory number SSR 183-620
Property owner Dow Ironton #2
Operator

#2 Ironton - Section 7, Hamilton Twp., Lawrence County, Ohio, Total depth 2031 ft. The Sp. Gr. on this sample appears low indicating some dilution.

| | |
|---|---|
| Spec. Gr. at 20/20C° | 1.1897 |
| °Be' | 23.12 |
| % $CaCl_2$ | 8.99 |
| % $MgCl_2$ | 2.88 |
| % NaCl | 9.90 |
| % KCl | 0.21 |
| Ratio $\frac{\%CaCl_2}{\%MgCl_2}$ | 3.12 |
| % Br | 0.1496 |
| % I | 0.0011 |

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

File No. 307
County Lawrence
Township Elizabeth
Section 4
15' Quad. Ironton
7½' Quad.

# TESTS ON SAMPLES

Material sampled Brine
Name of bed depth 250' and 2250'
Sampled by
Date of sampling 3-16-53

Tests made by Dow Chemical
Laboratory number SS$^{A}$ 186-217
Property owner Dow Ironton well 4 T.D.234
Operator

Sample taken from bailer at depth indicated after acidifying and com,etion of bailing.

| | | |
|---|---|---|
| Sample depth from surface (ft.) | 250 | 2250 |
| Sp. Gra. at 20°C | 1.2045 | 1.2062 |
| °Be' | 24.62 | 24.79 |
| % $CaCl_2$ | 9.84 | 9.82 |
| % $MgCl_2$ | 3.52 | 3.39 |
| Ratio $\frac{\%CaCl_2}{\%MgCl_2}$ | 2.80 | 2.90 |
| % NaCl | 9.9 | 10.5 |
| % KCl | 0.24 | 0.24 |
| % Br | 0.1485 | 0.1525 |
| % $I_2$ | 0.0013 | 0.0013 |

PI-91

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Box 34

APPENDIX 9.1-A

INTERFERENCE TEST ANALYSIS

### 8.3.4 Pressure Transient Well Tests and Final Injection Interval Parameter Assignments

Three types of well tests were conducted and analyzed during the calibration process conducted in order to model the Aristech Chemical Corporation, Haverhill, Ohio site: pressure fall-off, step-rate, and inter-well pressure interference tests. Analysis of these tests, along with the discussion of other related injection interval parameter assignments are included in the following section.

Fall-Off Test Analysis

Preliminary reservoir characterization for the Aristech Chemical Corporation, Haverhill, Ohio facility was accomplished through the analysis of injection pressure fall-off tests. Figures 8.3.4-1 and 8.3.4-2 exhibit plots of these pressure fall-off tests as pressure versus the logarithm of elapsed shut-in time.

The first step in analysis of the pressure fall-off portion of pressure transient data is based upon treating each well as injecting for a long time at a constant rate, q, prior to shut-in. Basic transient pressure theory (Collins, 1961) then indicates that the bottomhole pressure should decrease in accord with

$$(1) \qquad P_{BH} = P_{FL} - 2420.6 \frac{q\mu}{Kh} \left[-Ei \left(- \frac{\phi\mu c R^2}{1.056 \times 10^{-3} K \Delta t}\right) + 2S\right]$$

where

S = skin factor (dimensionless)

R = "effective" well radius (feet)

$P_{FL}$ = bottomhole pressure flowing just prior to shut-in (psi)

$\phi$ = porosity (fraction)

q = flow rate (gpm)

$\mu$ = viscosity of reservoir fluid (cp.)

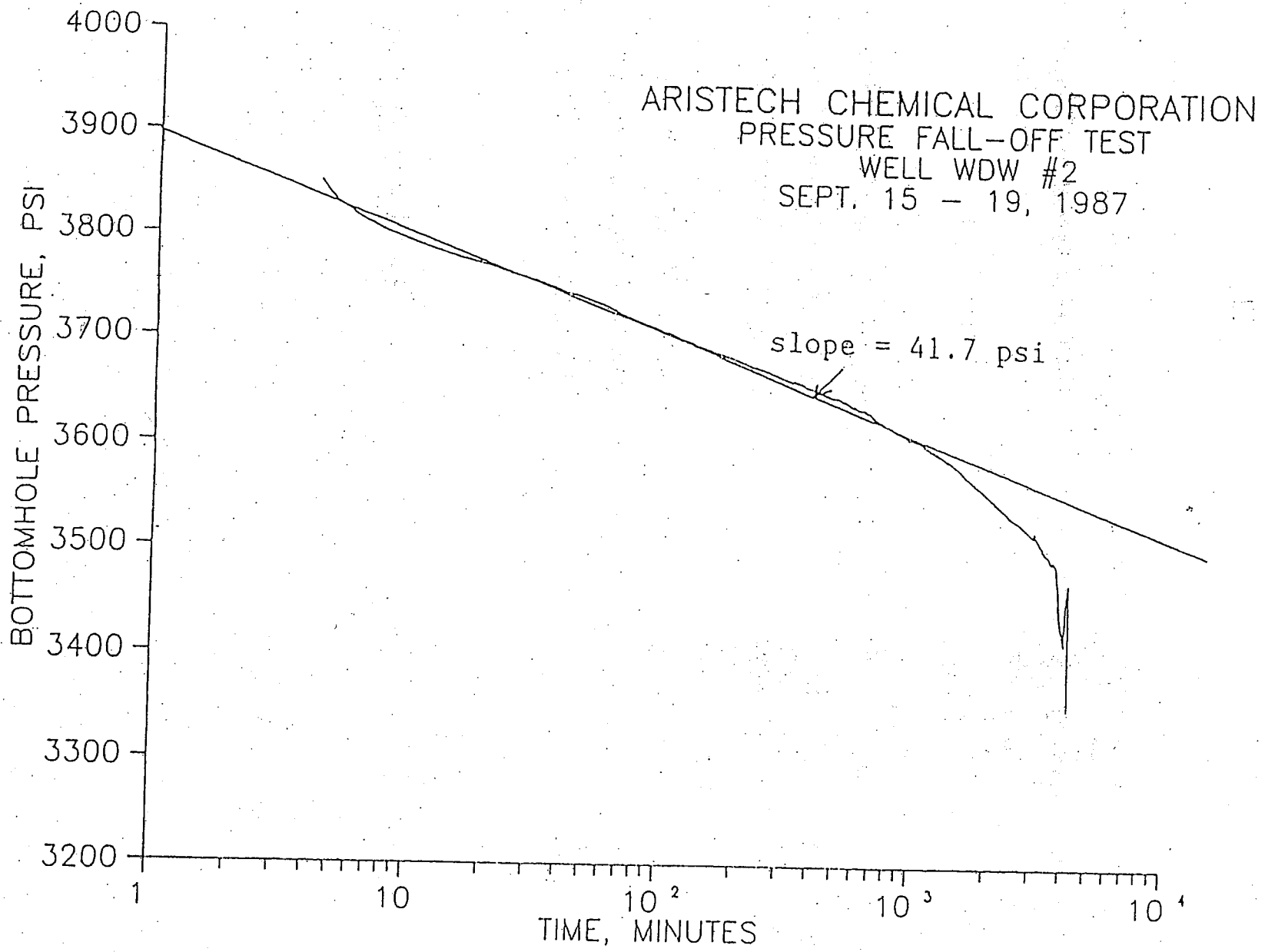
ARISTECH CHEMICAL CORPORATION
PRESSURE FALL-OFF TEST
WELL WDW #2
SEPT. 15 - 19, 1987
slope = 41.7 psi
BOTTOMHOLE PRESSURE, PSI
4000
3900
3800
3700
3600
3500
3400
3300
3200
1
10
10 2
10 3
10 4
TIME, MINUTES

FIGURE 8.3.4-1

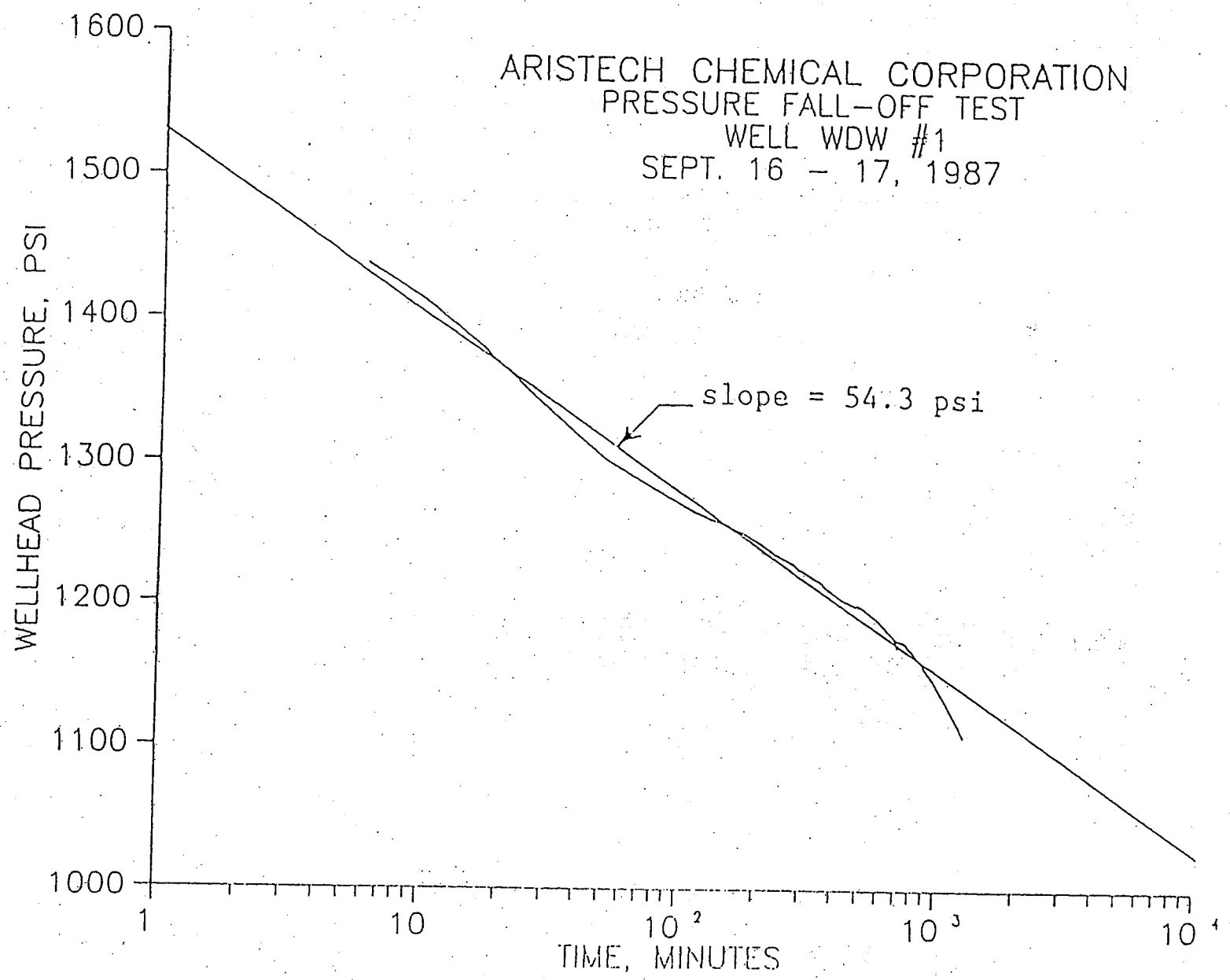
ARISTECH CHEMICAL CORPORATION
PRESSURE FALL-OFF TEST
WELL WDW #1
SEPT. 16 - 17, 1987
slope = 54.3 psi
WELLHEAD PRESSURE, PSI
1600
1500
1400
1300
1200
1100
1000
1
10
10 2
10 3
10 4
TIME, MINUTES

FIGURE 8.3.4-2

P1-91
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Box 34

characteristics of the Mt. Simon disposal interval and account for the over-calculation of pressure during the early time of the November interference test.

## 9.2 Step-Rate Test Analysis

Figure 9.2-1 exhibits the results of the November 30, 1989 step-rate test executed at Aristech Chemical Corporation WDW No. 3. This test was carried out using rates of 21.2 gpm, 27.6 gpm, 31.2 gpm and 33.6 gpm. Figure 9.2-1 indicates that a pressure-sensitive increase in permeability begins when the bottomhole injection pressure reaches a threshold value. Since an injection rate starting at 21.2 gpm caused the pressure to exceed the threshold value prior to stabilization during the first flow period, a specific value for this threshold can not be calculated. However, a qualitative review of the data shows that this critical pressure is less than 3400 psi, and more nearly 3200 psi at a depth of 5416 feet below ground level (BGL). This corresponds to a gradient of between 0.59 psi/ft. and 0.63 psi/ft. When pressure is above a gradient of this magnitude, increases in permeability will occur in the Mt. Simon.

The probable mechanism for this observed pressure-sensitive permeability is the opening of an extensive network of pre-existing micro-fractures in the Mt. Simon. Both lithology descriptions and core data discussed in the geology section and appendices of this document support this view.

The anticipated factor limiting the vertical extension of this fracture opening process is that closing stresses in less competent rocks will be greater than those in the Mt. Simon. These issues are addressed in greater detail in Appendix 9.2-A.

A second step-rate test was performed on WDW No. 3 in March of 1991. Results and analysis of this test will be forwarded to Ohio EPA when they become available.

## 9.3 In-Situ Stress Tests

Numerous in-situ stress tests are scheduled to be run in the test/monitor well which is currently being constructed at Aristech. These test results will have a direct bearing on the calculation of maximum permitted injection pressures at the Aristech facility. Results of the stress testing will be submitted to Ohio EPA as an addendum to this repermit application.

P1-91
Report is about
250 pages long
Vol. IV

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Box 34

APPENDIX 9.0-A

RAW DATA - PRESSURE FALL-OFF, STEP RATE AND INTERFERENCE TESTS FOR WELLS NO. 1, NO. 2 AND NO. 3

PI-91

Bacode 002636

Box 34

APPENDIX 7.3-B

CHEMICAL ANALYSIS OF LOGAN AND BEREA FORMATIONS

SAMPLES FROM TEST/MONITOR WELL

# Test Well Analytical Report
## Berea

| | | Potable Water | Berea Formation Fluid Sample 1 | Duplicate | Avg. |
|---|---|---|---|---|---|
| **InOrganics** | | | | | |
| Alkalinity | ppm | N.A. | 8 | N.A. | 8 |
| Ammonia-Nitrogen | ppm | N.A. | 150 | N.A. | 150 |
| Bromide | ppm | N.A. | 564 | 558 | 561 |
| Bicarbonate | ppm | N.A. | 10 | N.A. | 10 |
| Carbonates | ppm | N.A. | 0 | N.A. | 0 |
| Chloride | ppm | | 82500 | 82500 | 82500 |
| Dissolved Oxygen | ppm | N.A. | <0.03 | N.A. | <0.03 |
| Nitrates | ppm | N.A. | 135000 | 133000 | 134000 |
| Tot.Dissol.Solids | ppm | N.A. | 2680 | N.A. | 2680 |
| Tot.Suspnd Solids | umohms/cm | N.A. | 192000 | N.A. | 192000 |
| Specific Conductance | units | N.A. | 1.095 | 1.095 | 1.095 |
| Specific Gravity | ppm | N.A. | 5.2 N | N.A. | 5.2 N |
| Silicates | ppm | N.A. | <5 | <5 | <5 |
| Sulfates | | | | | |
| Viscosity | | | | | |
| **Metals** | | | | | |
| Aluminum | ppm | N.A. | 0.186b | N.A. | 0.186b |
| Barium | ppm | N.A. | 141 E | N.A. | 141 E |
| Calcium | ppm | N.A. | 9790 | N.A. | 9790 |
| Hex.Chromium | ppm | | 0.0248 N | N.A. | 0.025 N |
| Tot.Chromium | ppm | N.A. | 188 E | N.A. | 188 E |
| Iron | ppm | N.A. | 0.719 S | N.A. | 0.719 S |
| Lead | ppm | N.A. | 2960 | N.A. | 2960 |
| Magnesium | ppm | N.A. | 2.540 EN | N.A. | 2.540 EN |
| Manganese | ppm | N.A. | 260 | N.A. | 260 |
| Potassium | ppm | N.A. | 32900 | N.A. | 32900 |
| Sodium | | | | | |
| **Volatiles** | | | | | |
| Acetone | ppm | 0.005 BJ | 0.410 BJ | N.A. | N.D. BL |
| Toluene | ppm | 0.002 J | 0.640 | N.A. | 0.640 L |
| Formic Acid | ppm | N.A. | <10 | <10 | <10 |
| **Other Volatiles** | | | | | |
| Methylene Chloride | ppm | 0.005 B | 0.420 B | N.A. | N.D. BL |
| Benzene | ppm | N.D. | 0.200 J | N.A. | 0.200 J |
| Methyl Ethyl Ketone | ppm | 0.120 | N.D. | N.A. | N.D. L |
| Chloroform | ppm | 0.023 | N.D. | N.A. | N.D. |
| Bromoform | ppm | 0.001 J | N.D. | N.A. | N.D. |
| Bromodichloromethane | ppm | 0.012 | N.D. | N.A. | N.D. |
| Dibromochloromethane | ppm | 0.006 | N.D. | N.A. | N.D. |
| Ethylbenzene | ppm | 0.039 | 0.200 J | N.A. | 0.200 J |
| Xylenes (total) | ppm | 0.190 | 2.000 | N.A. | 2.0 |
| 4-Methyl-2-Pentanone | ppm | 0.017 | N.D. | N.A. | N.D. |

# Test Well Analytical Report
## Berea

| | | Potable Water | Berea Formation Fluid Sample 1 | Duplicate | Avg. |
|---|---|---|---|---|---|
| **Semi-Volatiles** | | | | | |
| Acetophenone | ppm | N.D. | N.D. | N.D. | N.D. |
| Alpha-Picoline | ppm | N.D. | N.D. | N.D. | N.D. |
| Aniline | ppm | N.D. | N.D. | N.D. | N.D. |
| Phenol | ppm | N.D. | N.D. | N.D. | N.D. |
| Cumene (screen) | ppm | N.D. | N.D. | N.D. | N.D. |
| DiMethylBenzylAlcohol | ppm | N.D. | N.D. | N.D. | N.D. |
| DiPhenylAmine | ppm | N.D. | N.D. | N.D. | N.D. |
| **Other Semi-Volatiles** | | | | | |
| 2-Methylnaphthalene | ppm | N.D. | N.D. | N.D. | N.D. |
| N-Nitrosodiphenylamine | ppm | N.D. | N.D. | N.D. | N.D. |
| bis(2Ethylhexyl)Phthalate | ppm | N.D. | 0.004 J1 | 0.003 J1 | 0.004 J1 |
| | | | 0.009 J | 0.005 J | 0.007 JL |
| **Total Phenolics** | | | | | |
| Formation | ppm | N.A. | <0.050 | N.A. | <0.050 |
| Before Formation | ppm | N.A. | <0.050 | N.A. | <0.050 |
| After Formation | ppm | N.A. | 0.090 | 0.070 | 0.080 |

Footnotes:

1 - N-Nitrosodiphenylamine can not be seperated from Diphenylamine

b - reported value obtained was less than the CRDL (Contract Required Detection/Reporting Limit) but greater than or equal to the IDL (Instrument Detection Limit).

U - value was less than the IDL or was not detected.

E - reported value was estimated because of interference.

N - spiked sample recovery was not within control limits.

B - analyte is found in the associated blank as well as the sample. Possible blank contamination: the data user should evaluate this data carefully.

J - estimated value. Mass spectral data indicates the presence of a compound below the PQL (Procedural Quantification Limit).

L - common laboratory cross-contaminant. Result is reported as "non-detect" if result is less than 10 times the concentration found in any associated blank. Also, cross-contaminant may be introduced into sample upon dilution, even where it does not appear in any associated blank.

S - reported value was determined by method of standard additions.

ND (or N.D.) - Not Detected. If the sample concentration is less than 10 times the concentration of a material found in the blank, then the result is taken as "non-detected". Also, "non-detected" is used when one sample of a pair has a reading, but duplicate or split samples does not show similar readings.

NA (or N.A.) - not analyzed.

P1-91

Barcode 002636

Box 34

APPENDIX 7.3-C

CHEMICAL ANALYSES OF WATER SAMPLES, WDW NO. 3

BEREA FORMATION

Formation Water Analysis Sample Collected From

Repeat Formation Test

Completed April 14, 1989

Depth 707 feet MD

Technical Testing Laboratories Inc.

# LABORATORY ANALYSIS REPORT

ARISTECH CHEMICAL CORPORATION

WDW #3 ICD LAB GRAB WATER
707 FT DEPTH

Date Sampled 04/14/89

Laboratory Number J0457

Sampled by CLIENT
Date Received 04/17/89

Respectfully Submitted:

ANALYSIS FOR REQUESTED PARAMETERS
ALL RESULTS ARE ON AN AS RECEIVED BASIS

| PARAMETER | RESULT | MDL | UNITS | METHOD | ANALYZED DATE/TIME/ANALYST |
|---|---|---|---|---|---|
| TOTAL DISSOLVED SOLIDS | 54,000 | 100 | MG/L | E160.1 | 04/24/89 22:30 TS |
| ALKALINITY | 33 | 1 | MG/L | E310.1 | 04/17/89 18:00 CMC |
| TOTAL SUSPENDED SOLIDS | 52 | 5 | MG/L | E160.2 | 04/19/89 21:20 NF |
| SULFATES | 82 | 5 | MG/L | E375.4 | 05/05/89 09:30 SG |
| CHLORIDE | 29,000 | 1 | MG/L | E325.3 | 04/25/89 21:00 CMC |
| HEXAVALENT CHROMIUM | ND | 0.01 | MG/L | SM312B | 04/18/89 18:00 CMC |
| ALKALINITY,CARBONATE | ND | 1 | MG/L | E310.1 | 04/17/89 18:00 CMC |
| ALKALINITY, BICARBONATE | 33 | 1 | MG/L | E310.1 | 04/17/89 18:00 CMC |
| NITROGEN, AMMONIA | 51 | 0.5 | MG/L | E350.2 | 04/20/89 13:00 TF |
| NITROGEN, NITRATE | ND | 0.06 | MG/L | E353.3 | 04/18/89 21:00 SK |
| Acetone[67-64-1] | 450 | 10 | ug/L | EPA624 | 04/24/89 22:54 SLH D |
| Toluene[108-88-3] | 1000 | 10 | ug/L | EPA624 | 04/24/89 22:54 SLH D |
| Dimethylbenzyl alcohol | ND | 25 | ug/L | SW8270 | 15/14/89 14:06 RCM |
| Phenol[108-95-2] | 29 | 25 | ug/L | SW8270 | 15/14/89 14:06 RCM |
| Diphenylamine[122-3-4] | ND | 25 | ug/L | SW8270 | 15/14/89 14:06 RCM |
| alpha-Picoline | ND | 25 | ug/L | SW8270 | 15/14/89 14:06 RCM |
| Acetophenone[98-86-2] | ND | 25 | ug/L | SW8270 | 15/14/89 14:06 RCM |
| Aniline[62-53-3] | ND | 25 | ug/L | SW8270 | 05/14/89 14:06 RCM |
| Formic Acid[64-18-6] | 1100 | 50 | MG/L | GC/FID | 05/16/89 11:00 RCM |

ND: Not detected at a concentration greater than or equal to the MDL - Method Detection Limit

FID1: Analysis by GC/FID using the method 8010 column(SP1000/Carbopack).

REF: USEPA; Test Methods For Evaluating Solid Waste; SW-846,3rd Ed.;Nov,1986.

D: Result was obtained from the 1/10 dilution analyzed on 5/02/89 at 18:56.

IS**: Insufficient Sample to complete analysis

REF: USEPA; Methods For Chemical Analysis Of Water And Wastes; March,1983.

Technical Testing Laboratories Inc.

# LABORATORY ANALYSIS REPOR

I[illegible]CH CHEMICAL CORPORATION

W #3 ICD LAB GRAB WATER
7 FT DEPTH

te Sampled 04/14/89

[illegible]aboratory Number J0457

[illegible]ampled by CLIENT
[illegible]e Received 04/17/89

[illegible]ully
[illegible]ed:

[illegible]ASE

ANALYSIS FOR RE[illegible]ED PARAMETERS
ALL RESULTS ARE ON [illegible] RECEIVED BASIS

| PARAMETER | RESU[illegible] | MDL | UNITS | METHOD | DATE [illegible] | ANALYST |
|---|---|---|---|---|---|---|
| lene Hydroperoxide | ND | 25 | ug/L | SW8270 | 05/14 [illegible] | RCM |
| COSITY | IS** | | | | | |
| SOLVED OXYGEN(Lab.Determination) | IS** | 0.5 | MG/L | E360.1 | 05/19 [illegible]<br>05/19 [illegible] | TS<br>TS |

Not detected at a concentration greater than or equal to the MDL - Method Detection Limit

: Analysis by GC/FID using the method 8010 [illegible](SP1000/Carbopack).

USEPA; Test Methods For Evaluating Solid Wastes; SW-846,3rd Ed.;Nov,1986.

Result was obtained from the 1/10 dilution analyzed on 5/02/89 at 18:56.

: Insufficient Sample to complete analysis

USEPA; Methods For Chemical Analysis Of Water And Wastes; March,1983.

Technical Testing Laboratories Inc.

# LABORATORY ANALYSIS REPORT

NISTECH CHEMICAL CORPORATION

WDW #3 ICD LAB GRAB WATER
707 FT DEPTH

Date Sampled 04/14/89

Laboratory Number J0457

Sampled by CLIENT
Date Received 04/17/89

Respectfully Submitted:

ANALYSIS FOR REQUESTED METALS

| PARAMETER | RESULT | MDL | UNITS | METHOD | ANALYZED DATE/TIME/ANALYST |
|---|---|---|---|---|---|
| BARIUM(Total) | 9.2 | 0.01 | MG/L | E200.7 | 05/04/89 18:00 MS |
| CHROMIUM(Total) | ND | 0.025 | MG/L | E200.7 | 05/04/89 18:00 MS |
| LEAD(Total) | ND | 0.08 | MG/L | E200.7 | 05/04/89 18:00 MS |
| IRON(Total) | 2.7 | 0.015 | MG/L | E200.7 | 05/05/89 18:00 MS |
| MANGANESE(Total) | 0.5 | 0.004 | MG/L | E200.7 | 05/05/89 18:00 MS |
| ALUMINUM(Total) | ND | 0.1 | MG/L | E200.7 | 05/05/89 18:00 MS |
| CALCIUM(Total) | 3000 | 0.2 | MG/L | E200.7 | 05/05/89 18:00 MS |
| MAGNESIUM(Total) | 730 | 0.2 | MG/L | E200.7 | 05/05/89 18:00 MS |
| POTASSIUM(Total) | 96 | 0.1 | MG/L | E258.1 | 05/05/89 12:00 DK |
| SODIUM(Total) | 9900 | 0.02 | MG/L | E273.1 | 05/05/89 12:00 DK |

ND: Not detected at a concentration greater than or equal to the MDL - Method Detection Limit

REF: USEPA; Test Methods For Evaluating Solid Waste; SW-846,3rd Ed.;Nov,1986.

REF: USEPA; Methods For Chemical Analysis Of Water And Wastes; March,1983.

NIAGARAN FORMATION (SALINA)

Formation Water Analysis Sample Collected From

Swab Test

Completed July 18, 1989

Depth 1500 feet - 1570 feet MD

Aristech WDW #3 Niagaran Formation Sample
Lancaster Laboratory Incorporated No.: WW 1414238
Date Submitted: 7/20/89

| ANALYSIS | RESULT AS RECEIVED | | LIMIT OF QUANTITATION | |
|---|---|---|---|---|
| Sodium | 42,500. | mg/L | 0.5 | mg/L |
| Potassium | 1,210. | mg/L | 0.5 | mg/L |
| Calcium | 36,400. | mg/L | 0.05 | mg/L |
| Magnesium | 8,970. | mg/L | 0.05 | mg/L |
| Temperature (Measured in the field, value reported separately) | | | | |
| Barium | 1.1 | mg/L | 0.5 | mg/L |
| Alkalinity to pH 8.3 | <1. | mg/L | 1. | mg/L |
| Alkalinity to pH 4.5 | 68. | mg/L | 1. | mg/L |
| Aluminum | 12.9 | mg/L | 0.1 | mg/L |
| pH (Measured in the field, value reported separately) | | | | |
| Specific Gravity | 1.17 | | | |
| Specific Conductance | 445,000. | µmhos/cm | 1. | µmhos/cm |
| Total Dissolved Solids | 277,000. | mg/L | 100. | mg/L |
| Dimethyl Benzyl Alcohol | 0.19 J | mg/L | 0.02 | mg/L |
| Phenol | 0.14 | mg/L | 0.02 | mg/L |
| Diphenylamine | N.D. | | 0.02 | mg/L |
| Alpha-Picoline | N.D. | | 0.02 | mg/L |
| Total Suspended Solids | 337. | mg/L | 7. | mg/L |
| Sulfate | 180. | mg/L | 50. | mg/L |
| Chloride | 139,000. | mg/L | 20. | mg/L |
| Nitrate Nitrogen | <10. | mg/L | 10. | mg/L |
| Carbonate | <1. | mg/L | 1. | mg/L |
| Bicarbonate | 68. | mg/L | 1. | mg/L |
| Dissolved Oxygen | 5.9 | mg/L | 0.5 | mg/L |
| Iron | 122. | mg/L | 0.05 | mg/L |
| Manganese | 2.3 | mg/L | 0.2 | mg/L |
| Viscosity | 2. | cps | 1. | cps |
| Acetone | 0.11 | mg/L | 0.01 | mg/L |
| Cumene Hydroperoxide* | | | | |
| Acetophenone | N.D. | | 0.02 | mg/L |
| Ammonia Nitrogen | 133. | mg/L | 0.5 | mg/L |
| Aniline | <0.02 | mg/L | 0.02 | mg/L |
| Total Chromium | 0.25 | mg/L | 0.05 | mg/L |
| Formic Acid | <5. | mg/L | | |
| Toluene | 0.26 | mg/L | 0.005 | mg/L |
| Lead | <0.3 | mg/L | 0.3 | mg/L |

* - Cumene hydroperoxide could not be determined due to impure reference material, as well as what appeared to be degradation in the chromatographic system.



The ERM Group

< - Indicates the result is less than the smallest amount which can be accurately quantitated.

N.D. - Indicates none detected.

J - Indicates this value is an estimate.

Note: These results have been transcribed by ERM, Inc. from the Lancaster Laboratories Inc. analysis report for the Niagaran Formation sample (LLI# WW 1414238).

P1-91
Barcode 002636
Box 34

APPENDIX 7.3-D

CHEMICAL ANALYSES, FORMATION SAMPLES IN SCIOTO COUNTY BRINE WELLS

No. 20

Brine Sample No. 20
U. S Lab No 182

GEOLOGICAL SURVEY OF OHIO
WILBER STOUT, State Geologist
COLUMBUS

BULLETIN 37

# TESTS ON SAMPLES

Material sampled Brine
Name of bed Berea sand

Sampled by W. M. Knight, Portsmouth
Date of sampling March, 1931
Tests made by Downs Schaaf, analyst

County Scioto
Township Jefferson
Section 9 (Houston Hollow)
Property owner Chas. Ziegler lease #2
Operator Local company, Edward Kleffner, president, W. M. Knight, secretary, 502 Union S Portsmouth

1.0770 20°C

Specific gravity, 1.078 at 15°C. Mineral sediment, none.

| | Composition of saline matter | |
|---|---|---|
| Cl | 62.78 | — 68.95 Gr/Liter |
| Br | 0.47 | — .5170 Gr/Liter |
| $SO_4$ | 0.05 | |
| $CO_3$ | none | |
| $HCO_3$ | 0.02 | |
| Na | 22.86 | — 25.13 Gr/Liter |
| K | 0.20 | — .220 |
| Ca | 10.80 | |
| Mg | 2.65 | |
| $(Al.Fe)_2O_3$ | 0.15 | |
| $SiO_2$ | 0.02 | |
| Sr | ---- | |
| | 100.00 | |

Total dissolved solids 110.0 grams per liter
109.86 gm/L @ 1.0770
102.0 " " kilogram

Driller's record

Elevation of well head, 655 ft.

| | Top | Bottom |
|---|---|---|
| Berea sand | 256 | 315 |
| Total depth | | 339 |

Pumps about one-inch stream of brine regularly.
Water 8 feet in sand or at 264 feet.

Brine Sample No. 46
DS Lab. No. 263

No.

GEOLOGICAL SURVEY OF OHIO
WILBER STOUT, State Geologist
COLUMBUS

BULLETIN 37

# TESTS ON SAMPLES

Material sampled Brine
Name of bed Second Water of Big Lime

Sampled by W. R. Maxey
Date of sampling Oct., 1931
Tests made by Downs Schaaf

County Lawrence
Township Elizabeth
Section 25
Property owner Ceramic Clay Co. No.
Operator Ohio Fuel Gas Co.

1.159 @ 20°C

Specific gravity, 1.16 at 15°C. Mineral sediment, none

Composition of saline matter

| | | |
|---|---|---|
| Cl | 152,218 | 62.69 |
| Br | 1,967 | 0.81 |
| $SO_4$ | 291 | 0.12 |
| $CO_3$ | — | none |
| $HCO_3$ | 486 | 0.02 |
| Na | 45,211 | 18.62 |
| K | 1,627 | 0.67 |
| Ca | 31,857 | 13.12 |
| Mg | 8,110 | 3.34 |
| $(Al.Fe)_2O_3$ | 85 | 0.035 |
| $SiO_2$ | 12 | 0.005 |
| Sr | 1,371 | 0.57 |
| | | 100.000 |

243.02 grams per liter
Total dissolved solids 242.81 g/C
209.5 grams per kilogram

Drillers record

Brine from a depth of about 2,800 ft.

| | Top | Bottom | |
|---|---|---|---|
| Sand | 520 | 540 | No water |
| Sand | 585 | 597 | 25,500 cu.ft.at 592 |
| Salt sand | 665 | 710 | ½ bbl. water 675-680 |
| Sand | 720 | 760 | 3 " " 740 |
| Maxton sand | 760 | 770 | |
| Big Injun sand | 865 | 1078 | |
| Hamden sand | 1340 | 1350 | |
| Berea grit sand | 1480 | 1528 | Hole full water. No oi or gas |
| Niagara lime | 2340 | 2948 | Brine sample about 2800 |
| Clinton sand | 3199 | 3207 | 94,560 cu.ft. No oil o water |
| Total depth | | 3252 | |

Sample #121

82751

GEOLOGICAL SURVEY OF OHIO
JOHN H. MELVIN, State Geologist
COLUMBUS

# TESTS ON SAMPLES

Material sampled Brine
Name of bed Trempealeau
Depth 3840' Bailer sample
Sampled by
Date of sampling Nov. 1964
Tests made by Dow Chemical
W7-512

Quad. Sciotoville
County Scioto
Township Harrison
Section SE 17
Property owner Albert E. Will #
Operator Young & Henneberger
Well permit #202

Brine Bottle No. 93

| | |
|---|---|
| Sp. Gr. at 25/25°C | 1.1771 |
| °Be' | 21.8 |
| % $CaCl_2$ | 6.04 |
| % $MgCl_2$ | 2.17 |
| Ratio %$CaCl_2$/%$MgCl_2$ | 2.78 |
| % NaCl | 12.76 |
| % KCl | 0.53 |

FORM PB 7-62

# PAN AMERICAN PETROLEUM CORPORATION

RESEARCH DEPARTMENT

WATER ANALYSIS

Note - This is Old Blue Sample #121

W-398-D

Lab. No. T-16758

Well No. 1

Albert R. Will

County Scioto State Ohio

Quarter or Survey Twp. Harrison 1/4 SE Blk. Section 17 T. R.

Exact Location Sample Series No.

Producing Stratum PBTD Total Depth

Stratum Yielding Sample Trempealeau From To

Condition of Well Method Used Bailer Cable Tool

Sample Collected From Date Collected Date Received

Collected by Date File

Transmittal Letter by

(Central Division)

| Radicle | Per Cent by Analysis | (a) P. P. M. | (b) | (a) X (b) | Per Cent Reacting Value | Calculated Compound | P. P. M. |
|---|---|---|---|---|---|---|---|
| | | | | | | $Na_2SO_4$ | |
| Na | 23.19 | 55,397 | .0435 | 2,409.85 | 28.27 | NaCl | 140,828 |
| Ca | 10.50 | 25,100 | .0499 | 1,252.49 | 14.69 | $Na_2CO_3$ | |
| Mg | 3.05 | 7,300 | .0822 | 600.06 | 7.04 | $NaHCO_3$ | 47 |
| Fe | | | | | | $CaSO_4$ | 248 |
| | | | | | | $CaCl_2$ | 69,311 |
| | | | | | | $CaCO_3$ | |
| $SO_4$ | .07 | 175 | .0208 | 3.64 | .04 | $Ca(HCO_3)_2$ | |
| Cl | 63.18 | 151,000 | .0282 | 4,258.20 | 49.95 | $MgSO_4$ | |
| $CO_3$ | 0 | 0 | .0333 | 0 | 0 | $MgCl_2$ | 28,572 |
| $HCO_3$ | .01 | 34 | .0164 | .56 | .01 | $MgCO_3$ | |
| $H_2S$ | | | | | | $Mg(HCO_3)_2$ | |
| | | | | | | | |

Total solids as a summation of radicles 239,006 P.P.M.

Total solids by evaporation and ignition of residue at low red heat 259,760 P.P.M.

Sample as received: Resistivity: ohms/M'M .046 at 77°F. | pH Value 5.4 | Specific Gravity 60°/60°F. 1.178

## PROPERTIES OF REACTION IN PER CENT

PRIMARY SALINITY: $SO_4 + Cl$ = ..... with equal value Na (K) ..... = 56.54

SECONDARY SALINITY: If $SO_4 + Cl$ is greater than Na (K) ..... = 43.44

Then $SO_4 + Cl$ = ..... with equal value of Ca + Mg ..... =

PRIMARY ALKALINITY: Excess Na (K) over $SO_4 + Cl$ = ..... with equal value of $CO_3$ + S ..... = .02

SECONDARY ALKALINITY: Excess Ca + Mg over $SO_4 + Cl$ = ..... with equal value of $CO_3$ + .....

CHLORIDE SALINITY: $Cl \div (SO_4 + Cl)$ = ..... X 100% ..... = 99.92

SULPHATE SALINITY: $SO_4 \div (SO_4 + Cl)$ = ..... X 100% ..... = .08

NOTE: Multiply Parts per Million by .0583 to obtain Grains per Gallon.

REMARKS:

K. W. Bolt
R. S. Tremaine
G. W. Schmidt (4)

mg/l (ppm)

Iodide 0
Bromide 520

Analyst James J. Elliott Date 12-15-

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

File No. 308

County Scioto

Township Bloom

Section 35

15' Quad. Oak Hill

7½' Quad.

# TESTS ON SAMPLES

Material sampled Brine

Name of bed depths of 1000', 1500' and 1900'

Sampled by

Date of sampling 1-4-53

Tests made by Dow Chemical

Laboratory number SSR 184-613

Property owner Dow Ironton #3 T.D. 2030

Operator

Samples taken at completion of bailing

First Day 1910-1940 Second Day 1950-1972

| Sample No. | 2 | 2 | 1 |
|---|---|---|---|
| Depth from top of well | 1900 | 1500 | 1000 |
| Sp. Gr. at 20°C | 1.1967 | 1.1967 | 1.1967 |
| °Be' | 23.83 | 23.83 | 23.83 |
| % $CaCl_2$ | 9.30 | | |
| % $MgCl_2$ | 3.09 | | |
| $\frac{\%CaCl_2}{\%MgCl_2}$ | 3.0 | | |
| %KCl | 0.26 | | |
| % NaCl | 10.3 | | |
| % Br | .1521 | | |
| % $I_2$ | .0012 | | |

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

File No. 305

County Scioto

Township Green

Section Lot 29

15' Quad. Greenup

7½' Quad.

# TESTS ON SAMPLES

Material sampled Brine

Name of bed

Sampled by

Date of sampling 3/12/53

Tests made by Dow Chemical

Laboratory number SSR 186-831

Property owner Dow Ironton Well 5 T.D. 16

Operator

Located 4 miles south of Wheelersburg on U. S. 52

| | | |
|---|---|---|
| Sample depth from surface | 200 | 1500 |
| Sp. Gr. at 20°C | 1.1817 | 1.1817 |
| °Be' | 22.30 | 22.30 |
| % $CaCl_2$ | 8.67 | 8.64 |
| % $MgCl_2$ | 2.98 | 3.00 |
| Ratio $\frac{\%CaCl_2}{\%MgCl_2}$ | 2.9 | 2.9 |
| % NaCl | 9.4 | 9.4 |
| % KCl | 0.22 | 0.24 |
| % $Br_2$ | 0.1372 | 0.1371 |
| % $I_2$ | 0.0010 | 0.0010 |

Samples taken at completion of bailing.

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

File No. 306
County Lawrence
Township Hamilton
Section 5
15' Quad. Greenup
7½' Quad.

# TESTS ON SAMPLES

Material sampled Brine
Name of bed Depth
Sampled by
Date of sampling 12-4-62

Tests made by Dow Chemical
Laboratory number SSR 183-620
Property owner Dow Ironton #2
Operator

#2 Ironton - Section 7, Hamilton Twp., Lawrence County, Chio, Total depth 2031 ft. The Sp. Gr. on this sample appears low indicating some dilution.

| | |
|---|---|
| Spec. Gr. at 20/20C° | 1.1897 |
| °Be' | 23.12 |
| % $CaCl_2$ | 3.99 |
| % $MgCl_2$ | 2.88 |
| % NaCl | 9.90 |
| % KCl | 0.21 |
| Ratio $\frac{\%CaCl_2}{\%MgCl_2}$ | 3.12 |
| % Br | 0.1496 |
| % I | 0.0011 |

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

File No. 307

County Lawrence

Township Elizabeth

Section 4

15' Quad. Ironton

7½' Quad.

# TESTS ON SAMPLES

Material sampled Brine

Name of bed depth 250' and 2250'

Sampled by

Date of sampling 3-16-53

Tests made by Dow Chemical

Laboratory number SS$^{4}$ 186-217

Property owner Dow Ironton well 4 T.D.2

Operator

Sample taken from bailer at depth indicated after acidifying and com.etion of bailing.

| Sample depth from surface (ft.) | 250 | 2250 |
|---|---|---|
| Sp. Gra. at 20°C | 1.2045 | 1.2062 |
| °Be' | 24.62 | 24.79 |
| % $CaCl_2$ | 9.84 | 9.82 |
| % $MgCl_2$ | 3.52 | 3.39 |
| Ratio $\frac{\%CaCl_2}{\%MgCl_2}$ | 2.80 | 2.90 |
| % NaCl | 9.9 | 10.5 |
| % KCl | 0.24 | 0.24 |
| % Br | 0.1485 | 0.1525 |
| % $I_2$ | 0.0013 | 0.0013 |

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Box 34

# APPENDIX C

## DRILL STEM AND SWAB TESTS

| | |
|---|---|
| APPENDIX C.1 | DRILL STEM TEST NO. 1 AND SWAB TEST<br>LOGAN<br>164.20 FEET TO 261.50 FEET |
| APPENDIX C.2 | DRILL STEM TEST NO. 2 AND SWAB TEST<br>BEREA<br>679.2 FEET TO 734.0 FEET |
| APPENDIX C.3 | DRILL STEM TEST NO. 3 AND SWAB TEST<br>LOCKPORT<br>1757.4 FEET TO 1790.7 FEET |
| APPENDIX C.4 | DRILL STEM TEST NO. 4 AND SWAB TEST<br>UPPER KNOX<br>4012 FEET TO 4035 FEET |
| APPENDIX C.5 | DRILL STEM TEST NO. 4A<br>UPPER KNOX<br>4006 FEET TO 4035 FEET |
| APPENDIX C.6 | DRILL STEM TEST NO. 5 AND SWAB TEST<br>ROSE RUN<br>4181 FEET TO 4225 FEET |
| APPENDIX C.7 | DRILL STEM TEST NO. 6 AND SWAB TEST<br>LOWER KNOX<br>4446.7 FEET TO 4480 FEET |

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APPENDIX C.4

DRILL STEM TEST NO. 4 AND SWAB TEST
UPPER KNOX
4012 FEET TO 4035 FEET

ARISTECH CHEMICAL CORPORATION
TEST/MONITOR WELL
DRILL STEM TEST NO. 4 - FLUID RECOVERY
4/14-18/91

| DATE | TIME | ELAPSED TIME (HRS) | TANK GUAGE (INCHES) | TOTAL VOLUME (GALLONS) | INCREMENTAL VOLUME (GALLONS) | VOLUME THIS TEST (GALLONS) |
|---|---|---|---|---|---|---|
| 4/14 | 20:30 | PRIOR TO TEST START START TEST | 10.250 | 1273.5 | | 0.0 |
| | 23:30 | 0.00 | 10.250 | 1273.5 | 0.0 | 0.0 |
| 4/15 | 01:00 | 0.50 | 10.250 | 1273.5 | 0.0 | 0.0 |
| | 02:00 | 1.50 | 10.375 | 1292.8 | 19.3 | 19.3 |
| | 03:00 | 2.50 | 10.500 | 1312.0 | 19.2 | 38.5 |
| | 04:00 | 3.50 | 10.625 | 1331.3 | 19.3 | 57.8 |
| | 05:00 | 4.50 | 10.750 | 1350.5 | 19.3 | 77.0 |
| | 06:00 | 5.50 | 10.875 | 1369.8 | 19.3 | 96.3 |
| | 07:00 | 6.50 | 10.875 | 1369.8 | 0.0 | 96.3 |
| | 08:00 | 7.50 | 11.000 | 1389.0 | 19.3 | 115.5 |
| | 09:00 | 8.50 | 11.250 | 1427.5 | 38.5 | 154.0 |
| | 10:00 | 9.50 | 11.375 | 1446.8 | 19.3 | 173.3 |
| | 11:00 | 10.50 | 11.500 | 1466.0 | 19.3 | 192.5 |
| | 12:00 | 11.50 | 11.500 | 1466.0 | 0.0 | 192.5 |
| | 13:00 | 12.50 | 11.500 | 1466.0 | 0.0 | 192.5 |
| | 14:00 | 13.50 | 11.625 | 1485.3 | 19.3 | 211.8 |
| | 15:00 | 14.50 | 11.750 | 1504.5 | 19.2 | 231.0 |
| | 16:00 | 15.50 | 12.000 | 1543.0 | 38.5 | 269.5 |
| | 17:00 | 16.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 18:00 | 17.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 19:00 | 18.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 20:00 | 19.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 21:00 | 20.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 22:00 | 21.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 23:00 | 22.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 24:00 | 23.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| 4/16 | 01:00 | 24.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 02:00 | 25.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 03:00 | 26.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 04:00 | 27.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 05:00 | 28.50 | 12.000 | 1543.0 | 0.0 | 269.5 |
| | 06:00 | 29.50 | 12.000 | 1543.0 | 0.0 | 269.5 |

NOTE: 6:00 A.M. GAUGE OF TANK INDICATED 11-7/8" IN TANK
WAIT FOR POOL WELL SERVICE SWAB UNIT
POOL RIGGED UP, DEPTHOMETER INDICATED FLUID LEVEL WAS @ 1611 FT.
WILL RESTART TEST AND LET CUM. FLUID TO DATE MAKE UP PART OF FLUID
LEVEL INCREASE (FOR PURPOSES OF THREE TUBE VOLUMES, NOW = 1216 GAL

| | | | | | |
|---|---|---|---|---|---|
| 18:00 | 0.00 | 12.000 | 1543.0 | 0.0 | 269.5 |
| 18:30 | 0.50 | 13.000 | 1697.0 | 154.0 | 423.5 |
| 19:00 | 1.00 | 13.250 | 1735.5 | 38.5 | 462.0 |
| 19:20 | 1.33 | 13.625 | 1793.3 | 57.8 | 519.8 |
| 19:40 | 1.67 | 14.375 | 1908.8 | 115.5 | 635.3 |
| 20:15 | 2.250 | 14.625 | 1947.3 | 38.5 | 673.8 |
| 21:00 | 3.00 | 14.750 | 1966.5 | 19.3 | 693.0 |
| 22:00 | 4.00 | 14.875 | 1985.8 | 19.3 | 712.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 23:00 | 5.00 | 15.000 | 2005.0 | 19.3 | 731.5 |
| 4/17 | 01:00 | 7.00 | 15.125 | 2024.3 | 19.3 | 750.8 |
| | 03:00 | 9.00 | 15.750 | 2120.5 | 96.3 | 847.0 |
| | 05:00 | 11.00 | 16.000 | 2158.0 | 37.5 | 884.5 |
| | 07:00 | 13.00 | 16.125 | 2178.4 | 20.4 | 904.9 |
| | 08:00 | 14:00 | 16.500 | 2236.5 | 58.1 | 963.0 |
| | 10:00 | 16:00 | 17.000 | 2314.0 | 77.5 | 1040.5 |
| | 12:00 | 18:00 | 17.000 | 2314.0 | 0.0 | 1040.5 |
| | 14:00 | 20:00 | 17.000 | 2314.0 | 0.0 | 1040.5 |
| | 16:00 | 22:00 | 17.250 | 2352.5 | 38.5 | 1079.0 |
| | 18:00 | 24:00 | 17.625 | 2410.3 | 57.8 | 1136.8 |
| | 20:00 | 26.00 | 17.625 | 2410.3 | 0.0 | 1136.8 |
| | 22:00 | 28.00 | 17.750 | 2429.5 | 19.3 | 1156.0 |
| | 24:00 | 30.00 | 17.875 | 2448.8 | 19.3 | 1175.3 |
| 4/18 | 02:00 | 32.00 | 18.000 | 2468.0 | 19.3 | 1194.5 |
| | 04:00 | 34.00 | 18.250 | 2506.5 | 38.5 | 1233.0 |
| | READY FOR COLLECTION OF REPRESENTATIVE SAMPLE | | | | | |
| | LET WELL RECHARGE UNTIL 08:00, 4/18/91 | | | | | |
| | 08:00 | 38.00 | 18.250 | 2506.5 | 0.0 | 1233.0 |
| | 10:00 | 40.00 | 18.375 | 2525.8 | 19.3 | 1252.3 |
| | 11:00 | 41.00 | 18.625 | 2564.3 | 38.5 | 1290.8 |
| | 12:00 | 42.00 | 18.875 | 2602.8 | 38.5 | 1329.3 |
| | 13:00 | 43.00 | 19.125 | 2641.3 | 38.5 | 1367.8 |
| | 14:00 | 44.00 | 19.250 | 2660.5 | 19.3 | 1387.1 |
| | 15:30 | 45.50 | 19.500 | 2699.0 | 38.5 | 1425.6 |

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APPENDIX C.5

DRILL STEM TEST NO. 4A
UPPER KNOX
4006 FEET TO 4035 FEET

| ARISTECH TEST WELL | 4 | 4-A | 4006.7 - 4035.0 | ENVIROCORP |
|---|---|---|---|---|
| LEASE NAME | WELL NO. | TEST NO. | TESTED INTERVAL | LEASE OWNER/COMPANY NAME |

| LEGAL LOCATION SEC. - TWP. - RNG. | FIELD AREA | HAVERHILL | COUNTY | SCIOTO | STATE | OHIO SM |
|---|---|---|---|---|---|---|

ENVIROCORP

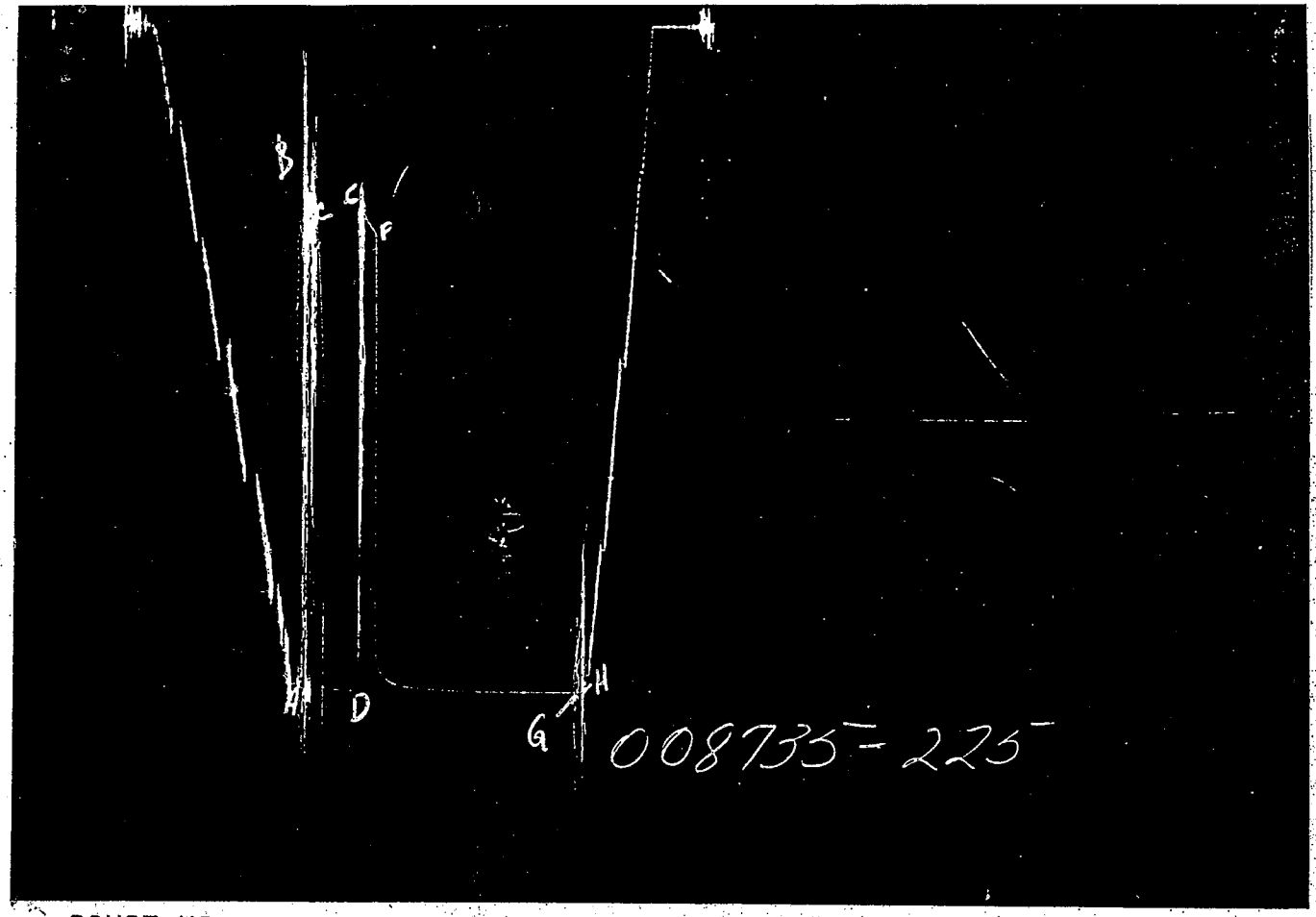
LEASE : ARISTECH TEST WELL

WELL NO. : 4

TEST NO. : 4-A

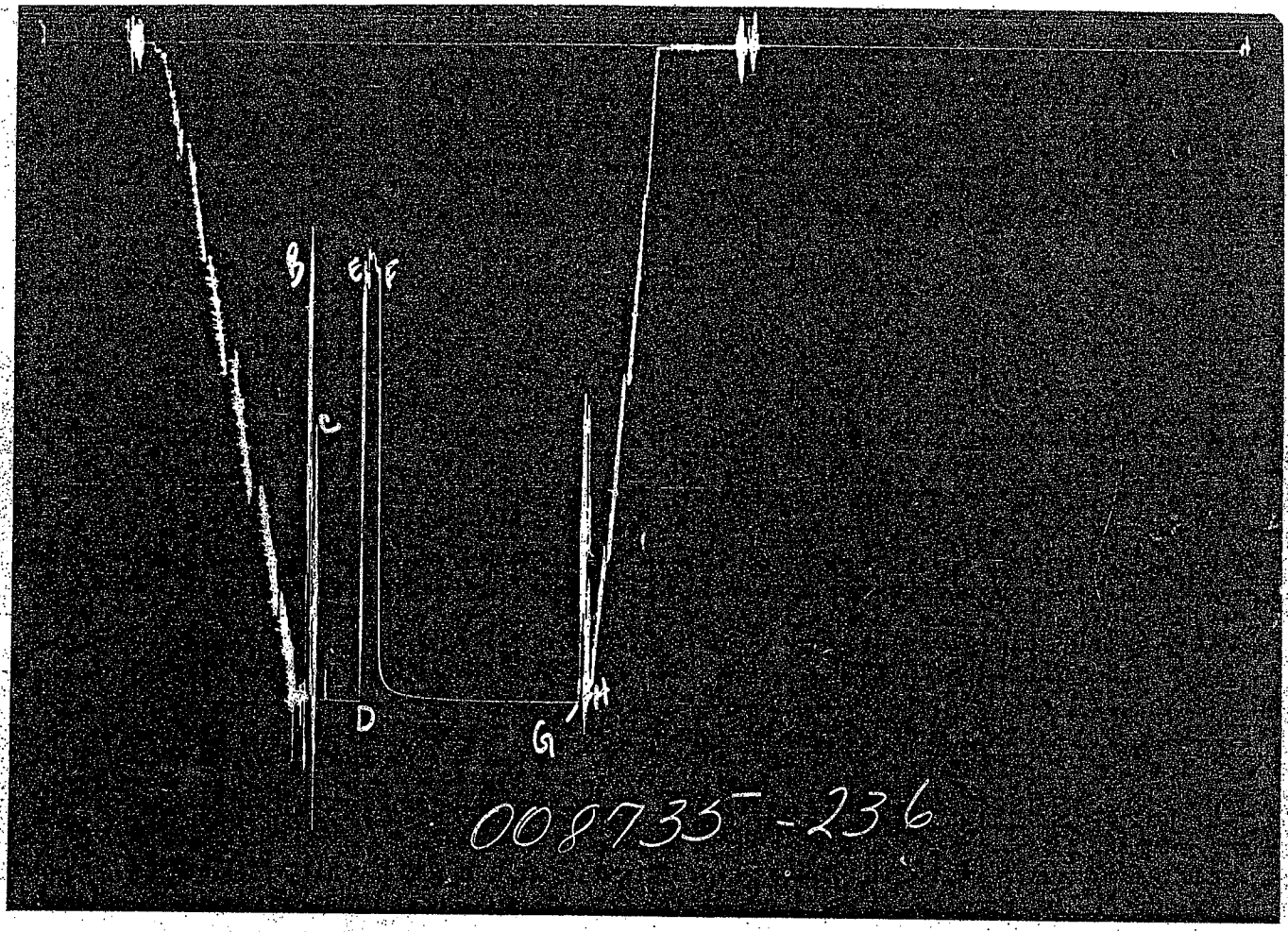
TICKET NO. 00873500
25-APR-91
KALKASKA

DST REPORT PRODUCED BY HRS
A DIVISION OF HALLIBURTON COMPANY




GAUGE NO: 225 DEPTH: 3986.1 BLANKED OFF: NO HOUR OF CLOCK: 72

| ID | DESCRIPTION | PRESSURE | | TIME | | TYPE |
|---|---|---|---|---|---|---|
| | | REPORTED | CALCULATED | REPORTED | CALCULATED | |
| A | INITIAL HYDROSTATIC | 1755 | 1783.6 | | | |
| B | INITIAL FIRST FLOW | 4 | 461.7 | 18 | 32 | F |
| C | FINAL FIRST FLOW | | 479.5 | | | |
| C | INITIAL FIRST CLOSED-IN | | 479.5 | 159 | 159 | C |
| D | FINAL FIRST CLOSED-IN | 1769 | 1784.7 | | | |
| E | INITIAL SECOND FLOW | 490 | 487.7 | 54 | 58 | F |
| F | FINAL SECOND FLOW | 545 | 559.5 | | | |
| F | INITIAL SECOND CLOSED-IN | 545 | 559.5 | 718 | 715 | C |
| G | FINAL SECOND CLOSED-IN | 1769 | 1786.7 | | | |
| H | FINAL HYDROSTATIC | 1769 | 1783.5 | | | |




GAUGE NO: 236 DEPTH: 4031.8 BLANKED OFF: YES HOUR OF CLOCK: 72

| ID | DESCRIPTION | PRESSURE | | TIME | | TYPE |
|---|---|---|---|---|---|---|
| | | REPORTED | CALCULATED | REPORTED | CALCULATED | |
| A | INITIAL HYDROSTATIC | 1771 | 1790.8 | | | |
| B | INITIAL FIRST FLOW | | 628.0 | 18 | 32 | F |
| C | FINAL FIRST FLOW | | 1049.1 | | | |
| C | INITIAL FIRST CLOSED-IN | | 1049.1 | 159 | 159 | C |
| D | FINAL FIRST CLOSED-IN | 1798 | 1815.1 | | | |
| E | INITIAL SECOND FLOW | | 664.8 | 54 | 58 | F |
| F | FINAL SECOND FLOW | | 617.1 | | | |
| F | INITIAL SECOND CLOSED-IN | | 617.1 | 718 | 715 | C |
| G | FINAL SECOND CLOSED-IN | 1805 | 1812.8 | | | |
| H | FINAL HYDROSTATIC | 1805 | 1790.4 | | | |

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Report is about
80 pages

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APPENDIX C.7

DRILL STEM TEST NO. 6 AND SWAB TEST
LOWER KNOX
4446.7 FEET TO 4480 FEET

ARISTECH CHEMICAL CORPORATION
TEST/MONITOR WELL
DRILL STEM TEST NO. 6 - FLUID RECOVERY
5/09/91

| DATE | TIME (HRS) | ELAPSED TIME (HRS) | TANK GAUGE (INCHES) | TOTAL VOLUME (GALLONS) | INCREMENTAL VOLUME (GALLONS) | VOLUME THIS TEST (GALLONS) |
|---|---|---|---|---|---|---|
| 5/09 | 08:00 | PRIOR TO TEST START START TEST | 34.250 | 4970.5 | 0.0 | 0.0 |
| | 09:30 | 1.50 | 34.750 | 5047.5 | 77.0 | 77.0 |
| | 10:00 | 2.00 | 38.000 | 5551.0 | 503.5 | 580.5 |
| | 10:30 | 2.50 | 40.000 | 5871.0 | 320.0 | 900.5 |
| | 11:00 | 3.00 | 42.750 | 6328.0 | 457.0 | 1357.5 |
| | 11:30 | 3.50 | 45.500 | 6803.0 | 475.0 | 1832.5 |
| | 12:00 | 4.00 | 49.000 | 7419.0 | 616.0 | 2448.5 |
| Stop swabbing continuously, have achieved three tubing volumes. | | | | | | |
| | 13:30 | 5.50 | 49.500 | 7507.0 | 88.0 | 2536.5 |
| | 15:00 | 7.00 | 50.000 | 7595.0 | 88.0 | 2624.5 |
| | 16:00 | 8.00 | 50.750 | 7670.5 | 75.5 | 2700.0 |
| | 16:30 | 8.50 | 52.000 | 7946.0 | 275.5 | 2975.5 |
| | 17:00 | 9.00 | 53.000 | 8122.0 | 176.0 | 3151.5 |
| Begin sampling at 19:00. Dave Evans with OEPA on location to observe. | | | | | | |
| | 19:00 | 11.00 | 55.500 | 8562.0 | 440.0 | 3591.5 |
| | 20:00 | 12.00 | 58.000 | 9001.0 | 439.0 | 4030.5 |
| | 21:00 | 13.00 | 63.000 | 9881.0 | 880.0 | 4910.5 |
| | 22:00 | 14.00 | 68.000 | 10760.0 | 879.0 | 5789.5 |
| | 23:00 | 15.00 | 68.250 | 10804.5 | 44.5 | 5834.0 |
| Finish sampling at 22:30. | | | | | | |

ARISTECH TEST WELL
DST NO.6 - LOWER KNOX (4447 FT. - 4480 FT.)
FLUID LEVEL AND "TUBING VOLUME" DETERMINATION
May 9, 1991

TEST INTERVAL - 4480 FT. - 4447 FT., 33.0 FT.
TOTAL VOLUME OF 4" HOLE = .6528 GAL./FT.
VOLUME BELOW PACKER = 21.54 GALLONS

*DUE TO THE FLUID INFLUX AND RECHARGING CAPABILITY OF THIS TEST ZONE, THREE TUBING VOLUMES WERE CALCULATED USING THE ENTIRE TUBING STRING.

TUBING VOLUME IS .1624 GAL./FT., PACKER IS SET AT 4447 FT.
THUS, ONE "TUBING VOLUME" = .1624 * (4447 FT)
ONE "TUBE VOLUME" = 722 GALLONS
SYSTEM VOLUME = 744 GALLONS

THREE TUBING VOLUMES = 2231 GALLONS
---

HRS

ARISTECH CHEMICAL % ENVIROCORP

LEASE : TEST WELL

WELL NO. : 4

TEST NO. : 6

# DRILL STEM TEST REPORT

# HALLIBURTON RESERVOIR SERVICES

A Halliburton Company

| | | | | |
|---|---|---|---|---|
| TEST WELL | 4 | 6 | 4446.7 - 4480.0 | ARISTECH CHEMICAL % ENVIROCORP |
| LEASE NAME | WELL NO. | TEST NO. | TESTED INTERVAL | LEASE OWNER/COMPANY NAME |

# NOMENCLATURE

| | | |
|---|---|---|
| $B$ | = Formation Volume Factor | (Res. Vol/Std Vol) |
| $c$ | = System Total Compressibility | (Vol/Vol) psi |
| $DR$ | = Damage Ratio | |
| $h$ | = Estimated Net Pay Thickness | Ft. |
| $k$ | = Permeability | md. |
| $m$ | = (Liquid) Slope Extrapolated Pressure Plot<br>= (Gas) Slope Extrapolated $m(P)$ Plot | psi/cycle<br>MM psi/cp/cycle |
| $m(P_x)$ | = Real Gas Potential at $P_x$ | MM psi/cp |
| $m(P_f)$ | = Real Gas Potential at $P_f$ | MM psi/cp |
| $AOF_r$ | = Maximum Indicated Absolute Open Flow at Test Conditions | MCFD |
| $AOF$ | = Minimum Indicated Absolute Open Flow at Test Conditions | MCFD |
| $P_x$ | = Extrapolated Static Pressure | Psig |
| $P_f$ | = Final Flow Pressure | Psig |
| $Q$ | = Liquid Production Rate During Test | BPD |
| $Q_o$ | = Theoretical Liquid Production w/Damage Removed | BPD |
| $Q_g$ | = Measured Gas Production Rate | MCFD |
| $r_i$ | = Approximate Radius of Investigation | Ft. |
| $r_w$ | = Radius of Well Bore | Ft. |
| $S$ | = Skin Factor | |
| $t$ | = Total Flow Time Previous to Closed In | Minutes |
| $\Delta t$ | = Closed In Time at Data Point | Minutes |
| $T$ | = Temperature Rankine | R |
| $\phi$ | = Porosity (fraction) | |
| $\mu$ | = Viscosity of Gas or Liquid | cp |
| $Log$ | = Common Log | |

| TEST WELL | 4 | 6 | 4445.7 - 4480.0 | ARISTECH CHEMICAL % ENVIR |
|---|---|---|---|---|
| LEASE NAME | WELL NO. | TEST NO. | TESTED INTERVAL | LEASE OWNER/COMPANY NAME |

| ATION IP. - RNG. | ARISTECH PLANT | FIELD AREA | HAVERHILL | COUNTY | SCIOTO | STATE | OHIO |
|---|---|---|---|---|---|---|---|

ARISTECH CHEMICAL % ENVIRODCORP

LEASE : TEST WELL

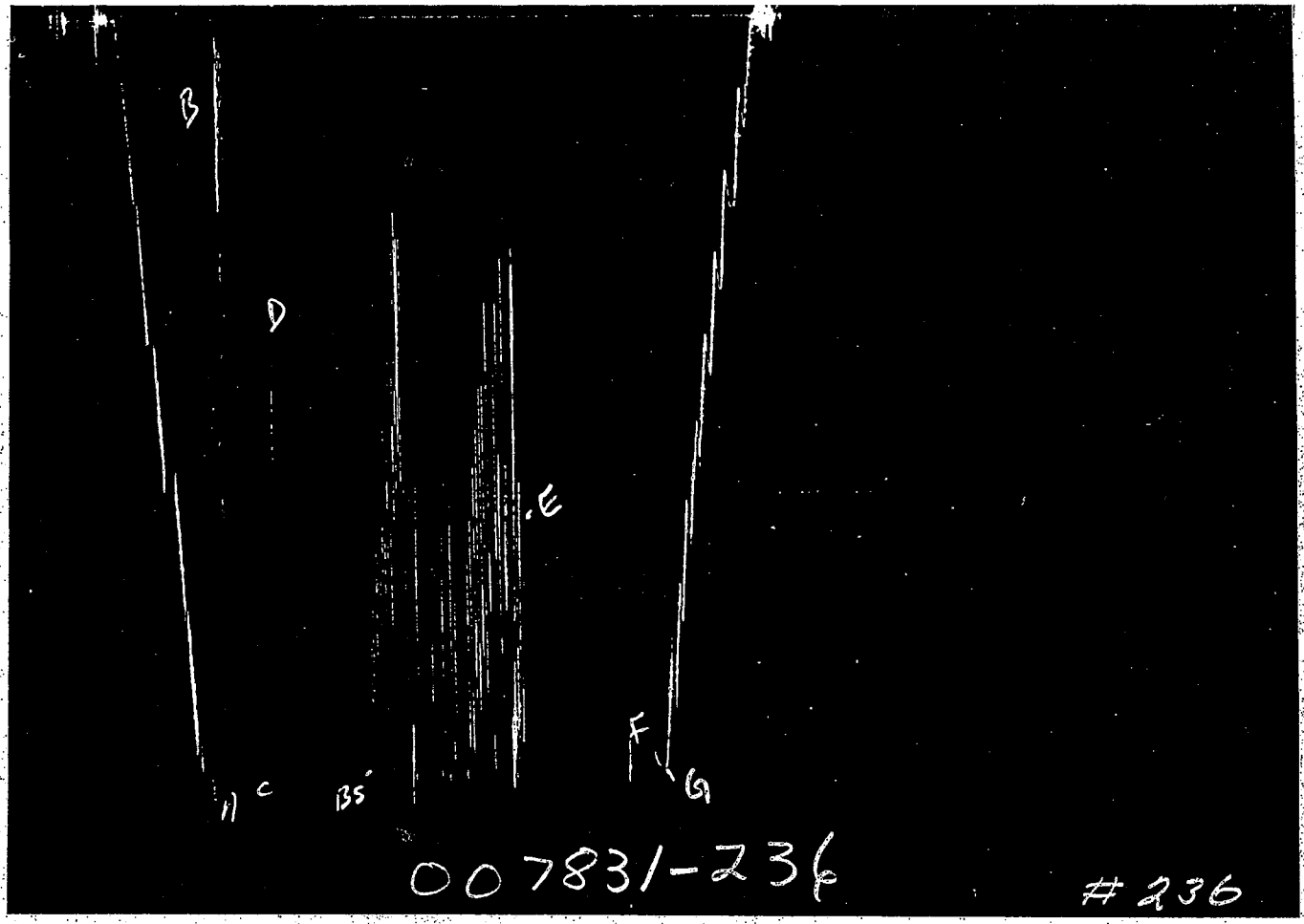
WELL NO.: 4

TEST NO.: 6

TICKET NO. 00783100

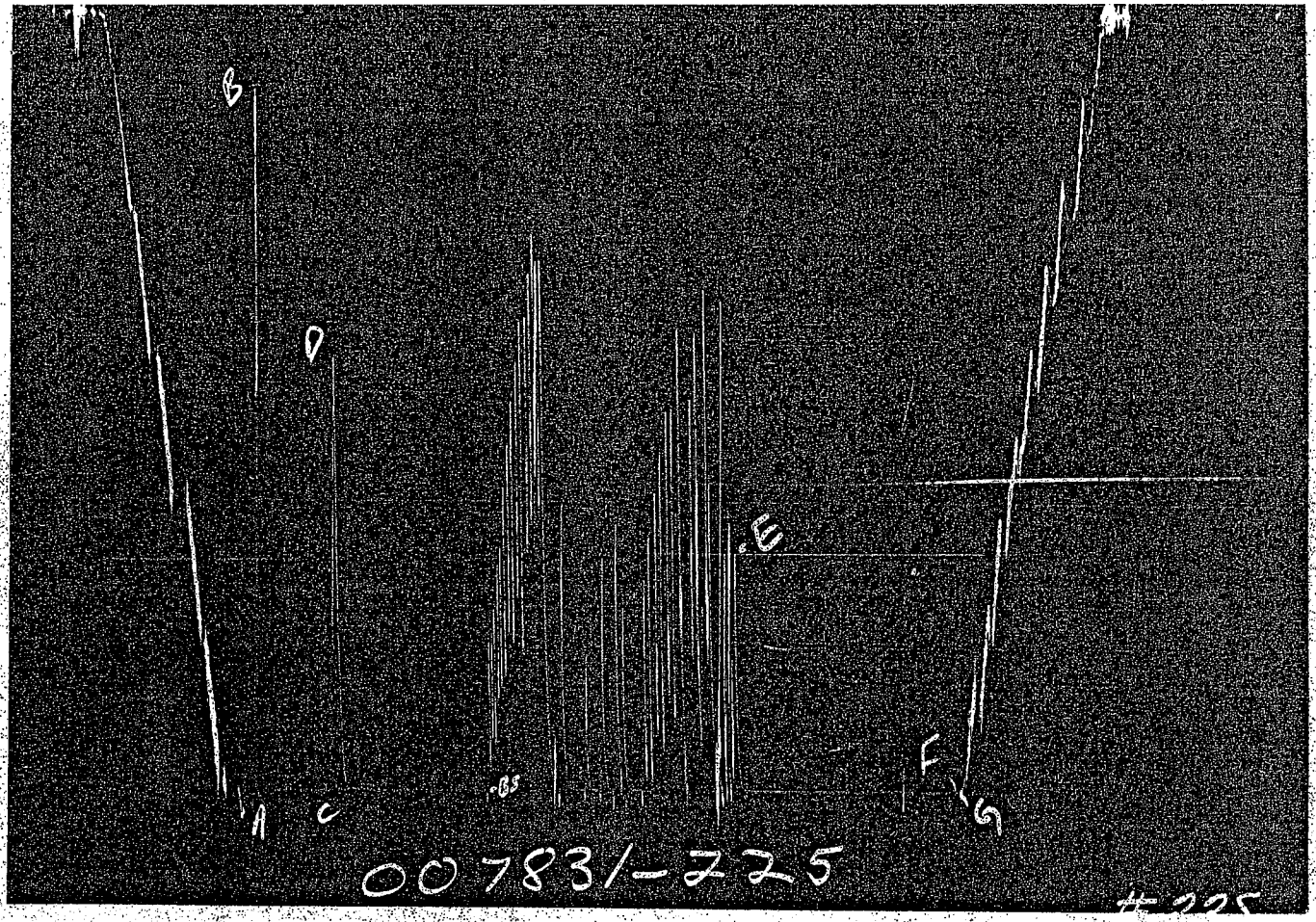
20-MAY-91

KALKASKA




GAUGE NO: 236 DEPTH: 4427.8 BLANKED OFF: NO HOUR OF CLOCK: 120

| ID | DESCRIPTION | PRESSURE | | TIME | | TYPE |
|---|---|---|---|---|---|---|
| | | REPORTED | CALCULATED | REPORTED | CALCULATED | |
| A | INITIAL HYDROSTATIC | 2118 | 2116.9 | | | |
| B | START OF BUILDUP | 25 | 118.1 | 283 | 272 | C |
| C | END OF BUILDUP | 2061 | 2058.4 | | | |
| D | INITIAL FIRST FLOW | 870 | 862.6 | 1446 | 1405 | F |
| E | FINAL FIRST FLOW | 2061 | 1372.2 | | | |
| E | INITIAL SECOND CLOSED-IN | 2061 | 1372.2 | 734 | 786 | C |
| F | FINAL SECOND CLOSED-IN | 2061 | 2060.4 | | | |
| G | FINAL HYDROSTATIC | 2063 | 2060.4 | | | |




GAUGE NO: 225 DEPTH: 4477.0 BLANKED OFF: YES HOUR OF CLOCK: 72

| ID | DESCRIPTION | PRESSURE | | TIME | | TYPE |
|---|---|---|---|---|---|---|
| | | REPORTED | CALCULATED | REPORTED | CALCULATED | |
| A | INITIAL HYDROSTATIC | 2140 | 2139.0 | | | |
| B | START OF BUILDUP | 206 | 205.6 | 283 | 272 | C |
| C | END OF BUILDUP | 2085 | 2083.6 | | | |
| D | INITIAL FIRST FLOW | 916 | 914.1 | 1446 | 1405 | F |
| E | FINAL FIRST FLOW | 2081 | 1437.5 | | | |
| E | INITIAL SECOND CLOSED-IN | 2081 | 1437.5 | 734 | 786 | C |
| F | FINAL SECOND CLOSED-IN | 2082 | 2080.3 | | | |
| G | FINAL HYDROSTATIC | 2082 | 2081.0 | | | |

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Box 34
CITED
DGS CORE # 3248

APPENDIX 6.3-L

TERRATEK PETROGRAPHIC STUDY OF THE CORED INTERVAL

5915 FEET - 6109 FEET

# PETROGRAPHIC ANALYSIS OF THE MOUNT SIMON FORMATION FROM

# ARISTECH CHEMICAL CORPORATION'S

# WASTE DISPOSAL WELL, #3
# SCIOTO COUNTY, OHIO

PREPARED FOR:

ENVIROCORP SERVICE & TECHNOLOGY, INC.
7020 PORT WEST DRIVE, SUITE 100
HOUSTON, TEXAS 77024

PREPARED BY:

PETROGRAPHIC SERVICES GROUP
TERRA TEK GEOSCIENCE SERVICES
360 WAKARA WAY
SALT LAKE CITY, UTAH 84108

FEBRUARY 1990
TTGS FILE NO. 5398

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**SUMMARY**

Petrographic analysis and a lithologic description were performed on core material from the Cambrian Mount Simon Formation and the underlying granitic basement from Aristech Chemical Corporation's Waste Disposal Well #3, Scioto County, Ohio. Petrographic analysis consisting of thin section microscopy, X-ray diffraction, and scanning electron microscopy was performed on 23 samples. The cored interval between 5915' - 6109' can be divided into three lithofacies: (1) a dolomite facies from 5915' to 6010', (2) a sandstone facies from 6010' to 6079', and (3) granitic rocks from 6079' to 6109'. Ten samples were analyzed from the sandstone and dolomite facies and three specimens were selected from the granitic basement.

The dolomite facies is dominated by sandy dolomite but also includes dolomitized oolitic and stromatolite lithologies. Matrix porosity within the dolomite facies is generally poorly developed. Individual dissolution pores are scattered and appear isolated. Late stage dolomite and anhydrite infill or line many pores. Isolated dissolution porosity within potassium feldspars is present in sandy dolomite samples. Naturally occurring fractures are present throughout most of this facies (see lithologic description for fracture distribution). Some natural fractures are mineralized or partially mineralized, but significant porosity and permeability are associated with fractures. Routine analysis of full diameter samples indicated fracture permeabilities of up to 600 md, whereas matrix permeability is generally less than 0.2 md.

The sandstone facies is characterized by fine to medium grained arkose and subarkose. Median grain size ranges from 1.32 to 3.27 phi, and grain size generally decreases with depth. Composition is also related to grain size; the two coarser grained samples plot in the subarkose field of a Folk (1974) classification diagram. Grains are typically rounded to subangular with finer grains, which are commonly potassium feldspar, showing the greatest angularity. Sorting ranges from well sorted to moderately sorted. Several samples exhibit a bimodal grain size distribution which

tends to decrease sorting. The effects of compaction are variable, even within an individual sample.

Grain coating/pore-lining clays are dominated by chlorite and mixed-layer chlorite-smectite. SEM analysis suggests that grain coating chlorite precipitated early and has partially inhibited the precipitation of authigenic silica and potassium feldspar overgrowths.

A variety of different cements is present within these sandstones. These cements include: silica, potassium feldspar, anhydrite, and dolomite. Minor amounts of calcite were also observed. The abundance of dissolution porosity suggests that pore-filling and grain replacing calcite was once much more widespread, but has since been dissolved.

Porosity and permeability are best developed in a zone from 6021' to 6043'. Porosity here reflects a combination of secondary intergranular and intragranular porosity. Many of the potassium feldspars show severe dissolution. Large holes within grains are common as are "moldic" pores formed by complete grain dissolution. Matrix permeability is in the 1 to 10 md range. At least two different generations of fractures are present: an early gouge filled set, and a later partially mineralized fracture set. The latter fracture set will provide significant fracture permeability.

The three granitic samples (6081, 6090, and 6103, are medium- to coarsely-crystalline perthite granites anhedral-crystalline-textured aggregated dominated by perthite but also composed of quartz, orthoclase albite or oligoclase, various mafic minerals, and trace to minor amounts off magnetite/ilmenite, apatite, and zircon. The samples are texturally similar, but two (6081 and 6090) are intensely altered, veined, and perhaps weathered such that all original mafic minerals and most primary plagioclase have been converted to secondary phases. The relatively fresh sample, 6103, contains both primary clinopyroxene and hornblende. Chlorite and mixed-layer chlorite/smectite (identified by XRD) are the principal alteration phases in all three granite samples.

None of the three granites is particularly porous (maxium est. 0.7%)--in the case of 6103 because of its relatively pristine

condition, and in the case of 6081 and 6090 because of intense alteration and veining which sealed most fracture porosity. In all three rocks however, minor porosity occurs as: (1) intercrystalline vugs, most commonly in association with diseminated magnetite/ilmenite grains and grain aggregates; (2) open, late-stage microfractures which both follow and cross-cut older veinlets; these conceivably could have been induced by the drilling process; (3) irregularly distributed microporosity in chlorite-chlorite/smectite aggregates as well as within most microveinlets.

## INTRODUCTION

Petrographic analysis consisting of thin section microscopy, X-ray diffraction, and scanning electron microscopy was performed on twenty-three samples of the Mount Simon Formation and of the underlying Precambrian Granite from Aristech Chemical Corporation's waste disposal well #3, Scioto County, Ohio. A lithologic description was also performed on the 158 ft. of core recovered from this well. Petrographic sample depths and the specific analyses performed on each sample are listed in Table 1.

Table 1

Sample Analyzed

| Depth | Thin Section | Bulk XRD | Clay XRD | SEM |
|---|---|---|---|---|
| 5920 | X | X | | |
| 5928 | X | X | | X |
| 5933 | X | X | | X |
| 5935 | X | X | X | |
| 5976 | X | X | | X |
| 5988 | X | X | | X |
| 5997 | X | X | | X |
| 6001 | X | X | X | X |
| 6007 | X | X | | |
| 6013 | X | X | X | X |
| 6019 | X | X | X | X |
| 6025 | X | | X | X |
| 6029 | X | X | X | X |
| 6034 | X | X | X | X |
| 6039 | X | X | X | X |
| 6044 | X | X | X | X |
| 6051 | X | X | X | X |
| 6060 | X | X | X | |
| 6069 | X | X | X | X |
| 6074 | X | X | | |
| 6081 | X | X | | |
| 6090 | X | X | | |
| 6103 | X | X | | |

Terratek, 1990, well #3

## Diagenesis

The following diagenetic sequence is envisioned for the Sandstone Facies.

1. Deposition of sand and minor clay in a shallow marine setting.
2. Bioturbation, especially in clay rich laminae.
3. Precipitation of grain-coating chlorite.
4. Compaction.
5. Precipitation of silica and potassium feldspar cement on framework grains.
6. Precipitation of pore-filling calcite cement along with calcite replacement of potassium feldspars.
7. Continued physical and chemical compaction resulting in stylolite formation.
8. Formation of gouge filled fractures.
9. Dissolution of calcite resulting in varying amounts of secondary porosity.
10. Dolomitization of remaining calcite and dolomite replacement of clastic grains.
11. Second fracturing event.
12. Precipitation of mixed-layer chlorite-smectite.
13. Precipitation of pore-filling ankerite.
14. Precipitation of minor fracture-filling calcite and dolomite.
15. Precipitation of pyrite.
16. Precipitation of pore-filling anhydrite.
17. Precipitation of other minor fracture filling chlorite.

Teravtek, 1990, well #3

## Diagenesis

The following generalized diagenetic sequence is envisioned for the dolomite facies:

1. Deposition of carbonate and clastic grains along with varying amounts of lime mud in a shallow marine setting.
2. Compaction.
3. Precipitation of pore-filling calcite cement.
4. Dolomitization.
5. Dissolution and the formation of secondary porosity.
6. Fracturing and stylolite formation (mineralized fracture set).
7. Precipitation of pore/fracture filling dolomite.
8. Precipitation of pore/fracture filling ankerite.
9. Pyrite precipitation.
10. Precipitation of pore/fracture filling anhydrite.
11. Fracturing (partially open fracture set).
12. Precipitation of minor pore-lining clays.

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Barcode 002637

Box 35

# APPENDIX I

## DESCRIPTION OF FORMATION TESTING PROCEDURES

To: Connie Walker

From: Jack Slechta

Subject: Description of a Swab/DST

Date: December 3, 1990

ATKEARNEY

Swab

A swab is a device equipped with an upward-opening check valve that is designed to fit snugly within the well casing or tubing that provides a means of removing fluid from the well when pressure is insufficient to support flow. The swab is lowered on a wire line to a point well below the surface of the fluid in the well and rapidly withdrawn to the surface, lifting above it the fluid through which it has been lowered. Removing a part of the column of accumulated fluid within it reduces the pressure within the lower end of the flow tubing or casing. This process encourages more fluid to flow rapidly in from the surrounding formation creating upward momentum of the entire column of fluid. In some cases, the swab is used simply as a mechanical lifting device for removing fluids from wells without any intention of inducing flow.

Drill Stem Test

A drill stem test is a method of testing a formation to determine its potential productivity before installing casing in a well. Incorporated in the drill stem testing tool are a packer, valves or ports which may be opened and closed from the surface, and a pressure-recording device. The tool is lowered to the bottom of the hole on a string of drill pipe and the packet set, isolating the formation to be tested from the formations above and supporting the fluid column above the packer. A port on the tool is opened to allow the trapped pressure below the packer to bleed off into the drill pipe, gradually exposing the formation to atmospheric pressure and allowing the well to produce. The well fluids may thus be sampled and inspected.

Repeat Formation Tester

The Repeat Formation Tester (RFT) tool is designed to take an unlimited number of formation pressure measurements at the surface during a single trip in the borehole. Instead of using explosives to activate the tool, the RFT tool is operated by an electrically driven hydraulic pump. The hydraulic operation provides the capability of repeated set-retract operations. RFT pressure measurements are accurate within 0.13 percent making the data applicable for pressure profiles to fluid density, fluid contacts, differential depletion, and reservoir inter-communication.

The RFT tool can also take one segregated fluid sample from a single test depth or two samples from different depths during a single trip in the borehole. When the tool is set, the body is held away from the borehole wall by a packer on one side and backup pistons on the other. A filter in the probe on the hydraulic pump greatly reduces flowline plugging. The minimum recommended hole size to use the RFT tool is 6 1/2 inches, and the standard chamber size is a 1 gallon and 2 3/4 gallon, or two 2 3/4-gallon capacity per sample.

Appendix G-L

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Box 35

# REPORT OF DRILLING AND TESTING WASTE DISPOSAL WELL NO. 3

## ARISTECH CHEMICAL CORPORATION
HAVERHILL, OHIO

ENVIROCORP PROJECT NO. 30-1237

JANUARY 29, 1990

PREPARED BY

ENVIROCORP SERVICES & TECHNOLOGY, INC.
SOUTH BEND, INDIANA

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# 1.0 INTRODUCTION

This report summarizes the construction of the Aristech Chemical Corporation Waste Disposal Well No. 3. Envirocorp Services & Technology, Inc. was contracted to construct the well.

Well No. 3 was spudded on April 7, 1989 when the cement used to set the conductor pipe was drilled out. Drilling operations were completed on October 4, 1989 when the last of the drilling equipment was removed from the wellsite. The well is currently on a suspended status, as of the date of this report, awaiting a permit to operate. A bridge plug is set inside the 7 inch protection casing, the injection tubing and packer have not been installed. A well schematic is included as Drawing 30-1237-1.

# 2.0 SUMMARY OF LOGGING AND TESTING RESULTS

For the sake of readability, the summary of well operations does not reference to the appendices containing the information gathered while constructing Well No. 3. The information can be found in the appendices as listed in Table No. I.

## TABLE I
## ARISTECH CHEMICAL CORPORATION
## DISPOSAL WELL NO. 3
## TABLE OF APPENDICES

| APPENDIX | VOLUME | CONTENTS |
|---|---|---|
| A | 2 | Open Hole Geophysical Logs |
| B | 3 | Cased Hole Geophysical Logs and Selected Engineering Logs |
| C | 4 | Drill Stem and Swab Tests |
| D | 4 | Mud Log |
| E | 4 | Drilling and Completion Fluids |
| F | 4 | Directional Survey |
| G | 4 | Core Data - Rock Mechanics and Rock Properties |
| H | 4 | Summary of Casing and Cement |
| I | 5 | Chemical Analyses |
| J | 5 | Mechanical Integrity Geophysical Logs |

The geophysical log measurements obtained from the open (uncased) hole are contained in Appendix A. Table II summarizes the logs run and the appropriate appendix. Information concerning formation porosities, indicated fluid resistivities, and apparent lithologys are obtained from the open hole logs. A Borehole Televiewer was run to obtain indications of fracturing within the strata immediately overlying the Mt. Simon injection interval.

Cased hole geophysical logs, run for evaluation of cement bonding, cement placement, and the condition of the protection casing are contained in Appendix B. Appendix B also contains logs run through the drillstring to confirm packer setting depths for the swab tests conducted during construction of the well.

Formation tests were conducted as shown in Table III. Tests No. 2 and No. 9 (conventional D.S.T.) gave indication of a permeable formation. Reservoir characteristics were calculated from the recorded pressure data. A summary of tests 2 and 9:

| Test No. | Formation (test depth) | Extrapolated Reservoir Pressure (psig) | Permeability (md) | Flow Capacity (md-ft.) |
|---|---|---|---|---|
| 2 | Rose Run (4503'-4588') | 2010.8 | 22.72 | 340.83 |
| 9 | Mt. Simon (5978'-6109') | 2645.9 | 1.63 | 212.13 |

Further details are contained in Appendix C. Tests No. 4, No. 6, No. 7, and No. 9 (swab tests) also gave indication of permeable formations (Test No. 9 was a combination conventional D.S.T. and swab test).

The swab tests were conducted for the purpose of obtaining a representative sample of fluids contained within the formation tested. The mechanical nature of the test procedure precluded obtaining any reservoir data other than producing bottom hole pressure while swabbing. Appendix C also contains the swab test summaries. Three tests, No. 1, No. 3, and No. 5 gave indication of non-permeable formations. Test No. 8 was inconclusive due to mechanical problems.

The formation fluid samples obtained were split with the Ohio Environmental Protection Agency and analyzed by independent laboratories. The complete laboratory results are found in Appendix I; the summary of analytical results are found in Table VI.

A mud logger was employed to analyze the drill cuttings circulated from the hole during the drilling operation. A final mud log is included as Appendix D. Appendix E contains information on the drilling fluid. A conventional bentonite base drilling fluid was utilized throughout the construction of the well until the protection casing was set. The Mt. Simon injection interval was cored in it's entirety using a salt-polymer system. The salt-polymer mud was employed to minimize formation damage.

# TABLE II

## ARISTECH CHEMICAL CORPORATION

## DISPOSAL WELL NO. 3

## SUMMARY OF GEOPHYSICAL LOGGING

| SUITE NO. | DATE(S) | LOG RUN | DEPTH LOGGED | APPENDIX | REMARKS |
|---|---|---|---|---|---|
| 1 | 4/11/89 | Induction | SFC - 880' | A-5 | -- |
| | | Sonic | SFC - 880' | A-2 | -- |
| | | Caliper | SFC - 880' | -- | -- |
| | | Gamma Ray | SFC - 880' | A-5 | -- |
| 1A | 4/14/89 | R.F.T. (summary) | SFC - 880' | A-8 | Repeat formation tester sample recovered was split with O.E.P.A. |
| ENG | 4/16/89 | TEMP | SFC - 780' | B-1 | Temperature log to evaluate cement placement. Note: Eng = Engineering Log, See note below (*). |
| 2 | 4/18/89 | CBL/VDL | 98' - 877' | B-2 | Cement bond log with variable density. |
| ENG | 4/24/89 - 5/26/89 | Survey | | F | Wellbore direction and deviation measurements. |
| ENG | 6/7/89 | GR/Neutron with CCL | SFC - 4590' | B-14 | Verify packer setting depth. (Gamma Ray/Neutron with casing collar locator). |
| 3 | 6/17/89 | DLL/MSFL | SFC - 5852' | A-4 | Dual latherolog |
| | | LDT/CNL | SFC - 5852' | A-1 | Litho-density/compensated neutron |
| | | DI/SP/GR | SFC - 5852' | A-5 | Dual induction/spontaneous potential/Gamma Ray |
| | | Cyberlook | 875' - 5852' | A-3 | |
| ENG | 6/19/89 | GR-CCL | SFC - | B-15 | Verify packer setting depth. |
| ENG | 7/13/89 | GR - CCL | SFC - 1800' | B-16 | Verify packer setting depth. |
| ENG | 7/17/89 | GR - CCL | SFC - 1500' | B-17 | Verify packer setting depth. |
| 4 | 8/7/89 - 8/15/89 | DLL/MSFL | 5620' - 5925' | A-4 | Due to severe hole problems, logging was not completed until 8/15/89. |
| | | LDT/CNL | 5610' - 5950' | A-1 | |
| | | Sonic | SFC - 5957' | A-2 | |
| | | BHT | 4000' - 5950' | A-7 | BHT = Borehole Televiewer |
| | | Directional Survey | 800' - 5908' | A-6 | |
| | | CBL/VDL | 65' - 790' | B-3 | Relogged surface casing |
| | | Cyberlook | 5700' - 5900' | A-3 | |
| ENG | 8/20/89 | Temp. | SFC - 3000' | NI | Locate top of cement |
| ENG | 8/22/89 | CBL/VDL | 2000' - 3030' | NI | Evaluate cement |
| | | CET | 2000' - 3030' | NI | |

## TABLE II (CONTINUED)
## ARISTECH CHEMICAL CORPORATION
## DISPOSAL WELL NO. 3
## SUMMARY OF GEOPHYSICAL LOGGING

| SUITE NO. | DATE(S) | LOG RUN | DEPTH LOGGED | APPENDIX | REMARKS |
|---|---|---|---|---|---|
| ENG | 8/27/89 | CBL/VDL | 2200' - 5950' | B-4 | Evaluate cement |
| | | CET | 2200' - 5950' | B-5 | |
| ENG | 8/28/89 | Temp. | SFC - 3274' | NI | Evaluate annular injection procedure |
| ENG | 8/30/89 | CBL/VDL | SFC - 5950' | B-6 | Evaluate cement |
| | | CET | SFC - 5950' | B-7 | |
| 5 | 9/11/89 - 9/12/89 | CBL/VDL | SFC - 5950' | B-10 | |
| | | CET | SFC - 5950' | B-11 | CET = cement evaluation tool |
| | | ETT-D | SFC - 5950' | NI | ETT = Electromagnetic Thickness (casing inspection) |
| | | Temp. | SFC - 5950' | B-8 | |
| | | MFC | SFC - 5950' | B-9 | MFC = Multi-Finger Caliper |
| 6 | 9/20/89 | DLL | 5880' - 6088' | A-4 | |
| | | Sonic | 5880' - 6092' | A-2 | Sonic log has been computer processed |
| | | LDT/CNL | 5880' - 6088' | A-1 | |
| | | Cyberlook | 5880' - 6088' | A-3 | |
| 7 | 9/28/89 | ETT-D | 20' - 6006' | B-9 | Base log for future reference |
| | | ETT-D Quicklook | 850' - 6006' | B-10 | |

* NOTE: Engineering logs run for field evaluation of operations are not always distributed as final copies.

NI = not included

# TABLE III

## ARISTECH CHEMICAL CORPORATION

## DISPOSAL WELL NO. 3

## SUMMARY OF DRILL STEM TESTS

| TEST NO. | APPENDIX | TEST INTERVAL | TEST TYPE | RECOVERY |
|---|---|---|---|---|
| 1 | C1 | 701' - 751' (Berea) | Conventional | No recovery. |
| 2 | C2 | 4503' - 4588' (Rose Run) | Conventional | Recovered 1020' (10.0 bbls.) fluid in drillpipe. |
| 3 | C3 | 5598' - 5733' (Rome/Conasauga) | Conventional | Recovered 2 gallons from sampler. |
| 4 | C4 | 4491' - 4591' (Rose Run) | Swab Test | Recovered 188 bbls. formation fluid. |
| 5 | C5 | 4171' - 4232' (St. Peter) | Swab Test | Recovered load fluid only, no formation fluid. |
| 6 | C6 | 1788' - 1858' (Newburg) | Swab Test | Recovered 93.7 bbls. formation fluid. |
| 7 | C7 | 1500' - 1570' (Bass Islands - "Niagaran") | Swab Test | Recovered 87.3 bbls. formation fluid with trace oil. |
| 8 | C8 | 5963' - 6109' (Mt. Simon) | Conventional | Misrun, No test. |
| 9 | C9 | 5978' - 6109' (Mt. Simon) | Conventional & Swab | Recovered 127.0 bbls. formation fluid. |

## TABLE IV

## ARISTECH CHEMICAL CORPORATION

## DISPOSAL WELL NO. 3

## SUMMARY OF CORE RECOVERY

| Core No. | Depths Cut Measured Depth, Ft. | Amount Cut (Ft.) | Amount Recovered (Ft.) | Remarks |
|---|---|---|---|---|
| 1 | 5600-5654 | 54 | 54 | Conasauga/Rome Confining Interval |
| 2 | 5654-5695 | 41 | 41 | Conasauga/Rome Confining Interval |
| 3 | 5695-5733 | 38 | 38 | Conasauga/Rome Confining Interval |
| 4 | 5915-5973 | 58 | 29 | Severe Hole Problems Prior To Coring |
| 5 | 5973-5978 | 5 | 3 | Two Trips With Core Possible Top of Mt. Simon @ 5981. |
| 6 | 5982-6027 | 45 | 45 | Tentative Top Mt. Simon Porosity @ 6011.5 Ft. |
| 7 | 6027-6073 | 46 | 46 | |
| 8 | 6073-6097 | 24 | 24 | Granite "Basement" @ 6079 Ft. Measured |
| 9 | 6097-6109 | 12 | 12 | Total Depth 6109 Ft. |

## TABLE V

## ARISTECH CHEMICAL CORPORATION

## DISPOSAL WELL NO. 3

## SUMMARY OF MEASURED ROCK MECHANICAL PROPERTIES

## (REFERENCE APPENDIX NO. G-1)

| Measured Depth | Closure Gradient (PSI/FT) (2) | True Vertical Depth (3) | (2)*(3) Closure Pressure (PSI) | Hydrostatic Pressure At Depth-Fresh Water | Closure Pressure At Surface-Fresh Water |
|---|---|---|---|---|---|
| 5678 | 0.871 | 5252 | 4574.5 | 2310.9 | 2263.6 |
| 5708 | 0.912 | 5279 | 4814.4 | 2322.8 | 2491.6 |
| 5709 | 0.920 | 5280 | 4857.6 | 2323.2 | 2534.4 |

The well was drilled directionally to a bottom hole location that is approximately 1695 feet North and 1116 feet East of the surface location at a measured depth of 6109 feet. A copy of the directional survey information is included as Appendix F.

Cores were cut from measured depths of 5600 feet to 5733 feet, 5915 feet to 5978 feet and 5982 feet to 6109 feet. Table IV summarizes the core recovery. Appendix G-2 contains details of the Rome/Conasauga cores and Appendix G-3 contains the Mt. Simon core information. In addition, mechanical rock properties were measured on three samples as summarized in Table V. A detailed report on the determination of the rock mechanical properties is included in Appendix G-1.

The surface casing, 10-3/4" 40.5 lb/feet K-55 with short thread and coupling, was set at 883 feet and cemented to surface with 475 sacks of cement. Appendix H-1 contains the O.D.N.R. Record of Casing, Cementing and Mudding as well as the treatment report supplied by the cement contractor. The protection casing, 7" 26 lb/ft. K-55 with long thread and coupling, was set at 5978 feet. The bottom two joints of protection casing were MN-80 grade for corrosion resistance. After cementing the first stage with 467 sacks "Lite Poz" (yield 2.26 cu.ft./sack) and tailing in with 170 sacks Class A (yield 1.18 cu.ft./sack), the staging collar was opened in preparation for cementing the second stage. It was not possible to circulate through the stage collar with mud returns to surface and the second stage cement was aborted. Appendix H-2 contains the report on cementing equipment installed on the protection casing as well as the installation summary. Thickening time and compressive strength tests were performed on the cement blend proposed for the protection casing. The test results are contained in Appendix H-3.

Mechanical Integrity Testing (MIT) included various unofficial pressure tests of the protection casing. An official annular test is to be performed subsequent to installation of the injection tubing. Results of the Oxygen Activation Log run as a part of the MIT are contained in Appendix J-1. Appendix J-2 contains the Radioactive Tracer (RAT) survey.

# TABLE VI

## ARISTECH CHEMICAL CORPORATION

## DISPOSAL WELL NO. 3

## SUMMARY OF CHEMICAL ANALYSES

| Formations: | Berea/ Cuyahoga | Rose Run #1 | Rose Run #2 | Niagaran (Bass Isl.) | Newburg | Mt. Simon |
|---|---|---|---|---|---|---|
| Depths: (feet) | 195 - 722 | 4503 - 4588 | 4491 - 4591 | 1500 - 1570 | 1788 - 1858 | 5978 - 6109 |

| Tests | Units | | | | | | |
|---|---|---|---|---|---|---|---|
| Sodium | mg/L | 9,900 | 46,500 | 44,600 | 42,500 | 42,700 | 14,000 |
| Potassium | mg/L | 96 | 3,700 | 3,330 | 1,210 | 1,430 | 421 |
| Calcium | mg/L | 3,000 | | 38,500 | 36,400 | 38,700 | 2,850 |
| Magnesium | mg/L | 730 | 4,900 | 6,070 | 8,970 | 9,150 | 424 |
| Temperature | °C | | | 24.6 | 23.0 | | 21.8 |
| Barium | mg/L | 9.2 | 2.5 | 1.8 | 1.1 | 1 | <0.1 |
| Alkalinity (to pH 8.3) | mg/L | | | <1 | <1 | <1 | 1,430 |
| Alkalinity (to pH 4.5) | mg/L | 33 | 295 | 129 | 68 | 640 | 2,170 |
| Aluminum | mg/L | N.D. | N.D. | <1 | 12.9 | 5.4 | 2 |
| pH | | 7.0 | | 5.76 | 6.22 | | 9.58 |
| Specific Gravity | | 1.03 | | 1.19 | 1.17 | 1.2 | 1.05 |
| Specific Conductance | umohs/cm | 60,000 | | 607,000 | 445,000 | 551,000 | 84,400 |
| Total Dissolved Solids | mg/L | 54,000 | 270,000 | 287,000 | 277,000 | 327,000 | 48,400 |
| DiMethyl Benzyl Alcohol | mg/L | N.D. | 74 | 44 | 0.19[J] | N.D. | 150 |
| Phenol | mg/L | 0.0 | 520 | 400 | 0.14 | N.D. | 940 |
| Diphenylamine | mg/L | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Alpha-Picoline | mg/L | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Total Suspended Solids | mg/L | 52 | 945 | 220 | 337 | 64 | 1,550 |
| Sulfate | mg/L | 82 | 380 | 330 | 180 | 130 | 2,490 |
| Chloride | mg/L | 29,000 | 160,000 | 170,000 | 139,000 | 179,000 | 21,200 |
| Nitrate Nitrogen | mg/L | N.D. | N.D.** | 220 | <10 | <10 | <10 |
| Carbonate | mg/L | N.D. | N.D. | <1 | <1 | <1 | 1,480 |
| Bicarbonate | mg/L | 33 | 295 | 129 | 68 | 640 | <1 |
| Dissolved Oxygen | mg/L | | N.D. | <0.5 | 5.9 | <0.5 | 9.5 |
| Iron | mg/L | 2.7 | 130 | 60.8 | 122 | 64 | 15.7 |
| Manganese | mg/L | 0.5 | 5.8 | 2.35 | 2.3 | 2.9 | 0.4 |
| Viscosity | cps | | N.D. | 3 | 2 | 3 | 2 |
| Acetone | mg/L | 0.4 | 72 | 210 | 0.11 | 0.024 | 800 |
| Cumene Hydroperoxide | mg/L | N.D. | 0.74 | * | * | * | * |
| Acetophenone | mg/L | N.D. | 6.6 | 6 | N.D. | N.D. | 35 |
| Ammonia Nitrogen | mg/L | 51 | 56 | 80.5 | 133 | 129 | 409 |
| Aniline | mg/L | N.D. | N.D. | N.D. | <.02 | N.D. | 3.1[J] |
| Total Chromium | mg/L | N.D. | N.D.** | <0.1 | 0.25 | 0.15 | <0.05 |
| Formic Acid | mg/L | 1,100 | 180 | 169 | <5 | <5 | 1,335 |
| Toluene | mg/L | 1 | N.D. | N.D. | 0.26 | 0.12 | 11 |
| Lead | mg/L | N.D. | 35 | <0.3 | <0.3 | <0.2 | 0.03 |

* Cumene Hydroperoxide could not be determined due to possible degredation and impure standards.

** Matrix Interference

[J] indicates that the value is estimated.

## 3.0 SUMMARY OF FIELD ACTIVITIES

The following section summarizes the field activities associated with the construction sequence performed on the Aristech Waste Disposal Well (WDW) No. 3. A detailed chronological report of the daily field activities comprises Appendix 3.0 of this document. At the appropriate times, daily mud checks were performed and the results of these tests can be found in Appendix E. As the hole was drilled directionally, gyro surveys were run periodically and various contract companies were utilized during the course of this project. Great Western Drilling Ray Resources Rig No. 7 performed the actual drilling. Eaton Well Drilling drilled the conductor well. Schlumberger ran the well logs, and Smith Directional Equipment was used to directionalize the well.

On February 2, 1989 Envirocorp (formerly Ken E. Davis Associates) personnel began the initial field work for the location of WDW No. 3 at the Aristech Chemical Corporation.

On February 9, the conductor well was drilled, cased with 16 inch casing, and cemented to the surface by Eaton Well Drilling. Approximately one month later, Ray Resources rigged up their equipment. The cement plug was located in the 16 inch conductor pipe at a depth of 77 feet. When a depth of 880 feet was reached, the Schlumberger equipment was rigged up and the Dual Induction log (DIL), Gamma Ray (GR), Sonic, and Caliper logs were run. A mud check was conducted the next day to assist in log calculation of formation resistivities. The Baker inflatable packers for the Drill Stem Test (DST) were set in place at depths of 705 feet and 755 feet, creating a 50 foot test interval. A Dowell Nitrogen Unit was utilized during the DST since the Ohio Environmental Protection Agency (EPA) requested nitrogen jetting be incorporated into the procedure. Split samples of the drilling mud were then taken in conjunction with the Ohio EPA.

On April 14, using a Repeat Formation Tool (RFT) fluid samples were taken at depths of 200 feet and 700 feet. The Cuyahoga Sandstone and the Berea Sandstone Formations are found at these depths. The Aristech laboratory analyzed these samples for total dissolved solids (TDS) and obtained a result of 35,000 ppm for the Berea Formation. Aristech's sample No. 5 registered 49,000 micro-mohs and the Ohio EPA samples No. 1 and No. 2 registered 50,000 and 60,000 micro-mohs respectively. In an attempt to acquire an additional water sample for the Ohio EPA the RFT was run for a second time to a depth of 214 feet. A build-up test was also performed at this depth. The attempt to take a grab sample at 214 feet was unsuccessful, however, a sufficient quantity of water was collected between 60 feet and 714 feet. A second build-up test was conducted and then the Steven's Casing crew ran 10 3/4 inch casing touching bottom at a depth of 879 feet.

On April 16, the casing was cemented with 475 sacks filling the casing hole annulus to the surface as witnessed by the Ohio Department of Natural Resources (ODNR). The cement was Class A with 3% Calcium Chloride having a calculated yield of 1.18 cubic feet/sack. A Schlumberger temperature log was then run from a depth of 750 feet to the surface for evaluation of the cement placement. Results of the temperature log indicated continuous cement. The casing head and blow out preventor were then set in place. The cement was drilled from 775 feet MD to 880 feet MD, the bottom of the cement. The hole was then drilled beyond this point to

a depth of 945 feet MD, placing the bottom in the Ohio Brown Shale. A Cement Bond Log with Variable Density Log (CBL/VDL) was run from 878 feet to the surface and the Smith Data Directional Equipment was set up. On April 19, they started to directionalize the well. A gyro survey was run from 878 feet up to the surface. Another gyro survey, run at 1350 feet MD, determined the inclination and direction to be 7.6° N 45.3° E and the true vertical depth (TVD) to be 1348.7 feet. The gyro survey was executed again at depths of 1774 feet MD and 1836 feet MD showing an inclination and direction of 19° N 38° E.

From April 19 through May 16, 878 feet MD to 4400 feet MD, directional surveys were run repeatedly with the last of the series showing a drift angle and bearing of 32.5° N 38.5° E. The well was also reamed periodically to a diameter of 9.5 inches down to a depth of 3958 feet MD.

On May 17, the hole was drilled to a depth of 4588 feet, within the Rose Run Formation. The following day, the hole was nitrogen jetted and after the fifth cleansing, split samples for DST No. 2 were collected in cooperation with the Ohio EPA. These DST samples were representative of the area between 4503 feet MD and 4588 feet MD. Drill pipe samples were collected at a depth of 1000 feet MD and four fluid samples were collected from the sample chamber at a pH of 6.8 and a temperature of 76° F.

Drilling resumed on May 19 and at the end of six days the depth had been increased from 4575 feet MD to 5344 feet MD placing the bottom in the Knox Formation. Directional surveys were run often during this drilling episode. At 5239 feet MD and 4827 feet TVD, a gyro survey determined the inclination and direction to be 27.5° N 34° E.

Based on a review of the mud logs from Aristech's WDW No. 1 and WDW No. 2, the core point of WDW No. 3 was chosen to be at a depth of 5600 feet MD, placing it within the Conasauga Foundation. A series of these cores were taken between May 26 and May 31. Core No. 1 was cut from 5600 feet MD to 5654 feet MD (54 feet); Core No. 2 was cut from 5654 feet MD to 5695 feet MD (41 feet); and Core No. 3 was cut from 5695 feet MD to 5733 feet MD (38 feet). Each core was described, photographed, and preserved for future reference according to standard operating procedure. On the last day of coring, the mud filtrate was tested for phenol content. The concentration was less than 10 ppm.

A third DST was performed June 2 within the Rome/Conasauga formation, from 5598 feet MD to 5733 feet MD. Results of DST No. 3 indicated a virtually nonpermeable formation as only 65 feet of drilling mud (0.3 barrels) entered the drill string during the two flow periods of the test. The duration of flow period number one was 480 minutes and flow period number two was 130 minutes. After review of the DST Chart by the Ohio EPA, approval was granted to drill within 100 feet of the Mt. Simon Formation. This point was reached on June 4 at a depth of 5875 feet MD.

On June 8, packers were once again placed into the Rose Run Foundation based on a request by the Ohio EPA for additional DST samples. The packers were set at depths of 4491 feet MD and 4591 feet MD achieving

a total space of 100 feet. A Gamma Ray Neutron log was run to verify these depths. The hole was then swabbed through the drill pipe from June 8 through June 13 with a total of 158 barrels of fluid having been recovered during this time interval. Twenty-one split samples were collected during Episode No. 1. After Aristech's laboratory determined that three consecutive samples had been collected which were identical with respect to temperature, pH, conductivity, and phenol concentration, 21 additional split samples were collected, Episode No. 2, in an uncontaminated atmosphere. A total of 188 barrels of fluid had been recovered during this test. A Litho Density Tool as well as a Compensated Neutron log (CNL), Dual Laterolog, Micro SFL log, and a Dual Induction log with gamma ray (GR) and Spontaneous Potential (SP) were run from the current depth of 5872 feet MD to the base of the surface casing.

On June 20, the packers were set with a 61 foot spacing having been anchored at 4171 feet MD and 4232 feet MD to test the St. Peter Formation. Gamma Ray and Neutron logs were run in addition to a Casing Collar indicator (CCL) to confirm the packer depth. Twenty-four barrels of fluid had been recovered with this test but it had been determined there was no apparent fluid entry from this formation. Fresh water was pumped into the formation in an attempt to clean the formation. This fresh water treatment resulted in failure of the bottom packer. Subsequently, swabbing was initiated and a total of 109 barrels of fluid were recovered.

Due to the poor condition of the annular mud, it became necessary to concentrate on circulating and conditioning the mud from June 23 through June 28. Excessive chlorides in the mud resulted in a high water loss and created "wall cake" in the well and increased the drag on the pipe causing it to become paralyzed. Starch, defoamer, and polymer were added to enhance circulation and increase viscosity. The pipe was finally freed and extracted after six days of conditioning.

Drilling was suspended until July 14, while procedures for further drilling were clarified between Aristech and OEPA. On July 14, the packers were set for a swab test of the interval from 1788 feet MD to 1858 feet MD, placing it within the Newburg Formation. Swabbing began and samples were taken over the course of two days with a total of 93.7 barrels of recovered fluid. Four days later, a swab test was run on the Bass Islands Group of Silurian age (referred to as the Niagaran Formation by the Ohio EPA), specifically at an interval between 1500 feet MD and 1570 feet MD, creating a 70 foot space between the packers. Swabbing resulted in 67.1 barrels of recovered fluid. Samples were taken on July 19 completing the test.

Operations resumed July 30 pursuant to agreement betweeen Aristech and OEPA. After several days of circulating and conditioning the mud with the casing point calculated at 5985 feet, coring of the Rome Foundation began on August 2. The coring started at 5915 feet MD with the core point calculated at 5985 feet MD. A 29 foot core was obtained. The hole was then reamed in its entirety which was to a depth of 5973 feet MD. An additional one foot core was retrieved after reaching a depth of 5978 feet MD. Through a review of WDW No. 1 density logs, it was suspected that the Mt. Simon Formation might have been porous at a depth of 5981 feet MD, therefore, coring was terminated. Over the course of several days, it was necessary to ream the well, 8.5 inches to 9.5 inches, prior to running the logs. On August 11, a Sonic TD-SFC, a directional survey TD-SFC,

and an additional Litho Density Neutron log were run. Attempts to use a borehole televiewer failed due to an equipment malfunction. Feeling the original CBL was inconclusive, a second CBL-VDL was also run from 790 feet MD to the surface casing. The second test indicated good bonding had been achieved.

On August 16, permission to drill an additional five feet was received. These last five feet were drilled in two stages. Two feet were drilled then Tally No. 1 was taken, measuring 5975.24 feet. The last three feet were then drilled and Tally No. 2 was measured at 5973.62 feet. The geolograph was determined to be at 5983 feet MD. At this time, 158 joints of 7 inch well casing were placed into WDW No. 3. The casing was to be cemented in two stages. After cementing the first stage, the stage collar (which had been set at 3127 feet) was opened in preparation for cementing the second stage. The well could not be circulated after opening the staging tool. A temperature log was conducted indicating the top of the cement was at 2250 feet. The stage tool was closed after squeezing 50 sacks of cement through the tool. After waiting several more days, a CBL was run from 2000 feet MD to 3030 feet MD.

On August 25, cement was drilled from the stage tool and then the cement was drilled from 5719 feet MD, the top of the first stage cement (inside casing), to 5968 feet MD. A Cement Evaluation Tool (CET) was used from 5950 feet MD to the surface and indicated several voids and a possible cave-in. A CBL and a temperature survey were run from 2200 feet MD to 5950 feet MD. Additional CBL and CET logs from 5950 feet MD to the surface were run at 2200 psi. The top of the cement was confirmed to be at 2600 feet MD.

The next task was to run a one-inch tremie line into the annular space between the 10 3/4-inch and 7 inch casings. Cement was pumped through this line from a depth of 1275 feet MD to the surface. After curing several days, multiple logs were run on the cement and casing. A temperature log survey, and Electromagnetic Thickness Tool (ETT), and a CBL-VDL (no pressure) were run between the absolute bottom and the surface. A CET (no pressure) was also utilized and the 7 inch casing was pressure tested at 3000 psi.

On September 13, the drilling of the remaining cement continued as well as coring into a new formation upon reaching 6027 feet MD. A 45 foot core from the Mt. Simon formation was pulled and documented. From this description, the main porosity of Mt. Simon was picked at 6011.5 feet MD and drilling resumed. During the next several days, a 46-foot core was taken between 6027 feet MD and 6073 feet MD. A 24-foot core was taken between 6073 feet MD and 6097 feet MD, and a 12-foot core was taken from between 6097 feet MD and 6109 feet MD. The coring was completed September 20. The next day, a Laterolog, Litho Density log, and a Compensated Neutron Porosity log were run across the open hole interval.

On September 22, a borehole televiewer and sonic were utilized, a directional survey was run, and the DST on the Mt. Simon Formation was initiated. The packers were set for a test interval between 5978 feet MD and 6109 feet MD. Samples were taken on September 26 and a total of 205 barrels of fluid were recovered during the test. Two days later, an ETT was run from 5978 feet MD to the surface.

On September 30, a bridge plug was at 5884 feet and the drilling mud was inhibited against corrosion. The system was pressure tested at least three times at 3000 psi and held at 2900 psi. Dismantling the drilling equipment began and was completed October 4.

The well was reentered on November 16, 1989 to prepare for an interference test to be performed as a part of the land ban petitioning process. The bridge plug was retrieved and a packer set, on tubing, at a depth of 5941 feet. 1000 gallons of 15% HC1 acid were pumped into the Mt. Simon formation with a maximum surface treating pressure of 700 psig. After recovery of the load fluid, all three Aristech wells were equipped with necessary pressure recording equipment and the interference test was completed on November 30, 1989. Subsequent to the interference test, a step rate test was performed on Well No. 3. The results of both tests are contained and discussed in the petition document, which will be submitted upon its completion in accordance with Aristech's permit to drill.

On December 13, 1989, a Radioactive Tracer Survey (RAT) was run and an Oxygen Activation Log (OAL) was completed on the 14th. Results of both surveys gave indication that all injected fluid was entering the Mt. Simon formation with no fluid movement past the injection packer or upward outside the casing.

The packer was removed from the well and the bridge plug reinstalled, at 5941 feet. The Well was returned to a suspended status, waiting for permission to install injection tubing on December 19, 1989.

Appendix G-3

# REPORT OF DRILLING AND TESTING OF THE MONITOR WELL (DEEP WELL NO. 4)

## ARISTECH CHEMICAL CORPORATION
HAVERHILL, OHIO

ENVIROCORP PROJECTS NO. 30-1708 AND NO. 30-1754

P 4-91

Barcode 002637

Box 35

JULY 12, 1991

PREPARED BY
ENVIROCORP SERVICES & TECHNOLOGY, INC.
SOUTH BEND, INDIANA

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DRAWING 30-1708-1: MONITOR WELL STRATIGRAPHIC COLUMN

## APPENDICES

APPENDIX A: OPEN HOLE GEOPHYSICAL LOGS
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APPENDIX G: IN-SITU STRESS TEST, RECORDED DATA
APPENDIX H: CORE ANALYSIS - SELECTED INTERVALS

# 1.0 INTRODUCTION

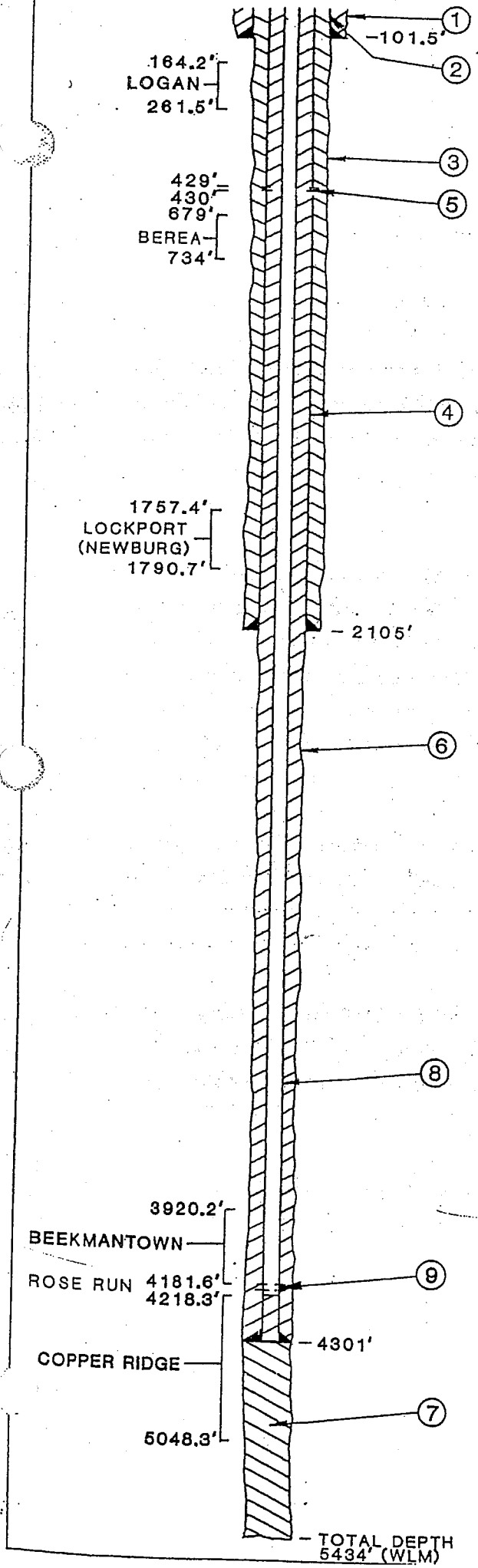
This report summarizes the construction and testing of Aristech Chemical Corporation's Monitor Well (Deep Well No. 4). Envirocorp Services & Technology, Inc. was contracted to construct the well.

The Monitor Well was constructed in accordance with the approved well plan with minor modifications as dictated by hole conditions. Any deviations to the well plan were communicated to Ohio EPA by the Aristech representative. The sampling was done as required and results of the sampling were not adversely impacted by hole conditions. All fluid samples obtained are representative of fluids contained in the formations to be tested pursuant to the well plan. The well has been perforated in the Rose Run but has not been swabbed to ensure fluid entry at this time. It is anticipated that reliable fluid and pressure information will be obtained over the life of the well in accordance with the well plan.

The Monitor Well was spudded on January 17, 1991. Seven inch casing was set at 101.5 feet below ground surface and cemented to surface. Unless otherwise noted, depths are measured from ground surface. A four inch core hole was then drilled to 2170 feet. During this initial coring operation, representative formation fluid samples were obtained from the Logan, Berea and Lockport formations. The details of the sampling events and the validated analytical results will be submitted under separate cover. The hole was reamed out to six and one half inches in diameter to a depth of 2105 feet to enable the placement of a four and one half O.D. casing in the hole. The casing was set at 2105 feet and cemented to surface in two stages.

Four inch coring continued, with representative fluid samples being collected from the Beekmantown (also known as Upper Knox), Rose Run and Copper Ridge (also known as Lower Knox). The well was cored to a total depth of 5434 feet WLM (wire line measurement). All cores from 101.5 feet to bottomhole were recovered split and stored as required by the well plan. No cores were taken in the unconsolidated alluvium or bedrock above 101.5 feet. A monitor well stratigraphic column is included as Drawing 30-1708-1. After total depth was achieved, 28 in-situ stress tests were performed for determination of fracture gradients in the formations below 3550 feet. Analysis of the in-situ stress tests are being submitted under separate cover. The well was then plugged back to a depth of 4303 feet and 2-3/8 inch monitor well casing was installed. The monitor well casing was then cemented to surface with 160 sacks of cement.

A Cement Bond Log (CBL/VDL) was run on the monitor well casing. The casing was perforated in the Rose Run Formation from 4186 feet to 4222 feet. The CBL/VDL confirmed proper cementing of the casing from bottom hole to surface. A pressure monitor was installed on June 27, 1991. A schematic of the well as completed is shown as Figure 1.0.




DETAILS AS CONSTRUCTED

1. 9 7/8" HOLE TO 101.5'

2. 7" O.D. 17 LB/FT H-40 FLUSH JOINT CASING (6.5" I.D.) SET AT 101.5' AND CEMENTED TO SURFACE WITH 25 SACKS OF CLASS A CEMENT AND 1 SACK SALT

3. 4" CORE HOLE REAMED TO 6 1/2"

4. 4 1/2" O.D. 10.5 LB/FT J-55 ST & C CASING SET AT 2105' GROUND LEVEL AND CEMENTED TO 454' WITH 100 SACKS OF PREMIUM CEMENT, 10.8% MICROBOND, .6% HALAD 344, 2% $CaCl_2$, 5% CFR2P, 1/4 LB FLOCELE FOLLOWED BY 175 SACKS OF PREMIUM CEMENT, 10.8% MICROBOND, .6% HALAD 344, 2% $CaCl_2$, AND .5% CFR2P. SECOND STAGE OF CEMENT FROM 454' TO SURFACE 100 SACKS OF STANDARD BULK CEMENT WITH 4% GEL AND 5 SACKS OF 5% $CaCl_2$

5. PERFORATIONS: 4 RADIAL BETWEEN 429' & 430' FOR CIRCULATION OF SECOND STAGE OF CEMENT

6. 4" CORE HOLE TO TOTAL DEPTH 5427' (5434' WLM, WIRELINE MEASUREMENT)

7. PLUGGED BACK FROM 5427' TO 4303' WITH 137.5 SACKS CLASS A CEMENT (YIELD 1.18 CUBIC FT/SACK)

8. 2 3/8" O.D. 4.6 LB/FT J-55 NON UPSET TUBING SET AT 4301' AND CEMENTED TO SURFACE WITH 110 SACKS HALIBURTON LIGHT FOLLOWED BY 50 SACKS 50/50 POZMIX

9. PERFORATIONS, 4186' TO 4222', 2 HOLES/FT

NOT TO SCALE

ENVIROCORP
ENVIROCORP SERVICES & TECHNOLOGY, INC.
HOUSTON, TX.
SOUTH BEND, IN
BATON ROUGE, LA.

FIGURE 1.0
ARISTECH CHEMICAL CORP.
HAVERHILL, OHIO
MONITOR WELL SCHEMATIC

| | | |
|---|---|---|
| DATE: 5/10/91 | CHECKED BY: KCP | JOB NO: 30-1708 |
| DRAWN BY: GRL | APPROVED BY: | DWG. NO: |

## 2.0 SUMMARY OF LOGGING AND TESTING RESULTS

The specific information acquired while drilling the Monitor Well has been included in the attached appendices. The contents of these appendices has been listed in Table I. The appendices have been referenced where applicable instead of incorporating lengthy discussions.

**TABLE I**

**Aristech Chemical Corporation**

**Monitor Well**

**TABLE OF APPENDICES**

| APPENDIX | CONTENTS |
|---|---|
| A | Open Hole Geophysical Logs |
| B | Cased Hole Geophysical Logs and Selected Engineering Logs |
| C | Drill Stem and Swab Tests |
| D | Core Log |
| E | Directional Surveys |
| F | Summary of Casing and Cementing |
| G | In-Situ Stress Test, Recorded Pressure Data |
| H | Core Analyses of Ohio DNR-Selected Samples |

The geophysical log measurements obtained from the open (uncased) hole logging are contained in Appendix A. Table II summarizes the logs. Information concerning formation porosities, indicated fluid resistivities, and apparent lithologies can be obtained from the open hole logs.

Cased hole geophysical logs, run for evaluation of cement bonding and cement placement are contained in Appendix B. Selected engineering logs are also contained in Appendix B.

Drill Stem Test (DST) and Swab Tests were conducted as shown in Table III. Further details are contained in Appendix C.

The swab tests were conducted for the purpose of obtaining a representative sample of fluids contained within the formation tested. Appendix C also contains the swab test summaries. A summary of the chemical analytes from the representative samples is included as Table V. Further information concerning the analyses is contained in the analytical report, submitted under separate cover.

In-situ stress testing was performed for the determination of fracture gradients. Table VI summarizes the in-situ stress test intervals. The recorded pressure data for each interval tested is contained in Appendix G. Further information is contained in the Report of In-Situ Stress Testing, submitted under separate cover.

Five core samples were chosen by Ohio DNR for geophysical analyses. The results of the analyses are contained in Appendix H. Porosity and permeability were measured and petrographic analyses were done. The petrographic analyses included thin section microscopy, X-ray diffraction analyses and scanning electron microscopy.

## TABLE II

## Aristech Chemical Corporation

## Monitor Well

## SUMMARY OF GEOPHYSICAL LOGGING

| Depth | Log Run | Properties Measured | Appendix | Remarks |
|---|---|---|---|---|
| 2169' - 138' | CNL/FDC | Porosity | A.1 | Measures neutron porosity and density porosity. Includes gamma ray which is the main correlating log device. |
| 2169' - 830' | Sonic | Porosity | A.2 | Measures open hole porosity. Could be used to correlate seismic reflection data. |
| 2169' - 138' | Induction | Resistivity | A.3 | Measures resistivity of formation fluids. Gives qualitative indication of permeability. |
| 5434' - 2106' | CNL/FDC | Porosity | A.4 | Measures neutron porosity and density porosity. Includes gamma ray which is the main correlating log device. |
| 5434' - 2106' | Sonic | Porosity | A.5 | Measures open hole porosity. Could be used to correlate seismic reflection data. |
| 5434' - 2106' | Induction | Resistivity | A.6 | Measures resistivity of formation fluids. Gives qualitative indication of permeability. |
| 2108' - 138' | CBL/VDL | Sonic Device | B.1 | Gives indication of cement placement and bonding. Surface casing evaluation. |
| 1982' - Surface | Temp. Log | Temperature | B.2 | Measures differences in temperature behind casing. |
| 5360' - 5150' | CCL | Gamma Ray | B.3 | Correlation log run to confirm packer depth for first in-situ stress test. |
| 4122' - 170' | CBL/VDL | Sonic Device | B.4 | Gives indication of cement placement and bonding. Monitor casing evaluation. |

## TABLE III

## Aristech Chemical Corporation

## Monitor Well

## SUMMARY OF DRILL STEM TESTS AND SWAB TESTS

| Test No. | Appendix | Test Interval (ft.) | Test Type | Recovery |
|---|---|---|---|---|
| DST 1 | C.1 | Logan<br>164.2 - 261.5 | Conventional &<br>Swab Test | Pressure Recorded 63.7 psi<br>Recovered representative sample |
| DST 2 | C.2 | Berea<br>679.2 - 734 | Conventional &<br>Swab Test | Pressure Recorded 324.3 psi<br>Recovered representative sample |
| DST 3 | C.3 | Lockport<br>1757.4 - 1790.7 | Conventional &<br>Swab Test | Pressure Recorded 837.7 psi<br>Recovered representative sample |
| DST 4 | C.4 | Beekmantown<br>4012 - 4035 | Conventional &<br>Swab test | Pressure not Recorded<br>Recovered representative sample |
| DST 4-A | C.5 | Beekmantown<br>4006 - 4035 | Conventional | Pressure Recorded 1805.7 psi |
| DST 5 | C.6 | Rose Run<br>4181 - 4225 | Conventional &<br>Swab Test | Pressure Recorded 1912.2 psi<br>Recovered representative sample |
| DST 6 | C.7 | Copper Ridge<br>4446.7 - 4480 | Conventional &<br>Swab Test | Pressure Recorded 2078.2 psi<br>Recovered representative sample |

A continuous core was cut from a measured depth of 101.5 feet to 5434 feet. Table IV summarizes the formation intervals. The core log is included in Appendix D.

## TABLE IV

## Aristech Chemical Corporation

## Monitor Well

## SUMMARY OF FORMATION TOPS FROM CORE LOG

| Measured Depth (ft.) | Formation |
|---|---|
| * | Logan |
| 426.8 | Cuyahoga |
| 659 | Sunbury |
| 679.1 | Berea |
| 823.6 | Ohio Shale |
| 1296.5 | Olentangy |
| 1436.9 | Delaware |
| 1500 | Salina |
| 1669.8 | Lockport |
| 1879.8 | Rochester |
| 2089.9 | Dayton |
| 2156.1 | Brassfield |
| 2206.7 | Cincinnati Group |
| 3244.3 | Trenton |
| 3319.8 | Black River |
| 3845.7 | Wells Creek |
| 3920.2 | Beekmantown |
| 4181.6 | Rose Run |
| 4218.3 | Copper Ridge |
| 5048.3 | Conasauga |
| 5192.5 | Rome |
| 5434 | Total Depth |

* Coring began in the Logan Formation at 101.5 feet.

# TABLE V

## Aristech Chemical Corporation

## Monitor Well

## SUMMARY OF TARGET ANALYTES

InOrganics
- Alkalinity
- Ammonia-Nitrogen
- Bromide
- Bicarbonate
- Carbonates
- Chloride
- Dissolved Oxygen
- Nitrates
- Tot. Dissol. Solids
- Tot. Suspnd. Solids
- Specific Conductance
- Specific Gravity
- Silicates
- Sulfates
- Viscosity

Metals
- Aluminum
- Barium
- Calcium
- Hex.Chromium
- Tot.Chromium
- Iron
- Lead
- Magnesium
- Manganese
- Potassium
- Sodium

Volatiles
- Acetone
- Toluene
- Formic Acid

Semi-Volatiles
- Acetophenone
- Alpha-Picoline
- Aniline
- Phenol
- Cumene
- DiMethylBenzylAlcohol
- DiPhenylAmine
- BisPhenol A

Total Phenolics
- Before
- Formation
- After

## TABLE VI

## Aristech Chemical Corporation

## Monitor Well

## IN-SITU STRESS TEST INTERVALS

| Date | Test No. | Tool Spacing | Depth to M.P.P.* | Formation | Pump-in Rate, GPM | Packer Inflation Pressure |
|---|---|---|---|---|---|---|
| 5/31/91 | 1 | 4 | 5388 | Rome | 2.1 - 4+ | 1000 |
| 5/31/91 | 2 | 4 | 5375 | Rome | 2.3 | 850 |
| 5/31/91 | 3 | 4 | 5362 | Rome | 2.3 | 750 |
| 5/31/91 | 4 | 4 | 5317 | Rome | 2.3 | 500 |
| 6/1/91 | 5 | 4 | 5243 | Rome | 2.3 | 650 |
| 6/1/91 | 6 | 4 | 5200 | Rome | 2.4 | 900 |
| 6/1/91 | 7 | 4 | 5176 | Conasauga | 2.4 | 775 |
| 6/1/91 | 8 | 4 | 5119 | Conasauga | 2.3 | 650 |
| 6/1/91 | 9 | 4 | 5070 | Conasauga | 2.5 | 850 |
| 6/1/91 | 10 | 4 | 4977 | Beekmantown | 2.4 | 750 |
| 6/2/91 | 11 | 4 | 4823 | Beekmantown | 2.4 | 520 |
| 6/2/91 | 12 | 4 | 4474 | Beekmantown | 2.4 | 700 |
| 6/2/91 | 13 | 4 | 4257 | Beekmantown | 2.3 | 745 |
| 6/2/91 | 14 | 4 | 4212 | Rose Run | 2.3 | 400 |
| 6/3/91 | 15 | 4 | 4196 | Rose Run | 2.3 | 675 |
| 6/3/91 | 16 | 4 | 4188 | Rose Run | 2.4 | 640 |
| 6/3/91 | 17 | 4 | 4176 | Copper Ridge | 2.4 | 675 |
| 6/3/91 | 18 | 4 | 4162 | Copper Ridge | 2.3 | 660 |
| 6/3/91 | 19 | 4 | 4142 | Copper Ridge | 2.5 | 520 |
| 6/3/91 | 20 | 4 | 4123 | Copper Ridge | 2.5 | 670 |
| 6/3/91 | 21 | 4 | 3972 | Copper Ridge | 2.5 | 520 |
| 6/3/91 | 22 | 4 | 3902 | Wells Creek | 2.4 | 670 |
| 6/3/91 | 23 | 4 | 3782 | Black River | 2.5 | 520 |
| 6/3/91 | 24 | 4 | 3550 | Black River | 2.4 | 465 |
| 6/4/91 | 25 | 4 | 5381 | Rome | 2.3 | 595 |
| 6/4/91 | 26 | 10 | 5147 | Conasauga | 7.0 | 630 |
| 6/4/91 | 27 | 10 | 4628 | Beekmantown | 6.9 | 580 |
| 6/4/91 | 28 | 10 | 4055 | Copper Ridge | 7.0 | 680 |

* Mid Point Packers

## 3.0 SUMMARY OF FIELD ACTIVITIES

The following section summarizes the field activities associated with the construction of the Aristech Monitor Well. Deviation surveys were run at different depths and the results are included in Appendix E. The well was drilled using a continuous coring rig. Formation fluid samples were collected during the swab tests by $CH_2M$ Hill. The chemical analyses results from $CH_2M$ Hill are reported in "Aristech Chemical Corporation, Haverhill Plant, UIC Monitoring Well, Formation Fluid Sampling and Analysis Report" submitted under separate cover. A detailed chronological summary of the daily field activities has been included in Section 4.0.

On January 14, 1991 Envirocorp personnel began the initial field work for the location of the Monitor Well at Aristech Chemical Corporation's Haverhill, Ohio facility.

The 7-inch casing was set at a depth of 101.5 feet and cemented to the surface. A 5-inch flush joint casing (temporary drilling protection string) was set and continuous coring of the formation began with a 94 mm core bit. Coring continued to a depth of 261.5 feet. The drill string was pulled out of the hole and Halliburton's drill stem test (DST) equipment was rigged up and run into the hole. The test interval for DST No. 1 was from 164.2 feet to 261.5 feet. After the initial portion of the DST of the Logan formation was completed, three tubing volumes of formation fluid were swabbed prior to collection of the representative sample by $CH_2M$ Hill.

The coring continued into the Berea formation until a depth of 734.0 feet was reached. The drill string was tripped out and Halliburton's DST equipment was rigged up and run into the hole for DST and Swab Testing. At this depth DST and Swab Test No. 2 were performed over the interval 679.2 feet to 734.0 feet. Representative fluid samples were collected for chemical analysis by $CH_2M$ Hill after three tubing volumes were swabbed.

When DST and Swab Test No. 2 was completed, the coring continued into the Lockport formation until a depth of 1790.7 feet was reached. The drill string was pulled from the hole and Halliburton's DST equipment was rigged up and run into the hole for DST and Swab Test No. 3. The interval tested was from 1757.4 feet to 1790.7 feet. During the second opening of the test assembly, three tubing volumes were swabbed and a representative sample of formation fluid was recovered for chemical analysis. Fluid samples were collected by $CH_2M$ Hill for chemical analysis.

After the completion of DST and Swab Test No. 3, the continuous coring drill string was run back into the hole and coring resumed. Coring continued through the Rochester formation and into the Dayton formation to a depth of 2170.0 feet.

Schlumberger Logging Services rigged up to run the geophysical logs. Neutron, density, gamma ray, caliper, dual induction and sonic logs were run on the open hole from 2169.0 feet to 138.0 feet. The sonic log was run from 2169.0 feet to 830 feet. There was insufficient submergence above 830 feet for the tool to function properly.

Once the open hole geophysical logs were completed, a 6-1/2 inch bit was run into the hole and reaming began. The hole was reamed from 101.5 feet to 2105 feet.

On March 19, 1991, 48 joints of 4-1/2 inch 10.5 lb. casing was set at 2105 feet ground level. The casing was cemented with 100 sacks of premium cement containing 10.8% Microbond, 6% Halad 344, 2% $CaCl_2$, 5% CFR 2P, and 1/4 lb. of Flocele, followed by 175 sacks of premium cement, containing 10.8% Microbond, 6% Halad 344, 2% $CaCl_2$, and .5% CFR 2P. The cement did not circulate to the surface. Young Wireline Service was called to run a differential temperature log to locate the cement top.

The differential temperature log was not able to pin point the top of the cement so Schlumberger was called in to run a CBL/VDL. The top of cement was indicated at 454 feet from ground level. Halliburton was contacted to do an additional cement stage using 100 sacks of standard bulk cement with 4% gel and 5 sacks of 5% $CaCl_2$. Schlumberger perforated the 4-1/2 inch casing with four shots radially from 429 feet to 430 feet. Halliburton began pumping cement into the 4-1/2 inch casing perforations. Approximately 2 barrels of cement were circulated to the surface. After the cement was set, it was drilled out at the 430 foot level where the stage cement job had been done and at the bottom of the casing. Schlumberger was then called in to run a cement bond log on the casing (CBL/VDL). Coring resumed from 2170 feet with a 94 mm core bit on March 24, 1991.

After drilling the cement from the surface casing, coring continued to a depth of 4035 feet. The drill string was pulled out of the hole and Halliburton's drill stem test (DST) equipment was rigged up and run into the hole. The test interval for DST No. 4 was from 4006.7 feet to 4035 feet. After the initial portion of the DST of the Beekmantown formation was completed, three tubing volumes of formation fluid were swabbed prior to collection of a representative sample by $CH_2M$ Hill. The test was rerun (DST 4A) to obtain pressure data because the clocks in the pressure recording equipment had run out during the first test.

The coring continued into the Rose Run member of the Knox formation until a depth of 4225 feet was reached. The drill string was tripped out and Halliburton's DST equipment was rigged up and run into the hole for DST and Swab Testing. DST/Swab Test No. 5 was performed over the interval 4181 feet to 4225 feet. After three tubing volumes were swabbed, representative fluid samples were collected for chemical analysis by $CH_2M$ Hill.

After DST/Swab Test No. 5 and sample collection was completed, the coring continued into the Copper Ridge member of the Knox Group until a depth of 4480 feet was achieved. The drill string was pulled from the hole and Halliburton's DST equipment was rigged up and run into the hole for DST/Swab Test No. 6. The interval tested was from 4446.7 feet to 4480 feet. Formation fluid was swabbed until three tubing volumes were removed prior to sample collection for chemical analysis. Representative fluid samples were collected by $CH_2M$ Hill for chemical analysis.

After the completion of DST/Swab Test No. 6 and sample collection, the continuous coring drill string was run back into the hole and coring resumed. Coring continued through the Copper Ridge formation, the Conasauga Shale and into the Rome formation to a total depth of 5434 feet below land surface.

Schlumberger Logging Services rigged up to run the geophysical logs. Neutron, density, gamma ray, caliper, dual induction and sonic logs were run on the open hole from 5434 feet to 2105 feet.

The core rig was released and a completion unit was rigged up on the well in preparation for in-situ stress testing. Using an inflatable straddle packer assembly, twenty-eight intervals were tested for the determination of fracture gradients and closure stress. Pressures recorded during the in-situ stress testing are contained in Appendix G. Analysis of the test results is contained in "Results: In-Situ Stress Measurements at the Aristech Chemical's Haverhill Facility, Research and Engineering Consultants, July 1991" submitted under separate cover. A discussion of the theory is contained in "Protocol: In-Situ Stress Measurements at the Aristech Chemical's Haverhill Facility, Research and Engineering Consultants, January 1991."

Upon completion of the in-situ stress testing, Halliburton rigged up in preparation for plugging the wellbore back to the agreed monitoring point. Using the balanced plug method, 84 sacks of Halliburton Standard cement were emplaced from total depth up to 4292 feet. After waiting for the cement to harden for 24 hours, the top of the cement plug was tagged at a depth of 4523 feet. An 18 sack plug was spotted and subsequently tagged at 4517 feet after 24 hours WOC (waiting on cement). A third plug, 35 sacks, was emplaced at 4517 feet. After reverse circulating at 4288 feet, the well was secured for a 24 hour WOC period. The third plug was tagged at a depth of 4298 feet with the work string.

On Monday, June 10, 1991, 2-3/8 inch 4.6 lb/ft J-55 non upset tubing was run into the well to serve as the monitor casing. The casing was set at 4301 feet, based upon the casing tally. Each connection was wrapped with teflon tape and torqued to 600 ft-lbs. The casing was internally hydrotested to a minimum of 4600 psi during installation. On Tuesday, June 11, the casing was cemented to surface with 110 sacks Halliburton Light cement (mixed to 12.4 lb/gal slurry weight to minimize the hydrostatic gradient) followed by 50 sacks 50/50 Pozmix. Approximately three barrels of cement slurry was circulated to surface. The well was secured for a five day WOC.

After waiting for the cement to harden, Schlumberger Well Service rigged up to run the CBL/VDL. The logging tools could not be lowered below 4131 feet and the well was logged from 4131 feet to surface. The log showed that cement had been emplaced from 4131 feet to a depth of 168 feet. A 1-1/4 inch workstring was picked up and run into the well and removed the obstruction from 4131 feet.

On Monday, June 24, 1991, the interval 4269 feet (PBTD) to 4131 feet was logged and the well was perforated from 4186 feet to 4222 feet. A tubing stop was set in the casing at a depth of 4148 feet to insure a stationary gauge depth. A pressure monitor was installed and routine and periodic pressure recording commenced on June 27, 1991.

P2-91

Barcode 002637

Box 35

APPENDIX G

IN-SITU STRESS TEST, RECORDED DATA

ARISTECH CHEMICAL CORPORATION
IN-SITU STRESS TEST TUBING TALLY

.CORRELATE TO ATLAS WIRELINE GAMMA RAY-CCL
.PUP JOINT IS LOCATED AT 5345 FT. TO 5349.5 FT.

.TOP OF PUP IS 42.99 FT. ABOVE MID POINT PACKERS
.BOTTOM OF PUP IS 38.94 FT. ABOVE MID POINT PACKERS

5345 FT+ 42.99 FT= 5387.99 FT IS MPP
5349.5 FT+ 38.94 FT= 5388.44 FT IS MPP

MID POINT PERFS (MPP) IS 5388 FT. FOR THIS TEST

* FIRST JOINT 32.30 FT, 3.85 IS ABOVE FLOOR, NET IS 28.45 FT

| TEST# | LAID DOWN TUBING <-JOINT# (LENGTH) | | LENGTH OF STRING (TO MPP) | STRING ABOVE FLOOR | DEPTH OF TEST | REMARKS |
|---|---|---|---|---|---|---|
| 1 | | | 5388.00 | N.A. | 5388 | 5/31/91 |
| 2 | | | 5388.00 | 13.0 | 5375 | |
| 3 | | | 5388.00 | 26.0 | 5362 | |
| | 1 28.45 | * | 5359.55 | | | AMT IN HOLE |
| 4 | 2 32.63 | | 5326.92 | 10.0 | 5317 | 5/31-6/1/91 |
| | 3 30.66 | | 5296.26 | | | ADD PUPS |
| 5 | 4 32.71 | | 5263.55 | 21.0 | 5243 | DELETE PUPS |
| | 5 27.80 | | 5235.75 | | | |
| 6 | 6 26.04 | | 5209.71 | 9.7 | 5200 | |
| 7 | | | 5209.71 | 34.0 | 5176 | |
| | 7 27.15 | | 5182.56 | | | |
| | 8 25.45 | | 5157.11 | | | |
| 8 | 9 27.52 | | 5129.59 | 10.6 | 5119 | |
| | 10 26.35 | | 5103.24 | | | |
| 9 | 11 27.60 | | 5075.64 | 5.6 | 5070 | |
| | 12 27.18 | | 5048.46 | | | |
| | 13 26.09 | | 5022.37 | | | |
| 10 | 14 27.07 | | 4995.30 | 18.1 | 4977 | 6/1/91 |

TRIP TO DOWNLOAD MEMORY GAUGES, TRIP BACK IN TO TEST

| | | | | | |
|---|---|---|---|---|---|
| 15 | 27.30 | 4968.00 | | | |
| 16 | 27.75 | 4940.25 | | | |
| 17 | 28.80 | 4911.45 | | | |
| 18 | 26.95 | 4884.50 | | | |
| 19 | 32.70 | 4851.80 | | | |
| 11 20 | 27.55 | 4824.25 | 1.3 | 4823 | 6/2/91 |
| 21 | 32.31 | 4791.94 | | | |
| 22 | 26.55 | 4765.39 | | | |
| 23 | 31.15 | 4734.24 | | | |
| 24 | 26.80 | 4707.44 | | | |
| 25 | 27.60 | 4679.84 | | | |
| 26 | 25.20 | 4654.64 | | | |
| 27 | 30.45 | 4624.19 | | | |
| 28 | 32.60 | 4591.59 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 29 | 32.70 | 4558.89 | | | |
| | 30 | 32.65 | 4526.24 | | | |
| | 31 | 32.55 | 4493.69 | 19.7 | 4474 | |
| | 32 | 32.65 | 4461.04 | | | |
| | 33 | 26.00 | 4435.04 | | | |
| | 34 | 32.45 | 4402.59 | | | |
| | 35 | 31.80 | 4370.79 | | | |
| | 36 | 32.45 | 4338.34 | | | |
| | 37 | 31.85 | 4306.49 | | | |
| 13 | 38 | 31.70 | 4274.79 | 17.8 | 4257 | |
| 14 | 39 | 32.42 | 4242.37 | 30.4 | 4212 | |
| 15 | 40 | 31.72 | 4210.65 | 14.7 | 4196 | 6/3/91 |
| 16 | | | 4210.65 | 22.7 | 4188 | |
| 17 | 41 | 32.32 | 4178.33 | 2.3 | 4176 | |
| 18 | | | 4178.33 | 16.3 | 4162 | |
| 19 | 42 | 32.33 | 4146.00 | 4.0 | 4142 | |
| 20 | | | 4146.00 | 23.0 | 4123 | |
| | 43 | 31.75 | 4114.25 | | | |
| | 44 | 31.75 | 4082.50 | | | |
| | 45 | 32.45 | 4050.05 | | | |
| | 46 | 26.90 | 4023.15 | | | |
| 21 | 47 | 32.42 | 3990.73 | 18.7 | 3972 | |
| | 48 | 31.30 | 3959.43 | | | |
| 22 | 49 | 32.40 | 3927.03 | 25.0 | 3902 | |
| | 50 | 31.80 | 3895.23 | | | |
| | 51 | 32.39 | 3862.84 | | | |
| | 52 | 32.51 | 3830.33 | | | |
| | 53 | 31.70 | 3798.63 | 16.6 | 3782 | |
| | 54 | 31.38 | 3767.25 | | | |
| | 55 | 32.48 | 3734.77 | | | |
| | 56 | 32.47 | 3702.30 | | | |
| | 57 | 32.36 | 3669.94 | | | |
| | 58 | 31.78 | 3638.16 | | | |
| | 59 | 27.75 | 3610.41 | | | |
| 24 | 60 | 29.47 | 3580.94 | 30.9 | 3550 | |

TRIP IN TO RETEST ROME FORMATION

| | | | | | | |
|---|---|---|---|---|---|---|
| 25 | 0 | | 5391.85 | 10.9 | 5381 | 6/4/91 |

TRIP OUT WITH PACKERS TO CHANGE INJECTION INTERVAL FROM FOUR FEET TO TEN FEET. THE INTERVAL CHANGE RESULTS IN A NET CHANGE IN STRING LENGTH (TO MID POINT OF PACKERS) OF THREE FEET. TOTAL LENGTH OF STRING IS NOW 5391 FEET.

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 5391.00 | | | |
| | 1 | 28.45 | 5362.55 | | | 6/4/91 |
| | 2 | 32.63 | 5329.92 | | | |
| | 3 | 30.66 | 5299.26 | | | |
| | 4 | 32.71 | 5266.55 | | | |
| | 5 | 27.80 | 5238.75 | | | |
| | 6 | 26.04 | 5212.71 | | | |
| | 7 | 27.15 | 5185.56 | | | |
| 2 | 8 | 25.45 | 5160.11 | 13.0 | 5147 | |
| | 9 | 27.45 | 5132.66 | | | |
| | 10 | 26.33 | 5106.33 | | | |

| | | | | | |
|---|---|---|---|---|---|
| | 11 | 27.65 | 5078.68 | | |
| | 12 | 27.18 | 5051.50 | | |
| | 13 | 26.10 | 5025.40 | | |
| | 14 | 27.05 | 4998.35 | | |
| | 15 | 27.60 | 4970.75 | | |
| | 16 | 25.16 | 4945.59 | | |
| | 17 | 27.34 | 4918.25 | | |
| | 18 | 26.69 | 4891.56 | | |
| | 19 | 28.79 | 4862.77 | | |
| | 20 | 26.95 | 4835.82 | | |
| | 21 | 31.16 | 4804.66 | | |
| | 22 | 26.86 | 4777.80 | | |
| | 23 | 32.40 | 4745.40 | | |
| | 24 | 31.74 | 4713.66 | | |
| | 25 | 32.32 | 4681.34 | | |
| 27 | 26 | 32.31 | 4649.03 | 21.0 | 4628 |
| | 27 | 31.74 | 4617.29 | | |
| | 28 | 31.74 | 4585.55 | | |
| | 29 | 32.43 | 4553.12 | | |
| | 30 | 26.91 | 4526.21 | | |
| | 31 | 32.37 | 4493.84 | | |
| | 32 | 31.30 | 4462.54 | | |
| | 33 | 32.70 | 4429.84 | | |
| | 34 | 27.53 | 4402.31 | | |
| | 35 | 32.34 | 4369.97 | | |
| | 36 | 26.58 | 4343.39 | | |
| | 37 | 30.50 | 4312.89 | | |
| | 38 | 32.66 | 4280.23 | | |
| | 39 | 32.72 | 4247.51 | | |
| | 40 | 32.66 | 4214.85 | | |
| | 41 | 32.61 | 4182.24 | | |
| | 42 | 32.65 | 4149.59 | | |
| | 43 | 25.97 | 4123.62 | | |
| | 44 | 32.39 | 4091.23 | | |
| 28 | 45 | 31.77 | 4059.46 | 4.5 | 4055 |

TESTING COMPLETED.

P2-91

002637

Box 35

CITED

DGS CORE # 3409

# APPENDIX H

## CORE ANALYSIS - SELECTED INTERVALS

# PETROGRAPHIC ANALYSIS OF SELECTED SAMPLES FROM ARISTECH CHEMICAL CORP.'S TEST/MONITOR WELL HAVERVILL, OHIO

PREPARED FOR:

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PREPARED BY:

TERRATEK GEOSCIENCE SERVICES
PETROGRAPHIC SERVICES GROUP
360 WAKARA WAY
SALT LAKE CITY, UTAH 84108

JUNE 1991
TTGS FILE NO. 5960

## INTRODUCTION

Five core samples from the Knox Group and underlying Rome Formation from Aristech Chemical Corporation's test/monitor well in Haverhill, Ohio, were sent to TerraTek for routine porosity/permeability measurements and petrographic analysis. Petrographic analysis performed on these Cambro-Ordovician samples consists of thin section microscopy, X-ray diffraction analysis, and scanning electron microscopy. Table 1 lists depths and stratigraphic interval for each sample.

**Table 1**
**Samples Analyzed**

| Depth | Stratigraphic Interval |
|---|---|
| 4021.0 - 22.1 | Knox Group - Beekmantown Member |
| 4192.9 - 94.0 | Knox Group - Rose Run Member |
| 4201.9 - 03.1 | Knox Group - Rose Run Member |
| 4591.5 - 93.1 | Knox Group - Copper Ridge Member |
| 5196.6 - 97.0 | Rome Formation |

# ANALYTICAL PROCEDURES

## 1. Petrographic Analysis

Thin section samples were impregnated with blue dye epoxy or red fluorescent epoxy under high vacuum to access matrix porosity, microfractures, and micropores within the sample rock fabric. Samples were then slabbed, mounted to either standard thin section slides or oversized 2" x 3" glass slides, and ground to a thickness of approximately 30 microns. Portions of thin sections were stained with Alizarin Red and potassium ferricyanide to facilitate identification of dolomite, calcite, and ferroan carbonates. Individual samples were analyzed to determine rock classification, mineralogy, diagenesis, and porosity type(s).

## 2. X-Ray Diffraction Analysis (XRD)

Bulk Analysis: Representative one-gram splits of bulk samples are ground in acetone in agate mortar to <325 mesh (<45 um) then scanned at 2°2$\theta$ per minute from 2-65°2$\theta$. Diagnostic peaks of minerals identified on resulting diffractograms are rescanned on duplicate samples. Approximate weight percentages of the minerals are determined by comparing diagnostic peak intensities with those generated by standard pure phases mixed in various known proportions.

Clay Analysis: Bulk samples, at least 35 grams if possible, are sonically disaggregated in deionized water, allowed to settle sufficiently to yield the desired particle size fraction (generally <2 um or <5 um), decanted, and centrifuged. The resulting slurries are smeared on glass slides and x-rayed at 1°$\theta$ per minute following air-drying (2-37°), vapor glycolation for 24 hours at 60°C (2-22°), heating to 250°C for one hour (2-15°) and heating to 550°C for one hour (2-25°). Approximate weight percentages of the layer silicates identified on diffractograms corresponding to these treatments are determined by comparison of diagnostic peak intensities with those generated by pure reference clays in appropriate mixtures.

### 3. Scanning Electron Microscopy (SEM)

SEM samples prepared from core material were mounted on an SEM sample mount and coated under high vacuum with gold. Samples were then examined using a Hitachi S-450 SEM equipped with a Kevex energy dispersive X-ray spectrometer. Samples were examined and photographed at a range of magnifications to exhibit the morphology of the rock fabric and pore system. Identification of pore-lining or pore-filling components was made whenever possible.

## KNOX GROUP, BEEKMANTOWN MEMBER

Sample 4021 from the Beekmantown Member of the Knox Group is characterized by finely crystalline dolomite. X-ray diffraction (Table 2) indicates that dolomite and quartz are the dominant components. Minor amounts of late stage pyrite were also observed in thin section. Relicts of a somewhat laminated bioturbated fabric are present, but dolomitization has been fairly pervasive and destroyed most original texture.

Porosity is dominated by vugs of various sizes. Many are elongate features parallel to laminations, which may be the remnants of a fenestral fabric. Very little intercrystalline porosity was observed in the matrix. Most vugs are lined to filled by euhedral dolomite crystals. Larger vugs, which range up to 2 cm in diameter, commonly contain dolomite rhombs up to 5 mm in diameter. The quartz measured in the x-ray diffraction is a pore-filling component which precipitated prior to the euhedral dolomite. Pore-filling quartz is somewhat irregularly distributed, whereas pore-lining/filling euhedral dolomite is present in almost all vugs. Pyrite is also a late pore-filling component. Several narrow fractures were also observed.

A porosity value of 2.2% was measured in the routine analysis. Visual inspection of the interval suggests that porosity varies somewhat locally. Some vugs may also be isolated and ineffective. Maximum horizontal permeability of 231 md was measured in one direction but only 0.02 md in the other horizontal direction and in a vertical orientation. The high horizontal value indicates that some vugs are well interconnected, at least on the scale of the whole core. No fractures large enought to account for this high permeability value exist in the full diameter sample.

# TABLE 2

## X-ray Diffraction Analysis

| Sample No. | 4201 | | 4202 | | 4192 | | 4593 | | 5196.5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bulk | Clay | Bulk | Clay | Bulk | Clay | Bulk | Clay | Bulk | Clay |
| Quartz | 14 | | 98 | | 84 | | 13 | | Tr | |
| Plagioclase | | | | | | | 1 | | | |
| K-feldspar | | | 2 | | | | 11 | | 1 | |
| Dolomite | 86 | | | | 16 | | 71 | | 98 | |
| Pyrite | | | | | Tr | | 2 | | | |
| Halite | | | Tr | | | | | | | |
| Kaolin | | | | | | | | | | |
| Illite (± 10A Mica) | | | | | | | 2 | 78 | Tr | 72 |
| M.L. Chlorite/ Smectite | | | | | | | Tr | 22 | Tr? | 28 |

The diagenetic sequence envisioned for this sample is as follows:

1. Deposition of carbonate mud in a shallow marine setting.
2. Compaction and lithification of lime mud.
3. Fracturing.
4. Dolomitization and dissolution.
5. Precipitation of pore-filling quartz.
6. Precipitation of pore-lining/filling euhedral dolomite.
7. Precipitation of pore filling pyrite.

## KNOX GROUP, ROSE RUN MEMBER

Two samples, 4193' and 4202', were analyzed from the Rose Run Member of the Knox Group.

Sample 4193' is composed mainly of chert. This rock was originally an oolitic limestone but has been completely silicified. Original textures and fabrics have been preserved through replacement of calcitic textural elements by silica. Ooids range from medium to coarse sand size and were originally cemented by calcite. Ooids with both radial and concentric internal structure are present. Silicified intraclasts are also present but are much less abundant than ooids. Partially open and partially filled fractures disrupt the fabric and form a brecciated mosaic of silicified clasts.

A number of different conventional or unconventional porosity types were observed in this sample. On one hand, two different generations of fractures are present. An earlier set formed prior to silicification and is partially filled by silicified isopachous calcite and ankerite, which precipitated following silicification. Significant amounts of porosity remain along this fracture set. The second generation of fractures occurred relatively late. These fractures are partially open and form an orthogonal network across the sample. Conventionally, interparticle porosity is present between ooids, and intraparticle porosity is present within ooids and intraclasts. Intraparticle porosity is dominated by microporosity as indicated by SEM analysis. Finally, vugs and dissolution voids are also present. Dissolution porosity formed prior to silicification. Interparticle, intraparticle, and vuggy porosity present prior to silicification was not destroyed during silica diagenesis.

A routine porosity value of 9.1% was measured for this sample. Of the porosity types present, fracture porosity and interparticle porosity are the most significant. Microintraparticle and vuggy porosity are less abundant than fracture and intraparticle

poroisty. Intraparticle porosity within carbonate grains is likely ineffective in transmitting fluids. Measured permeabilities range form 0.07 md to 6.0 md. Fractures likely play an important role in permeability. Vertical permeability (0.07 md) is reduced by low angle stylolites near the middle of the full diameter sample.

Diagenesis of this interval is relatively complex. The following is a generalized sequence indicating major diagenetic events:

1. Deposition of carbonate grains in a shallow marine setting.
2. Cementation by calcite.
3. Compaction and fracturing.
4. Precipitation of isopachous fracture lining calcite cement.
5. Dissolution and formation of vuggy porosity.
6. Pyrite precipitation.
7. Silicification.
8. Precipitation of fracture-filling ankerite in early fractures.
9. Formation of late orthogonal fracture set.

Sample 4202', also from the Rose Run Member is a quartz rich sandstone and plots in the upper portion of the subarkose field of a Folk (1974) sandstone classification diagram (Figure 1). Monocrystalline quartz is the dominant framework component although minor amounts of polycrystalline quartz are also present. Potassium feldspar is dominated by microcline and constitutes 2% to 3% of framework grains. Lithic grains and chert constitute another 2% to 3% of the major mineralogy. Many lithics are partially dissolved and are probably sedimentary rock fragments. No accessory grains were observed in this thin section.

The sample is dominated by fine to medium grained sand. Median grain size of 2.02 $\phi$ was measured for 50 random grains (Figure 2). Framework grains are rounded and moderately well to well sorted. Grain contacts are dominated by point and long contacts, indicating relatively minor compaction.

# Figure 1. Modal Analysis

Company : Aristech Chemical Corporation
Well : Test/Monitor, Haverhill, Ohio
Formation : Knox, Rose Run Member
n = 1

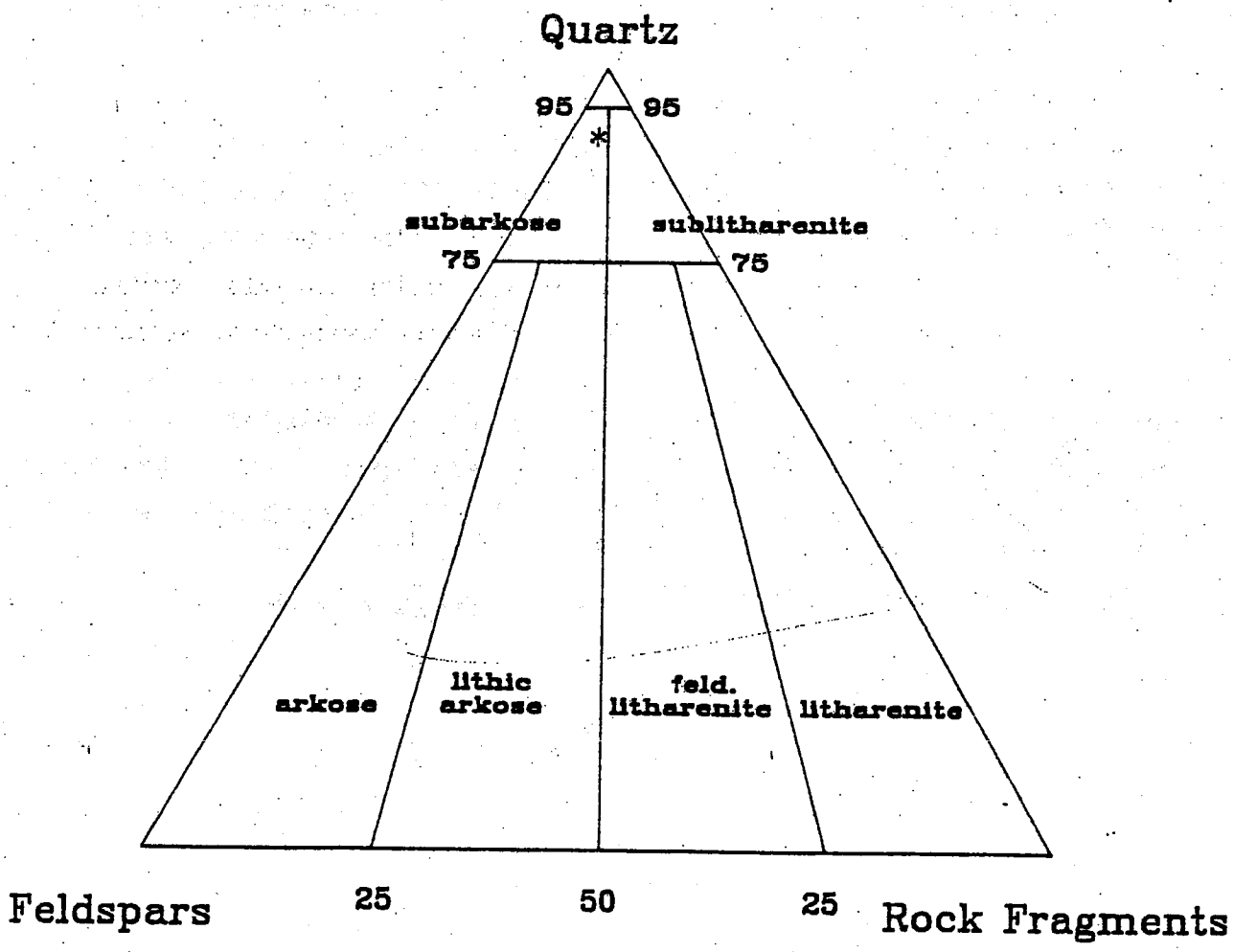
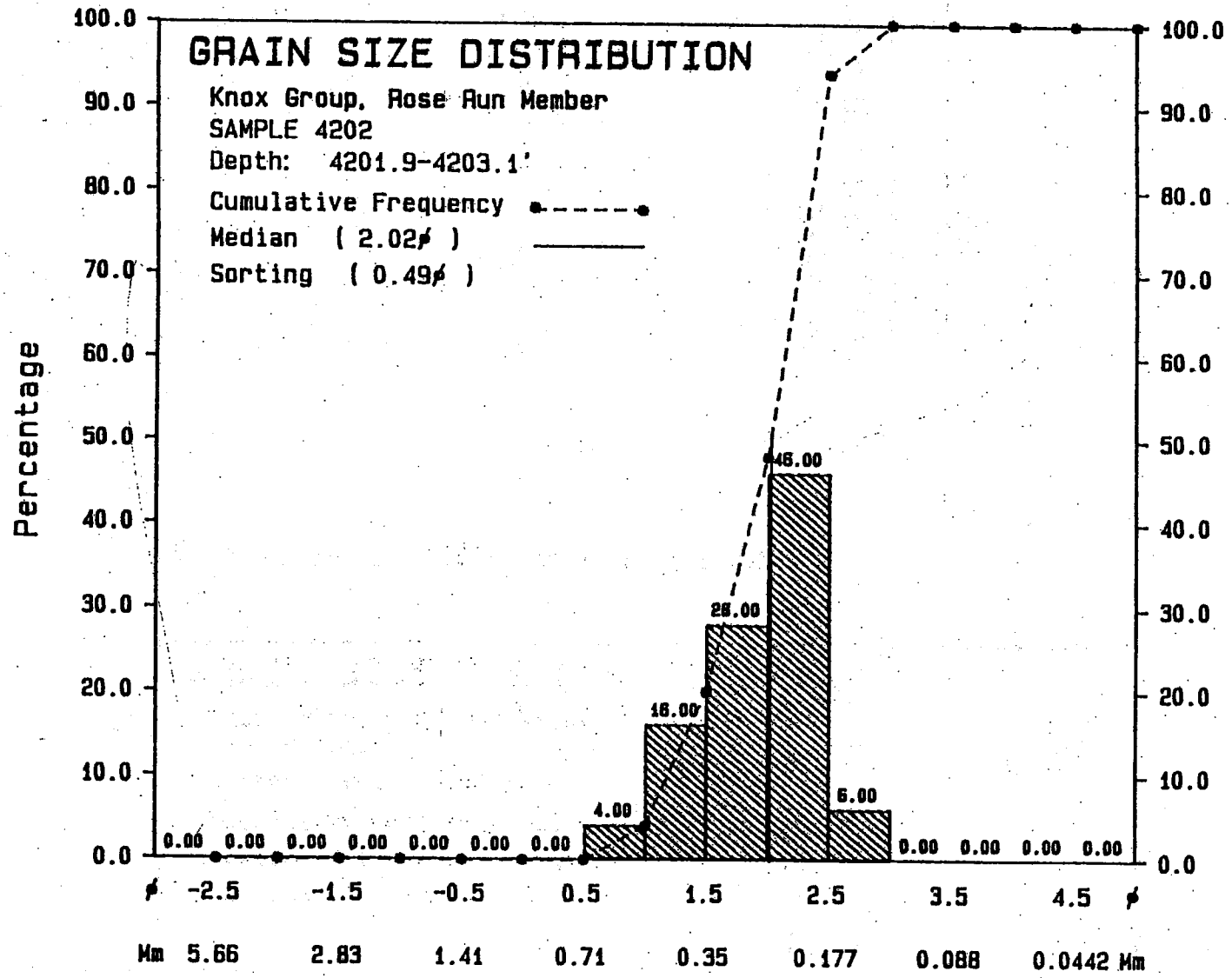


FIGURE 2. GRAIN SIZE HISTOGRAM OF SAMPLE 4202.



X-ray diffraction analysis (Table 2) shows very little clay in the sample. SEM analysis encountered minor amounts of mixed-layer illite-smectite. Illite-smectite exhibits pore-lining and pore-filling morphologies, but constitutes less than 1% of the bulk composition.

Quartz and feldspar are the dominant cements. Both are present as overgrowths on framework grains. No carbonate cement was observed, but may have been a factor in the diagenetic history. Calcite, if once present, has been removed through dissolution.

Porosity is dominated by intergranular and "moldic" pores formed by the complete dissolution of framework grains. Lithic and feldspar grains, along with carbonate cements that may have been present, have been removed by acidic formation waters. Short, high-angle, partially open fractures are present but probably only affect this interval locally. Minor amounts of intragranular porosity within partially dissolved grains were also observed.

Porosity and permeability are greatest in this sample. Intergranular porosity constitutes a major portion of the 12.1% measured in the routine analysis. Horizontal permeability measurements do not show significant variation, suggesting that fractures do not significantly affect permeability.

The following diagenetic sequence is envisioned for this sample:

1. Deposition in a shallow marine setting.
2. Compaction
3. Formation of silica and feldspar overgrowths.
4. Calcite cementation.
5. Fracturing.
6. Dissolution.
7. Formation of minor pore-lining and pore-filling illite-smectite.

## KNOX GROUP, COPPER RIDGE MEMBER ("B" ZONE?)

Sample 4593', from the Copper Ridge Member of the Knox Group, is characterized by silty dolomite interlaminated with thin siltstone or very fine sandstone laminae. Dolomite laminae are finely crystalline and contain scattered quartz and feldspar silt. Silt and very fine sand also occur in this laminae. Siltstone laminae are lightly bioturbated and define ripple marks in one portion of the sample. Siltstone laminae are cemented by a combination of quartz and dolomite cements. Rounded to elongate siliceous nodules are aligned parallel to some laminations. These nodules were evaporitic in origin, probably anhydrite nodules that silicified later. Several stylolites were also observed at the interface between rock types.

X-ray diffraction analysis (Table 2) indicated that quartz and feldspar grains are about equal in abundance. Illite and mixed-layer chlorite-smectite are the dominant clay minerals. SEM analysis indicates that these clays have pore-lining and pore-filling morphologies in siltstone laminae. Clays appear more abundant in siltstone laminae than in the silty dolomite. Pyrite is also present and is typically a late stage replacive or pore-filling component.

Porosity is dominated by microporosity in siltstone laminae. Porosity is also observed within the silicified evaporite nodules. Porosity in silicified nodules is present between quartz crystals and individual pores can be relatively large. Former evaporite nodules are, however, limited in extent and typically isolated. Porosity within nodules is likely isolated and ineffective. The 2.7% porosity measured in this sample is primarily microporosity within siltstone laminae. Very little porosity was observed in silty dolomite laminae. Permeability is relatively low, reflecting the dominance of microporosity.

The following diagenetic sequence is envisioned for this sample:

1. Deposition in a restricted shallow marine setting.
2. Bioturbation.
3. Compaction and formation of stylolites.
4. Silicification of evaporite nodules; silica cementation of siltstone laminae.
5. Precipitation of pore-filling and replacive pyrite.

## ROME FORMATION

Sample 5196 represents the Cambrian Rome Formation and is characterized by medium to coarsely crystalline dolomite. As indicated by X-ray diffraction (Table 2), dolomite is the dominant mineral component. The minor amount of quartz and feldspar measured in the XRD analysis occurs as scattered detrital grains. Clay minerals are concentrated in discontinuous more finely crystalline patches, which may be burrows. Texture and distribution of these clayey, finely crystalline patches are suggestive of bioturbation. Dolomitization has been extensive and obliterated almost all original fabric. Wispy compaction-related stylolites are present in clayey portion of the sample.

Vugs and, to a lesser degree, fractures dominate porosity. Vuggy porosity is well developed throughout most of the sample. Most vugs and fractures are lined to partially filled by euhedral dolomite crystals. The outer edges of pore-lining dolomite rhombs are composed of ankerite indicating a change in formation water chemistry with time. Some parts of the sample are poorly impregnated with the fluorescent epoxy, suggesting isolation of vugs or extremely small pore throats.

Porosity measured in the routine analysis is 3.6%. Permeability measurements show significant variation indicating the probable importance of fractures to permeability. Fractures are present in both clayey and clay-free portions of the sample. Vugs were only observed in clay-free areas.

The diagenetic sequence for this sample is as follows:

1. Deposition of carbonate material in a shallow marine setting.
2. Lithification.
3. Compaction and stylolite formation.
4. Fracturing.
5. Dolomitization and dissolution forming vuggy porosity.
6. Precipitation of pore-lining/filling dolomite.
7. Precipitation of pore-lining/filling ankerite.

## TABLE 3

### Full Diameter Permeability and Porosity Data
### Aristech Test/Monitor Well

| Sample Number | Depth (ft) | Permeability | | | Porosity (%) | Grain Density (gm/cc) | Lithology |
|---|---|---|---|---|---|---|---|
| | | Kmax (md) | K-90 (md) | Vert (md) | | | |
| 1 | 4021.0-22.0 | 231 | .02 | .02 | 2.2 | 2.79 | Dol,ltgy,cxl,vgy,frac,suc,if |
| 2 | 4193.0-94.0 | 6.0 | 3.3 | .07 | 9.1 | 2.65 | Cht,ltbrn-ltgrn,wthrd,mgr, ss stk,sty |
| 3 | 4202.0-03.0 | 86 | 70 | 1.4 | 12.7 | 2.64 | Ss,wh,mgr,sil,bdd,sty |
| 4 | 4592.5-93.1 | .10 | .06 | <.01 | 2.7 | 2.73 | Ss,mgy,vfgr,v/dol,calc xls,sty, dd |
| 5 | 5196.5-97.0 | 1.8 | .04 | 1.7 | 3.6 | 2.84 | Dol,ltgy-ltgrn,c-vcxl,vgy,intxl,sty |

**DESCRIPTION SCHEME FOR CARBONATE SEDIMENTARY ROCKS:**

**ROCK TYPE, COLOR, GRAIN SIZE / CRYSTAL SIZE, POROSITY TYPE, ACCESSORIES**

KEY TO ABBREVIATIONS:

aff - anhydrite filled fracture
alt - altered
anhy - anhydrite(ic)
arg - argillaceous
bdd - bedded
bent - bentonite
bf - buff
biot - bioturbated
bit - bitumen
bl - blue(ish)
blk - black
bnd - banded
brec - breccia(ted)
brn - brown
bur - burrowed
c - coarse
calc - calcite(areous)
carb - carbonaceous
cff - calcite filled fracture
cgl - conglomerate
chky - chalky
chlor - chlorite
cht - chert
chty - cherty
cly - clay(ey)
clyst - claystone
dism - disseminated
dk - dark
dff - dolomite filled fracture
dol - dolomite(ic)
f - fine
fen - fenestral
fis - fissile
fos - fossil(iferous)
frac - fracture
fri - friable
gff - gauge filled fracture
glauc - glauconitic
gn - green
gr - grain(ed)
grnl - granule
gy - gray
gyp - gypsum(iferous)
hem - hematite(ic)
if - incipient fracture
incl - inclusion
intprt - interparticle
intrprt - intraparticle
intxl - intercrystalline
lam - laminated
lav - lavender
lig - lignite(ic)
ls - limestone
lt - light
m - medium
mar - maroon
mas - massive
mic - micro
mica - micacious
mol - moldic
nod - nodule(s)
o - oil
of - open fracture
ool - oolitic
org - organic
orng - orange
pbl - pebble
pel - peloids
pff - pyrite filled fracture
pis - pisolitic
pk - pink
pof - partially open fracture
ppvgs - pinpoint vugs
ptg - parting(s)
purp - purple
pyr - pyrite(ic)
qff - quartz filled fracture
qtz - quartz
red - red
sa - salty
sdy - sandy
sh - shale
shy - shaley
sid - siderite
sil - silica(eous)
sl/ - slightly
sltst - siltstone
slty - silty
ss - sandstone
stn - stain(ed)(ing)
str - streak
styl - stylolite
suc - sucrosic
tan - tan
v/ - very
vc - very coarse
vf - very fine
vgy - vuggy
wh - white
wthrd - weathered
yel - yellow
xl - crystalline

DRILL STEM TEST, 6/6/68
USS Chemicals
Final Shut-in Period, Haverhill Disposal Well No. 1
Mt. Simon Sand, Scioto County, Ohio
Test Depth – 4988 Feet True Vertical Sub-Sea Depth

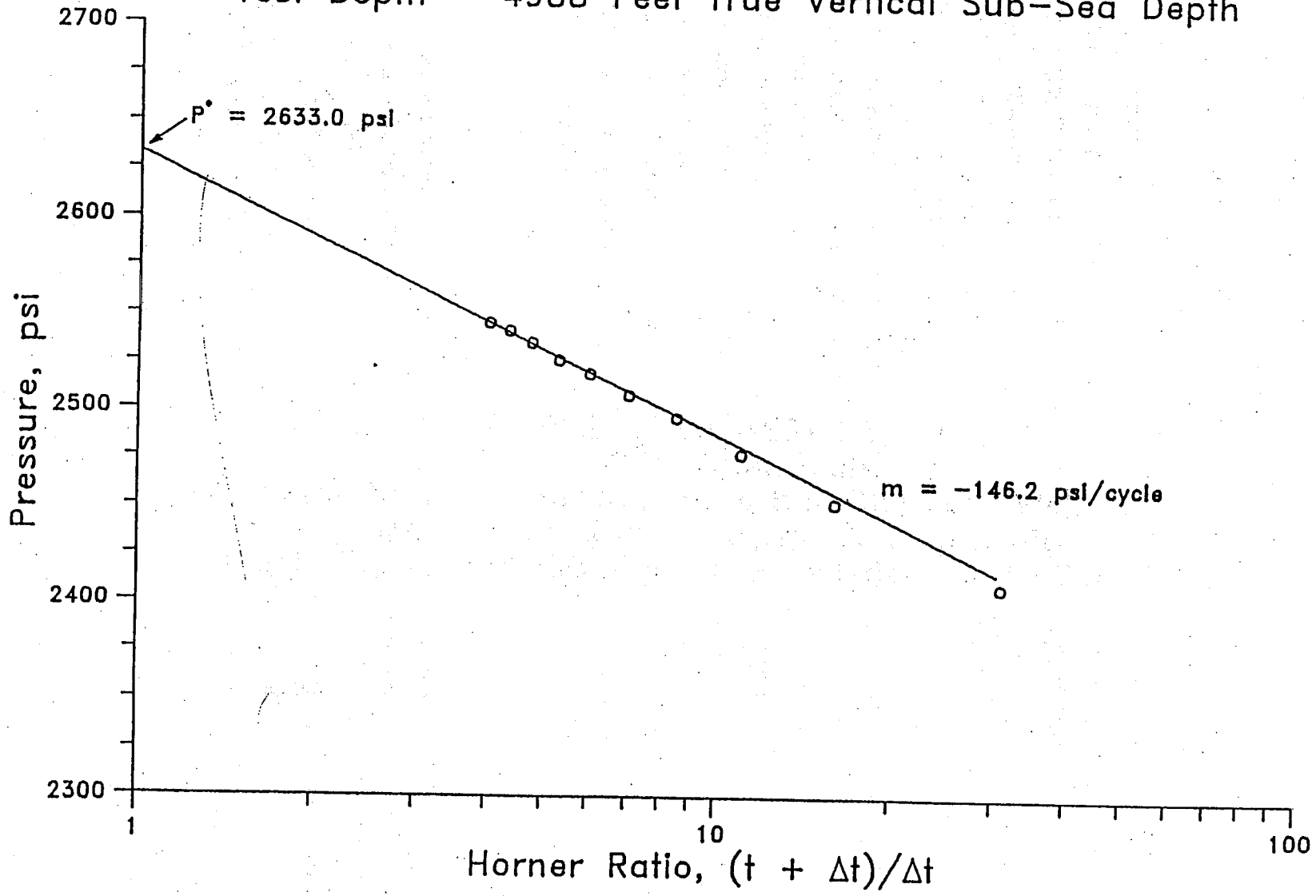



Figure 3

REC, INC.
June 1989

APPENDIX G-4

A REPORT TO ARISTECH CHEMICAL CORPORATION
ON STEP-RATE TESTING, WELL NO. 3
(PREPARED BY RESEARCH & ENGINEERING CONSULTANTS, INC., 1991)

P4-91

Barcode
002637
Box 35

# A REPORT

# TO

# ARISTECH CHEMICAL CORPORATION
# HAVERHILL, OHIO
# ON

# STEP-RATE TESTING, WELL NO. 3
# MARCH 23 - 25, 1991

**PREPARED BY**

**RESEARCH & ENGINEERING CONSULTANTS, INC.**
**ENGLEWOOD, COLORADO**

**APRIL 30, 1991**

## INTRODUCTION

Aristech Chemical Corporation (Aristech) requested that Research & Engineering Consultants, Inc., (REC) design a step-rate test procedure to be executed in their Well No. 3 at Haverhill, Ohio by Envirocorp. Aristech also requested that REC provide an engineer on-site for the test and that REC evaluate the test data. The Envirocorp report, dated April 2, 1991, describes the step-rate field activities while this report describes the design of the test and evaluation of the data.

## RATIONALE FOR THE TEST

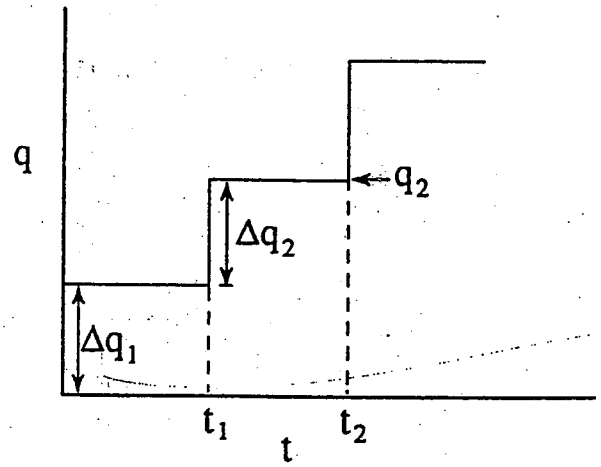
The proposed test was planned in response to an Ohio EPA request. It was noted by that agency that the step-rate test previously conducted in Well No. 3 was not entirely satisfactory because of equipment problems. Specifically, the inability to pump at very low rates precluded obtaining an essential part of the test data.

## THEORETICAL BACKGROUND

The basis for design and evaluation of a step-rate test is that superposition of fundamental flow solutions applies to flow of a slightly compressible fluid in a porous medium with unchanging properties. Specifically, for injection into a well with a rate history described by a step function

$$(1) \qquad q = q_n = \sum_{i=1}^{n} \Delta q_i \qquad t_{i-1} < t < t_n$$

as shown in Figure 1.




Step Rate History

FIGURE 1

the bottomhole pressure is [see Collins, 1961]

$$(2) \qquad P(t_n) = P_n = P_o + \sum_{i=1}^{n-1} \Delta q_i \frac{\mu}{4\pi K h} \left\{ F\left( \frac{\varphi \mu c r_w^2}{K(t_n - t_i)} \right) + 2S \right\}$$

Here consistent units apply and the symbols are:

$K$ = permeability
$\phi$ = porosity fraction
$\mu$ = viscosity
$h$ = thickness of interval
$S$ = skin factor
$P_o$ = static shut-in pressure
$r_w$ = well radius

In this, the function F is well approximated by the exponential integral function

$$(3) \qquad F(x) = \int_x^{\infty} \frac{\bar{e}^{\xi}\, d\xi}{\xi}$$

which is a tabulated function. Now if the skin factor is changed suddenly from one fixed value to a new value at some point in time, then after this time, the pressure is given by

$$(4) \qquad P'(t_n) = P_n = P_o + \sum_{i=1}^{n-1} \Delta q_i \frac{\mu}{4\pi K h} \left\{ F\left( \frac{\varphi \mu c r_w^2}{K(t_n - t_i)} \right) + 2S' \right\}$$

Here, if we subtract Eq. (2) from Eq. (4), there results, by virtue of Eq. (1),

$$(5) \qquad P_n' - P_n = \frac{2\mu}{4\pi K h} (S' - S)\, q_{n-1}$$

This shows that if one should plot the data of $P_n$ versus $q_{n-1}$ then there should be a change in slope of the resulting graph by the amount

$$(6) \qquad \text{slope change} = \frac{2\mu}{4\pi K h} (S' - S)$$

at the point where S changed.

For example, if $P_n$ versus $q_{n-1}$ is well approximated by a straight line

$$P_n = a + b\, q_{n-1} \,, \quad n > n_c \tag{7}$$

and similarly for the $P_n'$,

$$P_n' = a' + b' q_{n-1} \,, \quad n < n_c \tag{8}$$

then b' - b is given by Eq. (6).

Now, if a well is hydraulically fractured by injection, this effectively introduces a negative change in skin factor. In fact, for a vertical hydraulic fracture of length $2L_f$, bisected by the wellbore, the change in skin factor is, for an infinitely conductive fracture,

$$S' - S = -\ell n \frac{L_f}{2r_w} \tag{9}$$

Thus, a step-rate test can determine the bottomhole injection pressure at which a fracture is created by identifying the point of a sharp change in slope of the P vs. q plot. However, a more *gradual* change in slope can occur simply due to a slow change in the skin factor in the following manner.

If the formation permeability is $K_D$, from the well radius out to some radius $r_D$, and has value K beyond $r_D$,, then the skin factor can be shown to be,

$$S = \left( \frac{K}{K_D} - 1 \right) \ell n \frac{r_D}{r_w} \tag{10}$$

Hence, if the increase in pore pressure near the wellbore, due to injection, simply "dilates" the pores, this will cause $K_D$ to be greater than K and S to be more negative. This "pressure sensitive permeability" causes a progressively more negative skin factor and hence a gradual decrease in slope of the P versus q plot as pressure increases. This effect will precede the event of fracture initiation, if the formation is previously unfractured, or fracture opening if already fractured, as pressure increases.

The phenomenon of pressure sensitive permeability is directly related to that of permeability reduction due to compaction. For example, Figure 2 exhibits laboratory data showing the decrease in permeability of core plugs due to an increase in confining pressure on the sample. Here, the level of pore pressure was less than 100 psi in all cases i.e. atmospheric effluent pressure. Thus, it is the difference, confining pressure minus pore pressure, which determines permeability variation.

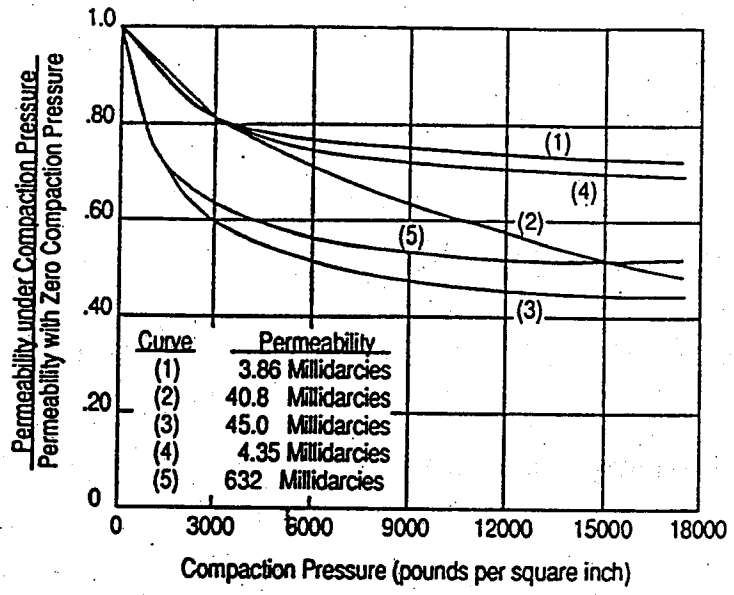



FIGURE 2

Effect of compaction on permeability of consolidated rocks. (After Fatt and Davis, 1952)

Now, to initiate a fracture in unfractured rock, the wellbore bottomhole pressure must reach the value

(11) $$P_{BD} = 3S_h - S_H - P_o + T,$$

but fracture opening can occur at the pressure

(12) $$P_{FO} = 3S_h - S_H - P_p$$

if such fractures do exist (Hiamson & Fairhurst, 1967). Here, $P_{BD}$ is the "formation breakdown" pressure and $P_{FO}$ is the "fracture opening" pressure. These pressures are given in terms of the existing principal horizontal tectonic stresses, $S_h$ (minimum) and $S_H$ (maximum), and the insitu pore pressure $P_p$. It is the tensile strength of rock, T, which defines the difference in $P_{BD}$ and $P_{FO}$. These relationships are based on the premise of a vertical fracture, as opposed to a horizontal fracture, and indeed it is well documented (Howard and Fast, 1970) that for depths below about 2,000 feet subsurface stresses are such that this will be the case.

## TEST DESIGN AND DATA EVALUATION

There are many misconceptions about step-rate testing which are prevalent in the industry. Among these are the assumptions that each rate should be sustained to reach a steady-state pressure. Another is that all rate steps must be equal in magnitude and

duration. However, none of these presumptions are really correct. Indeed, all one must do to obtain a good test is to be sure that adequate data points are obtained at pressures below and above the critical pressure. That is, one is simply trying to identify the critical pressure at which the skin factor of the well changes (becomes more negative) and any rate sequence which accomplishes this can, in principle, be used. However, evaluation of a step-rate test is made very much simpler if rate steps of equal duration and magnitude are employed; then, one simply plots the observed bottomhole pressure at the end of each rate step, just prior to the next rate change, versus the rate at that point. The resulting graph should be essentially a "straight line" with a slope change at the critical pressure.

It is essential, however, that the initial rate step must not cause the wellbore pressure to exceed the critical pressure. Indeed, the previous step-rate test in Well No. 3 was not entirely satisfactory because the initial rate was too high. This was a consequence of equipment problems. (A low-rate pump was not available).

Based upon the data obtained durng the previous step-rate test in Well No. 3, and estimates of the critical pressure from other Mt. Simon wells, a maximum lowest rate was estimated which would not cause bottomhole pressure to exceed the critical value ($\approx$ 0.6 x Depth) while injecting at this rate for two hours. Then this rate was proposed as the increment, $\Delta q$, to be used for all steps and step durations were limited to 15 minutes. However, upon re-entering Well No. 3, it was found that fill material was in the wellbore and this was cleaned out using coil tubing only to a slant well depth of 6015 ft. Thus, approximately the upper 10 ft of the total 35 ft of Mt. Simon formation was fully exposed to receive injected fluids. This was deemed acceptable for the test since it is the threshold pressure for fracture opening or initiation near the top of the Mt. Simon which is of critical interest.

Three step-rate tests were then executed with rate sequences and resulting pressure data as displayed in Figures 3, 4 and 5. Here, as in the previous step-rate test, there were some mechanical problems; and only in the final test, Step-Rate Test #3, was a truly satisfactory test obtained. The end-step pressures, plotted versus the corresponding rates, do show the classic "two straight line" pattern. The intersection of these two straight lines defines the critical pressure usually identified as $P_{BD}$ or $P_{FO}$. In this case, the intersection would definitely be $P_{FO}$, fracture opening pressure, since there was a previous step-rate test. Although Well No. 3 was never fractured during a wellbore stimulation, the rock was slightly fractured during the three previous step rate tests. Therefore, $P_{FO}$ is represented as the intersection of the two lines. There is also evidence of curvature beginning at a lower pressure indicating pressure sensitive permeability.

Now to evaluate these three tests more completely, the data were used with the Injection Forecast model of REC by a history matching process. In this case, the model essentially evaluates Eq. (2) for an input rate history. Thus, by adjusting values of the parameter groups

$$P_o\ ,\ \frac{\mu}{Kh}\ ,\ \frac{\phi\mu ch}{Kh}\ ,\ \text{and S}$$

a match of observed and computed pressures can be achieved.

Model results were generated for two cases, one in which S was maintained at a constant value of 3.0 and one in which the value of S was adjusted to achieve a match in observed and computed pressures. These results are shown in Tables II and III for the fixed parameters shown in Table I below.

**TABLE I**

$P_o$ = 2630 psi
$\mu$ = 0.56 cp
K = 20 md
$\varphi$ = 0.11
c = $5.5 \times 10^{-6}$ $psi^{-1}$
h = 35 ft.

Note that, although six parameters are listed as fixed, some of these can in fact be varied provided that the group values defined above remain fixed. This follows, of course, simply because parameters enter the calculation only in these specific groups.

Observe that the model study indicates in Table III that in the first step-rate injection test the skin factor was very large at the start of injection then steadily decreased and became negative only after a pressure above 3400 psi was reached. This behavior is typical of a well with significant particulate formation permeability damage which "cleans up" with injection. The negative skin indicates either fracture opening or pressure sensitive permeability as discussed above.

The second step-rate test was almost classical and began with a skin of about 3. This skin is consistent with wellbore fill obstructing some of the formation. Observe that skin was reduced with increasing pressure becoming -3 at a pressure above 3400 psi. However, the jump in rate from 20 gpm to 79 gpm was too large and did not allow defining intermediate skin changes.

The third and final test was completely satisfactory. The beginning skin of 0.1 with gradual reduction and ultimately becoming negative to the value of -2.5 was truly classic in form. Comparison of observations and simulated results are shown graphically for Step-Rate Test No. 3 in Figure 6. The slight "overshoot" in computed pressures in the beginning of each step is due to the fact that the actual rate increases are not *instantaneous* as in the simulation.

These data clearly indicate a pressure sensitive permeability with a threshold pressure in the neighborhood of 3200 psi and a fracture opening pressure of 3375 psi. The negative skin factor of -2.5 is contributed by pressure sensitive permeability as well as possible opening of existing fractures. It is not possible to truly distinguish the relative contributions of these two mechanisms from these data.

## REFERENCES

Collins, R.E., Flow of Fluids Through Porous Materials, Reinhold Publishers, New York, (1961). New Printing REC, Inc., 1991.

Fatt, I. and Davis, D.H., Trans AIME, 195, 329 (1952).

Haimson, B.C. and Fairhurst, D., Soc. Pet. Engr J.7, 310, (1967).

Howard, G.C. and Fast, C.R., Hydraulic Fracturing, Soc. Pet. Engr., Monograph (1970).

TABLE II

ARISTECH CHEMICAL CO.
HAVERHILL, OH
WDW NO.3

BOTTOM HOLE PRESSURE REPORT

| Date | Time Days | Rate GPM | Vol MG | Skin | Pressure Obs Psi | Pressure Calc Psi | Bottom Hole Pressure PMin= 2000 PMax= 4000 |
|---|---|---|---|---|---|---|---|
| | | | | | | | HISTORY MATCH * = calc 0 = observ |
| STEP RATE TEST #1 | | | | | | | |
| 03/23/91 | 13:24 | 0.0 | 0 | 3.0 | 2630 | 2630 | **********0 |
| 03/23/91 | 13:36 | 1.7 | 0 | 3.0 | 3043 | 2688 | ********** 0 |
| 03/23/91 | 13:48 | 2.1 | 0 | 3.0 | 3076 | 2703 | ********** 0 |
| 03/23/91 | 14:00 | 2.3 | 0 | 3.0 | 3087 | 2713 | ********** 0 |
| 03/23/91 | 14:12 | 3.4 | 0 | 3.0 | 3128 | 2752 | ********** 0 |
| 03/23/91 | 14:24 | 5.0 | 0 | 3.0 | 3176 | 2809 | ********** 0 |
| 03/23/91 | 14:36 | 6.3 | 0 | 3.0 | 3216 | 2857 | ********** 0 |
| 03/23/91 | 14:49 | 8.5 | 0 | 3.0 | 3220 | 2937 | ********** 0 |
| 03/23/91 | 15:00 | 11.1 | 0 | 3.0 | 3264 | 3031 | ********** 0 |
| 03/23/91 | 15:14 | 17.9 | 0 | 3.0 | 3337 | 3274 | **********0 |
| 03/23/91 | 15:21 | 5.0 | 0 | 3.0 | 3150 | 2855 | ********** 0 |
| 03/23/91 | 15:39 | 0.0 | 0 | 3.0 | 2670 | 2663 | **********0 |
| 03/23/91 | 16:04 | 60.0 | 0 | 3.0 | 3555 | 4783 | **********0******** |
| STEP RATE TEST #2 | | | | | | | |
| 03/24/91 | 11:54 | 0.0 | 0 | 3.0 | 2615 | 2634 | **********0 |
| 03/24/91 | 12:15 | 0.7 | 0 | 3.0 | 2630 | 2658 | **********0* |
| 03/24/91 | 12:45 | 1.0 | 0 | 3.0 | 2639 | 2670 | **********0 |
| 03/24/91 | 13:16 | 1.8 | 0 | 3.0 | 2670 | 2700 | **********0* |
| 03/24/91 | 13:46 | 3.0 | 0 | 3.0 | 2721 | 2745 | **********0 |
| 03/24/91 | 14:16 | 5.6 | 0 | 3.0 | 2805 | 2841 | **********0* |
| 03/24/91 | 14:45 | 7.8 | 0 | 3.0 | 2929 | 2924 | **********0 |
| 03/24/91 | 15:03 | 0.0 | 0 | 3.0 | 2770 | 2656 | ********** 0 |
| 03/24/91 | 15:35 | 10.0 | 0 | 3.0 | 3118 | 3006 | ********** 0 |
| 03/24/91 | 15:37 | 20.0 | 0 | 3.0 | 3211 | 3314 | **********0** |
| 03/24/91 | 15:56 | 0.0 | 0 | 3.0 | 2663 | 2665 | **********0 |
| 03/24/91 | 16:24 | 79.0 | 0 | 3.0 | 3682 | 5478 | **********0****** |
| STEP RATE TEST #3 | | | | | | | |
| 03/25/91 | 10:00 | 0.0 | 0 | 3.0 | 2617 | 2637 | **********0 |
| 03/25/91 | 10:30 | 2.0 | 0 | 3.0 | 2662 | 2709 | **********0* |
| 03/25/91 | 11:00 | 3.1 | 0 | 3.0 | 2692 | 2751 | **********0** |
| 03/25/91 | 11:30 | 5.5 | 0 | 3.0 | 2756 | 2840 | **********0* |
| 03/25/91 | 12:00 | 8.1 | 0 | 3.0 | 2836 | 2938 | **********0** |
| 03/25/91 | 12:30 | 11.5 | 0 | 3.0 | 2956 | 3067 | **********0** |
| 03/25/91 | 12:59 | 15.0 | 0 | 3.0 | 3056 | 3201 | **********0*** |
| 03/25/91 | 13:30 | 20.6 | 0 | 3.0 | 3180 | 3414 | **********0**** |
| 03/25/91 | 13:59 | 24.1 | 0 | 3.0 | 3267 | 3554 | **********0***** |
| 03/25/91 | 14:30 | 29.4 | 0 | 3.0 | 3356 | 3760 | **********0******** |
| 03/25/91 | 15:00 | 35.3 | 0 | 3.0 | 3437 | 3989 | **********0********** |
| 03/25/91 | 15:30 | 41.2 | 0 | 3.0 | 3485 | 4221 | **********0********** |
| 03/25/91 | 15:34 | 0.0 | 0 | 3.0 | 3079 | 2906 | ********** 0 |
| 03/25/91 | 15:58 | 60.0 | 0 | 3.0 | 3622 | 4897 | **********0******* |

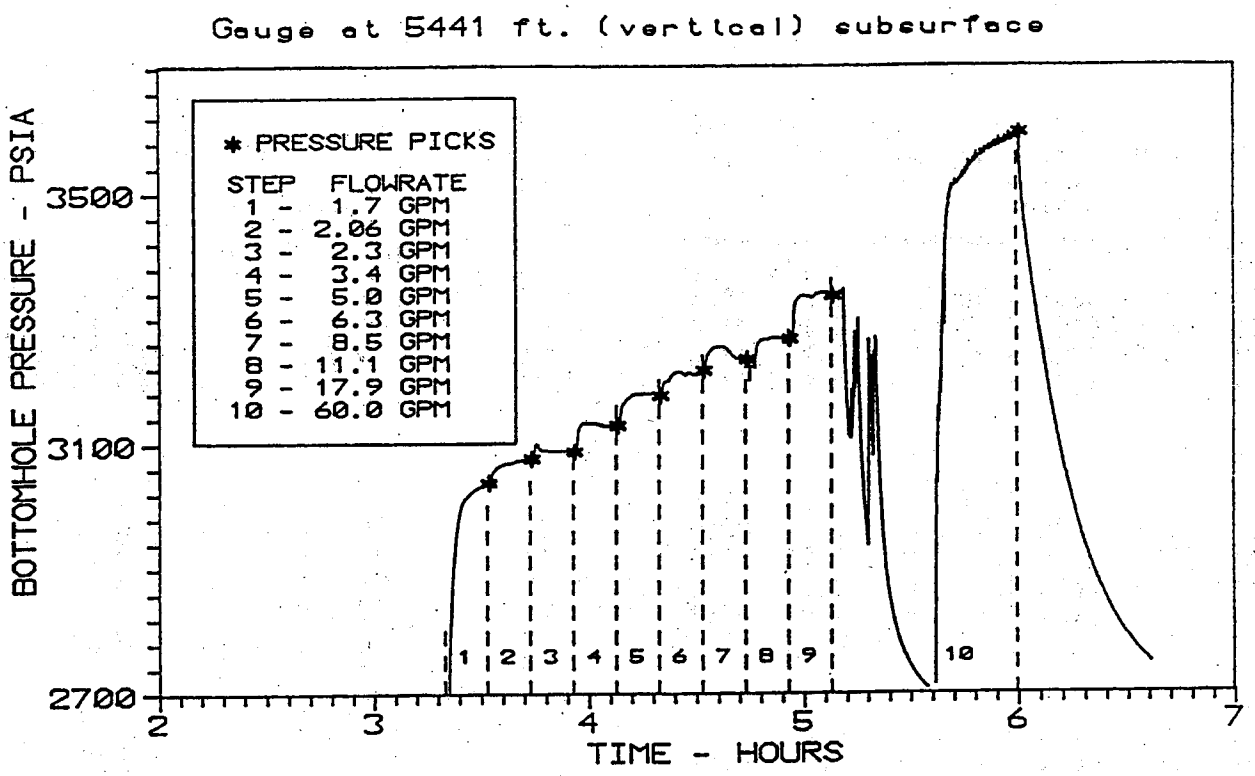
TABLE III

ARISTECH CHEMICAL CO.
HAVERHILL, OH
WDW NO. 3

BOTTOM HOLE PRESSURE REPORT

| Date | Time Days | Rate GPM | Vol MG | Skin | Pressure Obs Psi | Pressure Calc Psi | Bottom Hole Pressure PMin= 2000 PMax= 4000 * = calc 0 = observ |
|---|---|---|---|---|---|---|---|
| STEP RATE TEST #1 | | | | | | | |
| 03/23/91 | 13:24 | 0.0 | 0 | 35.0 | 2630 | 2630 | **********0 |
| 03/23/91 | 13:36 | 1.7 | 0 | 31.5 | 3043 | 2876 | ********** 0 |
| 03/23/91 | 13:48 | 2.1 | 0 | 28.0 | 3076 | 2902 | ********** 0 |
| 03/23/91 | 14:00 | 2.3 | 0 | 24.5 | 3087 | 2904 | ********** 0 |
| 03/23/91 | 14:12 | 3.4 | 0 | 21.0 | 3128 | 2989 | ********** 0 |
| 03/23/91 | 14:24 | 5.0 | 0 | 17.5 | 3176 | 3091 | **********0 |
| 03/23/91 | 14:36 | 6.3 | 0 | 14.1 | 3216 | 3127 | ********** 0 |
| 03/23/91 | 14:49 | 8.5 | 0 | 10.3 | 3220 | 3177 | **********0 |
| 03/23/91 | 15:00 | 11.1 | 0 | 7.1 | 3264 | 3206 | **********0 |
| 03/23/91 | 15:14 | 17.9 | 0 | 3.0 | 3337 | 3274 | **********0 |
| 03/23/91 | 15:21 | 5.0 | 0 | 4.0 | 3150 | 2875 | ********** 0 |
| 03/23/91 | 15:39 | 0.0 | 0 | 1.3 | 2670 | 2663 | **********0 |
| 03/23/91 | 16:04 | 60.0 | 0 | -2.5 | 3555 | 3505 | **********0 |
| STEP RATE TEST #2 | | | | | | | |
| 03/24/91 | 11:54 | 0.0 | 0 | 3.0 | 2615 | 2634 | **********0 |
| 03/24/91 | 12:15 | 0.7 | 0 | 2.9 | 2630 | 2658 | **********0* |
| 03/24/91 | 12:45 | 1.0 | 0 | 2.7 | 2639 | 2669 | **********0 |
| 03/24/91 | 13:16 | 1.8 | 0 | 2.4 | 2670 | 2696 | **********0* |
| 03/24/91 | 13:46 | 3.0 | 0 | 2.2 | 2721 | 2736 | **********0 |
| 03/24/91 | 14:16 | 5.6 | 0 | 2.0 | 2805 | 2820 | **********0* |
| 03/24/91 | 14:45 | 7.8 | 0 | 1.8 | 2929 | 2890 | **********0 |
| 03/24/91 | 15:03 | 0.0 | 0 | 1.7 | 2770 | 2656 | ********** 0 |
| 03/24/91 | 15:35 | 10.0 | 0 | 1.5 | 3118 | 2949 | ********** 0 |
| 03/24/91 | 15:37 | 20.0 | 0 | 1.5 | 3211 | 3198 | **********0 |
| 03/24/91 | 15:56 | 0.0 | 0 | 3.0 | 2663 | 2665 | **********0 |
| 03/24/91 | 16:24 | 79.0 | 0 | -3.0 | 3682 | 3642 | **********0 |
| STEP RATE TEST #3 | | | | | | | |
| 03/25/91 | 10:00 | 0.0 | 0 | 0.1 | 2617 | 2637 | **********0 |
| 03/25/91 | 10:30 | 2.0 | 0 | 0.1 | 2662 | 2686 | **********0 |
| 03/25/91 | 11:00 | 3.1 | 0 | 0.1 | 2692 | 2716 | **********0* |
| 03/25/91 | 11:30 | 5.5 | 0 | 0.1 | 2756 | 2778 | **********0 |
| 03/25/91 | 12:00 | 8.1 | 0 | 0.1 | 2836 | 2847 | **********0 |
| 03/25/91 | 12:30 | 11.5 | 0 | 0.6 | 2956 | 2960 | **********0 |
| 03/25/91 | 12:59 | 15.0 | 0 | 0.6 | 3056 | 3062 | **********0 |
| 03/25/91 | 13:30 | 20.6 | 0 | 0.1 | 3180 | 3183 | **********0 |
| 03/25/91 | 13:59 | 24.1 | 0 | 0.0 | 3267 | 3274 | **********0 |
| 03/25/91 | 14:30 | 29.4 | 0 | -0.5 | 3356 | 3361 | **********0* |
| 03/25/91 | 15:00 | 35.3 | 0 | -1.0 | 3437 | 3442 | **********0 |
| 03/25/91 | 15:30 | 41.2 | 0 | -1.6 | 3485 | 3487 | **********0 |
| 03/25/91 | 15:34 | 0.0 | 0 | 0.0 | 3079 | 2906 | ********** 0 |
| 03/25/91 | 15:58 | 60.0 | 0 | -2.5 | 3622 | 3619 | **********0 |

FIGURE 3
STEP RATE TEST #1
ARISTECH CHEMICAL CORPORATION
WATER DISPOSAL WELL #3
MARCH 23, 1991



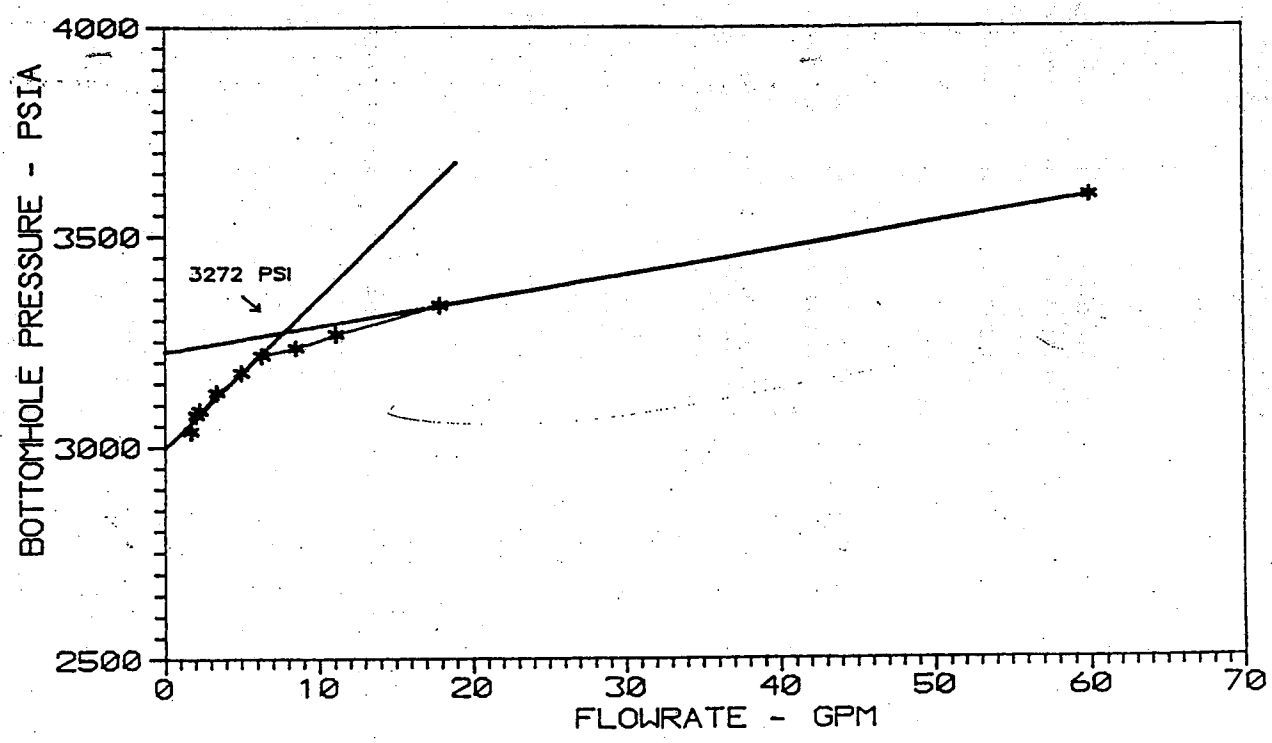
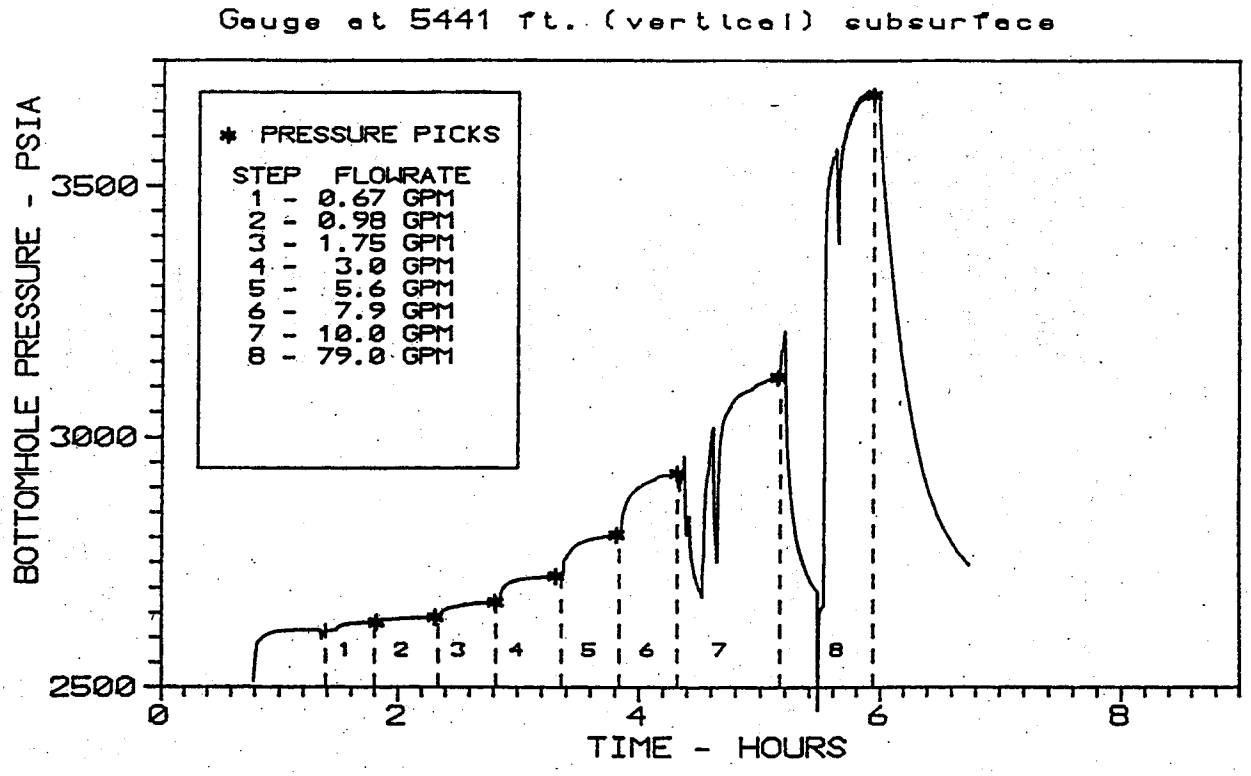
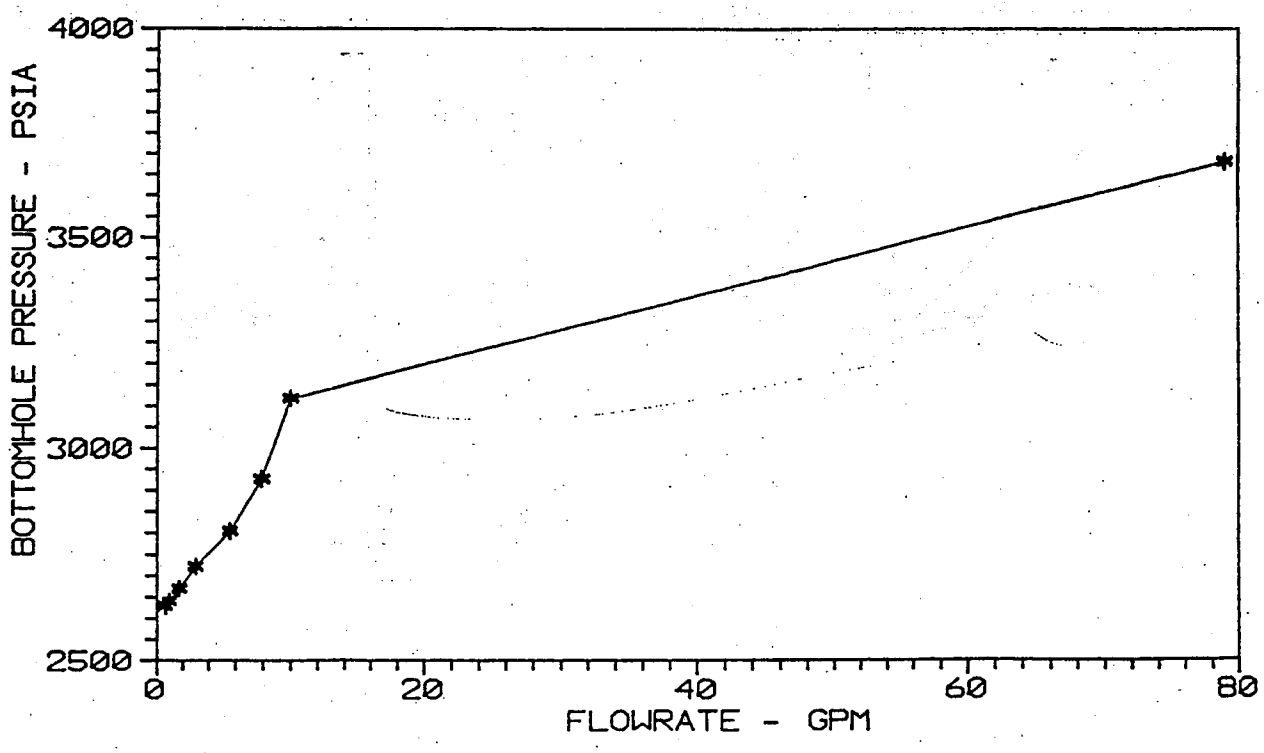
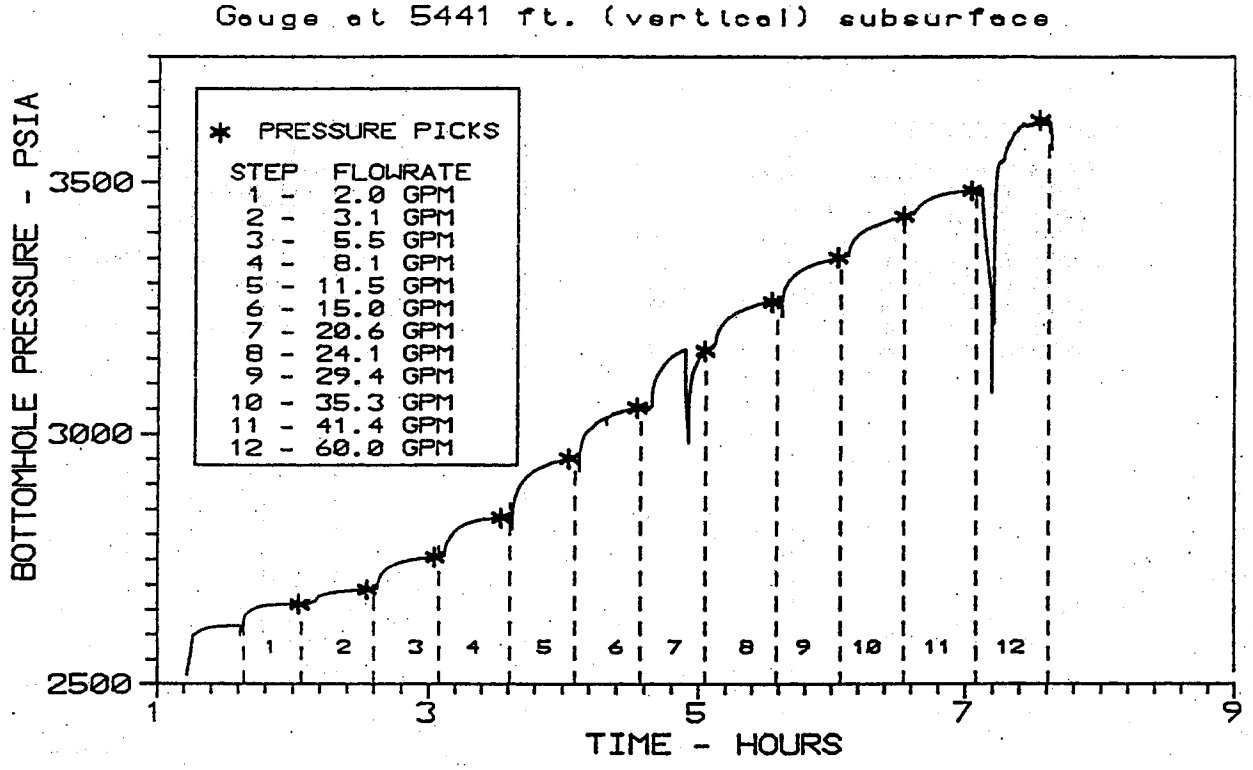



FIGURE 4
STEP RATE TEST #2
ARISTECH CHEMICAL CORPORATION
WATER DISPOSAL WELL #3
MARCH 24, 1991



# FIGURE 5
# STEP RATE TEST #3
# ARISTECH CHEMICAL CORPORATION
# WATER DISPOSAL WELL #3
# MARCH 25, 1991



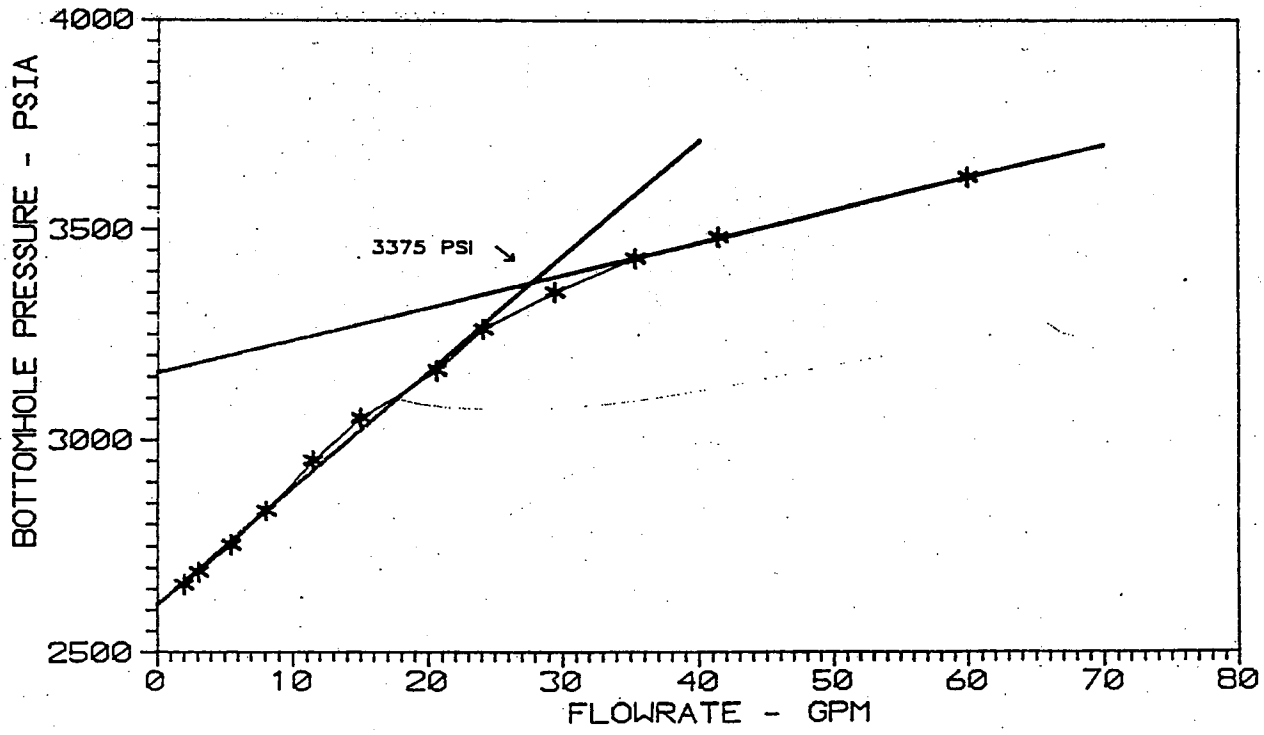
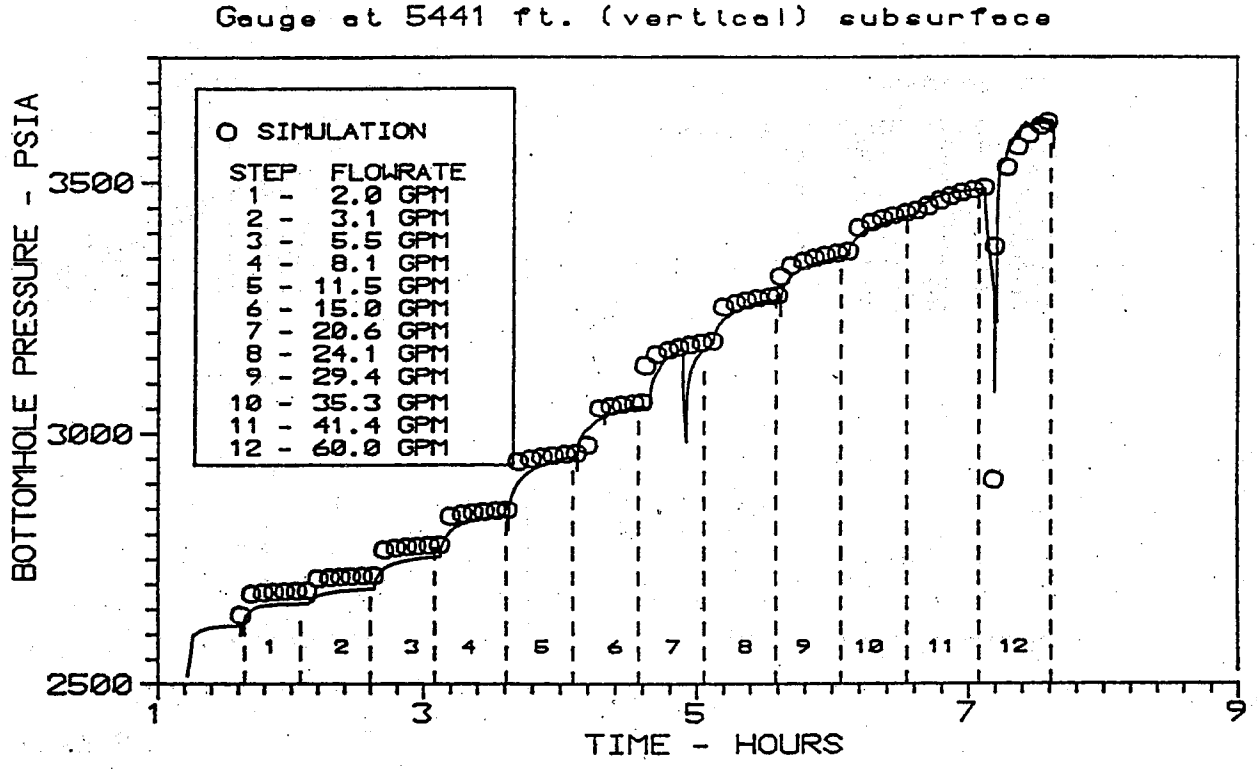



FIGURE 6
STEP RATE TEST #3
ARISTECH CHEMICAL CORPORATION
WATER DISPOSAL WELL #3
MARCH 25, 1991



P3-91 002437 Box 35

Allstech Chemical Corporation Haverhill Plant

# In-Situ Stress Measurement Data Summary (Monitor Well)

## Table 1

| Test Identification | Formation Name | Interval Depth (BGL) (ft) | Date Start 1st Inj. | Time +/-1 min. | Lithology/Description |
|---|---|---|---|---|---|
| Reference | Mt. Simon | (ft) | – | – | Sandstone |
| Z1 | Rome | 5386-5390 | 5/31/91 | 12:33 | Dolomite w/Shale |
| Z25 | Rome | 5379-5383 | 6/4/91 | 05:37 | Dolomite w/Shale/Fracs |
| Z2 | Rome | 5373-5377 | 5/31/91 | 16:34 | Dolomite |
| Z3 | Rome | 5360-5364 | 5/31/91 | 19:12 | Dolomite w/Shale/Sandstone |
| Z4 | Rome | 5315-5319 | 5/31/91 | 23:27 | Dolomite w/Healed Fracs |
| Z5 | Rome | 5241-5245 | 6/1/91 | 02:59 | Shaly Dolomite |
| Z6 | Rome | 5198-5202 | 6/1/91 | 06:41 | Dolomite w/Shale/Fracs/Vugs |
| Z7 | Conasauga | 5174-5178 | 6/1/91 | 08:21 | Dolomite w/Shale |
| Z26 | Conasauga | 5142-5152 | 6/4/91 | 16:39 | Shale |
| Z8 | Conasauga | 5117-5121 | 6/1/91 | 12:03 | Shale |
| Z9 | Conasauga | 5068-5072 | 6/1/91 | 17:57 | Shale/Dolomite w/Fracs |
| Z10 | Copper Ridge (Knox) | 4975-4979 | 6/1/91 | 21:49 | Dolomite |
| Z11 | Copper Ridge (Knox) | 4821-4825 | 6/2/91 | 10:10 | Dolomite |
| Z27 | Copper Ridge (Knox) | 4623-4633 | 6/4/91 | 21:18 | Dolomite |
| Z12 | Copper Ridge (Knox) | 4472-4476 | 6/2/91 | 14:56 | Dolomite w/Vugs/Fracs |
| Z13 | Copper Ridge (Knox) | 4255-4259 | 6/2/91 | 16:26 | Dolomite |
| Z14 | Rose Run (Knox) | 4210-4214 | 6/2/91 | 22:50 | Sandstone |
| Z15 | Rose Run (Knox) | 4194-4198 | 6/3/91 | 00:13 | Limestone/Chert |
| Z16 | Rose Run (Knox) | 4186-4190 | 6/3/91 | 01:41 | Sandstone |
| Z17 | Beekmantown (Knox) | 4174-4178 | 6/3/91 | 04:43 | Dolomite/Shale |
| Z18 | Beekmantown (Knox) | 4160-4164 | 6/3/91 | 05:48 | Dolomite |
| Z19 | Beekmantown (Knox) | 4140-4144 | 6/3/91 | 08:43 | Dolomite |
| Z20 | Beekmantown (Knox) | 4121-4125 | 6/3/91 | 10:11 | Dolomite |
| Z28 | Beekmantown (Knox) | 4050-4060 | 6/5/91 | 01:29 | Dolomite w/Shale |
| Z21 | Beekmantown (Knox) | 3970-3974 | 6/3/91 | 13:28 | Dolomite |
| Z22 | Wells Creek | 3900-3904 | 6/3/91 | 17:00 | Dolomite/Limestone |
| Z23 | Black River | 3780-3784 | 6/3/91 | 20:51 | Limestone |
| Z24 | Black River | 3548.5-3552.5 | 6/4/91 | 00:04 | Limestone w/Fracs |

Aristech Chemical Corporation Haverhill Plant
In-Situ Stress Measurement Data Summary (Monitor Well)

Table 2

| Test Identification | Formation Name | Rate (GPM) +/- ≈ 7% | Packer Set (PSI) | Injection Gauge Depth (ft) | Pp (PSI) | Pp (PSI/FT) |
|---|---|---|---|---|---|---|
| Reference | Mt. Simon | – | – | 5546*** | 2633*** | 0.475*** |
| Z1 | Rome | 2.1-4+ | 1000 | 5377 | 2560 | 0.483 |
| Z25 | Rome | 2.30 | 595 | 5370 | 2543 | 0.474 |
| Z2 | Rome | 2.30 | 850 | 5364 | 2609 | 0.486 |
| Z3 | Rome | 2.30 | 750 | 5351 | 2585 | 0.483 |
| Z4 | Rome | 2.30 | 500 | 5306 | 2568 | 0.484 |
| Z5 | Rome | 2.30 | 650 | 5232 | 2523 | 0.482 |
| Z6 | Rome | 2.40 | 900 | 5189 | 2501 | 0.482 |
| Z7 | Conasauga | 2.40 | 775 | 5165 | 2489 | 0.478 |
| Z26 | Conasauga | 7.00 | 630 | 5133 | 2473 | 0.482 |
| Z8 | Conasauga | 2.30 | 650 | 5108 | 2464 | 0.482 |
| Z9 | Conasauga | 2.50 | 850 | 5059 | 2427 | 0.48 |
| Z10 | Copper Ridge (Knox) | 2.40 | 750 | 4966 | 2373 | 0.478 |
| Z11 | Copper Ridge (Knox) | 2.40 | 520 | 4812 | 2320 | 0.482 |
| Z27 | Copper Ridge (Knox) | 6.90 | 580 | 4614 | 2217 | 0.48 |
| Z12 | Copper Ridge (Knox) | 2.40 | 700 | 4463 | 2157 | 0.483 |
| Z13 | Copper Ridge (Knox) | 2.30 | 745 | 4246 | 2045 | 0.482 |
| Z14 | Rose Run (Knox) | 2.30 | 400 | 4201 | 2009 | 0.478 |
| Z15 | Rose Run (Knox) | 2.30 | 675 | 4185 | 1999 | 0.478 |
| Z16 | Rose Run (Knox) | 2.40 | 640 | 4177 | 1991 | 0.477 |
| Z17 | Beekmantown (Knox) | 2.40 | 675 | 4165 | 1986 | 0.477 |
| Z18 | Beekmantown (Knox) | 2.30 | 660 | 4151 | 1976 | 0.476 |
| Z19 | Beekmantown (Knox) | 2.50 | 520 | 4131 | 1970 | 0.477 |
| Z20 | Beekmantown (Knox) | 2.50 | 670 | 4112 | 1954 | 0.475 |
| Z28 | Beekmantown (Knox) | 7.00 | 680 | 4041 | 1920 | 0.475 |
| Z21 | Beekmantown (Knox) | 2.50 | 520 | 3961 | 1893 | 0.478 |
| Z22 | Wells Creek | 2.40 | 670 | 3891 | 1859 | 0.478 |
| Z23 | Black River | 2.50 | 520 | 3771 | 1796 | 0.476 |
| Z24 | Black River | 2.40 | 465 | 3539.5 | 1678 | 0.474 |

*** Data from 1968 DST

# Aristech Chemical Corporation Haverhill Plant
# In-Situ Stress Measurement Data Summary (Monitor Well)

## Table 3

| Test Identification | Formation Name | Injection Gauge Depth (ft) | P I (PSI) | P I (PSI/FT) | P o (PSI) | P o (PSI/FT) | P E (PSI) | P E (PSI/FT) |
|---|---|---|---|---|---|---|---|---|
| Reference | Mt. Simon | – | – | – | – | – | – | |
| Z1 | Rome | 5377 | 4543*** | .845*** | – | – | 3500*** | .651-.730*** |
| Z25 | Rome | 5370 | 4249 | .791 | – | – | 3840 | .715 |
| Z2 | Rome | 5364 | 4002-4089 | .746-.762 | – | – | 3820 | .712 |
| Z3 | Rome | 5351 | 3837 | .717 | – | – | 3525 | .659 |
| Z4 | Rome | 5306 | 3653 | .688 | – | – | 3375 | .636 |
| Z5 | Rome | 5232 | 4073 | .778 | – | – | 3560 | .680 |
| Z6 | Rome | 5189 | 3880 | .748 | – | – | 3590*** | .692 |
| Z7 | Conasauga | 5165 | 3182 | .616 | – | – | 3075 | .595 |
| Z26 | Conasauga | 5133 | 3660 | .713 | – | – | >3450*** | >.672*** |
| Z8 | Conasauga | 5108 | – | – | 3924 | .768 | Pco = 3910 | Pco = 0.765 |
| Z9 | Conasauga | 5059 | 3347 | .661 | – | – | 3150 | .623 |
| Z10 | Copper Ridge (Knox) | 4966 | 3150 | .634 | – | – | 2725 | .549 |
| Z11 | Copper Ridge (Knox) | 4812 | 3286 | .683 | – | – | 2920 | .607 |
| Z27 | Copper Ridge (Knox) | 4614 | 3361 | .728 | – | – | 2920 | .633 |
| Z12 | Copper Ridge (Knox) | 4463 | – | – | 2860 | .641 | Pco = 2990 | Pco = .670 |
| Z13 | Copper Ridge (Knox) | 4246 | 2958 | .700 | – | – | 2390 | .563 |
| Z14 | Rose Run (Knox) | 4201 | 2948 | .702 | – | – | 2550 | .607 |
| Z15 | Rose Run (Knox) | 4185 | – | – | 4203 | 1.004 | Pco = 4420 | Pco = 1.056 |
| Z16 | Rose Run (Knox) | 4177 | 2910 | .700 | – | – | 2705 | .648 |
| Z17 | Beekmantown (Knox) | 4165 | 3086 | .741 | – | – | 2725 | .654 |
| Z18 | Beekmantown (Knox) | 4151 | 2812 | .677 | – | – | 2575 | .620 |
| Z19 | Beekmantown (Knox) | 4131 | 2771 | .671 | – | – | 2450 | .593 |
| Z20 | Beekmantown (Knox) | 4112 | 2717 | .661 | – | – | 2485 | .604 |
| Z28 | Beekmantown (Knox) | 4041 | 2904 | .719 | – | – | 2460 | .609 |
| Z21 | Beekmantown (Knox) | 3961 | 2941 | .742 | – | – | 2500 | .631 |
| Z22 | Wells Creek | 3891 | 2729 | .701 | – | – | 2220 | .571 |
| Z23 | Black River | 3771 | 2710 | .719 | – | – | 2145 | .569 |
| Z24 | Black River | 3539.5 | 2500 | .706 | – | – | 2080 | .588 |

Note *** = Significant uncertainity associated with these figures.

# Aristech Chemical Corporation Haverhill Plant
# In-Situ Stress Measurement Data Summary (Monitor Well)

## Table 4

| Test Identification | Formation Name | Shut-In Gauge Depth (ft) | ISIP (PSI) | ISIP (PSI/FT) | Interval Depth (BGL) | Approximate Formation Pressure Rise Required to Exceed Minimum Horizontal Stress (PSI) | |
|---|---|---|---|---|---|---|---|
| Reference | Mt. Simon | – | – | – | – | | – |
| Z1 | Rome | 5381 | 2650-3800*** | .492-.706*** | 5386-5390 | @ Pp = 0.48 | 65-1216*** |
| Z25 | Rome | 5374 | 3455-3690 | .643-.687 | 5379-5383 | | 876-1112 |
| Z2 | Rome | 5368 | 3420-3450 | .637-.643 | 5373-5377 | | 843-875 |
| Z3 | Rome | 5355 | 3450-3470 | .644-.648 | 5360-5364 | | 878-900 |
| Z4 | Rome | 5310 | 3225-3335 | .607-.628 | 5315-5319 | | 674-786 |
| Z5 | Rome | 5236 | 3295-3385 | .629-.646 | 5241-5245 | | 780-869 |
| Z6 | Rome | 5193 | 3375-3460 | .650-.666 | 5198-5202 | | 883-966 |
| Z7 | Conasauga | 5169 | 3020-3055 | .584-.591 | 5174-5178 | @ Pp = 0.48 | 538-574 |
| Z26 | Conasauga | 5137 | 3225-3275 | .628-.638 | 5142-5152 | | 760-812 |
| Z8 | Conasauga | 5112 | 3050-3565*** | .597-.697*** | 5117-5121 | | 598-1109*** |
| Z9 | Conasauga | 5063 | 2860-2925*** | .565-.578*** | 5068-5072 | | 430-496*** |
| Z10 | Copper Ridge (Knox) | 4970 | 2700-2725 | .543-.548 | 4975-4979 | @ Pp = 0.47 | 363-388 |
| Z11 | Copper Ridge (Knox) | 4816 | 2825-2850 | .587-.592 | 4821-4825 | | 563-588 |
| Z27 | Copper Ridge (Knox) | 4618 | 2690-2820 | .583-.611 | 4623-4633 | | 522-651 |
| Z12 | Copper Ridge (Knox) | 4467 | 2715-2810 | .608-.629 | 4472-4476 | | 616-710 |
| Z13 | Copper Ridge (Knox) | 4250 | 2310-2335 | .544-.549 | 4255-4259 | | 315-336 |
| Z14 | Rose Run (Knox) | 4205 | 2375-2410 | .565-.573 | 4210-4214 | @ Pp = 0.47 | 399-433 |
| Z15 | Rose Run (Knox) | 4189 | 3250-3630*** | .776-.867*** | 4194-4198 | | 1282-1663*** |
| Z16 | Rose Run (Knox) | 4181 | 2530-2575 | .605-.616 | 4186-4190 | | 564-610 |
| Z17 | Beekmantown (Knox) | 4169 | 2525-2575 | .606-.618 | 4174-4178 | @ Pp = 0.47 | 567-617 |
| Z18 | Beekmantown (Knox) | 4155 | 2435-2510 | .586-.604 | 4160-4164 | | 482-557 |
| Z19 | Beekmantown (Knox) | 4135 | 2360-2400 | .571-.580 | 4140-4144 | | 418-455 |
| Z20 | Beekmantown (Knox) | 4116 | 2340-2410 | .569-.586 | 4121-4125 | | 407-477 |
| Z28 | Beekmantown (Knox) | 4045 | 2260-2350 | .559-.581 | 4050-4060 | | 360-449 |
| Z21 | Beekmantown (Knox) | 3965 | 2310-2425 | .583-.612 | 3970-3974 | | 448-563 |
| Z22 | Wells Creek | 3895 | 2220-2215 | .570-.569 | 3900-3904 | @ Pp = 0.47 | 390-386 |
| Z23 | Black River | 3775 | 2080-2130 | .551-.564 | 3780-3784 | @ Pp = 0.47 | 306-355 |
| Z24 | Black River | 3543.5 | 2025-2050 | .571-.579 | 3548.5-3552.5 | | 358-386 |

Note*** = Significant uncertainty associated with this analysis

Aristech Chemical Corporation Haverhill Plant
Drill Stem Test Data Summary
Table 5

| Formation | Well | Date | Interval (ft KB) | Gauge Depth (ft KB) | P* (psi) | Note | Brine δ |
|---|---|---|---|---|---|---|---|
| **Logan** | Test | 1/21/91 | 164.2-261.5 | 157.7 | 63.7 | – | 1.033 |
| **Berea** | Test | 1/29/91 | 679.2-734 | 672.7 | 324 | – | 1.095 |
| | No. 3 | 4/13/89 | 701-751 | 710 | 333.3[1] | Low Perm/ Plugged | 1.03 |
| | No. 1 | 5/14/68 | 712-733 | – | – | Plugged | 1.005[1] |
| **Niagran** | No. 3 | – | – | – | – | – | 1.17 |
| **Newberg** | Test | 3/91 | 1757.4-1790.7 | 1750.9 | 837.7 | – | 1.097 |
| | No. 3 | – | – | – | – | – | 1.2 |
| | No. 1 | 5/16/68 | 1795-1835 | 1805 | 859 | Not P*, Plugging | 1.193 |
| **Beekmantown** (Upper Knox) | Test | 4/20/91 | 4009.5-4035.5 | 3995.5 | 1805.7 | – | 1.218 |
| **Rose Run** (Knox) | Test | 4/25/91 | 4181-4225 | 4170.0 | 1912.2 | – | 1.214 |
| | No. 3 | 5/15/89 | 4503-4588 | 4572.0 | 1968.8 | Deviated Well | 1.19 |
| | No. 1 | 5/26/68 | 4220-4265 | 4230.0 | 1895.6[1] | – | 1.199 |
| **Copper Ridge** (Lower Knox) | Test | 5/8/91 | 4446.7-4480 | 4440.2 | 2078.2 | – | 1.20 |
| **Mt. Simon** | No. 3 | 9/25/89 | 5978-6109 | 5965 | 2645.9 | Deviated Well | 1.05[2] |
| | No. 1 | 6/5/91 68 | 5520-5565 | 5545 | 2633 | – | 1.225 |
| **Lower Mt. Simon** | No. 1 | 6/6/91 68 | 5575-5617 | 5613 | — | No Perm. | – |

Notes: 1 - not representative value; insufficient sample/shut-in time  2 - fluid sample primarly injectate

P4-91

Barcode 002639

Box 37

# APPENDIX S-1

## IN-SITU STRESS MEASUREMENTS: PROTOCOL AND IN-SITU STRESS MEASUREMENTS AT THE ARISTECH CHEMICAL CORPORATION HAVERHILL FACILITY: RESULTS (PREPARED BY RESEARCH AND ENGINEERING CONSULTANTS, 1991)

PROTOCOL

# In-Situ Stress Measurements at the Aristech Chemicals Haverhill Facility

Prepared by
Research & Engineering Consultants, Inc.
Englewood, Colorado

January 9, 1991

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1991

# Results

# In-Situ Stress Measurements at the Aristech Chemical Corporation Haverhill Facility

July 17, 1991

REC

**Research & Engineering Consultants, Inc.**
5445 DTC Parkway, Suite 640
Englewood, Colorado 80111 (303) 741-5900

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**APPENDIX AA**

**ANALYSIS OF DST DATA FROM ARISTECH WELLS, 1989**
**(MEMO FROM REC TO ARISTECH)**

PY-91

002639

Box 37

MEMORANDUM

June 20, 1989

TO: Paul Kaplow/Aristech and John Fleniken/Envirocorp

FROM: Gene Collins / REC

RE: Analysis of DST data from Aristech Wells

**Objective:** REC has been requested to evaluate pressure data obtained in the Rose Run formation by a drill stem test (DST) in WDW No. 3 at the Aristech site in Scioto County, Ohio in May, 1989. These data are to be compared to results of the DST in the Rose Run in WDW No. 1 at this site in June, 1968.

Mr. Harlan Gerrish of the USEPA Region V, Chicago, Illinois has contended that these two tests indicate a **pressure rise** in the Rose Run of approximately 100 psi since 1968. REC has been asked to determine whether this is reasonable, based upon these data.

**Method:** The first step was to extrapolate the shut-in pressures for the second shut-in period of each DST test by using the Horner plot technique. This is a standard, well accepted method for determining shut-in pressures. This is a plot of shut-in pressure versus ln $(t + \Delta t) / \Delta t$, where t is the duration of the second flow period and $\Delta t$ is elapsed shut-in time in the second shut-in period. Theory [Horner (1951)] shows that these data should approach a straight line for larger $\Delta t$ with intercept $P^*$ as $\Delta t \rightarrow \infty$, where $P^*$ is the true shut-in pressure after all transients due to the flowing tests have disappeared.

The Horner plot for the 1989 Rose Run DST in WDW No. 3 is shown in Figure 1, while that for the 1968 Rose Run DST in WDW No. 1 is shown in Figure 2. Also shown in Figure 3 is the plot for the DST in the Mt. Simon formation obtained in WDW No. 1 in 1968 prior to beginning injection in the Mt. Simon. The resulting extrapolated $P^*$ pressure values are shown in Table I along with other pertinent data from these tests.

Table I

| Well | Date | Formation | Gauge Elev. (ft.,True S.L.) | P* Psi | Brine Sp.Gr. |
|---|---|---|---|---|---|
| WDW#1 | 5/25/68 | Rose Run | -3673 | 1896 | 1.199 |
| WDW#1 | 6/ 6/68 | Mt. Simon | -4988 | 2633 | 1.255 |
| WDW#3 | 5/15/89 | Rose Run | -3706 | 1969 | N/A |

**Data Corrections and Discussion:** Valid comparison of $P^*$ values for the Rose Run between the two wells requires that these be corrected for depth to a common datum relative to sea level. This difference in elevation between the two wells results in a naturally occurring higher pressure in the Rose Run in WDW No. 3 over that in WDW No. 1 by:

$$\Delta P = .433 \times 1.199 (3706 - 3673)$$

$$\Delta P = 17.13 \text{ psi}$$

Thus for the Rose Run, the pressure in WDW No. 3, corrected to the same elevation as in WDW No. 1, is:

$$P^*_{cor.} = 1969 - 17.13 = 1951.9 \text{ psi}$$

which is still higher than that in WDW No. 1 by 55.67 psi.

However, it appears that the DST data in WDW No. 1 are in error because the $P^*$ value from the DST, in relation to that for the Mt. Simon, varies from a well established relationship. (hydrostatic equilibrium consistency) Hydrostatic consistency between the Rose Run and Mt. Simon in 1968 is tested as follows:

Letting:

$P_1^*$ = (Rose Run, 1968 WDW No. 1)
$P_2^*$ = (Mt. Simon, 1968 WDW No. 1)

with $d_1$ and $d_2$ corresponding depths, we see that hydrostatics would require

$$P_2^* - P_1^* = 0.433 \frac{\gamma_1 + \gamma_2}{2} (d_2 - d_1) = 0.433 \gamma (d_2 - d_1)$$

where $\gamma_1$ and $\gamma_2$ are the respective specific gravities. Using the $P^*$ values above, we

compute the average of these, $\gamma$, implied as

$$\gamma = \frac{P_1^* - P_2^*}{.433\ (d_2 - d_1)} = \frac{2633 - 1896}{.433(4988 - 3673)}$$

or $\gamma = 1.294$

This differs markedly from $(\gamma_1 + \gamma_2) / 2$ which is 1.227. Thus it appears that $P_1^*$ and/or $P_2^*$ are in error since specific gravities are measured with greater accuracy and precision than DST pressures.

If we assign all of this inconsistency to the Rose Run pressure, we can use hydrostatics to compute a corrected Rose Run $P^*$ value from the Mt. Simon value. This is by using:

$$P_1^* = P_2^* - 0.433\frac{\gamma_1 + \gamma_2}{2}(d_2 - d_1)$$

which is:

$$P_1^* = 2633 - 0.433\ (1.227)\ (4988 - 3673)$$

or

$$P_1^* = 1934.4 \text{ psi}$$

This value for $P^*$ in the Rose Run in WDW No. 1 is 38.4 psi **higher** than the value from the DST.

Thus, with the datum corrected value for $P^*$ of the Rose Run in No. 3 and the hydrostatic corrected value for $P^*$ in the Rose Run in No. 1, we see a difference,

$$(P^*_{cor.} \text{ No. 3}) - (P^*_{cor.} \text{ No. 1}) = 1951.9 - 1934.4$$

$$= 17.5 \text{ psi}$$

This difference in pressures (at the same elevation datum) is within the range of error of mechanical gauges used in 1968. [Errors of = ±10 psi are not uncommon in older gauges]

## Reference

Horner, D.R.; Proc. 3rd World Pet. Cong., Sect. II, E. J. Brill, Leiden (1951).

# DRILL STEM TEST, 5/15/89
## Aristech Chemical Corporation
## Final Shut-in Period, WDW No. 3
## Rose Run Formation, Scioto County, Ohio
## Test Depth - 3706 Feet True Vertical Sub-Sea Depth

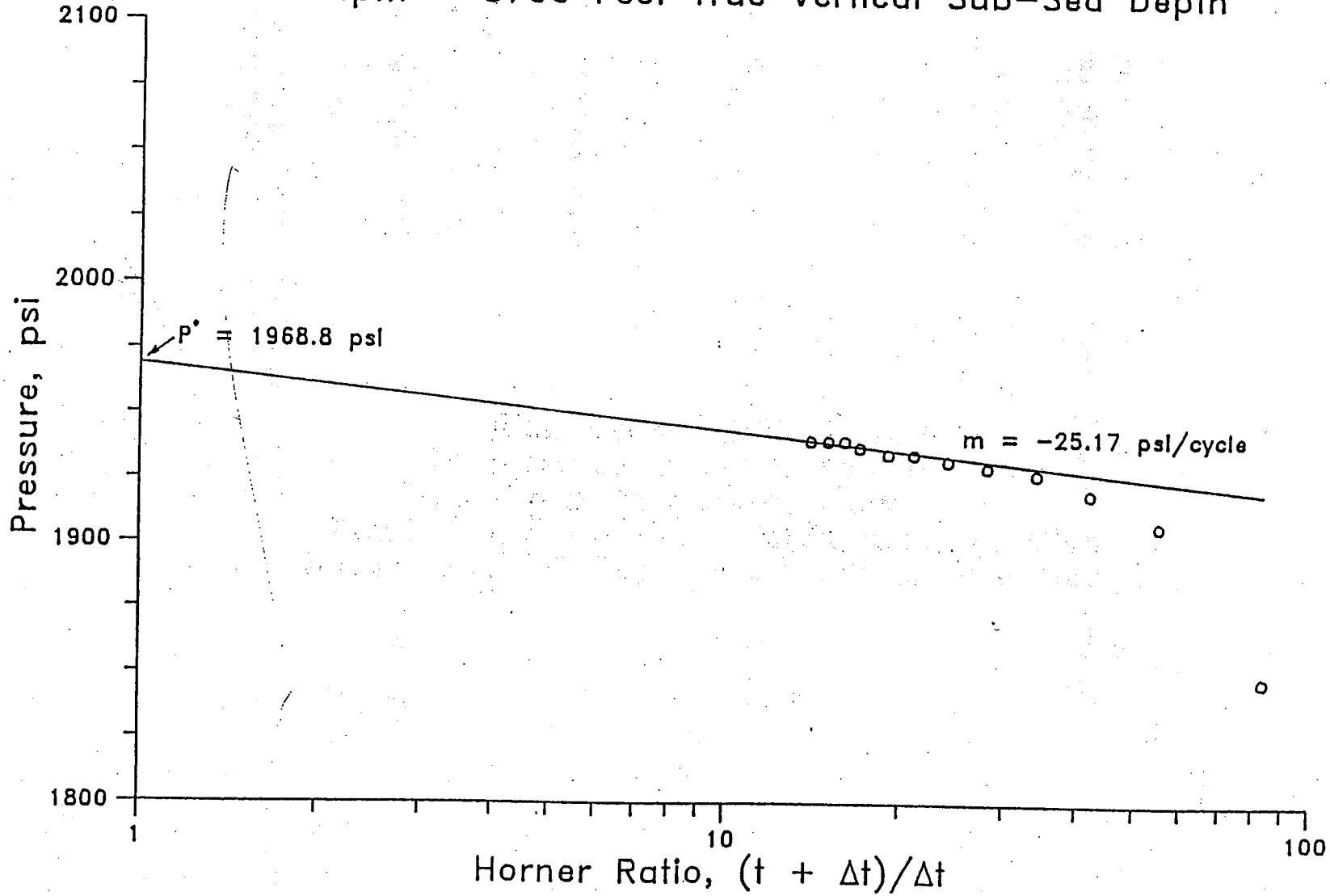


Figure 1

REC, INC.
June 1989

DRILL STEM TEST, 5/25/68
Aristech Chemical Corporation
Final Shut-in Period, WDW No. 1
Rose Run Formation, Scioto County, Ohio
Test Depth - 3673 Feet True Vertical Sub-Sea Depth

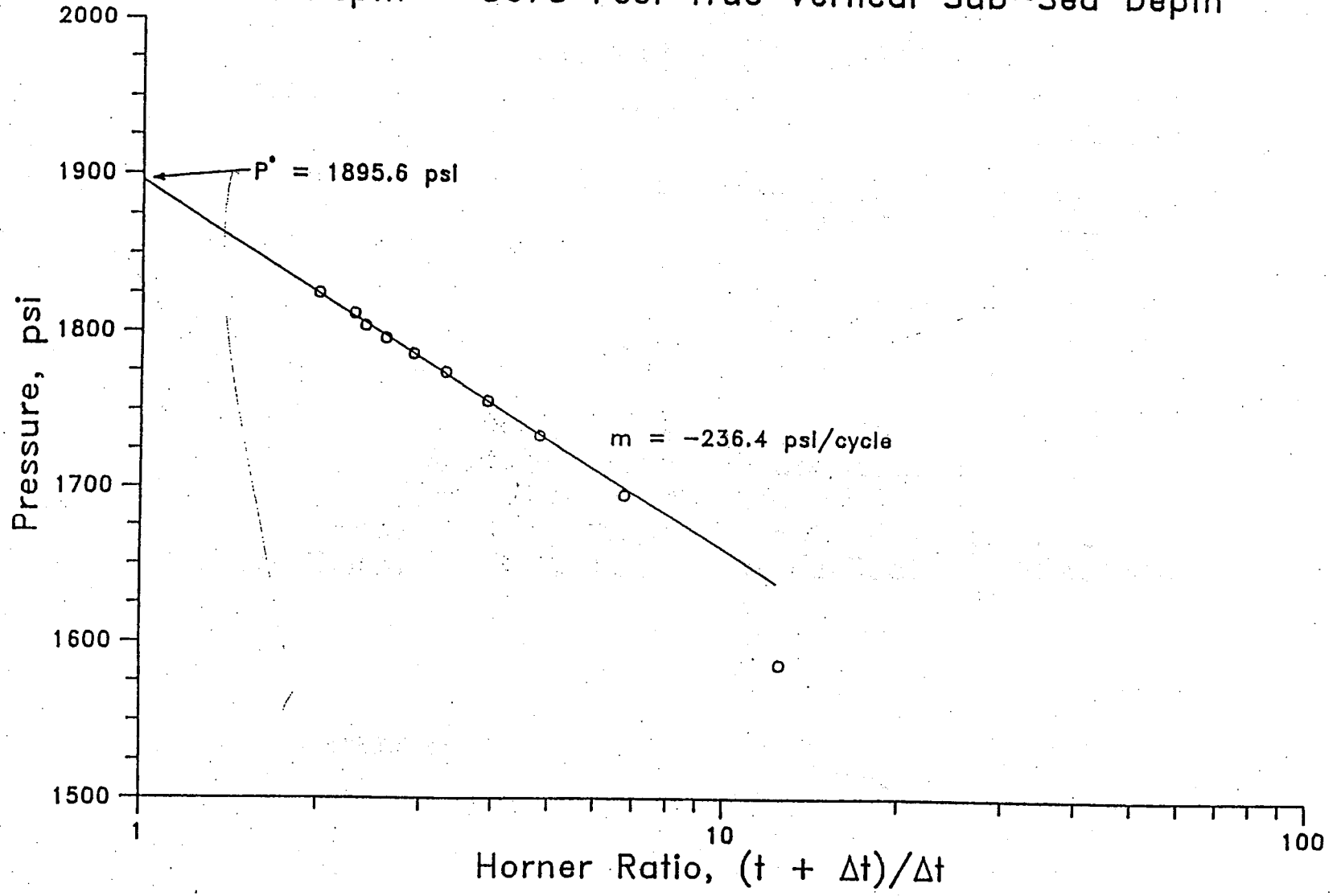


Figure 2

REC, INC.
June 1989

DRILL STEM TEST, 6/6/68
USS Chemicals
Final Shut-in Period, Haverhill Disposal Well No. 1
Mt. Simon Sand, Scioto County, Ohio
Test Depth - 4988 Feet True Vertical Sub-Sea Depth

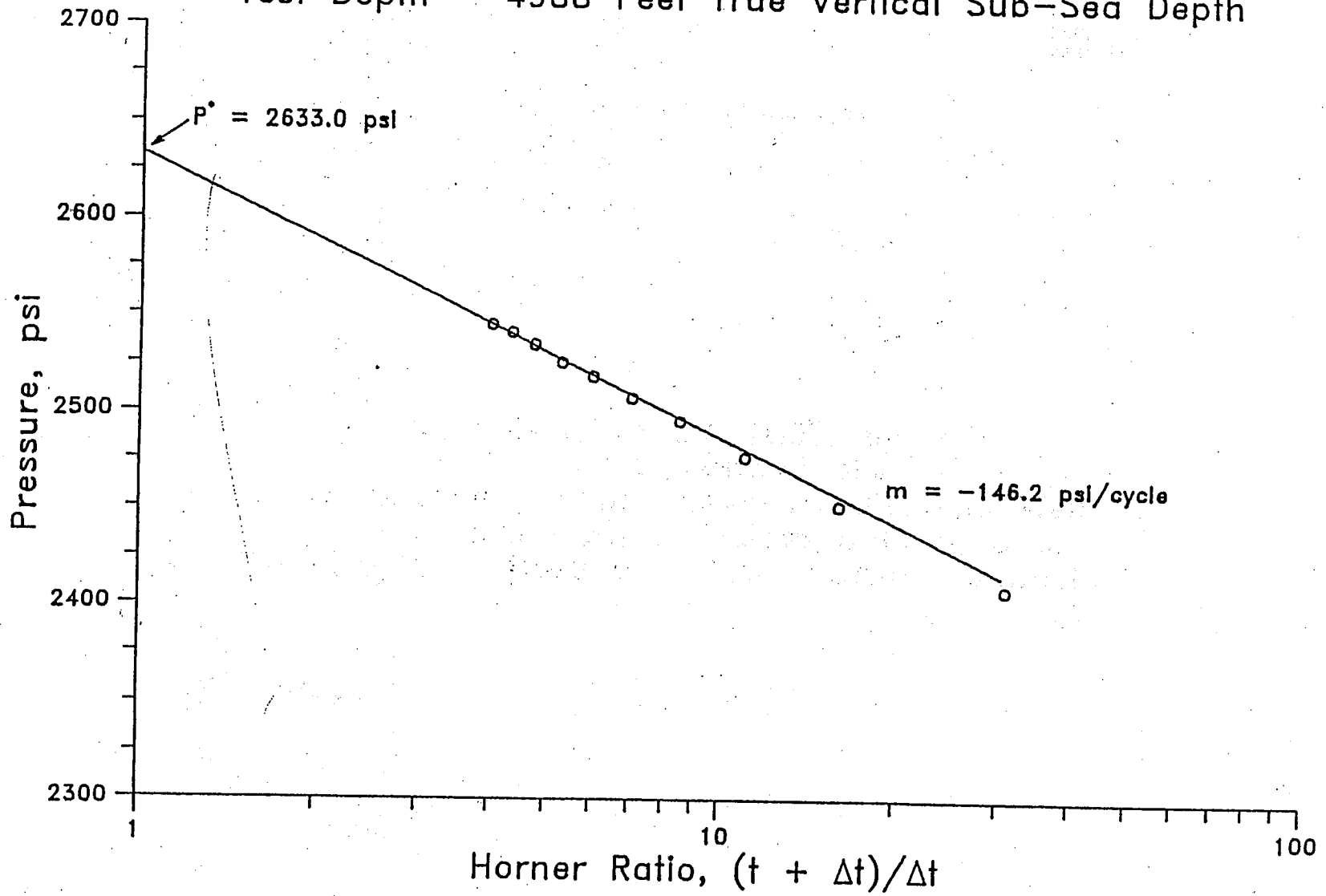


Figure 3

REC, INC.
June 1989

# APPENDIX BB

## SUMMARY OF STUDIES PERFORMED AND METHODOLOGIES

002639

Box 37

PY-91

## A. Organic and Inorganic Geochemistry

As summarized in previous sections, biogeochemical studies were conducted to determine fate and transport of chemical constituents. The chemical conditions within the hydrologic system were assessed (e.g., anaerobic vs. aerobic, saline vs. fresh water, host rock-fluid interaction, etc.), as well as both the potential for biodegradation and resulting compound-specific biodegradation products.

A number of transport and transformation processes can affect the concentrations of these compounds as the fluids migrate. These include volatilization from water to vapor phase (if present), cation exchange, and oxidation. The importance of each of these mechanisms was also assessed. Adsorption of both organic and inorganic constituents onto rock matrix and the potential for differential contaminant movement were examined, as well as a number of chemical transformations such as pH changes and the potential addition of other inorganic species through dissolution. These detailed chemical assessments were conducted to obtain a clear understanding of both the chemical system and potential chemical interactions.

B. Organic Chemical "Fingerprinting"

Groundwater samples from the Rose Run and injectate were re-analyzed using state-of-the-art LC/MS/MS techniques, wherein very detailed, compound-specific analyses are being conducted. Results of these analyses are pending. The results of chemical fingerprinting are included in Section IV of this report.

C. Hydrogeologic and Geologic Assessments

As previously stated, a site-specific geohydrologic assessment was conducted as part of the UIC petition and provided a good understanding of regional geology. A summary of the site and regional hydrogeologic conditions was discussed in Section III above. In the UIC study, a detailed examination (microscopic) of the core (Appendix A) was also conducted to provide detailed mineralogical information, and well logs (Appendix T), drilling data, and literature reviews all provided additional geologic information. Although hydrologic information in the area is limited, the Project Team assembled and interpreted available information to acquire an understanding of the hydrogeologic conditions (Appendix C). A regional structural geology (lineament) study was also conducted, wherein geomorphic and geophysical data were integrated to assess the nature of structural features.

D. Geophysical Information and Well Construction Assessments

Geophysical studies were conducted to provide both detailed site-specific and regional geologic, hydrologic, and geochemical support information. For example, Schlumberger was retained to assess whether the organic fluid content of the groundwater could be determined using well log data (Appendix F). A regional seismic survey was conducted to evaluate large-scale structural characteristics that were not apparent in cores or in the geologic literature (Appendices D and E). Well histories were studied, and mechanical integrity tests (MITs) were examined to assess well construction (Appendix G and H). The chemical nature of drilling fluids that were used during drilling of WDW No. 3 was also evaluated (Appendix U).

In addition, an aerial photography survey was conducted to examine historic land use in the facility area; the results of this survey prompted Aristech to conduct a field magnetometer survey over an approximately 1000 square foot area. The purpose of this magnetic survey was to determine if buried metal is present at the site, including, possibly, metallic well conductor casing that could be present. Results of this survey are included in Appendix V.

E. Data Validation, QA/QC

A large quantity of data collected from a number of sources and analyzed by various laboratories were used for this assessment. The use of quality data was a high priority for the project. Therefore, the Project Team conducted comprehensive data validation and quality assurance (QA)/quality control (QC) exercises for all data --geologic, chemical, hydrologic, geophysical, MIT, etc. These exercises assured that only the most reliable information was used in assessments (Appendices L and W).

F. Additional Site Studies

To complete this assessment and as discussed above, the Project Team evaluated the historic production at the Haverhill facility, as well as the manufacture of similar products (and waste disposal practices) in the Haverhill area. Harrison/Kroll conducted comprehensive interviews of area residents/employees, which also included a study of historic phenol manufacturing processes in the Haverhill region. Also, wells in the Aristech area that were drilled into the Rose Run Formation were identified (Appendix K). ERM also conducted a well and industry survey within a 50-mile radius of the Haverhill facility (Appendix X). Aerial photographs taken between 1951 and 1988, covering an approximately 10-mile radius surrounding the facility, were also examined. A field survey of the area immediately surrounding the facility was conducted, as well as a field magnetometer survey (Appendix V).

# ROSE RUN/ COPPER RIDGE REPORT

Barcode
002637
Box 35

## Volume I

Sections III & IV

August 15, 1991

ARISTECH

Prepared for:
Aristech Chemical Corporation

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- WDW No. 3 - Envirocorp Core Analyses
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- Test/Monitoring Well Core Log (Prepared under Contract to Envirocorp Services and Technology, 1991)

A-2 - Site-Specific Geology

B - Glossary of Terms, List of Acronyms, and List of Qualifiers for Chemical Data Tables

C - Summary of Geologic Units Above the Rose Run Formation, Haverhill, Ohio: A Synopsis of Data presented in the Aristech Haverhill Hazardous Waste Disposal Injection Restrictions Exemption, 1990

D - Report of Seismic Reflection Survey, 1990, and Responses to OEPA's NODs, 1991 (Prepared by Envirocorp Services and Technology, Inc.)

E - Assessment of Envirocorp Seismic Reflection Survey (Prepared by by Ms. Sally Zinke, 1990 and Revised 1991)

F-1 - Open Hole Log Analysis and Fracture Trend Analysis (Prepared by Envirocorp Services and Technology, Inc., 1990)

F-2 - Report by 1979 and 1983 Earthquakes (by Armbruster and Seeber)

F-3 - Geophysical Investigations (by University of Michigan)

F-4 - Origin of Earthquakes in Ohio and Kentucky, Correspondence from R. Street, University of Kentucky, to J.J. McNealey, 1990

G-1 - WDW No. 1 and WDW No. 2 Well History Summaries

G-2 - Report of Drilling and Testing WDW No. 3 (Prepared by Envirocorp Services and Technology, 1990) (does not include appendices)

G-3 - Report of Drilling and Testing of the Monitoring Well (Deep Well No. 4) (Prepared by Envirocorp Services and Technology, 1991)

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G-4 - A Report to Aristech Chemical Corporation on Step-Rate Testing, Well No. 3 (Prepared by Research & Engineering Consultants, Inc., 1991)

H - MIT Assessment (By Envirocorp Services and Technology, 1990)

I - Description of Formation Testing Procedures

J - Monthly Injection Histories, WDW No. 1 and WDW No. 2

K - Executive Summary (Harrison/Kroll Environmental Services Report Prepared for Porter, Wright, Morris & Arthur)

L - Chemistry Data:

Data Compilation Document

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DCD-Section III - Berea Formation
DCD-Section IV - Niagaran Formation
DCD-Section V - Lockport/Newburg Formations
DCD-Section VI - Trenton Formation
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DCD-Section VIII - Rose Run Formation
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DCD-Section X - Mt. Simon Formation
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Summary Document

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M - Assessment of Haverhill Fluid Chemistry (by Dr. Donald Langmuir, 1991)
N - Analytical Data of Semi-Solid Material in Wells 1984 and 1988 Analysis
O - Historic Injectate Phenol Concentration Plots, 1990
P - Ohio River Water Quality, ORSANCO Data, 1990
Q - Environmental Degradation of Injectate and Formation Compounds: Literature Search (Prepared by Battelle for J.J. McNealey, Porter, Wright, Morris & Arthur, 1989)
R - Possible Effects of Biodegradation of the Compounds found in the Rose Run (by Dr. C.H. Ward, Rice University, 1991)

S-1 - In-Situ Stress Measurements: Protocol, and In-Situ Stress Measurements at the Aristech Chemical Corporation Haverhill Facility: Results (Prepared by Research and Engineering Consultants, 1991)
S-2 - Description of Fluid Flow Modeling (Prepared by Research and Engineering Consultants, 1990)
T - Well Log Interpretation: Casing Inspection Log Description and Excerpts from Well Log Evaluation (by R.H. Merkel, AAPG Course Note Series #14, 1981)
U - Drilling Fluid Chemistry Data for WDW No. 3, 1989
V - Magnetometer Survey for Select Area at Aristech, Haverhill Plant (Prepared by Microgeophysics Corp., 1990)
W - QA/QC Summary of Aristech Geologic and Geophysical Data as of March 1990

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X - Industrial Facilities (Associated with Phenols) and Underground Injection Wells within 50 Miles of Haverhill, Ohio (Prepared by Environmental Resources Management, Inc., 1989)

Y - Select Annular Pressure Data, WDW No. 1 and WDW No. 2

Z - Corrosion and Precipitation Within Piping at Haverhill (Aristech Internal General Correspondence: 1972, 1980, 1981)

AA - Analysis of DST Data from Aristech Wells, 1989 (Memo from REC Aristech)

BB - Summary of Studies Performed and Methodologies:
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- Organic Chemical "Fingerprinting"
- Geophysical Information and Well Construction Assessments
- Data Validation, QA/QC
- Additional Site Studies

CC - True Vertical Depth Log, WDW No. 3

DD - Marathon Oil Report Re: Work on WDW No. 2, 1984, and Discussion Letter (Prepared by Envirocorp Services, Inc., 1991)

run which showed the interior liner to be in sound condition. The well was then reassembled, and a successful annular pressure test was performed. In September 1989, an annular pressure increase was noted. The pressure rise was discovered to be caused by a faulty packer seal (rather than any well problem that would allow injectate to enter adjoining rock formations). This problem was corrected with the installation of a new packer. A complete summary of WDW No. 1 history is included in Appendix G1.

### C.1.4 Formation Fluid Sampling

Fluid from a number of formations was sampled during drilling of WDW No. 1. Sampled and cored intervals are summarized in Table 2.

## C.2 WDW No. 2

### C.2.1 Well Construction

WDW No. 2 was directionally drilled to a measured depth of 6024 feet (which is equivalent to a vertical depth of 5568 feet) and was completed in August of 1978. The bottom hole location is 2087 feet west of the surface location. This well has a slightly different well construction than WDW No. 1: a 16-inch outer diameter conductor pipe was cemented in place from ground surface to 85 feet, while the surface casing was set from ground surface to 504 feet. The 7-inch protective casing was set to 6024 feet, and the Mt. Simon was perforated through this casing from 5930 to 5972 feet. Three and one-half inch injection tubing was installed from ground surface to the packer at 5862 feet, and 27 feet of injection tubing extends below the packer.

### C.2.2 Well Stimulation

Well No. 2 was perforated between 5930 feet to 5972 feet below ground surface and hydraulically stimulated with 2000 gallons of 15 percent hydrochloric acid to enhance the

Table 2

Formation Fluid Sample Collection and Core for WDW No. 1

| Interval | Test Type* | Recovered Fluid** |
|---|---|---|
| 712-733 ft. Berea | DST | 30 ft. drilling fluid (6.2 gallons) |
| 1795-1835 ft. Newburg | DST | 1410 ft. formation fluid (607.6 gallons) |
| 4220-4265 ft. Rose Run | DST | 660 ft. formation fluid (159.7 gallons) |
| 5520-5565 ft. Mt. Simon | DST | 1895 ft. formation fluid (897.3 gallons) |
| 5575-5617 ft. Lower Mt. Simon and Precambrian Granite | DST | 2 ft. drilling fluid (.4 gallons) |

Cored Intervals

| | |
|---|---|
| 710-733 ft: | Berea |
| 1895-1834.5 ft: | Newburg (plug) |
| 1805-1833 ft: | Newburg (full core) |
| 3979-4007 ft: | St. Peter (Beekmantown)*** |
| 4242-4246.5 ft: | Rose Run[1] |
| 4250-4261.8 ft: | Rose Run[1] |
| 5532-5561 ft: | Mt. Simon |
| 5563-5573 ft: | Mt. Simon |
| 5595-5617 ft: | Precambrian Gneiss |

* See Appendix I for description of sample collection (test) methods.

** Calculated fluid recovery (in gallons) assumes that the drill string consists of 600 feet, 6 1/4 inch O.D.; 2 1/4 inch I.D. drill collars; and the rest of the well is lined with 4 1/2 inch, 16.6 lb/ft. drill pipe.

*** Formation correlation based on Table 6.3-11 in the UIC Repermit Application (Appendix A1).

[1] Core actually collected approximately 10 feet higher than indicated log depth.

### C.2.4 Formation Fluid Sampling

No formation fluid sampling was conducted at WDW No. 2.

## C.3 WDW No. 3

### C.3.1 Well Construction

WDW No. 3 was completed in December of 1989 (Appendix G2), and was directionally drilled to a measured depth of 6091 (equivalent to a vertical depth of 5614 feet). The bottom hole location is approximately 2000 feet northeast of the surface location. A 16-inch outer diameter conductor pipe was set and cemented to 77 feet below ground surface. A 10-3/4-inch outer diameter surface casing was set and cemented to 879 feet below ground surface, and a 7-inch protective casing was set and cemented from ground surface to 5978 feet. The hole is open from 5978 to 6091 (within the Mt. Simon Formation).

### C.3.2 Well Stimulation

WDW No. 3 has not been artificially hydraulically stimulated.

### C.3.3 Well History

WDW No. 3 has not been placed in service. A bridge plug is installed in the well at a depth of 5934 feet. The injection tubing and packer have not been installed. WDW No. 3 was re-entered late in 1989 for interference testing among the three Aristech wells. Subsequent to the interference test, a step rate test was performed, a RAT was run, and an OAL was performed. Neither the RAT or the OAL gave any indication of fluid movement behind the casing or out of the injection interval.

During March 1991, the well was re-entered to perform additional step rate testing on the Mt. Simon injection interval. Three step rate tests were performed. The results from the third test are considered to be the best since the first two tests had operational problems (Appendix G4).

### C.3.4 Formation Fluid Sampling

A number of formation fluid samples and formation core samples were taken from WDW No. 3 while it was being drilled (Table 3a). The DSTs are listed in the order that they were conducted. The Berea, first Rose Run, Rome/Conasauga, and Mt. Simon DSTs were performed as the well was being drilled. Other DSTs were "straddle-packer"-type tests wherein samples were collected in the uphole formations after the well had been drilled to the Rome/Conasauga.

## C.4 Test/Monitoring Well

### C.4.1 Well Construction

The Test/Monitoring Well was approved for installation in early January and spudded on January 17, 1991 (Appendix G3). Seven-inch casing was set to 101.5 feet below ground surface and cemented in place to ground surface. A 4-inch core hole was then drilled to 2170 feet below surface. During this initial coring operation, representative formation fluid samples were obtained from the Logan, Berea, and Lockport Formations. The hole was reamed to a diameter of 6-1/2 inches to a depth of 2105 feet, followed by the setting of a 4-1/2-inch O.D. (outer diameter) casing.

Coring proceeded following setting of the casing. Representative fluid samples were collected from the Beekmantown (identified as Upper Knox when sampling), Rose Run, and Copper Ridge (identified as Lower Knox Formation during sampling). The well was then cored to a total depth of 5434 feet as determined by WLM (wire line measurement). After

Table 3a

Formation Fluid Sample Collection and Core for WDW No. 3
Presented in Order of Sample Collection

| Interval** | Test Type* | Recovered Fluid |
|---|---|---|
| 195 and 214 ft.<br>Logan (195 and 214 ft.) | *** | no data |
| 701-751 ft.<br>Berea (701-751 ft.) | DST | no fluid recovery*** |
| 4503-4588 ft.<br>Rose Run (4234-4267 ft.) | DST | 420 gallons |
| 5598-5733 ft.<br>Rome/Conasauga<br>(5150-5273 ft.) | DST | 2 gallons from sample chamber |
| 4491-4591 ft.<br>Rose Run (4183-4271 ft.) | Swab Test | 7896 gallons |
| 4171-4232 ft.<br>St. Peter (3910-3962 ft.)<br>(Beekmantown through Wells Creek)**** | Swab Test | no formation fluid recovery |
| 1788-1858 ft.<br>Newburg (1773-1834 ft.) | Swab Test | 3935.4 gallons |
| 1500-1570 ft.<br>Niagaran (1497-1567 ft.) | Swab Test | 3666.6 gallons |
| 5963-6109 ft.<br>Mt. Simon (5481-5614 ft.) | DST | misrun, no test |
| 5978-6109 ft.<br>Mt. Simon (5495-5614 ft.) | DST and Swab | 5334 gallons |

Table 3a (Con't)

Formation Fluid Sample Collection and Core for WDW No. 3
Presented in Order of Sample Collection

Cored Intervals**

| | |
|---|---|
| 5600-5654 (5151-5200): | Conasauga/Rome |
| 5654-5695 (5200-5237): | Conasauga/Rome |
| 5695-5733 (5237-5272): | Rome |
| 5915-5978 (5432-5495): | Rome |
| 5982-6027 (5499-5540): | Mt. Simon/Rome |
| 6027-6073 (5581-5603): | Mt. Simon |
| 6073-6097 (5603-5614): | Mt. Simon; Gneiss |
| Basement at 6079 | |
| 6097-6109 (5603-5614): | Gneiss Basement |

* See Appendix I for description of sample collection (test) methods.

** Measured depths; true vertical depth in parenthesis.

*** Sampled using Repeat Formation Tester, as described in Appendix I.

**** Formation correlation based on Table 6.3-11 in the UIC Repermit Application (Appendix A1).

total depth was achieved, 28 in-situ stress tests were performed. The well was then plugged back to a depth of 4303 feet and a 2-3/8 inch monitoring well casing was installed. The monitoring well casing was then cemented to the surface.

The casing was perforated in the Rose Run from 4186 feet to 4222 feet. A Cement Bond Log/Variable Density Log (CBL/VDL) was run, which confirmed proper cementing of the casing from bottomhole to surface. A pressure monitor was installed on June 27, 1991 to complete the well.

C.4.2 Well Stimulation and Well History

The well was not hydraulically fractured because it will be used for monitoring, not injection. The Test/Monitoring Well has only recently been completed, and has no well performance history.

C.4.3 Formation Fluid Sampling

As stated above, six formations were sampled during drilling of the Test/Monitoring Well. The Logan, Berea, Lockport/Newburg, Beekmantown (Upper Knox), Rose Run, and Copper Ridge (Lower Knox) Formations were sampled, as shown in Table 3b.

C.5 Summary: Mechanical Integrity Test (MIT) Results for WDW No. 1, WDW No. 2, and WDW No. 3

Envirocorp Services & Technology has reviewed the available MIT data and operating histories for WDW Nos. 1 and 2 at the Haverhill facility (Appendix H) and MIT data for WDW No. 3 subsequent to step-rate tests completed in 1991.

Based on a review of the data, the following conclusions were reached:

Table 3b

Formation Fluid Sample Collection for Test/Monitoring Well

| Interval | Test Type* | Recovered Fluid |
|---|---|---|
| 164.2-261.5<br>Logan | DST/Swab | 619 gallons |
| 679.2-734.0<br>Berea | DST/Swab | 231 gallons** |
| 1757.4-1790.7<br>Lockport/Newburg | DST/Swab | 905 gallons |
| 4006.7-4035<br>Upper Knox/Beekmantown | DST/Swab | 1426 gallons |
| 4181-4225<br>Rose Run | DST/Swab | 3389 gallons |
| 4446.7-4480<br>Lower Knox/Copper Ridge | DST/Swab | 5834 gallons |

* See Appendix I for description of sample collection (test) methods.

** Total fluid from 2nd swab event only.

a pressure limitation of 1711 psi. In 1986, this was increased to 1739 psi by OEPA after a review of injection data and modeling results.

### C.7 Historic Deep-Well Waste Disposal by Other Operators in the Haverhill Area

Harrison/Kroll Environmental Service Inc., was contracted in 1989 to identify chemical production facilities in the Haverhill area and to determine processes and waste disposal practices of these facilities from the 1950s to the 1970s (Appendix K). Harrison/Kroll was also asked to assemble information concerning wells drilled into the Rose Run in the Haverhill area and to interview former employees of local manufacturing facilities. Local residents were also interviewed.

Harrison/Kroll identified six facilities that operated in the past, or continue to operate, which produce waste streams with phenol-related constituents in the Haverhill area: Allied Chemical, Ironton; Dow Chemical, Ironton; Hooker Chemical, Ironton; Allied Chemical, Ashland, Kentucky; Ashland Oil, Catlettsburg, Kentucky; and Allied Chemical, South Point, Ohio. Documentation gathered from government offices does not indicate that waste disposal by deep well injection was conducted at any of the facilities. Interviews with local residents/former employees indicate that injection of wastes may have taken place, but there is no direct evidence of this activity.

## D. Fluid Chemistry

The chemical nature of the injectate, the Mt. Simon, Copper Ridge, and Rose Run Formation fluid, and the fluid from overlying formations are summarized below. This discussion also includes the results of studies concerning the chemical nature of the injectate, both historical and present, as well as formation brine characteristics before and after injection began. Additionally, the chemical characteristics of mixtures such as Mt. Simon + injectate, Rose Run + injectate, Copper Ridge + injectate, and Mt. Simon + Rose Run

fluids are also briefly summarized. Chemistry data are presented in Appendix L, while a detailed discussion of mixing calculations is presented in Appendix M.

## D.1 Injectate

Injection of liquid wastes into the Mt. Simon Formation at the Haverhill site has been conducted for over 20 years. Both historic and current injectate have been comprised principally of phenol-related waste waters, although products other than phenol have also been made at Haverhill and waste waters from these processes could have entered the injectate waste stream. A discussion concerning historic production/waste waters is therefore warranted.

### D.1.1 Manufacturing History of the Haverhill Facility and Origin of Injectate

As stated earlier in this report, the first manufacturing facility at the Haverhill site was constructed in 1962, by an Amoco and Pittsburgh Coke and Chemical joint venture. The two companies built an alcohol plant in which heptene and nonene were used to produce isooctyl and isodecyl alcohols. Wastes such as caustic wash waters were produced and organic heavy end wastes were either burned for energy recovery in the plant boilers or directed to the Alcohol Wastewater Treatment Lagoons, depending upon the specific waste type. USX bought the plant in 1965 and continued alcohol production until 1982. There are no records indicating that alcohol wastes were placed in the disposal wells.

USX constructed the Phenol No. 1 manufacturing plant in 1969. Wastewater from the phenol production was disposed in WDW No. 1. USX manufactured polystyrene from 1971 to 1981, but personal interviews with facility representatives indicate that no polystyrene wastes were injected in either WDW No. 1 or WDW No. 2. BPA production began in 1979. Wastes from production of this compound were initially directed to a wastewater disposal facility(ies), but were added to wastes placed into the injection wells in late 1979.

Table 4a (Cont'd)

Typical Constituents in 1989 Injectate

| Units - ppm | Injectate Sampled 6/14/89 | Injectate Sampled 11/20/89 | Injectate Sampled 4/12/90 | Range (ug/l) |
|---|---|---|---|---|
| 2-Methylbenzofuran | 1.2 | NI | NI | NI-1.2 |
| 2,3-Dimethylphenol | 2.2 | NI | NI | 22 |
| 2-(1-Methylethyl)phenol | 1.2 | NI | NI | 1.2 |
| 4-(1-Methyl-1-phenylethyl) phenol (cumyl phenol) | 26 | NI | 10 | 10-26 |
| 2-[1-(4-Hydroxyphenyl) 1-methylethyl] phenol (o,p-BPA) | 13 | NI | NI | 13 |
| Bisphenol A (BPA) | NA | NA | NA | NA |
| Cumene | 22 (TIC) | NA | 17 (TIC) | 17-22 |
| Formic Acid (as Formate) | NA | NA | NA | NA |
| Aluminum | 0.8 | 0.3 | 0.273 | .273-0.8 |
| Barium | ND | ND | 0.0164 | ND-0.0164 |
| Calcium | 21 | 38 | 164 | 21-164 |
| Chromium | 0.06* | 0.05 | 0.0948 | .05-0948 |
| Iron | 0.41 | ND | ND | ND-0.41 |
| Lead | ND | ND | ND | ND |
| Magnesium | 0.14 | ND | 0.279 | ND-0.279 |
| Manganese | ND | ND | ND | ND |
| Potassium | 17.1 | 10 | 169 | 10-169 |
| Sodium | 5080 | 11000 | 7410 | 5080-11000 |
| pH | 12.4 | 11.56 | NA | 11.56-12.4 |
| Specific Gravity | 1.01 | NA | NA | 1.01 |

NA = not analyzed (for)
NI = not identified, TIC
ND = analyzed for, but not detected
TIC = tentatively identified compound
* = concentration has been determined to be biased low
Complete list of chemical data qualifiers included in Appendix B

Table 4a (Cont'd)

Typical Constituents in 1989 Injectate

| Units - ppm | Injectate Sampled 6/14/89 | Injectate Sampled 11/20/89 | Injectate Sampled 4/12/90 | Range (ug/l) |
|---|---|---|---|---|
| Ammonia (as Nitrogen) | NA | NA | 328 | 328 |
| Ammonia | NA | 560 | NA | 560 |
| Bromide | ND | NA | ND | ND |
| Chloride | 2790 | 1900 | 1590 | 1590-2790 |
| Nitrate (as Nitrogen) | NA | NA | NA | NA |
| Sulfate | 1790 | 14000 | 8440 | 1790-14000 |
| $CaCO_3$ Alkalinity | NA | NA | 2790 | 2790 |
| Silica | NA | NA | 9 | 9 |
| Turbidity | NA | NA | NA | NA |
| Iodide | NA | NA | NA | NA |
| TDS | NA | NA | 22100 | 22100 |
| Resistivity (77°F) | NA | NA | NA | NA |
| Carbon Dioxide | NA | NA | NA | NA |

NA = not analyzed (for)
NI = not identified, TIC
ND = analyzed for, but not detected
TIC = tentatively identified compound
* = concentration has been determined to be biased low
Complete list of chemical data qualifiers included in Appendix B

Table 4b (Cont'd)

Typical Constituents in November 1990 Injectate

| Units - ppm | Injectate Sampled 11/19/90[1] |
|---|---|
| 4,4'-Methylenebisphenol | NA |
| 2-Methylbenzofuran | NA |
| 2,3-Dimethylphenol | NA |
| 2-(1-Methylethyl)phenol | NA |
| 4-(1-Methyl-1-phenylethyl) phenol (cumyl phenol) | NA |
| 2-[1-(4-Hydroxyphenyl) 1-methylethyl] phenol (o,p-BPA) | NA |
| Bisphenol A (BPA) | NA |
| Cumene hydroperoxide | 2.6 |
| Cumene | NA |
| Formic Acid (as Formate) | 1300 |
| Aluminum | NA |
| Barium | NA |
| Calcium | 13 |
| Chromium | ND/0.02[16] |
| Iron | NA |
| Lead | NA |
| Magnesium | NA |
| Manganese | NA |
| Potassium | NA |
| Sodium | NA |

NA = not analyzed (for)
ND = analyzed for, but not detected
16 = total/hexavalent
1 = analyses performed for select group of constituents; no TIC or raw data for validation available

Complete list of chemical data qualifiers included in Appendix B

Table 4b (Cont'd)

Typical Constituents in November 1990 Injectate

| Units - ppm | Injectate Sampled 11/19/90[1] |
|---|---|
| pH | 11.1 |
| Specific Gravity | NA |
| Ammonia (as Nitrogen) | NA |
| Ammonia | 1020 |
| Bromide | NA |
| Chloride | NA |
| Nitrate (as Nitrogen) | NA |
| Sulfate | NA |
| Diphenylamine | .07 |
| Specific Conductance | 42895 umho |
| $CaCO_3$ Alkalinity | NA |
| Silica | NA |
| Turbidity | NA |
| Iodide | NA |
| Resistivity (77°F) | NA |
| Carbon Dioxide | NA |
| Total Dissolved Solids | 5.3% |
| Temperature | 37°C |
| Total Suspended Solids | ND |

NA = not analyzed (for)
ND = analyzed for, but not detected
$^{16}$ = total/hexavalent
1 = analyses performed for select group of constituents; no TIC or raw data for validation available

Complete list of chemical data qualifiers included in Appendix B

As shown in Table 4a, typical organic constituents present in 1989 injectate include phenol, acetone, acetophenone, cumyl phenol, dimethylbenzyl alcohol (DMBA), aniline, cumene, and toluene. Wastewater from BPA production is also part of the injection waste stream, although analyses of the 1989 injectate did not include BPA, (one analysis did show the presence of the isomeric o,p-BPA, however). Current injectate (based on one November, 1990 sample) contains relatively lower concentrations of phenol, acetophenone, DMBA, and toluene, although aniline and acetone exhibit relatively higher concentrations in this specific sample. Cumene and cumyl phenol were not analyzed in the November, 1990 sample. It must be emphasized that the concentrations presented in both Tables 4a and 4b are representative of individual samples collected on a specific day, and constituent concentrations likely vary from day to day. Comprehensive chemical data lists and plots are presented in Appendices L and O.

Various inorganic constituents are also present in current and 1989 injectate, including potassium, calcium, magnesium, sulfates, and chloride. Although some of these inorganic constituents are also present in formation fluids, injectate concentrations are much different than in area formation waters. According to facility representatives, Ohio River water has always been the process water for injectate. This water is fresh and has contained a range of concentrations from zero to relatively low levels of inorganic and organic constituents such as chloride, sulfate, ammonia, phenol, lead, arsenic, dichloromethane, carbon tetrachloride, 1,2-dichloroethane, and tetrachloroethane. Methylene chloride and chloroform can be present in Ohio River water in excess of the $10^{-6}$ cancer risk level. A more thorough discussion of the Ohio River chemistry is presented in Appendix P.

Limited detailed historical analytical data are available on injectate chemistry. Most of such data are for the period after 1974 for phenol and after 1981 for several other organic and inorganic species. Monthly phenol concentrations in the injectate are presented as concentration plots that are included in Appendix O and complete injectate analyses are presented in Appendix L. The concentration plots show that the average yearly phenol concentrations varied from 1371 ppm to 8607 ppm with average phenol concentration

decreasing during recent years. The concentration data for phenol in the injectate is further generalized in Figure 5, which is a plot of available average annual phenol concentrations and their standard deviations from 1974 to 1989. Most notable are the relatively high and variable phenol concentrations evident between 1978 and 1984. Based on the plotted data, the mean phenol concentration in the injectate for this period is 5800±1900 ppm. For the entire period of this record, 1974 to 1989, the mean phenol injectate concentration is 5100±2100 ppm. This latter value is used in calculations involving hypothetical mixtures of groundwater and injectate (Appendix M).

The more general composition of injectate through time is given in Tables 5a and 5b. Data for several organic and inorganic species are available beginning in 1981. Because of the relatively high phenol concentrations in injectate from 1981 to 1984 and the much lower (declining) phenol concentrations in post-1984 injectate, the data in Tables 5a and 5b have been analyzed in two ways: the 1981 to 1984 data means are presented in Table 5a, while the overall data means for 1981 to 1990 are listed in Table 5b.

Mean concentrations in the injectate based on the data in Table 5a and 5b are summarized in Table 6. Only a few values are available for certain species such as Na, Cl, $SO_4$, and formic acid.

The variability of existing data as evident from its standard deviation (SD), which is usually quite large, bringing into question the value of using mean concentrations in data evaluations. However, tentative generalizations can be drawn. Total dissolved solids (TDS), and Na, Ca, and $SO_4$ are relatively constant between 1981 and 1989. The data for Cl suggest that values may have increased through time; however, given that only four analyses are available, such a conclusion cannot be stated with confidence. Although data variability is wide, the data for phenol presented in Table 6 suggest that phenol concentrations decreased after 1984, which is consistent with the plot in Figure 5. Because the number of phenol analyses used to derive the mean values plotted in Figure 5 greatly exceed the

Table 6

Mean Concentrations of Species in the Injectate, in ppm.

| 1981-1984 | | | | 1981-1989 | | | |
|---|---|---|---|---|---|---|---|
| Species | No. of Analyses | Mean | SD | No. of Analyses | Mean | SD | Remarks |
| Na<br>Ca | 2<br>2 | 9500<br>21 | 707<br>11 | 4<br>12 | 8770<br>25 | 2590<br>11 | Inorganics probably relatively constant '81-89 |
| Cl | 2 | 905 | 375 | 4 | 1625 | 933 | " |
| $SO_4$ | 2 | 9680 | 813 | 4 | 8790 | 5100 | " |
| TDS | 6 | 18800 | 3870 | 14 | 21500 | 5850 | " |
| Acetone | 9 | 577 | 281 | 20 | 818 | 641 | Increase '84-89 |
| Acetophenone | 8 | 344 | 337 | 18 | 216 | 249 | Decrease '84-89 |
| Aniline | 7 | 123 | 126 | 16 | 90 | 90 | Decrease '84-89 |
| Formic Acid | 3 | 1010 | 79 | 7 | 1430 | 1190 | Slight increase after 1984 |
| Phenol* | 8 | 3930 | 1410 | 19 | 2580 | 1755 | Decrease '84-89 |

SD denotes one standard deviation of the mean. Mean injectate concentrations were computed from all available data for the period 1981-1989. Mean concentrations of species in the injectate samples obtained during the period 1981-1984 are also shown separately because of the relatively higher phenol concentrations during this period.

*Based on the information presented in Figure 5, the average phenol concentration from 1978-1984 was 5800±1900 ppm, and from 1974-1984 was 5100±2100 ppm. The latter value has been used in all mixing calculations (Appendix M).

number in Table 6, mean phenol concentrations based on Figure 5 data are considered the more representative. An average value of 5100±2100 ppm for phenol in the injectate is assumed in the mixing calculations (presented in Appendix M), although results of mixing studies using a phenol mean with such a high standard deviation are tentative at best.

An extensive data validation effort was undertaken to determine the validity of the chemical information used in this study. However, data records for the historic phenol data were not sufficient to allow for any data validation.

## D.2 Formation Fluid Chemistry

Very limited information is available regarding the natural composition of formation fluid underlying the Haverhill area prior to the start of injection in 1968. Available data are from DSTs conducted in WDW No. 1 in 1968, from which samples from several formations were collected, including the Mt. Simon and Rose Run. However, 1968 data are suspect because they were collected prior to implementation of QA/QC procedures, and cannot be validated.

### D.2.1 Mt. Simon Formation Fluid Chemistry

Samples of Mt. Simon Formation fluids were collected from WDW No. 1 in 1968 before injection began into the formation at Haverhill. Analyses for inorganic constituents were conducted on the 1968 samples and the results are presented in Table 7a. These data indicate that the Mt. Simon fluid originally contained high concentrations of inorganic constituents such as chloride and was considered a brine. No data are available concerning the organic constituents that may have been present within formation waters in 1968.

Samples of formation fluid extracted from the Mt. Simon during drilling of WDW No. 3 (Table 7a) show that some of the same organic compounds found in injectate are also present in the Mt. Simon waters. However, concentrations of these compounds within the Mt. Simon are dilute compared to injectate concentrations. For example, phenol is present

Table 7a (Cont'd)

Mt. Simon Formation Fluid Analyses

| Units - ppm | WDW No. 1 Mt. Simon Fluid Sampled 1968 | WDW No. 3 Mt. Simon Fluid Sampled 9/22/89 |
|---|---|---|
| Benzoic acid | NA | 21 |
| Bis(2-ethylhexyl) phthalate | NA | ND |
| 2,2'-Methylenebisphenol | NA | 35 (TIC) |
| 4,4'-Methylenebisphenol | NA | 36 (TIC) |
| 2-Methylbenzofuran | NA | NI |
| 2,3-Dimethylphenol | NA | NI |
| 2-(1-Methylethyl)phenol | NA | NI |
| 4-(1-Methyl-1-phenylethyl) phenol (cumyl phenol) | NA | NI |
| 2-[1-(4-Hydroxyphenyl) 1-methylethyl] phenol (o,p-BPA) | NA | NI |
| Bisphenol A (BPA) | NA | NI |
| Cumene | NA | 4.6 (TIC) |
| Formic Acid (as Formate) | NA | 1370 |
| Aluminum | 0.5 (NV) | 2 |
| Barium | ND (NV) | ND |
| Calcium | 50600 (NV) | 2850 |
| Chromium | NA | ND |
| Iron | 39 (NV) | 15.7 |
| Lead | NA | 0.03 |

J = estimated value
NA = not analyzed (for)
ND = analyzed for, but not detected
NI = not identified, TIC
NV = unable to validate
TIC = tentatively identified compound
* = concentration has been determined to be biased low

Complete list of chemical data qualifiers included in Appendix B

Table 7a (Cont'd)

Mt. Simon Formation Fluid Analyses

| Units - ppm | WDW No. 1 Mt. Simon Fluid Sampled 1968 | WDW No. 3 Mt. Simon Fluid Sampled 9/22/89 |
|---|---|---|
| Magnesium | 7080 (NV) | 424 |
| Manganese | NA | 0.4* |
| Potassium | NA | 421 |
| Sodium | 58300 (NV) | 14000 |
| pH | 5.5 (NV) | NA |
| Specific Gravity | 1.225 (NV) | 1.05 |
| Ammonia (as Nitrogen) | NA | 409 |
| Ammonia | NA | NA |
| Bromide | 2160 (NV) | 200 |
| Chloride | 200000 (NV) | 21200 |
| Nitrate (as Nitrogen) | NA | ND |
| Sulfate | 140 (NV) | 2490 |
| $CaCO_3$ Alkalinity | 28 (NV) | NA |
| Silica | 2 (NV) | NA |
| Turbidity (TSS) | >150 (NV) | NA |
| Iodide | 1.3 (NV) | NA |
| TDS | 316000 (NV) | 48400 |
| Resistivity (77°F) | .047 Ohm-m (NV) | NA |
| Carbon Dioxide | 240 (NV) | NA |

J - estimated value
NA - not analyzed (for)
ND - analyzed for, but not detected
NI - not identified, TIC
NV - unable to validate
TIC - tentatively identified compound
* - concentration has been determined to be biased low

Complete list of chemical data qualifiers included in Appendix B

at approximately 940 ppm in the Mt. Simon at WDW No. 3, which is approximately 360 ppm less that the 1989 injectate concentration, and is less than approximately 10 percent of the average historic injectate phenol concentration. The acetophenone concentration within WDW No. 3 Mt. Simon brine is less than 50 percent of 1989 acetophenone injectate concentration. In contrast, in 1968, chloride in the Mt. Simon exceeded 200,000 ppm, but was 21,200 ppm in the 1989 analyses.

Available data indicate that inorganic constituents originally found in the Mt. Simon 1968 analyses still occur in 1989 waters, but at much lower concentrations due to mixing with injectate. Complete Mt. Simon analyses are presented in Appendix L.

### D.2.2 Copper Ridge Fluid Chemistry

A formation fluid sample was extracted from the Copper Ridge Formation in the Test/Monitoring Well approximately 250 feet below the Rose Run Formation (Tables 7b and 7c). Analytical results show that this sample of the Copper Ridge contained phenol, BPA, DMBA, acetophenone, benzoic acid, and acetone. Concentrations of some inorganic constituents including sodium, potassium, calcium, magnesium, and ammonium in the Test/Monitoring Well-Copper Ridge sample are practically identical to concentrations of these constituents within the WDW No. 3 Rose Run sample. However, other constituents such as nitrate nitrogen, iron, lead, and manganese are quite different from WDW No. 3 Rose Run sample concentrations.

### D.2.3 Rose Run Formation Fluid Chemistry

As with the Mt. Simon, the Rose Run Formation fluid (Table 8a) was also sampled and analyzed from WDW No. 1 in 1968 and was found to contain relatively high concentrations of inorganics such as chloride. No data are available concerning organic compound occurrences in the formation at the time this well was drilled.

Table 7b (Cont'd)

Copper Ridge (Lower Knox) Formation Fluid Analyses, 1991

| Units - ppm | Test/Monitoring Well Copper Ridge Fluid Sampled 5/9/91 |
|---|---|
| Bis(2-ethylhexyl) phthalate | 0.031[4] |
| 2,2'-Methylenebisphenol | 0.130 (TIC) |
| 4,4'-Methylenebisphenol | 2.90 (TIC) |
| 2-Methylbenzofuran | NI |
| 2,3-Dimethylphenol | NI |
| 2-(1-Methylethyl)phenol | NI |
| 4-(1-Methyl-1-phenylethyl) phenol (cumyl phenol) | NI |
| 2-[1-(4-Hydroxyphenyl) 1-methylethyl] phenol (o,p-BPA) | NI |
| Bisphenol A (BPA) | 0.840 |
| Cumene | ND |
| Formic Acid (as Formate) | ND |
| Aluminum | 1.330[3] |
| Barium | 3.810 |
| Calcium | 35000 |
| Chromium | ND* |
| Iron | 409 |
| Lead | 0.581 |
| Magnesium | 6190 |
| Manganese | 6.410 |

J - estimated value
NA - not analyzed (for)
ND - analyzed for, but not detected
NI - not identified, TIC
NV - unable to validate
TIC - tentatively identified compound
* - concentration was determined to be biased low
[2] - biased high quantitative estimate
[3] - matrix interference, result invalid
[4] - value invalid due to presence of compound in field blanks and associated method

Complete list of chemical data qualifiers included in Appendix B

Table 7b (Cont'd)

Copper Ridge (Lower Knox) Formation Fluid Analyses, 1991

| Units - ppm | Test/Monitoring Well Copper Ridge Fluid Sampled 5/9/91 |
|---|---|
| Potassium | 3610 |
| Sodium | 48200 |
| pH | NA |
| Specific Gravity | 1.2 (NV) |
| Ammonia (as Nitrogen) | 73.1 |
| Ammonia | NA |
| Bromide | 2090 |
| Chloride | 208000 |
| Nitrate (as Nitrogen) | ND |
| Sulfate | 229 |
| $CaCO_3$ Alkalinity | 56.0 |
| Silica | 10.803 |
| Turbidity (TSS) | 1680 |
| Iodide | NA |
| TDS | 293000 |
| Resistivity as Specific Conductance (77°F) | 439 mmhos |
| Carbon Dioxide | NA |

J - estimated value
NA - not analyzed (for)
ND - analyzed for, but not detected
NI - not identified, TIC
NV - unable to validate
TIC - tentatively identified compound
* - concentration was determined to be biased low
2 - biased high quantitative estimate
3 - matrix interference, result invalid
4 - value invalid due to presence of compound in field blanks and associated method

Complete list of chemical data qualifiers included in Appendix B

Table 7c (Cont'd)

Comparison of Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses for Copper Ridge Test/Monitoring Well

| Units - ppm | Formation Fluid | Mud Sample | Potable Water | Method Blank |
|---|---|---|---|---|
| Benzoic acid | 4.0 | ND | ND | ND |
| 2,2'-Methylenebisphenol | 0.130 | NI | NI | NI |
| 4,4'-Methylenebisphenol | 2.90 | NI | NI | NI |
| 2-Methylbenzofuran | NI | NI | NI | NI |
| 2,3-Dimethylphenol | NI | NI | NI | NI |
| 2-(1-Methylethyl)phenol | NI | NI | NI | NI |
| 4-(1-Methyl-1-phenylethyl) phenol (cumyl phenol) | NI | NI | NI | NI |
| 2-[1-(4-Hydroxyphenyl) 1-methylethyl] phenol (o, p, BPA) | NI | NI | NI | NI |
| Bisphenol A (BPA) | 0.840 | ND | ND | ND |
| Cumene | ND | ND | ND | ND |
| Formic Acid (as Formate) | ND | NA | NA | ND |
| Aluminum | 1.330 | NA | NA | ND |
| Barium | 3.810 | NA | NA | ND |
| Calcium | 35000 | NA | NA | ND |
| Chromium | ND | NA | NA | ND |
| Iron | 409 | NA | NA | ND |
| Lead | 0.581 | NA | NA | ND |
| Magnesium | 6190 | NA | NA | ND |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Table 7c (Cont'd)

Comparison of Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses for Copper Ridge Test/Monitoring Well

| Units - ppm | Formation Fluid | Mud Sample | Potable Water | Method Blank |
|---|---|---|---|---|
| Manganese | 6.410 | NA | NA | ND |
| Potassium | 3610 | NA | NA | ND |
| Sodium | 48200 | NA | NA | ND |
| pH | NA | NA | NA | NA |
| Specific Gravity | 1.200 | NA | NA | NA |
| Ammonia (as Nitrogen) | 73.10 | NA | NA | ND |
| Ammonia | NA | NA | NA | NA |
| Bromide | 2090 | NA | NA | ND |
| Chloride | 208000 | NA | NA | ND |
| Nitrate (as Nitrogen) | ND | NA | NA | ND |
| Sulfate | 229 | NA | NA | ND |
| $CaCO_3$ Alkalinity | 56.0 | NA | NA | ND |
| Silica | 10.80 | NA | NA | ND |
| TSS | 1680 | NA | NA | NA |
| Iodide | NA | NA | NA | NA |
| TDS | 293000 | NA | NA | NA |
| Resistivity as specific conductance (77°F) | 439 mmhos | NA | NA | NA |
| (Specific Conductance) | | | | |
| Carbon Dioxide | NA | NA | NA | NA |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Table 8a (Cont'd)

Rose Run Formation Fluid Analyses

| Units - ppm | WDW No. 1 Rose Run Fluid Sampled 1968 | WDW No. 3 Rose Run Fluid Sampled 6/14/89 | Test/Monitoring Well Rose Run Fluid Sampled 4/25/91 |
|---|---|---|---|
| 2-[1-(4-Hydroxyphenyl) 1-methylethyl] phenol (o,p-BPA) | NA | NI | NA |
| Bisphenol A (BPA) | NA | NA | ND |
| Cumene | NA | ND | ND |
| Formic Acid (as Formate) | NA | 168 | ND |
| Aluminum | 0.5 (NV) | ND | ND |
| Barium | ND | 1.8 | 4.71[7] |
| Calcium | 39800 (NV) | 38500 | 37000 |
| Chromium | NA | ND* | ND* |
| Iron | 35 (NV) | 60.8 | 171 |
| Lead | NA | ND | 0.028 J |
| Magnesium | 7610 (NV) | 6070 | 7010 |
| Manganese | NA | 2.35 | 3.22 |
| Potassium | NA | 3330 | 3810 |
| Sodium | 54100 (NV) | 44600 | 25500 |

J = estimated value
NA = not analyzed (for)
NI = not identified, TIC
ND = analyzed for, but not detected
NV = unable to validate
TIC = tentatively identified compound
* = concentration has been determined to be biased low
3 = matrix interference, result invalid
4 = value invalid due to presence of compound in field blanks and associated method
5 = volatile non-detects rejected due to presence of natural gas in formation
6 = semi-volatile concentrations considered biased low quantitative estimates due to presence of natural gas in formation
7 = matrix interference, result considered biased low quantitative estimate

Complete list of chemical data qualifiers included in Appendix B

Table 8a (Cont'd)

Rose Run Formation Fluid Analyses

| Units - ppm | WDW No. 1 Rose Run Fluid Sampled 1968 | WDW No. 3 Rose Run Fluid Sampled 6/14/89 | Test/Monitoring Well Rose Run Fluid Sampled 4/25/91 |
|---|---|---|---|
| pH | 6.7 | 5.76 | NA |
| Specific Gravity | 1.199 | 1.19 | 1.215 (NV) |
| Ammonia (as Nitrogen) | NA | 80.5 | 70.0 |
| Ammonia | NA | NA | NA |
| Bromide | 1950 | 1630 | 2200 |
| Chloride | 176000 | 170000 | 218000 |
| Nitrate (as Nitrogen) | NA | 220 | 0.04 |
| Sulfate | 74 | 330 | ND |
| $CaCO_3$ Alkalinity | 60 | NA | 100 |
| Silica | 2 (NV) | NA | 7.29[3] (TSS) |
| Turbidity | >150 | NA | 1770 |
| Iodide | 1.3 | NA | NA |
| TDS | 278000 | 287000 | 309000 |
| Resistivity (77°F) | .046 ohm-m | NA | 495 mmohs |
| Carbon Dioxide | 350 | NA | NA |

J = estimated value
NA = not analyzed (for)
NI = not identified, TIC
ND = analyzed for, but not detected
NV = unable to validate
TIC = tentatively identified compound
* = concentration has been determined to be biased low
3 = matrix interference, result invalid
4 = value invalid due to presence of compound in field blanks and associated method
5 = volatile non-detects rejected due to presence of natural gas in formation
6 = semi-volatile concentrations considered biased low quantitative estimates due to presence of natural gas in formation
7 = matrix interference, result considered biased low quantitative estimate

Complete list of chemical data qualifiers included in Appendix B

Table 8b (Cont'd)

Comparison of Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses for the Rose Run, Test/Monitoring Well

| Units = ppm | Rose Run Samples | | | |
|---|---|---|---|---|
| | Formation Fluid | Mud Sample | Potable Water | Method Blank |
| Methylene Chloride | 0.014 | 0.016 | 0.015 | 0.016 |
| 4-(1-Methyl-1-phenylethyl) phenol (cumyl phenol) | NI | NI | NI | NI |
| 2-[1-(4-Hydroxphenyl) 1-methylethyl] phenol (o,p BPA) | NI | NI | NI | NI |
| Bisphenol A (BPA) | ND | ND | ND | ND |
| Cumene | ND | ND | ND | ND |
| Formic Acid (as Formate) | ND | NA | ND | ND |
| Aluminum | ND | NA | 0.316 | ND |
| Barium | 4.710 | NA | 0.0386 | ND |
| Calcium | 37000 | NA | 30.90 | ND |
| Chromium | ND | NA | ND | ND |
| Iron | 171 | NA | 0.291 | ND |
| Lead | 0.028 | NA | 0.0005 | ND |
| Magnesium | 7010 | NA | 7.700 | ND |
| Manganese | 3.22 | NA | 0.0806 | ND |
| Potassium | 3810 | NA | 2.22 | ND |
| Sodium | 25500 | NA | 10.80 | ND |
| pH | NA | NA | NA | NA |
| Specific Gravity | 1.215 | NA | 1.001 | NA |
| Ammonia (as Nitrogen) | 70 | NA | 0.07 | ND |
| Ammonia | NA | NA | NA | NA |
| Bromide | 2200 | NA | ND | ND |
| Chloride | 218000 | NA | 14.6 | ND |
| Nitrate (as Nitrogen) | 0.04 | NA | 0.49 | ND |
| Sulfate | ND | NA | 69.5 | ND |
| Alkalinity (bicarbonate) | 122 | NA | 45 | ND |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Table 8b (Cont'd)

Comparison of Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses for the Rose Run, Test/Monitoring Well

| Units = ppm | Rose Run Samples | | | |
|---|---|---|---|---|
| | Formation Fluid | Mud Sample | Potable Water | Method Blank |
| Methylene Chloride | 0.014 | 0.016 | 0.015 | 0.016 |
| Silica | 7.29 | NA | 5.48 | ND |
| TSS | 1770 | NA | ND | NA |
| Iodide | NA | NA | NA | NA |
| TDS | 309000 | NA | 180 | NA |
| Resistivity as specific conductance (mmhos) | 495 | NA | 0.291 | NA |
| Carbon Dioxide | NA | NA | NA | NA |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Test/Monitoring Well-Rose Run concentrations either higher or lower than both the WDW Nos. 1 and 3 concentrations.

Langmuir has indicated (Appendix M) that the chemical similarity of inorganic constituents in the Mt. Simon and Rose Run from WDW No. 1, (which span a total vertical depth ranging from about 4800 to 5600 feet) indicates that fluids from these two rock units at this location are either interconnected or have similar histories of evolution. However, hydrogeologic data suggest that vertical interconnection of the Mt. Simon and Rose Run is unlikely given the presence of several low permeability shale horizons separating these formations in the stratigraphic column. Langmuir has also indicated that calculated 1968 (or "clean" 1991, Appendix M), Copper Ridge Test/Monitoring Well fluids are quite similar to 1991 Test/Monitoring Well Rose Run Formation fluid chemistries. This implies either interconnection or similar evolutionary history at this location, but more likely share a similar evolutionary history.

### D.2.4 Formation Fluid Chemistry Above the Rose Run

Analytical chemistry data are included in Appendix L for formation fluid samples from rock units above the Rose Run, collected from WDW Nos. 1 and 3 and the Test/Monitoring Well between 1968 and 1991. Test/Monitoring Well Formation fluid (1991) analyses for samples collected from formations above the Rose Run are presented in Table 8c, and analyses for WDW No. 3 (1989) are presented in Table 8d. No formation fluid samples were collected from WDW No. 2 (1978).

#### D.2.4.1 Data Quality

Analyses of formation fluids collected from WDW No. 1 and WDW No. 3 are suspect. As previously stated, all 1968 fluid samples were collected and analyzed prior to implementation of currently approved data QA/QC practices and therefore cannot be validated. Also, fluid samples collected from low permeability formations in WDW No. 1 and WDW No. 3 using

Table 8c (Con't)

Test/Monitoring Well Formation Fluid Analyses Above Rose Run Formation

| Units - ppm | Beekmantown Sampled 4/18/91 | Newburg Sampled 2/7/91 | Berea Sampled 1/29/91 | Logan Sampled 1/22/91 |
|---|---|---|---|---|
| Bisphenol A (BPA) | ND | NA | NA | NA |
| Cumene | ND | ND | ND | ND |
| Formic Acid (as Formate) | ND | ND | ND | NA |
| Aluminum | 2.230 | 0.193 | 0.186 | 10.60 |
| Barium | 3.05* | 0.865[11] | 141[7] | 40.70* |
| Calcium | 38500 | 33540 | 9790 | 2670 |
| Chromium | 0.291* | 0.0217[11] | 0.0248* | 0.0471* |
| Iron | 999 | 90.40[11] | 188[7] | 52.50* |
| Lead | 0.022 J | 0.330[2] | 0.719[10] | 0.976[10] |
| Magnesium | 7430 | 7875 | 2960 | 648 |
| Manganese | 13.80 | 0.881[11] | 2.540* | 0.926* |
| Potassium | 3750 | 1243 | 260 | 89.70 |
| Sodium | 34300 | ND | 32900 | 9330 |
| pH (field) | NA | NA | NA | NA |
| Specific gravity | 1.218(NV) | 1.193(NV) | 1.095(NV) | 1.035(NV) |

J = estimated value
NA = not analyzed or TIC data not yet available (for formation fluid analyses)
ND = not detected; below reporting limit or detection limit
NI = not identified, TIC
NV = unable to validate
pH = is a field measurement; # of samples given in circle
* = concentration was determined to be biased low
2 = biased on high quantitative estimate
3 = matrix interference, result invalid
4 = calibration standards responses below QC limits, results rejected
7 = matrix interferences, result considered biased low quantitative estimate
9 = calibration standards responses below QC limits, results rejected
10 = matrix spike analyses recoveries far outside QC limits, results rejected
11 = ICP serial dilution analysis QC criteria greatly exceeded, results rejected
14 = CRQL is considered estimate

Complete list of chemical data qualifiers included in Appendix B

Table 8c (Con't)

Test/Monitoring Well Formation Fluid Analyses Above Rose Run Formation

| Units - ppm | Beekmantown Sampled 4/18/91 | Newburg Sampled 2/7/91 | Berea Sampled 1/29/91 | Logan Sampled 1/22/91 |
|---|---|---|---|---|
| Ammonia (as Nitrogen) | 56.6 | 105 | 150 | 30.8 |
| Ammonia | NA | NA | NA | NA |
| Bromide | 2260 | 1680 | 564 | 150 |
| Chloride | 251000 | 164000 | 82500 | 26200 |
| Nitrate (as Nitrogen) | ND | 0.11 | ND | 0.12 |
| Sulfate | 51.8 | 64.3 | ND | 4.95 |
| $CaCO_3$ Alkalinity | 268 | 0 | 8 | 138 |
| Silica | 17.30[3] | 1.570[11] | 5.2[10] | 36.80[10] |
| Turbidity (TSS) | 7460 | 5900 | 2680 | NA |
| Iodide | NA | NA | NA | NA |
| TDS | 313000 | 290000 | 135000 | 42500 |
| Resistivity (77°F) as specific conductance (mmohs) | 393 | 430 | 192 | NA |
| Carbon Dioxide | NA | NA | NA | NA |

J = estimated value
NA = not analyzed or TIC data not yet available (for formation fluid analyses)
ND = not detected; below reporting limit or detection limit
NI = not identified, TIC
NV = unable to validate
pH = is a field measurement; # of samples given in circle
* = concentration was determined to be biased low
2 = biased on high quantitative estimate
3 = matrix interference, result invalid
4 = calibration standards responses below QC limits, results rejected
7 = matrix interferences, result considered biased low quantitative estimate
9 = calibration standards responses below QC limits, results rejected
10 = matrix spike analyses recoveries far outside QC limits, results rejected
11 = ICP serial dilution analysis QC criteria greatly exceeded, results rejected
14 = CRQL is considered estimate

Complete list of chemical data qualifiers included in Appendix B

Table 8d (Cont'd)

WDW No. 3 Formation Analyses Above the Rose Run Formation

| Units = ppm | Niagaran Sampled 7/18/89 | Newburg Sampled 7/15/89 | Berea Sampled 4/14/89 |
|---|---|---|---|
| Bis(2-ethylhexyl) phthalate | 0.053 | 0.02 | NA |
| 2,2-Methylenebisphenol | NI | NI | NA |
| 4,4-Methylenebisphenol | NI | NI | NA |
| 2-Methybenzofuran | NI | NI | NA |
| 2,3-Dimethylphenol | NI | NI | NA |
| 2-(1-Methylethyl) phenol | NI | NI | NA |
| 4-(1-Methylethyl) phenol (cumyl phenol) | NI | NI | NA |
| 2-[(1-methy-1-pheyl) 1-methyl ethyl]phenol (o,p BPA) | NA | NI | NA |
| Bisphenol A (BPA) | NA | NA | NA |
| Cumene | NI | NA | NA |
| Formic Acid (as Formate) | ND | NA | 1100 (NVM) |
| Aluminum | 12.9 | 5.4 | NA |
| Barium | 1.1* | 1* | 9.2 (T,NV) |
| Calcium | 36400 | 38700 | 3000 (T,NV) |
| Chromium | 0.25 | 0.15 | ND (T,NV) |
| Iron | 122 | 64 | 2.7 (T,NV) |
| Lead | ND* | 0.2* | ND (T,NV) |
| Magnesium | 8970 | 9150 | 730 (T,NV) |

NA - not analyzed (for)
ND - analyzed for, but not detected
NI - not identified, TIC
NV - unable to validate
NVM - method not validated
T - total metals analysis
TIC - tentatively identified compound
* - concentration has been determined to be biased low
[13] - value below CRQL, result is quantitative estimate
Complete list of chemical data qualifiers included in Appendix B

Table 8d (Cont'd)

WDW No. 3 Formation Analyses Above the Rose Run Formation

| Units = ppm | Niagaran Sampled 7/18/89 | Newburg Sampled 7/15/89 | Berea Sampled 4/14/89 |
|---|---|---|---|
| Manganese | 2.3 | 2.9* | 0.5 (T,NV) |
| Potassium | 1210 | 1430* | 96 (T,NV) |
| Sodium | 42500 | 42700 | 9900 (T,NV) |
| pH | NA | NA | NA |
| Specific Gravity | 1.17 | 1.2 | NA |
| Ammonia (as Nitrogen) | 133 | 129 | NA |
| Ammonia | NA | NA | NA |
| Bromide | NA | NA | NA |
| Chloride | 139000 | 179000 | 29000 (NV) |
| Nitrate (as Nitrogen) | ND | ND | NA |
| Sulfate | 180 | 130 | 82 (NV) |
| $CaCO_3$ Alkalinity | NA | NA | ND (NV) |
| Silica | NA | NA | NA |
| Turbidity | NA | NA | NA |
| Iodide | NA | NA | NA |
| TDS | 277000 | 327000 | 54000 (NV) |
| Resistivity (@ 77°F) | NA | NA | NA |
| Carbon Dioxide | NA | NA | NA |

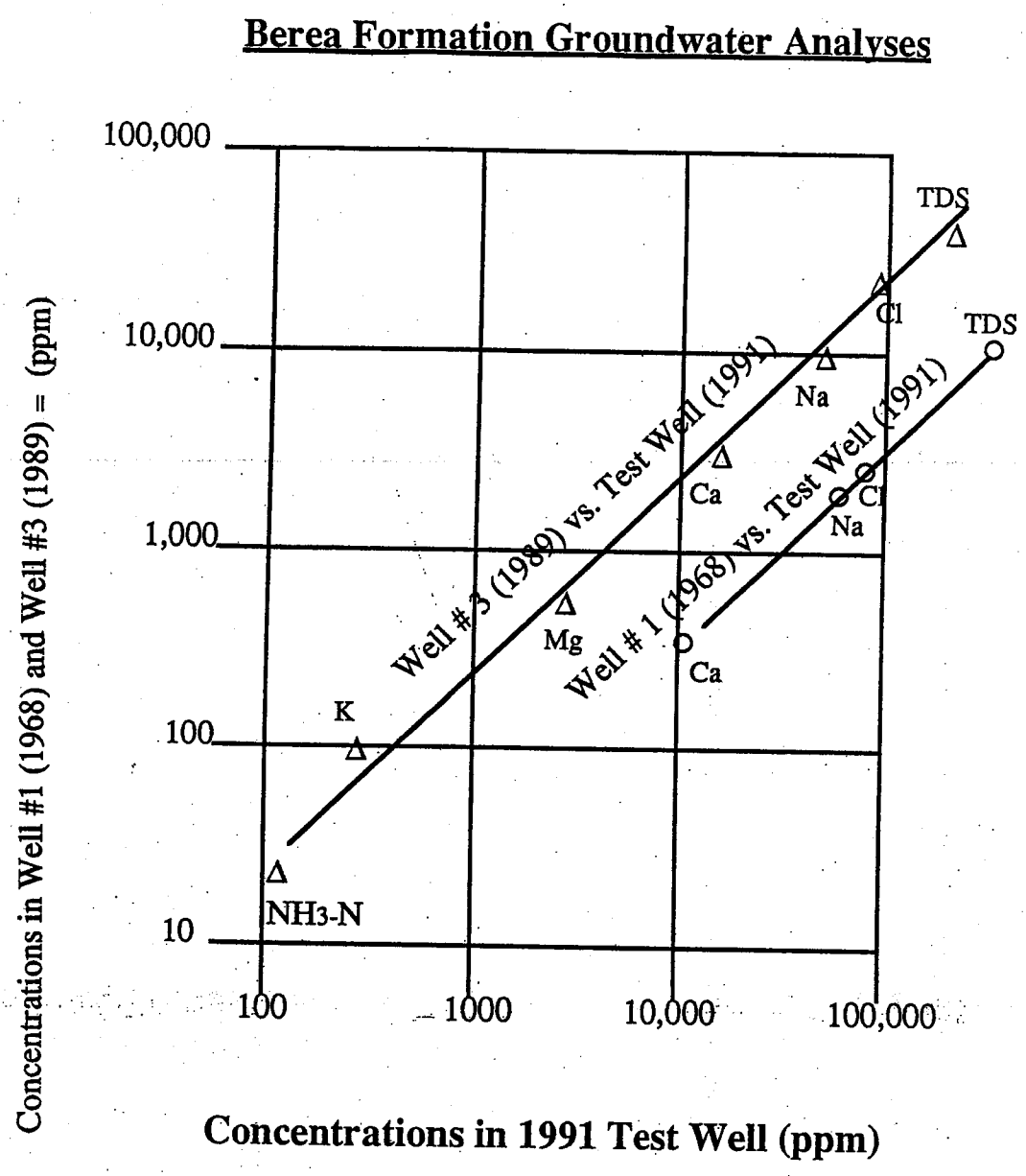
NA - not analyzed (for)
ND - analyzed for, but not detected
NI - not identified, TIC
NV - unable to validate
NVM - method not validated
T - total metals analysis
TIC - tentatively identified compound
* - concentration has been determined to be biased low
[13] - value below CRQL, result is quantitative estimate
Complete list of chemical data qualifiers included in Appendix B

DSTs or Repeat Formation Testers (RFTs) often contained drilling fluid (with little formation fluid) rather than "pure" formation fluid. For example, the Berea Formation fluid analyses reported from WDW No. 1, WDW No. 3, and the Test/Monitoring Well show very different analyte concentrations, which can be attributed to the admix of drilling fluid with extracted formation fluids in WDW No. 1 and WDW No. 3. This is best shown by comparing the concentrations of relatively unreactive major inorganic species or parameters (i.e., sodium, potassium, calcium, magnesium, chloride, nitrate, and TDS) in the WDW No. 1 (1968), WDW No. 3 (1989), and Test/Monitoring Well formation fluids (Figure 6). Assuming that the 1991 Berea Formation fluids were not diluted by drilling mud (which is supported by sample collection procedures), Figure 6 shows that the inorganic constituents in the 1968 Berea analyses have been diluted 22-fold on average relative to their concentrations in 1991 fluids. Inorganic species in 1989 Berea fluids have been diluted 2.7 fold on average relative to their concentrations in the 1991 fluids. Thus, chemistry data indicate that reported concentration differences between 1968, 1989, and 1991 Berea samples are due to admix of drilling mud in 1968 and 1989 samples.

The majority of formations above the Rose Run contain small quantities of organic constituents. These include compounds that can occur naturally (i.e., benzene), and also include typical anthropogenic compounds such as phenol and methylene chloride. Test Well analyses for the Beekmantown, Newburg, Berea, and Logan that compare formation fluid, mud, potable water, and method blank analyses (Tables 8e and 8f) show that organic constituent occurrence in these formations can be attributed to secondary contamination or naturally-occurring hydrocarbons. A more detailed discussion of this, including observed chemistries in WDW No. 3 fluids, is presented below.

### D.2.4.2 Formation Fluid Analyses

Beekmantown, Newburg (Lockport), Berea, and Logan Formation fluids were collected and analyzed in the Test/Monitoring Well (Table 8c); the Berea and Newburg were sampled in WDW No.1 and Berea, St.Peter (Beekmantown-Wells Creek), Niagaran, and Newburg




Plot shows that when 1989 vs. 1991 and 1968 vs. 1991 constituent concentrations are plotted against one another, straight-line relationships are achieved indicating similar dilution of all constituents by drilling mud.

**Figure 6. Comparison of Berea Formation Fluid Analyses for Select Inorganic Species for 1968, 1989 (WDW No. 3) and 1991 (Test/Monitoring Well) Samples**

Table 8e (Cont'd)

Comparison of Logan and Berea Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses

| Units = ppm | Logan Samples | | | | Berea Samples | | | |
|---|---|---|---|---|---|---|---|---|
| | Formation Fluid | Mud Sample | Potable Water | Method Blank | Formation Fluid | Mud Sample | Potable Water | Method Blank |
| Acetophenone | ND | NA | ND | ND | NA | NA | NA | ND |
| a,a-Dimethyl benzyl alcohol | ND | NA | ND | ND | NA | NA | NA | NA |
| Benzoic acid | ND | NA | ND | ND | ND | NA | ND | ND |
| 2,2'-Methylenebisphenol | NI | NA | NI | NI | NI | NA | NI | NI |
| 4,4'-Methylenebisphenol | NI | NA | NI | NI | NI | NA | NI | NI |
| 2-Methylbenzofuran | NI | NA | NI | NI | NI | NA | NI | NI |
| 2,3-Dimethylphenol | NI | NA | NI | NI | NI | NA | NI | NI |
| 2-(1-Methylethyl)phenol | NI | NA | NI | NI | NI | NA | NI | NI |
| 4-(1-Methyl-1-phenylethyl) phenol (cumyl phenol) | NI | NA | NI | NI | NI | NA | NI | NI |
| Bisphenol A | NA | NA | NA | NA | NA | NA | NA | ND |
| 2-[1-methyl-1-phenyl) 1-methylethyl phenol] o,p-Bisphenol A | NI | NA | NI | NI | NI | NA | NI | NI |
| Cumene | ND | NA | ND | ND | NA | NA | NA | ND |
| Formic Acid | ND | NA | NA | ND | ND | NA | NA | ND |
| Aluminum | 10.60 | NA | 0.24 | ND | 0.186 | NA | NA | ND |
| Barium | 40.70 | NA | 0.0347 | ND | 141 | NA | NA | ND |
| Calcium | 2670 | NA | 29.30 | ND | 9790 | NA | NA | ND |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Table 8e (Cont'd)

Comparison of Logan and Berea Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses

| Units = ppm | Logan Samples | | | | Berea Samples | | | |
|---|---|---|---|---|---|---|---|---|
| | Formation Fluid | Mud Sample | Potable Water | Method Blank | Formation Fluid | Mud Sample | Potable Water | Method Blank |
| Chromium | 0.0471 | NA | ND | ND | 0.0248 | NA | NA | ND |
| Iron | 52.50 | NA | 9.660 | ND | 188 | NA | NA | ND |
| Lead | 0.976 | NA | 0.0007 | ND | 0.719 | NA | NA | ND |
| Magnesium | 648 | NA | 6.340 | ND | 2960 | NA | NA | ND |
| Manganese | 0.926 | NA | 0.484 | ND | 2.540 | NA | NA | ND |
| Potassium | 89.70 | NA | 2.010 | ND | 260 | NA | NA | ND |
| Sodium | 9330 | NA | 9.270 | ND | 32900 | NA | NA | ND |
| pH | NA | NA | NA | NA | NA | NA | NA | NA |
| Specific Gravity | 1.035 | NA | NA | NA | 1.095 | NA | NA | NA |
| Ammonia (as nitrogen) | 30.8 | NA | NA | ND | 150 | NA | NA | ND |
| Ammonia | NA | NA | NA | NA | NA | NA | NA | NA |
| Bromide | 150 | NA | NA | ND | 564 | NA | NA | ND |
| Chloride | 26200 | NA | NA | ND | 82500 | NA | NA | ND |
| Nitrate (as nitrogen) | 0.12 | NA | NA | ND | ND | NA | NA | ND |
| Sulfate | 4.95 | NA | NA | ND | ND | NA | NA | ND |
| Alkalinity (bicarbonate) | 138 | NA | NA | ND | 10 | NA | NA | ND |
| Silica | 36.80 | NA | 4.420 | ND | 5.20 | NA | NA | ND |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Table 8e (Cont'd)

Comparison of Logan and Berea Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses

| Units = ppm | Logan Samples | | | | Berea Samples | | | |
|---|---|---|---|---|---|---|---|---|
| | Formation Fluid | Mud Sample | Potable Water | Method Blank | Formation Fluid | Mud Sample | Potable Water | Method Blank |
| TSS | 2780 | NA | NA | NA | 2680 | NA | NA | NA |
| Iodide | NA | NA | NA | NA | NA | NA | NA | NA |
| TDS | 42500 | NA | NA | NA | 135000 | NA | NA | NA |
| Resistivity (m-mhos) (specific Conductance) | 69 | NA | NA | NA | 192 | NA | NA | NA |
| Carbon Dioxide | NA | NA | NA | NA | NA | NA | NA | NA |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Table 8f (Cont'd)

Comparison of Newburg and Beekmantown Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses

| Units = ppm | Newburg Samples | | | | Beekmantown Samples | | | |
|---|---|---|---|---|---|---|---|---|
| | Formation Fluid | Mud Sample | Potable Water | Method Blank | Formation Fluid | Mud Sample | Potable Water | Method Blank |
| Aluminum | 0.193 | NA | NA | ND | 2.230 | NA | NA | ND |
| Barium | 0.865 | NA | NA | ND | 3.05 | NA | NA | ND |
| Calcium | 33540 | NA | NA | ND | 38500 | NA | NA | ND |
| Chromium | 0.217 | NA | NA | ND | 0.291 | NA | NA | ND |
| Iron | 90.40 | NA | NA | ND | 999 | NA | NA | ND |
| Lead | 0.330 | NA | NA | ND | 0.022 | NA | NA | ND |
| Magnesium | 7875 | NA | NA | ND | 7430 | NA | NA | ND |
| Manganese | 0.881 | NA | NA | ND | 13.80 | NA | NA | ND |
| Potassium | 1243 | NA | NA | ND | 3750 | NA | NA | ND |
| Sodium | ND | NA | NA | ND | 34300 | NA | NA | ND |
| pH | NA | NA | NA | NA | NA | NA | NA | NA |
| Specific Gravity | 1.193 | NA | NA | NA | 1.218 | NA | NA | NA |
| Ammonia (as nitrogen) | 105 | NA | NA | ND | 56.6 | NA | NA | ND |
| Ammonia | NA | NA | NA | NA | NA | NA | NA | ND |
| Bromide | 1680 | NA | NA | ND | 2260 | NA | NA | ND |
| Chloride | 164000 | NA | NA | ND | 251000 | NA | NA | ND |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Table 8f (Cont'd)

Comparison of Newburg and Beekmantown Formation Fluid, Drilling Mud, Potable Water, and Blank Analyses

| Units = ppm | Newburg Samples | | | | Beekmantown Samples | | | |
|---|---|---|---|---|---|---|---|---|
| | Formation Fluid | Mud Sample | Potable Water | Method Blank | Formation Fluid | Mud Sample | Potable Water | Method Blank |
| Nitrate (as nitrogen) | 0.11 | NA | NA | ND | ND | NA | NA | ND |
| Sulfate | 64.3 | NA | NA | ND | 51.8 | NA | NA | ND |
| Alkalinity (bicarbonate) | 29 | NA | NA | ND | 327 | NA | NA | ND |
| Silica | 1.570 | NA | NA | ND | 17.30 | NA | NA | ND |
| TSS | 5900 | NA | NA | NA | 7460 | NA | NA | NA |
| Iodide | NA | NA | NA | NA | NA | NA | NA | NA |
| TDS | 290000 | NA | NA | NA | 313000 | NA | NA | NA |
| Resistivity as specific conductance (mmhos) | 430 | NA | NA | NA | 393 | NA | NA | NA |
| Carbon Dioxide | NA | NA | NA | NA | NA | NA | NA | NA |

NA = not analyzed (for)
ND = not detected
NI = not identified, TIC
TIC = tentatively identified compound

Complete list of chemical data qualifiers included in Appendix B

Formations were sampled and analyzed from WDW No. 3 (Table 8d). A plot of major chemical species concentration variations with depth for Test/Monitoring Well samples is presented in Figure 7. (Also plotted, for comparison purposes at the bottom of the graph in Figure 7 are constituent concentrations in formations above and below the Rose Run.) The plot shows a general increase in TDS concentration from 42,500 ppm in the Logan Formation at the 164- to 262-foot depth, to 313,000 ppm in the Beekmantown at the 4010 to 4036-foot depth. Reversals in concentrations of sodium and magnesium below the Berea and Newburg down to the Beekmantown and Rose Run probably reflect natural differences in formation fluid chemistry. The reversal in constituent concentration in the Copper Ridge is likely due to the admix of injectate.

Comparisons of analyses presented in Tables 8c and 8d indicate that samples from formations above the Rose Run contained very little or no man-made organics such as phenol, acetone, and methylene chloride (i.e., Test/Monitoring Well samples). The concentration of these constituents is very low and contamination of the fluid samples from outside sources such as drilling mud and laboratories can be demonstrated (Table 8e). The Newburg and Niagaran samples from WDW No. 3 were collected from tests after the Rose Run was encountered, and Rose Run fluids (containing phenol) were allowed to circulate through the borehole for a number of weeks prior to the sampling of these overlying formations. Therefore, the occurrence of phenol in WDW No. 3 fluids collected from formations overlying the Rose Run can be attributed to contamination by Rose Run Formation fluid. The Berea in WDW No. 3 was sampled before drilling proceeded to underlying formations and therefore did not encounter circulating Rose Run fluids prior to sampling. However, this formation at WDW No. 3 shows low concentrations of acetone and phenol, as well as formic acid (Table 8d). Acetone and phenol may be due to lab/drilling mud contamination, but the occurrence of formic acid is anomalous. The value cannot be validated for a number of reasons such as incorrect reporting of analytical methods (see Appendix L for more complete discussion). However, because formic acid was not present in formation fluids from underlying strata at WDW No. 3, and was not detected in any of

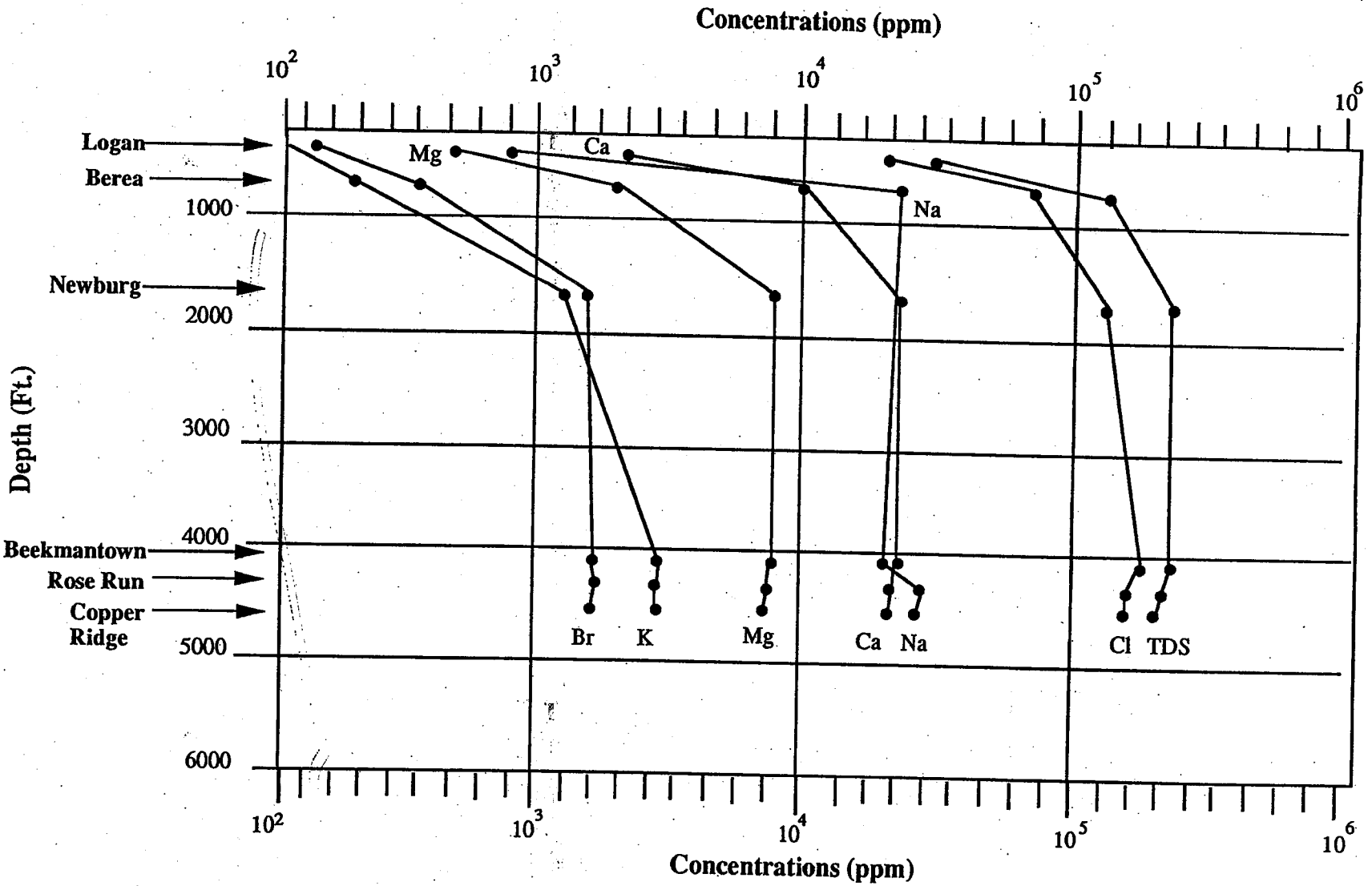



**Figure 7. Formation Fluid Inorganic Constituent Concentration vs. Depth, Test/Monitoring Well**

the test/monitoring samples, it is likely that the occurrence is unrelated to fluid migration and was somehow anonymously introduced.

Many of the formations sampled above the Rose Run contain benzene, toluene, and xylene (BTX) constituents as well as various alkenes and alkanes (Tables 8c and 8d). Additionally, many of the samples were described as having an "oily sheen" (i.e., Berea, Test/Monitoring Well). BTX constituents as well as other hydrocarbons are typical constituents of natural oil and gas, and are often found in drilling mud and potable water (Tables 8e and 8f) but do not occur in significant quantities in Aristech injectate (Table 4a). Therefore, the occurrence of these constituents in formations above the Rose Run can be attributed to natural hydrocarbons, drilling mud, or potable water.

D.2.4.3 Formation Fluid Chemistry Relative to the USDW

The deepest underground source of drinking water (USDW) in the Haverhill area is no deeper than the alluvium, which is approximately 80-90 feet below ground surface. This determination is based on analytical data collected from the Test/Monitoring Well which indicate that all bedrock units underlying Haverhill, including the Logan, exhibit TDS >10,000 ppm (Appendix L).

Through informal conversations with representatives from the ODNR, it has been determined that there are very little geochemical data for Logan Formation fluids, most of which are of questionable quality. Geophysical log calculations were therefore performed (Appendix A1) to estimate the calculated sodium chloride (NaCl) salinities for the Logan at WDW Nos. 1, 2, and 3. The calculated salinities were 25,000 ppm in WDW No. 1, 27,000 ppm in WDW No. 2, and 25,000 in WDW No. 3. This demonstrates that calculated salinities of the Logan have remained relatively consistent between 1968 and 1989. These values are not direct indicators of TDS, but it is likely that 1968, 1978, and 1989 TDS Logan values were higher than calculated salinities because NaCl salinity is part of (and therefore less than or equal to) the total TDS.

It is not possible to compare the calculated Logan salinities at WDW Nos. 1, 2, and 3 with a calculated Logan salinity in the Test/Monitoring Well because the log curves required to perform these calculations are not available in the Test/Monitoring Well. However, formation fluid analyses for the Logan at the Test/Monitoring Well showed a chloride content of 26,200 ppm, and sodium content of 9330 ppm, resulting in a sodium chloride salinity of 35,530, which is similar to the calculated log salinities for the Logan in the other wells.

In conclusion, available data support the Test/Monitoring Well analytical data which indicates that the USDW in the Haverhill area is above the Logan Formation.

D.2.5 Naturally-Occurring Organic Compounds in Formation Fluid

Natural oil and gas occur within rock units in southern Ohio, including rocks of Paleozoic age. The composition of oil and gas is highly variable and depends on such factors as source rock and thermal history of the region. However, several general families of compounds may comprise oil and gas, the most common being paraffins (both normal and branched), naphthenes (cyclopentanes and cyclohexanes) and aromatics (i.e., toluene, benzene, ethylbenzene). According to Sweeney, 1950 (Appendix A), sulfide compounds may also be present including open chain (i.e., hydrogen sulfide, aliphatic mercaptans/sulfides/disulfides and polysulfides) and ring (cyclic sulfides) structures as well as aromatic thiols/sulfides/disulfides and thiophene, thiopyrans, thionaphthene, thianthrene, and dibenzothiophene. Nitrogen-bearing compounds (such as pyridines, and quinolines) and metals such as vanadium, nickel, lead, cobalt, aluminum, and iron may also be present, although usually in low (0-.1 percent) concentrations.

Sweeney (Appendix L) states that "oxygen compounds appear to be one of the least important classes of chemicals in crude oil, on the basis of the reported work. Of the possible oxygen compounds in crude oil, naphthenic acids and phenols have been identified." Analyses for specific oxygen-bearing compounds that could be present in trace quantities in

Ohio crude oil/gas were not available in the literature examined. According to information acquired during drilling of WDW No. 3, "shows" (i.e., fluorescence, streaming cut) of natural hydrocarbons were present in the rocks below the Cuyahoga and above the Cincinnati Group. Also, relatively minor "gas effects" were detected on well logs in Cambrian rock, such as the Rose Run and Mt. Simon. No economic oil and gas reserves have been found in the Haverhill area, according to publicly available maps.

### D.2.6 Effect of Natural Formation Gas on Formation Fluids

Natural formation gas (methane) was encountered during sampling of the Rose Run in the Test/Monitoring Well. In order to address the possibility that natural formation gas could extract phenol, Aristech's research laboratory simulated this process (Appendix L).

Lacking a sample of the actual well water, a synthetic brine containing approximately 100 ppm phenol and saturated with NaCl was prepared, and cylinder methane was used to saturate the brine at 1800 psig. Analyses for phenol in the brine before and after pressurization/depressurization showed that, at most, only seven percent of the phenol was lost after three cycles. Phenol analyses were confirmed by several techniques (GC, LC, and 4-AAP-colormetric). While awaiting delivery of the methane cylinder, sparging tests were conducted at ambient pressure with brine and natural gas. The volume of purge gas was at least 2.5 times that expected to be dissolved in water at the pressure and temperature specified. In this case, at most, 12 percent of the phenol was lost. Both the pressurized cylinder and sparging tests showed that only a small fraction of phenol could have been lost during sampling of the Rose Run in the Test/Monitoring Well.

SRI supports the opinion that complete loss of phenol or other semi-volatile organics is highly unlikely via volatization or extraction by methane (Appendix L). Phenol has a low vapor pressure (.53 torr at 20°C) and high water solubility (93 g/L). The resultant Henry's constant (0.5 torr/molar terms) indicates that phenol should have remained in the fluid and not been vaporized by natural gas. SRI concluded, based on these data and the results of

Aristech's experiment, that the Test/Monitoring Well-Rose Run sample does not appear to have contained phenol or other semi-volatile constituents characteristic of Aristech Haverhill injectate.

### D.2.7 Isotope Analyses

Oxygen (18), deuterium, and direct tritium isotope analyses were performed on Beekmantown, Rose Run, and Copper Ridge Formation fluid samples from the Test/Monitoring Well (Appendix L). Analysis of the del-oxygen/deuterium data suggests that original fluids in the Beekmantown, Rose Run, and Copper Ridge were formed under the similar environments of deposition and formed either by evaporative concentration of a water similar to surface waters now present in the Haverhill area, or by the mixing of such a water with ancient sea water. No tritium was detected in the analyzed samples, indicating that the formation fluid samples contained below detection limit concentrations of post-1950 waters. Enriched tritium analyses is being performed for these samples, which has an order of magnitude lower detection limit. Results of these analyses will be available in September.

### D.2.8 Summary: Formation Fluid Chemistry

Chemical analyses to determine the presence of dissolved organic species in the formation fluids were not performed on the samples collected in 1968 (WDW No. 1). Consequently, it is unknown whether man-made organic substances were present in these formations prior to injection. However, natural hydrocarbons, albeit in non-economic concentrations, are present in rocks within the area as evidenced by trace oil and gas "shows." Man-made organic compounds were found in the 1989 Rose Run and Mt. Simon Formation fluids from WDW No. 3, as well as the Copper Ridge Formation fluid in the Test/Monitoring Well in 1991.

Organic constituents are present in formation fluids collected from units above the Rose Run. These constituents are attributed to secondary contamination by factors including

drilling mud, potable water, or laboratory contamination. The presence of naturally-occurring hydrocarbons (i.e., Berea, Test/Monitoring Well) in formations above the Rose Run can account for the occurrence of BTX constituents in these formation fluids.

## D.3 Mixing of Fluids

Chemical data indicate that the Copper Ridge at the Test/Monitoring Well, and the Rose Run at WDW No. 3 contain man-made compounds that are also found in Haverhill injectate. Calculated hypothetical mixtures of various Mt. Simon - Rose Run - Copper Ridge - injectate combinations have been used to determine theoretical concentrations that could be achieved by mixing these fluids. The data, assumptions, calculations, and conclusions for this task are included in Appendix M and are summarized below.

Inorganic constituents were used for mixing calculations because some of these are practically inert (unreactive) and should be conserved (unattenuated) when mixed. However, it must be emphasized that the significance of mixing calculations results depends upon the accuracy of the chemical analytical data used in the calculations. The 1968 WDW No. 1 analyses are questionable due to lack of supporting QA/QC documentation. The "average" injectate composition is also an assumption, based on limited data, and therefore has a wide error range (± approximately 2100 ppm for phenol, as shown in Figure 5). Additionally, analyses often exhibit poor charge balances (cations do not equal anions), bringing into question the results of the analyses. In light of these major uncertainties, the results of the mixing calculations should be considered semiquantitative at best.

The least reactive inorganic species (which, in these fluids, are sodium, chloride, and bromide) were used in calculations to compute the volume proportions involved in mixing. The mixing proportions are based on the following equation:

$$C_m V_m = C_1 V8_1 + C_2 V_2$$

where C = concentration
V = volume

The subscript "m" refers to the resultant mixtures, while subscripts "1" and "2" are the two fluids combined to produce the mixture "m".

The assumption can be made that $V_m = V_1 + V_2$, and $V_m = 1$. Given algebraic manipulation of this assumed relationship and the above equation, a second equation can be developed:

$$R_v = \frac{V_1}{V_2} = \frac{C_2 - C_m}{C_m - C_1}$$

where $R_v$ is the ratio of the volume of fluid 1, when mixed with fluid 2, that will produce "$C_m$", the observed concentration in the mixture. $R_v$s have been calculated for sodium, chloride, and bromide for various mixtures of average injectate, Mt. Simon fluids (1989 and 1968), Copper Ridge fluids (calculated 1968, and 1991), and Rose Run fluids (1968, 1989, and 1991). Results are presented in Table 9. In this table, the average $R_v$ calculated for each mixture is presented, followed by the standard deviation of that average, and the percentage of the $R_v$ value that the standard deviation represents.

In general, the most realistic mixtures are those with the lowest standard deviations as a percentage of their $R_v$ values. For example, in Table 9 it is apparent in equation No. 1 that 1989 Mt. Simon is probably the result of mixing injectate and 1968 Mt. Simon fluids because of the low percentage standard deviation value of $\pm$ 9 percent. However, the large uncertainties associated with 1968 analyses do not necessarily rule out the possibility of other mixtures. For example, in Table 9 a high percentage standard deviation is associated with mixing 1968 Rose Run fluids with average injectate to produce 1989 Rose Run fluids ($\pm$ 53 percent, equation No. 2, Table 9). This high percentage is because the chloride $R_v$ (which

## E.1 Biodegradation of Organic Constituents

The possibility of biodegradation under halophilic/anoxic conditions such as those in the Mt. Simon and Rose Run Formations is questionable. Data indicate that formation fluids are saline in the Rose Run at both WDW No. 3 and the Test/Monitoring Well, with chloride contents in excess of 170,000 ppm and 218,000 ppm, respectively. The Mt. Simon was originally saline with 200,000 ppm chloride, although mixing with injectate (discussed in a later section and in Appendix M) has lowered the chloride content to 21,200 ppm at WDW No. 3. The occurrence of reducing ions (ammonia, methane) in the WDW No. 3 Rose Run, Mt. Simon, and Copper Ridge indicates that subsurface conditions are anoxic. The presence of unaltered pyrite in the subsurface rocks also indicates that anoxic conditions are present.

Battelle Columbus conducted an extensive computer-based literature search to find studies concerning biodegradation at depths under these chemical conditions (Appendix Q). No articles, books, or any other publications were identified by Battelle or other team members. This indicates that biodegradation potential under both halophilic and anoxic conditions is poorly understood.

The existence of biodegradation was also assessed by Dr. C.H. Ward of Rice University (Appendix R). In terms of biological activity, Dr. Ward concluded that some data could be interpreted as possibly indicating the occurrence of biological anaerobic processes in the subsurface at Haverhill. For example, methylene chloride (dichloromethane) and 2-methyl-phenol (o-cresol) have been shown to be intermediates in anaerobic processes, and these compounds are present in the Rose Run at WDW No. 3 and in the Copper Ridge at the Test/Monitoring Well. Additionally, o-cresol can be an intermediate of anaerobic toluene degradation (toluene was detected in the Mt. Simon WDW No. 3 samples and in injectate, but not in the WDW No. 3 Rose Run or Test/Monitoring Well-Copper Ridge samples). If trace levels of oxygen were present, it is conceivable that o-cresol could also be the product of a toluene monooxygenase system; however, most of these systems are reported to produce p-cresol.

Dr. Ward also indicated that dichloromethane (which is present in the WDW No. 3 Rose Run Formation fluids that were sampled) has been shown to be a product of the reductive dechlorination of carbon tetrachloride and chloroform (Egli et al., 1988; Galli and McCarty, 1989). The work of Egli et al, shows this process occurring under sulfate-reducing conditions, which Dr. Ward deemed interesting considering the high sulfate concentration in the Rose Run at WDW No. 3. Neither of the parent compounds, however, were detected in the Aristech injectate. Dr. Ward indicated that several other compounds seen in samples from Mt. Simon at WDW No. 3 and in 1989 injectate (benzoic acid, phenol, acetone, aniline, toluene, and ethylbenzene) can degrade under anaerobic conditions, but there is not enough information to predict their fate in the subsurface at Haverhill. Dr. Ward also indicated that "although the physical/chemical parameters (salinity, pH-injectate, temperature, and pressure) tend to make this an inhospitable environment, all values (of environmental parameters for biological activity) are well within known limits....As new environments are explored, such as the deep sea hydrothermal vents where bacterial growth is known to occur at 250°C and 265 atm....(the) hypothesis that life can exist wherever there is liquid water appears more and more reasonable." In summary, Dr. Ward concluded that although biodegradation could conceivably occur, it is neither probable nor pervasive because the expected environment would greatly inhibit the process.

## E.2 Other Transformation/Attenuation and Transport Processes

Transformation, attenuation, and transport processes such as sorption, hydrolysis, oxidation, volatilization, and dissolution/mineral precipitation and adsorption could occur at ground surface, and may also occur in the subsurface. While some of these processes certainly occur, the extent to which they influence constituent distributions is also dependent upon subsurface conditions, as discussed below.

E.2.1 Sorption of Organic Compounds

Preferential sorption of compounds as they migrate laterally and vertically could influence the contaminant distribution in the subsurface. For example, preferential adsorption of compounds within rock layers could occur, but is dependent upon the partitioning behavior of the compound (Table 10). Data indicate that the extensive sorption of constituents in Aristech injectate will not occur, the reasoning for which is discussed below.

Sorption is a general term for the removal of a chemical constituent from the water phase into or onto a solid phase (material). In this case, there are three kinds of sorption processes: non-specific adsorption to mineral surfaces, specific partitioning between the water and any organic material on the rock ($K_{oc}$), and ion exchange onto cationic sites in clays. Non-specific sorption is the least likely to affect these compounds because of their high to moderate solubilities. The log $K_{ow}$ (octanol-water partition coefficient) and log $K_{oc}$ (organic carbon partition coefficient) both describe or allude to an organic material's propensity to partition to organic material within the system. The relationship between $K_{ow}$ and $K_{oc}$ is described by:

$$\text{Log } K_{oc} = 0.63\ K_{ow}$$
$$\text{Log } K_{oc} = \text{Log } K_{ow} - .21$$
$$\text{Log } K_{ow} - .21 = 0.63\ K_{ow}$$

Thus, values of $K_{oc}$ are about half of those for $K_{ow}$. Sorption slows or retards the movement of the organics relative to water and inorganic species such as sodium and chloride ions. The retardation factor, R, (Table 10) describes retention of a compound with 1 = no retention. R has been calculated using the following relationship:

$$R = 1 + \frac{\rho b}{n} K_{oc}\, OC$$ where:

## Table 10

### Physical Properties of Selected Chemicals (20-25°C)

| Compound | Water Solubility mg/L | Vapor Pressure Torr | log $K_{ow}$ | log $K_{oc}$[g] | $R_{0.1\%}$[i] | $H_c$[j] torr/M |
|---|---|---|---|---|---|---|
| Acetone | 1 X 10[6k] | 228[d] | -0.24[e] | -0.15 | 1.01 | 13 |
| Acetophenone | 5100[h] | 0.3[f] | 1.83[g] | 1.15 | 1.14 | 7.0 |
| Aniline | 36,600[a] | 0.6[d] | 0.84[d] | 0.53 | 1.03 | 1.5 |
| Benzene | 1780[a] | 95[d] | 2.12[c] | 1.34 | 1.22 | 4200 |
| Benzoic Acid | 2700[c] | <1[f] | 1.87[c] | 1.18 | 1.15 | <45 |
| a,a-Dimethylbenzyl Alcohol | 5000[h] | 1[f] | 1.88[e] | 1.18 | 1.15 | 30 |
| 2,3-Dimethylphenol | 1200[h] | 0.26[d] | 2.36 | 1.49 | 1.31 | 25 |
| Ethylbenzene | 152[b] | 10[d] | 3.15[e] | 1.98 | 1.95 | 7000 |
| Formic Acid | 5 X 10[5k] | 40[d] | -0.54[e] | -0.34 | 1.00 | ~2 |
| Phenol | 82,000[a] | 0.5[d] | 1.46[e] | 0.92 | 1.08 | 0.50 |
| alpha-Picoline | ~1 X 10[6k] | 10[f] | 1.06[e] | 0.67 | 1.05 | ~2 |
| Toluene | 1500 | 25[d] | 2.69[c] | 1.69 | 1.49 | 1500 |

[a] Kenaga, E.E., Ecotox. & Envi. Safety, 4:26-38 (1980).
[b] Thibodeaux, L.J., "Chemodynamics," John Wiley, New York (1979).
[c] Chiou, et al., Envi. Sci. and Tech., 11;425-478 (1977).
[d] Stull, D.R. Ind. Eng. Chem. 39:517-550 (1947)
[e] Leo, A.C. Hansch, and D. Elkins, Chem. Reviews, 71:525-616 (1971).
[f] Handbook of Chemistry and Physics, CRC Publishing, Boca Raton, FL, 5th Ed. (1976).
[g] Calculated from $K_{oc} = 0.63K_{ow}$. Karckhoff, S.W., D.S. Brown, and T.A. Scott, Water Research 13:241-248 (1979).
[h] Calculated from log (1/S) = 1.214 log $K_{ow}$ - 0.850, Lyman, N.J., Riehl, W.F., and D.H. Rosenblatt, "Handbook of Chemical Property Estimation Methods," McGraw-Hill, 1982, pp. 2-15.
[i] Estimation of maximum retention for 0.1% organic carbon.
[j] Values calculated from $H_c$ = P(torr)/Solubility (Moles/L).
[k] Estimated from S = 1/8 0.018L $Mol^{-1}$, See McKay, D., and W.Y. Shiu, J. Phys. Chem. Ref. Data 10:1175-1205 (1981).

$\rho b$ = bulk density (assumed - 2 g/ml)
n = porosity (assume n = .2)
Koc = organic carbon partition coefficient
OC = fraction of organic carbon in formation

Using the above equation, retardation factors were calculated and are presented in Table 10. An organic carbon content of 0.1 percent has been assumed. This calculation assumes that aqueous organics are in equilibrium with the natural organic matter in the mineral, a reasonable assumption given the slow rate of movement of the aquifer waters. However, enhanced migration caused by cosolvent effects (e.g., acetone which would lead to R ± 1.00), have not been included here. Any cosolvent effect would be important only for toluene and ethylbenzene which have R values much greater than 1.

Evaluation of these data indicate that, for the most part, compounds present within the injectate, Mt. Simon, Rose Run at WDW No. 3, and Copper Ridge will usually exhibit low $K_{oc}$ values. Also, geologic information indicates that there is little naturally occurring organic material within the rock column, particularly between the Mt. Simon and Rose Run. Therefore, major sorptive attenuation of compounds such as acetone, phenol, and benzene due to this mechanism will not occur, although attenuation of some compounds, such as phenol, may occur relative to other compounds with a lower $K_{oc}$, such as acetone.

Ion exchange as a sorptive mechanism has also been assessed. Geologic data indicate that clays are present in many of the rock units, including the Mt. Simon. Ion exchange of cations to clays such as illites could be an important attenuation process for amines such as picoline; aniline is less susceptible to ion exchange, but could be affected to a minor degree by this process. Inorganics such as ammonium, however, could be sorbed to clays by this process. In summary, data indicate that extensive sorption of organics will likely not occur, although sorption of constituents such as ammonia may occur due to ion exchange.

### E.2.2 Hydrolysis and Oxidation

Both hydrolysis and oxidation can significantly alter compounds. However, none of the major compounds found in these formation fluids are susceptible to hydrolysis under conditions present in the formations. Moreover, natural subsurface conditions are most likely anoxic. Therefore, oxidation is not considered a significant transformation mechanism.

### E.2.3 Vapor Phase Transport

Not only can organic compounds exist in the dissolved phase in liquids, a certain amount can also exist as a vapor phase (in equilibrium with the liquid phase). This is significant because a separate movement of compounds in the vapor phase can occur independent from the dissolved phase.

The volatility of compounds listed in Table 9 is proportional to their Henry's Law Constants, $H_c$, listed in the last column. Benzene, toluene, and ethylbenzene are by far the most volatile compounds listed in Table 10 and are most likely to partition to the vapor phase as well as to any organic matter. Dr. Mason Tomson, Rice University, has indicated that a mechanism which would allow for this phase transfer through 1000 feet of fluid-filled rock was not present in any of the evaluated scenarios.

In summary, while vapor phase transport of the particular organic compounds of interest in the Aristech situation could possibly occur to a limited extent, it probably could not transport large quantities of organic materials.

### E.2.4 Dissolution/Precipitation of Inorganic Constituents

Fresh water from the Ohio River with relatively low inorganic constituent concentrations (Appendix P) was used as make-up water for the injectate, which resulted in low inorganic concentrations in both the 1989 and current injectate (i.e., chloride). WDW No. 3 Mt.

Simon waters also have low TDS concentrations, indicating that substantial admix of formation and injectate water has occurred. If injectate entered the Rose Run or Copper Ridge, reduction of inorganic constituent concentrations would therefore also be expected. However, the inorganic chemistry of the Rose Run Formation at WDW No. 3 and Copper Ridge at the Test/Monitoring Well indicates that these waters are still quite saline/inorganic constituent-rich and that little admix with fresher water has occurred. It is possible that this is because surrounding rock has added cations and ions to formation fluids (through rock dissolution), essentially "masking" any dilution of inorganic constituent concentrations due to injectate.

Although rocks below Haverhill contain calcium and magnesium, (which are present in the Rose Run in relatively large quantities), acidic waters would be required to dissolve limestones and dolomites, and release calcium, magnesium, and carbonate. Since injectate is not alkaline, dissolution of subsurface rocks by injectate is unlikely. The addition of enough chloride to increase salinity of fresh water to the over 170,000 ppm chloride content in many subsurface formation fluids would require that fluids encounter a salt-bearing interval from which salts could be dissolved. Nowhere in the geologic history or core record is there any indication that salt beds are present that could provide the necessary inorganic constituents. Therefore, major dissolution of rock units by injectate has probably not occurred, and in fact, mineral precipitation upon mixing of injectate and natural formation fluids is more likely.

Computer calculations show that both 1968 (pre-injectate) and 1989 (post-injectate) Mt. Simon and Rose Run formation fluids are at saturation with calcite and gypsum/anhydrite (Appendix M). Mixing of 10 percent 1968 Mt. Simon fluids with 90 percent injectate likely created 1989 Mt. Simon fluids (Table 9); calculations indicate that this mixing has probably not caused significant calcite precipitation, but could have precipitated 10.3 grams of gypsum or 8.2 grams anhydrite from every liter of injectate-Mt. Simon mixture (Appendix M). The precipitation of gypsum or anhydrite in the subsurface due to injectate-formation fluid mixing could lead to minor plugging of smaller pore spaces.

## F. Subsurface Formation Pressures

As stated in previous sections, many formations were sampled during installation of WDW Nos. 1, 2, 3 and the Test/Monitoring Well. Along with extraction of formation fluid samples, tests were performed which revealed the in-situ formation pressures that were used to interpret relative fluid flow in Section IV. Formation pressure data are summarized below.

### F.1 Historic Sampling/Testing and Calculation Methodologies

Pressure measurements have been taken in many of the formations penetrated by Aristech deep wells, from the drilling and completion of WDW No. 1 in 1968 to the recent drilling of the Test/Monitoring Well completed in 1991. Generally, the data from the 1968 testing are of a more limited nature and are subject to some accuracy limitations. This is because technology that is now over 20 years old was used to collect 1968 pressure data, and the 1968 data were collected under much less stringent QA/QC procedures when compared to the more critically designed/reviewed testing conducted in 1989 and 1991.

Calculations made using the data are based on hydrostatics; pressure values taken at differing locations and depths were compared by correcting the values to the same elevation or datum depth. This correction was made by adding or subtracting the hydrostatic pressure of a column of fluid, which is equivalent to the difference between the depth at which a pressure was measured and the desired datum depth. Inferences regarding pressure changes can be made by comparing corrected pressure values from the 1968 tests to the newer corrected pressure values from the more recent 1989 and 1991 tests.

#### F.1.1 WDW No. 1

During the drilling and completion of WDW No. 1 in 1968, five DSTs were conducted. The formations tested were the Berea, Newburg, Rose Run, Mt. Simon, and Lower Mt. Simon (Table 2). The Berea test did not obtain a representative pressure because drilling mud

plugged the sampling tool. The first Mt. Simon test provided good data, but the lower Mt. Simon test was not useful due to very low formation permeability. Test data are summarized in Table 11.

F.1.2 WDW No. 2

No DST data were collected during the drilling and completion of WDW No. 2.

F.1.3 WDW No. 3

Five DSTs were conducted during the drilling and completion of WDW No. 3 in 1989. The formations tested were the Berea, Niagaran, Newburg, Rose Run, and Mt. Simon (Table 3a). The Berea test did not obtain an accurate pressure due to plugging of the tool and low formation permeability. Plugging also affected the data collected in the Niagaran and Newburg. Rose Run testing was successful, as was the first Mt. Simon test. Test data are summarized in Table 11.

F.1.4 Test/Monitoring Well

Six DSTs were conducted during the drilling and completion of the Test/Monitoring Well in 1991. The formations were the Logan, Berea, Newburg, Beekmantown, Rose Run, and Copper Ridge; all tests were successful (Table 3b). Test data are summarized in Table 11.

Table 12 summarizes the pressures and apparent pressure rises observed at the Aristech wells in the Rose Run and Copper Ridge. Pressure differences between the Rose Run and Copper Ridge at the Test/Monitoring Well and the same formations at the other wells is relatively small when compared to the pressure rises evident in the Mt. Simon injection interval between WDW Nos. 1 and 3.

## Table 11

Summary of Formation Pressure Data

| Formation | Well | Date | Interval (ft KB) | Gauge Depth (ft KB) | P* (psi) | Note | Brine density ($g/cm^3$) |
|---|---|---|---|---|---|---|---|
| Logan | Test | 1/21/91 | 164.2-261.5 | 157.7 | 63.7 | - | 1.033 |
| Berea | Test<br>No. 3<br>No. 1 | 1/29/91<br>4/13/89<br>5/14/68 | 679.2-734<br>701-751<br>712-733 | 672.7<br>710<br>- | 324<br>333.3[1] | -<br>Low Perm/Plugged<br>Plugged | 1,095<br>1.03<br>1.005[1] |
| Niagaran | No. 3 | - | - | - | - | - | 1.17 |
| Newburg | Test<br>No. 3<br>No. 1 | 3/91<br>-<br>5/16/68 | 1757.4-1790.7<br>-<br>1795-1835 | 1750.9<br>-<br>1805 | 837.7<br>-<br>859 | -<br>-<br>Not P*, Plugging | 1.097<br>1.2<br>1.193 |
| Beekmantown (Upper Knox) | Test | 4/20/91 | 4009.5-4035.5 | 3995.5 | 1805.7 | - | 1.218 |
| Rose Run (Knox) | Test<br>No. 3<br>No. 1 | 4/25/91<br>5/15/89<br>5/26/68 | 4181-4225<br>4503-4588<br>4220-4265 | 4170.0<br>4572.0[3]<br>4230.0 | 1912.2<br>1968.8<br>1895.6[1] | -<br>Deviated Well<br>- | 1.214<br>1.19<br>1.199 |
| Copper Ridge (Lower Knox) | Test | 5/8/91 | 4446.7-4480 | 4440.2 | 2078.2 | - | 1.20 |
| Mt. Simon | No. 3<br>No. 1 | 9/25/89<br>6/5/91 | 5978-6109<br>5520-5565 | 5965[3]<br>5545 | 2645.9<br>2633 | Deviated Well<br>- | 1.05[2]<br>1.225 |
| Lower Mt. Simon | No. 1 | 6/6/91 | 5575-5617 | 5613 | - | No Perm. | - |

[1] = not representative value; insufficient sample/shut-in time
[2] = fluid sample primarily injectate
*P = extrapolated reservoir pressure
[3] = values reported as measured depths

## Table 12

Copper Ridge and Rose Run Formation Pressures

| Formation | Well | Date | KB | TVD Depth (ft) RKB | BSL | P* (psi) | P* at Datum (psi) | Apparent ΔP (psi) |
|---|---|---|---|---|---|---|---|---|
| Rose Run | Test<br>No. 3<br>No. 1 | 4/25/91<br>5/15/89<br>5/26/68 | 545<br>560<br>557 | 4170<br>4266[1]<br>4230 | -3625<br>-3706<br>-3673 | 1912.8<br>1968.8<br>1934.4 | 1937.1<br>1951.7<br>1937.4 | 2.7<br>17.3<br>0 |
| Copper Ridge | Test<br>Estimated Original | 5/8/91<br>- | 545<br>- | 4440.2<br>- | -3895.2<br>-3895.2 | 2078.2<br>- | 2078.2<br>2050-2063 | 15-28<br>0 |

*P = extrapolated reservoir pressure
TVD = True vertical depth
[1] = TVD based on data from TVD log (Appendix CC)

F.1.5 In-Situ Stress Testing

During the period May 30, 1991 through June 5, 1991, 28 in-situ stress tests were conducted from the Rome Formation [approximately 5390' below ground surface (BGL)] upsection to the Black River Formation (approximately 3550 feet BGL) in the Test/Monitoring Well (Table 13). As discussed in the Protocol for this testing issued January 9, 1991, (Appendix S1), the purpose of these measurements was to determine the capability of the geologic column overlying the Mt. Simon and Rose Run Formations to contain fractures potentially induced by injection fluid pressure and well stimulations.

In-situ stress measurements are controlled injection tests in which an isolated portion of a formation is hydraulically fractured. The process is often referred to as a "mini-frac" test because of the relatively short test duration and the small volumes of fluid typically used. A straddle packer assembly and a down-hole shut-in tool are used with high resolution pressure gauges to collect data to determine formation fracture initiation pressures, fracture extension pressures, fracture opening pressures, fracture closure pressures, and estimates of formation pore pressures.

G. Fluid Flow Modeling

REC maintains a model called "Injection Forecast" to assess fluid movement within deep-well disposal systems. This program is a set of mathematical models specifically created to predict injectate/fluid transport in subsurface disposal formations throughout the country and is an analytical (rather than numerical) simulator. The REC model is an accepted standard model within the injection well industry.

Although this model places some limits on the configurations that can be used to model physical injection systems, the advantages inherent in analytical solutions (such as the accurate treatment of large rock property contrasts and a lack of sensitivity to numerical solution methods) made this simulator an appropriate tool for this assessment. Appendix

# TABLE 13
## Aristech Chemical Corporation
## Test/Monitoring Well
## IN-SITU STRESS TEST INTERVALS

| Date | Test No. | Tool Spacing | Depth to M.P.P.* | Formation | Pump-in Rate, GPM | Packer Inflation Pressure |
|---|---|---|---|---|---|---|
| 5/31/91 | 1 | 4 | 5388 | Rome | 2.1 - 4+ | 1000 |
| 5/31/91 | 2 | 4 | 5375 | Rome | 2.3 | 850 |
| 5/31/91 | 3 | 4 | 5362 | Rome | 2.3 | 750 |
| 5/31/91 | 4 | 4 | 5317 | Rome | 2.3 | 500 |
| 6/1/91 | 5 | 4 | 5243 | Rome | 2.3 | 650 |
| 6/1/91 | 6 | 4 | 5200 | Rome | 2.4 | 900 |
| 6/1/91 | 7 | 4 | 5176 | Conasauga | 2.4 | 775 |
| 6/1/91 | 8 | 4 | 5119 | Conasauga | 2.3 | 650 |
| 6/1/91 | 9 | 4 | 5070 | Conasauga | 2.5 | 850 |
| 6/1/91 | 10 | 4 | 4977 | Beekmantown | 2.4 | 750 |
| 6/2/91 | 11 | 4 | 4823 | Beekmantown | 2.4 | 520 |
| 6/2/91 | 12 | 4 | 4474 | Beekmantown | 2.4 | 700 |
| 6/2/91 | 13 | 4 | 4257 | Beekmantown | 2.3 | 745 |
| 6/2/91 | 14 | 4 | 4212 | Rose Run | 2.3 | 400 |
| 6/3/91 | 15 | 4 | 4196 | Rose Run | 2.3 | 675 |
| 6/3/91 | 16 | 4 | 4188 | Rose Run | 2.4 | 640 |
| 6/3/91 | 17 | 4 | 4176 | Copper Ridge | 2.4 | 675 |
| 6/3/91 | 18 | 4 | 4162 | Copper Ridge | 2.3 | 660 |
| 6/3/91 | 19 | 4 | 4142 | Copper Ridge | 2.5 | 520 |
| 6/3/91 | 20 | 4 | 4123 | Copper Ridge | 2.5 | 670 |
| 6/3/91 | 21 | 4 | 3972 | Copper Ridge | 2.5 | 520 |
| 6/3/91 | 22 | 4 | 3902 | Wells Creek | 2.4 | 670 |
| 6/3/91 | 23 | 4 | 3782 | Black River | 2.5 | 520 |
| 6/3/91 | 24 | 4 | 3550 | Black River | 2.4 | 465 |
| 6/4/91 | 25 | 4 | 5381 | Rome | 2.3 | 595 |
| 6/4/91 | 26 | 10 | 5147 | Conasauga | 7.0 | 630 |
| 6/4/91 | 27 | 10 | 4628 | Beekmantown | 6.9 | 580 |
| 6/4/91 | 28 | 10 | 4055 | Copper Ridge | 7.0 | 680 |

* Mid Point Packers

S2 includes a more comprehensive discussion of the mathematics and approach involved in the modeling system that was utilized to calculate fluid transport and pressures in these investigations.

Prior to using the Injection Forecast model for the investigation of fluid movement at the Haverhill area, site-specific parameters (input variables) that describe the Mt. Simon and Rose Run rock conditions at Haverhill were assigned from various tests and available records. This input was then used with the appropriate sub-models (chosen using site-specific criteria) to develop predictions for several different fluid movement scenarios, which are discussed in Section IV of this report. Effective parameters used in modeling the Rose Run Formation were:

Rose Run:

$k = 22.7$ md
$\phi = 0.112$
$h = 15$ feet
$\mu = 0.69$ cp
$c_T = 5.5 \times 10^{-6} psi^{-1}$

As previously stated, approximately 1120 million gallons of injectate were added to the Mt. Simon from 1968 until 1989 through WDW Nos. 1 and 2. REC has modeled the lateral movement of the 50 percent concentration injectate front which has resulted from injection into WDW Nos. 1 and 2 to estimate the lateral movement of injectate in the Mt. Simon through time (Figure 8). This front is defined as the location of the 50 percent injectate-50 percent formation water mixture boundary. REC calculates that the 50 percent concentration front for 1968 injectate has migrated over 5000 feet outward from WDW No. 1, and reached the portion of the Mt. Simon that occurs below the WDW No. 3 Rose Run intercept sometime in the mid-1970s.

Fluid transport and pressure rise modeling was also conducted to investigate scenarios which involve injectate entering the Copper Ridge Formation. Parameters used in this modeling included:

# MT. SIMON INJECTATE FRONT PROJECTIONS
## Aristech Chemical Corporation
## Haverhill, Ohio

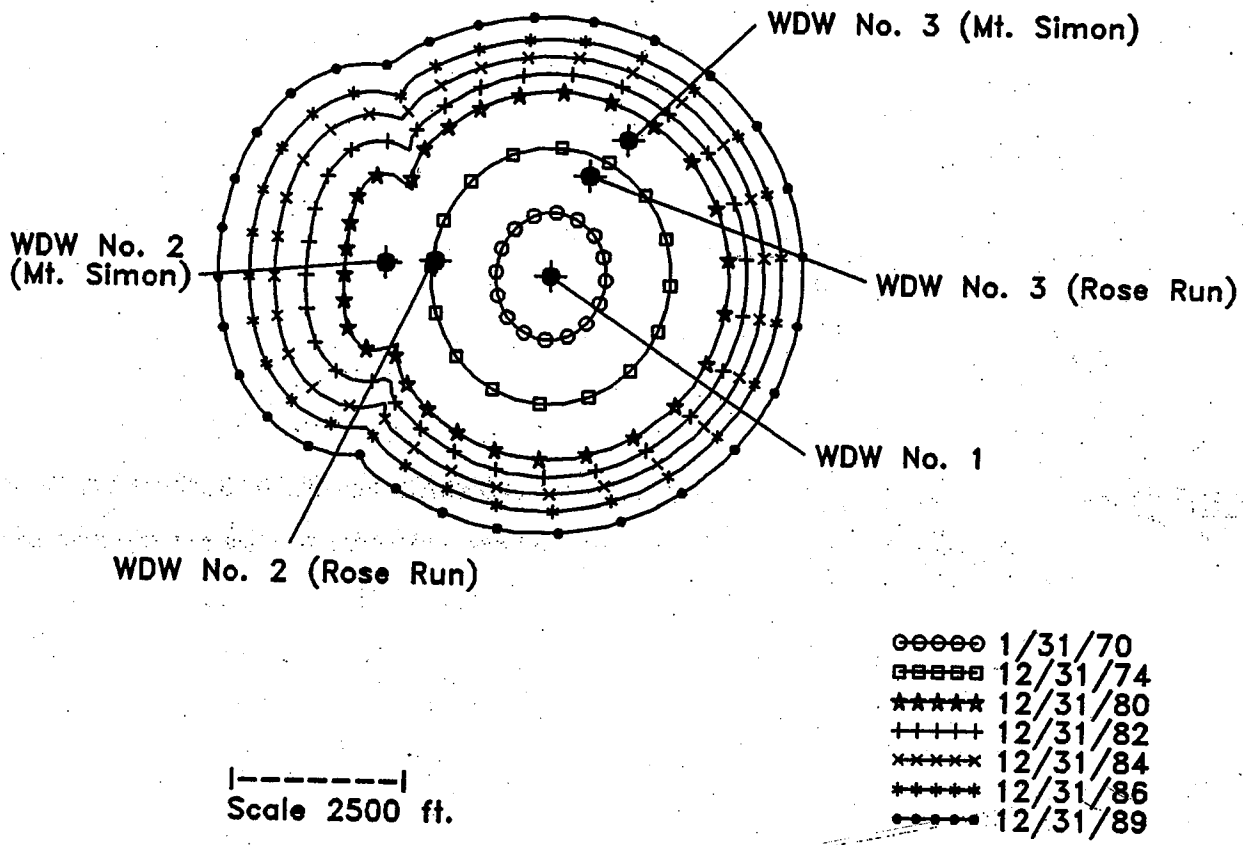



Figure 8. Location of the 50 Percent Injectate Front Movement Through Time in the Mt. Simon Formation.

$k = 135$ md
$\phi = 2$ to 5%
$h = 2$ to 40 feet
$\mu = 0.75$ md
$c_T = 5 \times 10^{-6} psi^{-1}$

These Copper Ridge data are based on log analysis, core analysis, DST data, and standard correlations (for compressibility and viscosity).

However, exceptionally high leak rates are generally required for this to occur, as well as over 20 percent of the injectate exiting the borehole through the casing hole or breach. If a lower leak rate is assumed, then the required pressure rise at the WDW No. 3 intercept is much higher than the observed pressure change.

The pressure build-up in the Rose Run Test/Monitoring Well is approximately 3 psi (compared to 17.5 ± 17 psi in the Rose Run at WDW No. 3). However, the Test/Monitoring Well-Rose Run intercept is approximately 960 feet from WDW No. 1, while the WDW No. 3 intercept is approximately 1340 feet from WDW No. 1. This pressure relationship is opposite of that expected even for a highly anisotropic system because higher pressure buildup would occur nearer the leak source at the Test/Monitoring Well, rather than at or near WDW No. 3 (assuming the leak source is at or near WDW Nos. 1 or 2).

In summary, modeling of pressure and fluid transport based on data collected from the cores, logs, and DSTs indicates that fluid could reach WDW No. 3 through a casing breach in WDW No. 1 or 2, but only under unrealistic leak rates and dispersivities, and unsupported assumptions about Rose Run heterogeneity.

### C.1.3 Geologic and Hydrogeologic Investigation Results

For Scenario 1 to be realistic, not only would injectate have to enter the Rose Run through a casing breach at a very specific location, but the Rose Run would also have to be extensively compartmentalized so that fluid and pressure effects would specifically reach WDW No. 3, bypassing the Test/Monitoring Well. Geologic information does not support compartmentalization of the Rose Run to such a degree that this would occur.

Well log and core analyses indicate that the Rose Run is a near shore to peritidal sandstone, which has been identified as tidal channel deposits (Appendix A2). Development of overlapping sand packages may occur as channels migrate laterally or as sands are reworked along a shoreline. Geophysical logs indicate that sand packages in WDW No. 1 directly

correlate with sandstone intervals at the Test/Monitoring Well, with no indication that a major facies change occurred between the two locations. This indicates that there is not such a major lithological change between WDW No. 1 and the Test/Monitoring Well that complete hydrologic isolation of the two locations would occur. Available cores indicate that the Rose Run is comprised almost exclusively of siliciclastic (quartz and feldspar) sand, with varying degrees of cementation and packing (see Appendix A2 for complete discussion). Core data also indicate that above this sandstone interval within the Rose Run, a silicified carbonate clastic unit is present. While this unit is significantly different than the underlying sandstone in terms of depositional environment, secondary alteration, and rock characteristics, the unit is not laterally or vertically pervasive enough to impact the "interconnectedness" of the Rose Run sandstones, particularly between WDW No. 1 and the Test/Monitoring Well.

In summary, although some lithologic and depositional differences occur within the Rose Run, these differences are not pronounced enough to result in complete compartmentalization of the Rose Run to such a degree that injectate would flow from WDW No. 1 or 2 to WDW No. 3, but completely bypass the Test/Monitoring Well. It must be pointed out that the Test/Monitoring Well is located between WDW No. 1 and WDW No. 3, and WDW No. 1 is approximately 350 feet closer to the Test/Monitoring Well than it is to WDW No. 3 (Figure 2).

It is also possible that one large short-term leak could have taken place with no continued leakage. However, hydrogeologic information does not indicate that natural flow gradients could naturally more a slug of fluid in the Rose Run from WDW No. 1 or 2 to the WDW No. 3 location (Figure 2) within the appropriate timeframe. The natural (non-injection related) groundwater flow velocity is probably less than two feet/year and the possible flow direction is to the north or west. Therefore, it would require 700 years to move fluid approximately 1400 feet from WDW No. 1 to WDW No. 3. Additionally, if the natural gradient is similar to that of the Mt. Simon, fluid would flow away from WDW No. 3, rather than toward WDW No. 3, from WDW Nos. 1 or 2. Without an induced pressure gradient,

it is highly unlikely that fluid could naturally migrate to WDW No. 3 over the lifetime of these wells.

### C.1.4 Process Chemistry and Formation Fluid Chemistry Study Results

As stated above, injectate contains constituents such as phenol, which can be corrosive and could have led to a tubing leak. Also, injectate chemistry was substantially altered in the early 1980s with the addition of aniline and BPA and reduction of acetone in the injectate (due to addition of the stripper). The injection wells began to plug (Appendix N) with calcium sulfate, calcium carbonate, and organic materials at this time, which was temporarily remedied through nitrogen jetting. Therefore, it is possible that if a casing breach occurred prior to the process chemistry change, the alteration of injectate chemistry during the early 1980s and resulting precipitation of material downhole could have sealed a hole(s) or casing breach. However, it is highly unlikely that constituent precipitation could have been rapid or pervasive enough to plug an ongoing leak, particularly of the rate/ volume required to make this scenario plausible. Therefore, although data indicate that the process chemistry changes required to plug leaks occurred, it is unlikely that plugging could be effective enough to seal an ongoing leak, particularly a leak of the requisite rates as indicated by modeling.

### C.1.5 Implications of Fluid Mixing Calculations

Mixing calculations indicate that 1989 WDW No. 3 Rose Run chemistry could be the result of mixing 15 percent injectate with 85 percent original Rose Run fluid (Table 9). Mixing calculations, therefore, support this scenario. However, assuming relative homogeneity (non-compartmentalization) of the Rose Run, a relatively large volume of fluid--likely tens of millions of gallons--is required to create WDW No. 3 Rose Run conditions from a direct leak at WDW No. 1 and/or WDW No. 2. Also, chemical mixing data suggest that this appropriate injectate/Rose Run mix requires unrealistic assumptions of dispersivity and leak rate to create the conditions at WDW No. 3.

C.1.6 Conclusion

In summary, Scenario No. 1 is generally not supported by available information. The bulk of the available historic well construction/operation and modeling information discussed above does not indicate that a breach in the outer casing has occurred, although a minor leak in the tubing could have occurred in WDW No. 1 or WDW No. 2 prior to the 1983-1984 workovers. Healing of unrecognizable casing failures by precipitation of material is supported by process chemistry information, although unrealistic assumptions concerning leak rate, dispersivity, volume, etc., would be required to explain observed pressures and to have contaminants migrate to WDW No. 3.

Geologic data do not support the compartmentalization of Rose Run sandstones to the degree that would be required to have contaminants flow to WDW No. 3, but not to the Test/Monitoring Well location. Mixing calculations indicate that the WDW No. 3 Rose Run fluid could have been the result of mixing 1968 Rose Run fluid with average injectate. However, Rose Run-injectate mixing calculations and modeling results also imply that a large volume (tens of millions of gallons) would have to have been added to the Rose Run to even approach the concentrations of organic constituents present at WDW No. 3. Modeling calculations also indicate that a significant pressure increase at WDW No. 3 would be evident from movement of contaminants to the WDW No. 3 Rose Run location, which is not the case. Therefore, the relatively large volume of injectate required to make this scenario possible from a chemical perspective is not consistent with known pressure data and modeling results.

C.2 Scenario 2: Vertical Conduit Near WDW Nos. 1 and 2

Scenario 2 deals with the addition of injectate-bearing fluid into the Rose Run from a location immediately adjacent to WDW Nos. 1 and/or 2, with flow in a significantly compartmentalized Rose Run Formation to the WDW No. 3 intercept, bypassing the Test/

Monitoring Well (Figure 11). In order for this to occur, it must be assumed that one or more of the following has taken place:

- Migration up the annulus between the outer casing and the borehole wall from the Copper Ridge to Rose Run;

- Migration upward through a vertical micro fracture system (i.e., caused by the induced fracturing near boreholes) between the Copper Ridge and Rose Run; and

- Migration up through an abandoned borehole or major, continuous fault from the Mt. Simon or Copper Ridge to the Rose Run.

It is also assumed that fluid added to the Rose Run at or near WDW Nos. 1 and/or 2 due to direct interconnection with the Mt. Simon from a fault or borehole is a mixture of injectate or 1989 Mt. Simon with 1968 Rose Run fluids. This is because the direct pathway allows for instantaneous interconnection of the Mt. Simon and Rose Run with no mixing with intervening formation fluids. If a conduit is assumed between the Copper Ridge and Rose Run only, then a mixture or displacement of Copper Ridge and 1968 Rose Run fluid is assumed. In all cases, compartmentalization of the Rose Run is required to move the migrating fluids to the WDW No. 3 location without encountering the Test/Monitoring Well-Rose Run. The possibility for this scenario rests upon well integrity, fluid flow modeling results, site geologic/hydrogeologic conditions, and fluid chemistry, which are discussed below.

### C.2.1 Well Integrity

Failure of the cement seal between the casing and borehole wall could have created a pathway from the Copper Ridge to the Rose Run, allowing injectate to enter the Rose Run at WDW Nos. 1 and 2 (Figure 11). However, MITs indicate that wells were sound when the tests were conducted in 1984, and the wells have demonstrated integrity in all tests since that time. Moreover, as discussed in Section B.1., the annular pressure fluctuations have

Figure 11

probably been the result of possible tubing problems coupled with temperature effects, which are solely internal to the well, rather than leakage of fluid outside of the casing along the borehole wall. Cement bond logs (CBLs) for WDW No. 1 (conducted in 1968, 1983 and 1985) and WDW No. 2 (conducted in 1984 and 1990) indicate that the outer casing-formation cement seal was intact when logged.

It is possible that a casing-formation cement bond failure occurred prior to 1984 and that injectate leaked up to the Rose Run from the Copper Ridge along the outside of the casing, with subsequent healing of the leak area due to precipitation of organic or inorganic plugging material. Injectate chemistry data indicate that plugging of the wells occurred in conjunction with process chemistry changes during the early 1980s, and resultant sealing of an open annulus could have taken place. Data indicate that relatively low quantities of calcite and gypsum would likely precipitate (Section III) with the majority of plugging due to precipitation of organics. However, unless calcite and gypsum only were precipitated, signal attenuation due to "low velocity" organics would likely have been apparent on CBL logs. This indicates that the CBL log would have detected the plug since it would be likely comprised predominantly of organics, but no such plug was observed in recent CBLs.

### C.2.2 Fluid Transport and Pressure Rise Modeling Results

Analysis of the in-situ stress tests and modeling of pressure rise based on available DST data indicate that the induced fracture systems near the active injection wells are arrested within the Copper Ridge. Therefore, the occurrence of an injection-induced microfracture system adjacent to the WDW No. 1 or 2 location between the Copper Ridge and Rose Run is not supported by available data. If a localized microfracture network which is either naturally occurring or caused by injection (which would be contrary to the known data derived from Test/Monitoring Well in-situ stress test measurements), were present and transmissive, it is possible that pressurization of the Rose Run could be nominal, assuming the injectate slowly migrates upward through the microfractures. However, for fluid to have moved from the WDW No. 1 vicinity to the WDW No. 3 Rose Run intercept, a large volume of fluid would

have to have been emplaced in the Rose Run requiring unrealistic pressure rises, dispersivities, leak rates, and other constraints similar to those discussed under Scenario 1 (Table 15). This large volume of fluid would also result in a pressure rise in the Rose Run at the Test/Monitoring Well location that is significantly in excess of the observed 3 psi pressure rise. Therefore, the dispersivity and leak rate constraints which limit Scenario 1 also apply to Scenario 2.

Pressure data also do not indicate that an ongoing annular leak, borehole or open fracture is present near WDW No. 1 or No. 2, since this requires that a large pressure rise (in excess of 70 psi) currently be present in the Rose Run at WDW No. 3 (Table 15), and a pressure rise significantly in excess of the observed 3 psi be present at the Test/Monitoring Well. Because this large pressure rise has not been observed in the Rose Run, the occurrence of an ongoing leak into the Rose Run near the active injection wells (through boreholes, fracture systems, or annular leak) is not supported by the pressure data.

### C.2.3 Geophysical and Other Studies to Locate Potential Boreholes

In support of the UIC Repermit Application for WDW No. 1 and 2, Envirocorp performed extensive search within a 6.1 mile radius of the Haverhill facility for artificial penetrations (wellbores) to the Rose Run. Records from numerous state agencies were reviewed, including maps from ODNR and records from the Kentucky Geological Survey. Also, a foot search for deep wells within a ten mile radius of Haverhill was performed by Harrison/Kroll. Two wells were found of the appropriate depth within the six mile radius, although no wells were confirmed within 3-4 miles of the Haverhill facility.

As stated above, the Harrison/Kroll and ERM studies did not identify any boreholes to the Rose Run, Copper Ridge, or Mt. Simon within a three-to-four mile radius around the facility. However, historic aerial photographs of the Haverhill area taken by the USDA from 1951-1988 indicate that an area of ground scarring was present in the plant area prior to construction of the facility in 1965. A magnetometer survey was conducted over a 1000-foot

area at 25-foot grid spacing, with 5-foot spacings in a more detailed area where severe ground scarring was noted (see report in Appendix V). In addition to the magnetometer survey, a gradient analysis was performed to assess the "orientation" of any anomalies detected in the survey, with particular emphasis in locating anomalies that could be vertical well bore casings. The survey indicated that a small magnetic anomaly was present in the suspect area, but the magnitude, size, and dimension of the anomaly indicated that it was probably not a vertical casing that could be associated with a heretofore unidentified wellbore. It must be pointed out that casing can be removed from borings prior to abandonment, and therefore, the absence of metal casing does not necessarily indicate that no boreholes are present. Similarly, surface scarring is not always associated with drilling activity. Norfolk/Southern, who owned the Haverhill property prior to 1965, had no record of any drilling activity in the area at or before this time.

### C.2.4 Geologic, Hydrogeologic, and Seismic Study Results

From a geologic perspective, it is unlikely that a conductive, continually open fracture (analogous to an open borehole) is present near WDW No. 1 or WDW No. 2 that would directly connect the Mt. Simon or Copper Ridge and Rose Run and allow for "instantaneous" interconnection of formation fluid. Also, geological and geophysical data show that no large-scale faulting is present within the seismic grid area. Recent reinterpretation of seismic data, originally acquired by Apex Geophysical, was performed by Envirocorp (Appendix D) and Ms. Sally Zinke (Appendix E), and included reprocessing of portions of line KD-6 in response to requests by OEPA. Both the Envirocorp reassessment and that performed by Ms. Zinke indicate that some faults are present at the Precambrian within a 16-mile radius of the Haverhill facility, but none are present within an approximately one-mile radius of the plant itself. The two reports recognized the presence of an apparent structure beneath the Aristech Haverhill facility along line KD-6 approximately between shotpoints 180 and 290; a break in seismic reflection continuity at the Rose Run level is also apparent on the same line below these shotpoints. However, the experts indicate that there are a number of factors that could have influenced this apparent structure, including noise,

data skips, and changes in the thickness of the overlying lower velocity material. After extensive data refinement and re-interpretation, both Ms. Zinke and Envirocorp believe that no true structural turnover or structural high is present in this area, and that the observed seismic response was likely a result of the above interferences. The break in seismic reflection near shotpoint 180 is attributed to noise because of "the lack of diffraction patterns associated with these breaks, along with their spatial relationship to continuous reflectors above and/or below [the Rose Run]" (Envirocorp, 1990, Appendix D).

A lineament trend study was conducted by Envirocorp to locate linear features evident at ground surface (Appendix F) using satellite imagery and aerial photographs. In this study, linear features were identified, and the location where these features intersected seismic lines were distinguished. The purpose of the study was to determine whether any faults identified through seismic study correspond with surface features, implying the occurrence of large-scale faults. Based on satellite imagery, the study concluded that "no linear trends are interpreted to pass through or very near the Haverhill site." The location of surface lineaments was then compared with the occurrence of subsurface faults identified in an earlier Apex geophysical study of the seismic lines to determine whether there was any association between surface lineaments and subsurface faults. The study drew no conclusions concerning the correspondence of surface features with subsurface faults because the early Apex study did not identify any faults with displacements greater than 30 feet within a 12-mile radius of the facility.

However, the seismic data have since been reprocessed and new reports interpreting the reprocessed lines were prepared by both Envirocorp (Appendix D) and Ms. Zinke (Appendix E). A comparison of the location of lineaments that occur on both the satellite imagery and aerial photograph lineament maps against seismic anomalies identified in the recent reinterpretations has been performed. This assessment shows that, in some instances, features such as faults or rollovers identified via seismic interpretation correspond to surface linear features, although this correspondence is neither common nor pervasive. The closest surface linear feature to the Haverhill facility that was identified on both the aerial

photograph and satellite imagery lineament maps occurs over 1.5 miles east of the plant, and does not correspond to a subsurface feature as evidenced by the seismic data. In conclusion, seismic data do not indicate that either a structural "roll-over" or fault is present in the immediate area of the Aristech Haverhill plant. The seismic data has a resolution of approximately 30 feet, and therefore, features smaller than this would not be detected.

If a pressure-induced fluid rise from the Mt. Simon/Copper Ridge near WDW No. 1 or No. 2 to the Rose Run at WDW No. 3 somehow occurred, extreme heterogeneity (compartmentalization) of the Rose Run is required for injectate to reach WDW No. 3 without any flow to the Test/Monitoring Well location. As presented in Section IV-C.1., this is not realistic, given known site geologic conditions. Also, if fluid somehow naturally rose from the Copper Ridge or Mt. Simon to the Rose Run near WDW Nos. 1 or 2 with little pressurized flow, it is not possible that natural lateral (not pressure-induced) migration of fluid in the Rose Run would move fluid to the WDW No. 3 location because of both the probable low groundwater flow velocity and the southwest groundwater flow direction of the Rose Run.

### C.2.5 Fluid Chemistry

Based on mixing calculations, it is most likely that 1989 Rose Run fluid was formed by mixing approximately 22 percent injectate and approximately 78 percent original (1968) Mt. Simon fluid, which displaced rather than mixed with 1968 Rose Run fluids (Table 9, Equation 4). Although less likely, 1989 Rose Run could also be formed by mixing approximately 15 percent injectate and 85 percent of original (1968) Rose Run fluid. It is also possible that 1989 Rose Run chemistry could be the result of a 1968 Copper Ridge (78%) and injectate (22%) fluid mixture that displaced rather than mixed with Rose Run fluid.

Mixing calculations show that formation of the 1989 WDW No. 3 Rose Run by mixing 1989 Mt. Simon and original (1968) Rose Run fluids is unlikely based on chemical evidence

(Table 9). Mixing data also show that fluid recovered from the Rose Run at WDW No. 3 cannot be formed by mixing 1991 Copper Ridge (at the Test/Monitoring Well) and 1968 Rose Run (Appendix M) because concentrations of major species are greater in both 1991 Copper Ridge and Rose Run fluids than they are in 1989 Rose Run fluid. Mixing calculations also show that 1991 Rose Run and the calculated 1968 Copper Ridge fluid chemistries at the Test/Monitoring Well are very similar (Appendix M). This implies either some sort of interconnection between the formations, or a similar history and evolution of these waters; there is no geologic evidence in support of natural formation interconnection.

As stated in previous sections, mixing calculations are based on questionable data, and results are tenuous, at best. Calculations show relative likelihood of various fluid mixtures, but actual percentages probably vary from those presented above because of questionable fluid chemistries.

Although mixing calculations show that a number of fluid mixtures could have created WDW No. 3 Rose Run fluid chemistry, the constraints that limit the plausibility of Scenario 1 also apply to Scenario 2. For example, if almost pure injectate migrated upward from the Mt. Simon to the Lower Knox and then into the Rose Run near WDW No. 1 or 2, large volumes of injectate would have to have been added to the Rose Run to produce the Rose Run-injectate mixing conditions at the WDW No. 3 location. It is unlikely that such a large volume leak could have occurred without direct indication of this leak which is not apparent from the available data. In all cases, large volumes of fluid are required to create conditions at WDW No. 3.

### C.2.6 Conclusion

Based on the modeling, geologic, well construction/well integrity, and hydrologic data, Scenario 2 is an unlikely explanation for organic constituent occurrence in the Rose Run Formation near the WDW No. 3 location. From a chemical mixing perspective, it is possible to derive fluid of similar composition to those at the WDW No. 3 location and there is some

indication that natural Rose Run-Copper Ridge fluid flow may have occurred based on calculated Copper Ridge chemistries. However, in view of the available geologic information, fluid transport modeling and pressure build-up that could occur in such a system, Scenario 2 is not likely.

### C.3 Scenario 3: Vertical Conduit Near WDW No. 3

Upward migration of fluid from the Mt. Simon to the Rose Run through a vertical fracture or open borehole localized near the bottomhole location of WDW No. 3 that allows for instantaneous interconnection between the Mt. Simon or Copper Ridge and Rose Run was also considered (Figure 12). However, this Scenario is slightly different from that presented in the Rose Run Interim Document (1990) because it also includes the consideration of a permeable zone (i.e., vugular intervals or localized microfracture system) that acts as a conduit between the Copper Ridge and Rose Run near WDW No. 3. This conduit has been hypothesized to have sufficient vertical permeability to allow for slower upward migration of fluids from the Copper Ridge to the Rose Run. Under this scenario, therefore, instantaneous interconnection between the Rose Run and Mt. Simon or Copper Ridge through a single fracture or borehole was considered, as well as a relatively slow leak from the Copper Ridge to the Rose Run (near WDW No. 3). Fluid transport and pressure modeling results, hydrogeologic conditions, hydrologic studies, and fluid chemistry were evaluated.

#### C.3.1 Fluid Transport and Pressure Rise Modeling Results

Simulation studies show that flow through a large, single open fracture or borehole directly connecting either the Mt. Simon and Rose Run or Copper Ridge and Rose Run near WDW No. 3 could occur with a nominal pressure rise in the Rose Run at WDW No. 3 and an even smaller pressure rise in the Rose Run at the Test/Monitoring Well. Therefore, fluid flow modeling cannot be used to rule out the occurrence of such a localized pathway existing near the WDW No. 3 location based on the available pressure and chemistry data.

Figure 12

If a leak from the Copper Ridge to the Rose Run is occurring close to the WDW No. 3 location, pressure at the leak entry into the Rose Run would be only marginally higher than that found at the WDW No. 3 intercept. However, it is important to note that neither this pressure rise nor the maximum pressure which can be present in the Copper Ridge (and be consistent with available data) is great enough to open or propagate fractures in the same manner as within the Copper Ridge at the WDW No. 1 or 2 wellbores. This would happen only if these pressures could overcome the minimum horizontal in-situ stresses measured at WDW No. 3, which are likely very similar to those determined by in-situ stress tests at the Test/Monitoring Well (600 psi). It is unlikely that the in-situ stresses at the WDW No. 3 intercept are significantly lower than those measured at the Test/Monitoring Well (approximately 1000' Southwest), since there is no direct evidence of significant structure (i.e., major structural flexure) or other geologic perturbations to account for such significant lateral variations in stress. It is also probable that any such localized vertical pathway would need to be relatively permeable (> 1 md) for the small pressure differentials between the Rose Run and Copper Ridge (less than 30 psi) to cause significant vertical fluid movement.

### C.3.2 Geologic, Hydrogeologic, Borehole Identification Study Results

Geologic information shows that there is little likelihood for open fracture "plumbing systems" to be maintained that would allow immediate upward movement of fluid and "instantaneous" interconnection of the Mt. Simon and Rose Run or of the Copper Ridge and Rose Run near WDW No. 3. Although core analyses indicate that relatively discontinuous microfractures (both healed and unhealed) can occur, as stated in Scenario 2, there is no geologic evidence to suggest the presence of a large open fracture(s) that directly connects these formations. Seismic data support the contention that a large fault is not present within the assessed grid in the Haverhill area. Because it is assumed that the hypothetical fracture is close to WDW No. 3, the low natural fluid flow rate would not be a constraint in that fluids would not be required to move a great distance to the WDW No. 3 Rose Run location.

As stated under Scenario 2 discussions, the Harrison/Kroll investigation did not identify any boreholes within three to four miles of the Aristech Haverhill area. The magnetometer study performed at the Aristech Haverhill plant did not identify the presence of cased boreholes within the area of investigation. The exhaustive Area of Review exercise discussed under Scenario 2 also revealed no boreholes to the Rose Run within a four-mile radius of the Aristech Haverhill Plant.

Log and core analyses show that the interval between the Rose Run and this uppermost Copper Ridge porous bleed-off zone is comprised of shaley microcrystalline dolomites with little vugular development, and that it has a particularly low porosity above the uppermost Copper Ridge porous bleed-off zone (Figure 12, Appendix A-2). Log analyses for all wells at Haverhill confirm that this interval has relatively low porosity throughout the site (except near the Rose Run-Copper Ridge conformable contact), and likely has a low vertical permeability. Lateral facies variation to a more porous dolomite can occur in this interval beyond the general area of the injection wells, but it is not possible to determine where this hypothetical porous zone might develop based on log analyses. It is also possible that a small microfracture system completely restricted to this upper Copper Ridge-Rose Run interval is present somewhere near Haverhill, because these do occur in other natural settings. If such a system is present within the given interval, it is not evident in either the log or core analyses, and it is probably outside the area of the injection wells. To summarize, geologic data do not support the occurrence of large-scale open faults/fractures in the area, and there is no direct evidence that a localized permeable/porous zone is present between the Copper Ridge and Rose Run at WDW No. 3.

### C.3.3 Fluid Chemistry

Under this scenario and assuming flow from the Mt. Simon to Rose Run, it is possible either that (1) 1989 Mt. Simon fluid entered the Rose Run and mixed with Rose Run fluid, or (2) that an average injectate/1968 Mt. Simon fluid mix entered the Rose Run and displaced (rather than mixed with) Rose Run fluid. Of these possibilities, the second is the more

probable, based on the organic and inorganic chemistry (Table 9). This is supported by fluid chemistry composition, since the 1989 Rose Run does not contain all of the constituents present in 1989 Mt. Simon fluid, such as aniline.

The scenario also considers Copper Ridge-Rose Run interconnection. Calculations indicate that a mixture of 1991 Copper Ridge and 1968 Rose Run fluids could not create the 1989 WDW No. 3 Rose Run composition, but the 1989 Rose Run composition could be formed if a 1968 Copper Ridge injectate mixture displaced rather than mixed with the Rose Run. However, modeling studies and chemistry data indicate that relatively low volumes of injectate have entered the Copper Ridge. This implies that although it is possible to create 1989 Rose Run Chemistry through displacement by a 1968 (calculated) Copper Ridge fluid (Appendix M), it is not known whether the appropriate injectate volume would be present at WDW No. 3 in the Copper Ridge to create such a displacement mixture.

Calculated 1968 Copper Ridge chemistry at the Test/Monitoring Well is quite similar to 1991 Test/Monitoring Well-Rose Run chemistry, implying either similar evolutionary histories or natural interconnection between the two formations at this location (Appendix M). This potential interconnection at the Test/Monitoring Well therefore raises questions concerning the possibility of natural interconnection in other locations, such as the WDW No. 3 location.

To summarize, mixing data indicate that it is possible to create 1989 Rose Run fluid through displacement of the Rose Run fluid by a 1968 Copper Ridge/injectate mixture or a 1968 Mt. Simon fluid and injectate mixture. It is also possible that natural interconnection of the Rose Run and Copper Ridge occurs near the Test/Monitoring Well location, based on mixing calculations, and this relationship could also apply to the WDW No. 3 location. However, it is also quite possible that the apparent chemical similarities of the 1968 (calculated) Copper Ridge and 1968 and 1991 Rose Run chemistries are due to similar depositional/ evolutionary histories of the two formations, which is generally supported by geologic data (Appendices M and A2).

### C.3.4 Conclusion

Scenario 3 cannot be ruled out based on available data. Fluid transport and pressure rise modeling cannot rule out this scenario, because the observed pressure rises are consistent with a localized interconnection near WDW No. 3, but these data can also be consistent if no interconnection occurs in the area. Interconnection of the Mt. Simon or Copper Ridge and Rose Run by a major fault or fracture system is not supported by geologic data. Although geologic data indicate that a Copper Ridge to Rose Run interconnection at WDW No. 3 is not likely, these data cannot confirm or deny the presence of such an interconnection outside of the immediate injection well area. No boreholes were found in the Haverhill area that could connect the Mt. Simon/Copper Ridge and Rose Run. Chemical mixing data indicate it is possible to produce 1989 Rose Run WDW No. 3 chemistry by mixing injectate and 1968 Rose Run waters, or by displacing the original Rose Run fluids with either a 1968 Mt. Simon and injectate mixture, or calculated 1968 Copper Ridge and injectate mixture. Mixing data also indicate that the calculated 1968 Copper Ridge at the Test/Monitoring Well and the 1991 Rose Run at the Test/Monitoring Well are quite similar, implying similar evolutionary histories or localized interconnection at this location (which could occur at other locations as well).

## C.4 Scenario 4: Contamination by Drilling Fluids

Invasion of drilling fluid into surrounding formations can result in contamination of formation waters (Figure 13). However, chemical data indicate that drilling fluid used during installation of WDW No. 3 could not have caused the organic contamination apparent in WDW No. 3 Rose Run brines.

A variety of drilling additives were used during installation of WDW No. 3, including alpha-tetralone, glutaraldehyde, xanthan gum, modified starch, clay, ethyl cellulose, Poly-Plus™, Spersene™, Quick-Seal™, cottonseed hulls, and drilling paper. Small quantities of phenolic compounds may be present in these substances, but none contain free phenol. Analyses of

Figure 13

drilling muds used in WDW No. 3 indicate that the maximum phenol content never exceeded 10 ppm (total phenolic compound concentrations were higher; 16 ppm phenolics was reported in one WDW No. 3 mud sample). Furthermore, drilling fluid manufacturers indicate that the amount of free phenol within these additives is low (4 to 5 ppm). This information indicates that there is not enough phenol in drilling fluid to create the concentrations present in the WDW No. 3 Rose Run Formation waters. Also, the drilling fluids used in the drilling of WDW No. 3 do not contain the full range of constituents found in the 1989 Rose Run. Therefore, Scenario 4 is not a plausible explanation for organics in the Rose Run at WDW No. 3.

Drilling fluid likely affected formation fluid analyses in samples collected above the Rose Run (Appendix L). As discussed in Section III-D.2, formation fluid samples collected from WDW Nos. 1 and 3 in formations above the Rose Run were likely contaminated by drilling mud and/or potable water used during drilling, causing dilution of formation brines by adding fresh water and adding organics (i.e., phenol, BTX) to formation fluid samples. For example, a DST in the Berea was unsuccessful because of the low formation permeability, and formation fluid samples were then collected using a Repeat Formation Testing (RFT) tool. This tool collects a small volume of fluid from relatively close to the borehole, which was likely infiltrated by drilling fluid, and did not provide a sample of fluid from deeper portions of the formation (which would be more representative of actual formation fluid chemistry). As discussed in Section III, it is highly probable that the wide range of inorganic and organic species concentrations reported in chemical analyses of Berea fluids sampled in 1968 at WDW No. 1, in 1989 and WDW No. 3, and in 1991 at the Test/Monitoring Well, was caused either by secondary contamination (i.e., drilling fluid or laboratory artifact), or by naturally occurring substances. Considerable care was taken to avoid dilution of Berea formation fluid with drilling mud in the 1991 Test/Monitoring Well, and this Berea sample is likely very representative of Berea fluid with no drilling mud admix. The Berea in the Test/Monitoring Well had a TDS of 135,000 ppm. Figure 6 shows that based on TDS and other species concentrations, the 1968 and 1989 Berea samples have been contaminated by

drilling fluid, and also shows that simple dilution of the 1991 Berea fluid could create the earlier Berea formation fluid sample chemistries.

### C.5 Scenario 5: Third-Party Source

Injection of material into the Rose Run by a third party (Figure 14) is also a scenario that has been examined. This scenario was first posed because although the Rose Run fluids at WDW No. 3, Mt. Simon fluids, and injectate have some organic compounds in common, other compounds are unique to individual fluids (Table 16). The possibility of a third-party source has been investigated based on known disposal/manufacturing activities in the area, hydrogeologic study results, modeling of fluid transport and pressure, and injectate/formation fluid chemistries.

#### C.5.1 Possible Third-Party Sources: Harrison/Kroll Investigation

Compounds characteristic of phenol manufacturing processes have been found in both 1989 Rose Run and 1989 Mt. Simon waters samples collected from WDW No. 3. A number of processes other than the Aristech cumene/phenol/acetone process can be used to create phenol, some of which have been conducted at Ohio, West Virginia, and Kentucky facilities near the Aristech Haverhill facility (Appendix X). Harrison/Kroll (Appendix K) identified the presence of a number of wells in the general Haverhill area, with two of the wells drilled into Cambrian-age Rocks approximately four miles northeast of the Haverhill plant. Evidence gathered by Harrison/Kroll indicates that Dow Chemical may have drilled wells in the area to acquire and/or dispose of brines. One interviewee indicated that she thought wastes were disposed of in one of the wells, and that the well was only recently plugged. One well is referred to as the Albert Rase Well, approximately four miles from the Haverhill site, and apparently penetrated the Rose Run Formation. Interviews and other documentation indicate that the well remained open only one to two months, but liquid waste may have been hauled to the site while the well was open.

Figure 14

Table 16

Comparison of Constituents in 1989 WDW No. 3,
and 1990 Test/Monitoring Well Samples

| Units - ppm | Injectate Sampled 6/14/89 | Injectate Sampled 11/20/89 | WDW No. 3 Mt. Simon Fluid Sampled 9/22/89 | WDW No. 3 Rose Run Fluid Sampled 6/14/89 | Test/ Monitoring Well Copper Ridge Fluid Sampled 5/9/91 | Test/ Monitoring Well Rose Run Fluid Sampled 4/25/91 |
|---|---|---|---|---|---|---|
| Methylene Chloride | NA | ND | ND | 1.7 | 15[4] | 0.014[4] |
| Acetone | NA | 600 | 1200 | 210 | 110[4] | 0.034[4] |
| 2-Butanone | NA | ND | 5.4 | 3 | ND | ND[5] |
| Benzene | NA | 7.5 | 0.64 | ND | ND | 0.022* |
| 4-Methyl-2-pentanone | NA | ND | 0.37 | ND | ND | ND[5] |
| 2-Hexanone | NA | ND | 0.27 | ND | ND | ND[5] |
| Toluene | NA | 16 | 10 | ND | ND | 0.006* |
| Ethylbenzene | 1.1 (TIC) | ND | 0.33 | ND | ND | ND[5] |
| 2-Propanol | NA | NI | 0.18(TIC) | NI | NI | NI |
| 3-Methyl-2-butanone | NA | NI | 0.19(TIC) | NI | NI | NI |
| Methoxybenzene | NA | NI | 0.21(TIC) | NI | NI | NI |
| alpha-Picoline | 28 | NI | 13 J | ND | ND | ND |
| Aniline | 18.8 | NA | 3.1 J | ND | ND | ND |
| Phenol | 1300 | 250 | 940 | 400 | 240[2] | ND[6] |

J = estimated value
NA = not analyzed (for)
NI = not identified, TIC
ND = analyzed for, but not detected
TIC = tentatively identified compound
* = concentration has been determined to be biased low
[1] = semi-volatile holding time exceeded by three days
[2] = biased high quantitative estimate
[4] = value invalid due to presence of compound in field blanks and associated method
[5] = volatile non-detects rejected due to presence of natural gas in formation
[6] = semi-volatile concentrations considered biased low quantitative estimates due to presence of natural gas in formation

Complete list of chemical data qualifiers included in Appendix B

Table 16 (Cont'd)

Comparison of Constituents in 1989 WDW No. 3,
and 1990 Test/Monitoring Well Samples

| Units - ppm | Injectate Sampled 6/14/89 | Injectate Sampled 11/20/89 | WDW No. 3 Mt. Simon Fluid Sampled 9/22/89 | WDW No. 3 Rose Run Fluid Sampled 6/14/89 | Test/ Monitoring Well Copper Ridge Fluid Sampled 5/9/91 | Test/ Monitoring Well Rose Run Fluid Sampled 4/25/91 |
|---|---|---|---|---|---|---|
| 1,4-Dichloro-benzene | ND | 4.2 | ND | ND | ND | ND[6] |
| 2-Methylphenol (o-cresol) | ND | ND | ND | 0.22 | 0.160 | ND[6] |
| 4-Methylphenol (p-cresol) | ND | ND | ND | ND | 0.065 | ND[6] |
| Acetophenone | 93.7 | NA | 35 | 6 | 2.70 | ND |
| a,a-Dimethyl-benzyl alcohol | 270 | NA | 130 | 44 | 9.60 | ND |
| Benzoic acid | 8.6 | ND | 21 | 1.7 | 4.0 J | ND[6] |
| Bis(2-ethyl hexyl) phthalate | ND | ND | ND | ND | 0.031[4] | ND[6] |
| 2,2'-Methylene bisphenol | NI | NI | 35(TIC) | 7.2(TIC) | 0.130(TIC) | NI |
| 4,4'-Methylene bisphenol | NI | NI | 36(TIC) | 4.8(TIC) | 2.90(TIC) | NI |
| 2-Methyl-benzofuran | 1.2 | NI | NI | NI | NI | NI |

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Table 16 (Cont'd)

Comparison of Constituents in 1989 WDW No. 3, and 1990 Test/Monitoring Well Samples

| Units - ppm | Injectate Sampled 6/14/89 | Injectate Sampled 11/20/89 | WDW No. 3 Mt. Simon Fluid Sampled 9/22/89 | WDW No. 3 Rose Run Fluid Sampled 6/14/89 | Test/ Monitoring Well Copper Ridge Fluid Sampled 5/9/91 | Test/ Monitoring Well Rose Run Fluid Sampled 4/25/91 |
|---|---|---|---|---|---|---|
| 2,3-Dimethylphenol | 2.2 | NI | NI | NI | NI | NI |
| 2-(1-Methylethyl) phenol | 1.2 | NI | NI | NI | NI | NI |
| 4-(1-Methyl-1-phenylethyl) phenol (cumyl phenol) | 26 | NI | NI | NI | NI | NI |
| 2-[1-(4-Hydroxyphenyl) 1-methyl-ethyl] phenol (o,p-BPA) | 13 | NI | NI | NI | NI | ND |
| Bisphenol A | NA | NA | NI | NA | 0.840 | ND |
| Cumene | 22 (TIC) | NA | 4.6 (TIC) | ND | ND | ND |
| Formic Acid (as Formate) | NA | NA | 1370 | 168 | ND | ND |
| Aluminum | 0.8 | 0.3 | 2 | ND | 1.330[3] | ND |
| Barium | ND | ND | ND | 1.8 | 3.810 | 4.71[7] |
| Calcium | 21 | 38 | 2850 | 38500 | 35000 | 37000 |

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NI - not identified, TIC
ND - analyzed for, but not detected
TIC - tentatively identified compound
* - concentration has been determined to be biased low
[1] - semi-volatile holding time exceeded by three days
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Table 16 (Cont'd)

Comparison of Constituents in 1989 WDW No. 3,
and 1990 Test/Monitoring Well Samples

| Units - ppm | Injectate Sampled 6/14/89 | Injectate Sampled 11/20/89 | WDW No. 3 Mt. Simon Fluid Sampled 9/22/89 | WDW No. 3 Rose Run Fluid Sampled 6/14/89 | Test/ Monitoring Well Copper Ridge Fluid Sampled 5/9/91 | Test/ Monitoring Well Rose Run Fluid Sampled 4/25/91 |
|---|---|---|---|---|---|---|
| Chromium | 0.06* | 0.05 | ND | ND* | ND* | ND* |
| Iron | 0.41 | ND | 15.7 | 60.8 | 409 | 171 |
| Lead | ND | ND | 0.03 | ND | 0.581 | 0.028 J |
| Magnesium | 0.14 | ND | 424 | 6070 | 6190 | 7010 |
| Manganese | ND | ND | 0.4* | 2.35 | 6.410 | 3.22 |
| Potassium | 17.1 | 10 | 421 | 3330 | 3610 | 3810 |
| Sodium | 5080 | 11000 | 14000 | 44600 | 48200 | 25500 |
| pH | 12.4 | 11.56 | NA | 5.76 | NA | NA |
| Specific Gravity | 1.01 | NA | 1.05 | 1.19 | 1.2 (NV) | 1.215 (NV) |
| Ammonia (as Nitrogen) | NA | NA | 409 | 80.5 | 73.1 | 70.0 |
| Ammonia | NA | 560 | NA | NA | NA | NA |
| Bromide | ND | NA | 200 | 1630 | 2090 | 2200 |
| Chloride | 2790 | 1900 | 21200 | 170000 | 208000 | 218000 |
| Nitrate (as Nitrogen) | NA | NA | ND | 220 | ND | 0.04 |

J = estimated value
NA = not analyzed (for)
NI = not identified, TIC
ND = analyzed for, but not detected
TIC = tentatively identified compound
* = concentration has been determined to be biased low
[1] = semi-volatile holding time exceeded by three days
[2] = biased high quantitative estimate
[4] = value invalid due to presence of compound in field blanks and associated method
[5] = volatile non-detects rejected due to presence of natural gas in formation
[6] = semi-volatile concentrations considered biased low quantitative estimates due to presence of natural gas in formation
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Table 16 (Cont'd)

Comparison of Constituents in 1989 WDW No. 3,
and 1990 Test/Monitoring Well Samples

| Units - ppm | Injectate Sampled 6/14/89 | Injectate Sampled 11/20/89 | WDW No. 3 Mt. Simon Fluid Sampled 9/22/89 | WDW No. 3 Rose Run Fluid Sampled 6/14/89 | Test/ Monitoring Well Copper Ridge Fluid Sampled 5/9/91 | Test/ Monitoring Well Rose Run Fluid Sampled 4/25/91 |
|---|---|---|---|---|---|---|
| Sulfate | 1790 | 14000 | 2490 | 330 | 229 | ND |
| $CaCo_3$ Alkalinity | NA | NA | NA | NA | 56.0 | 100 |
| Silica | NA | NA | NA | NA | 10.803 | 7.29[3] |
| TSS | NA | NA | NA | NA | 1680 | 1770 |
| Iodide | NA | NA | NA | NA | NA | NA |
| TDS | NA | NA | 48400 | 287000 | 293000 | 309000 |
| Resistivity (or specific conductance) (77°F) | NA | NA | NA | NA | 439 mmohs | 495 mmohs |
| Carbon Dioxide | NA | NA | NA | NA | NA | NA |

J - estimated value
NA - not analyzed (for)
NI - not identified, TIC
ND - analyzed for, but not detected
TIC - tentatively identified compound
* - concentration has been determined to be biased low
[1] - semi-volatile holding time exceeded by three days
[2] - biased high quantitative estimate
[4] - value invalid due to presence of compound in field blanks and associated method
[5] - volatile non-detects rejected due to presence of natural gas in formation
[6] - semi-volatile concentrations considered biased low quantitative estimates due to presence of natural gas in formation
Complete list of chemical data qualifiers included in Appendix B

However, the bulk of the data gathered by Harrison/Kroll indicate that other identified manufacturers in the Haverhill area did not use deep-well injection to dispose of wastes. Harrison/Kroll concluded that, despite the possible prior use of wells for injection of waste into the Rose Run in other locations as early as 35 years ago and the existence of phenol/phenolic-based manufacturing facilities in the area, there is no confirmation that a third party injected any phenol/phenolic chemicals into the Rose Run or Mt. Simon Formations in the area around the Aristech facility. In fact, the closest wells of the appropriate depth are over four miles away from the Haverhill facility, and there is no conclusive information that these wells were used for waste disposal purposes.

### C.5.2 Hydrogeologic Study and Fluid Transport Modeling Results

Current hydrogeologic conditions and fluid modeling do not support a third-party origin because: 1) even if an injection well is present and wastes were clandestinely dumped (or pumped for a limited time) down a borehole, it is highly unlikely that natural subsurface groundwater flow velocity is sufficient to have moved the relatively small plume of anthropogenic materials which could have been emplaced in the Rose Run from an unidentified borehole more than two miles away; 2) fluid transport modeling shows that in order for this scenario to be plausible a relatively high volume injection well in the Rose Run within two miles of the Haverhill facility must have been present--no such well has yet been found; and 3) enhanced fluid transport velocity due to phase separation, etc., would not be sufficient to support a third-party origin.

### C.5.3 Fluid Chemistry

The concentration of inorganic constituents within the 1989 WDW No. 3 Rose Run fluid has remained relatively consistent since 1968, except for minor variations in most inorganic constituent concentrations. Mt. Simon fluids, however, have shown major reductions in the concentrations of most inorganic constituents between 1968 and 1989 due to mixing with injectate. Both Mt. Simon and Rose Run fluids contain anthropogenic organic compounds

such as phenol, acetone, and acetophenone. However, analyses of Rose Run and Mt. Simon fluids have also detected aromatic ring compounds that could conceivably have originated from two different phenol processes. Compounds such as phenol, which is most commonly generated by the cleavage of cumene hydroperoxide, are characteristic of Aristech waste. Other compounds present in analyses of Rose Run fluid samples, such as 2,2- and 4,4-methylenebisphenols, are created by phenol formaldehyde processes and are not characteristic of wastes produced by processes at Haverhill.

Given the distinct organic and inorganic chemistries of WDW No. 3 Rose Run and Mt. Simon fluids, and the possibility that other manufacturing processes could create the same organic wastes, a "chemical profile" of a hypothetical waste can be created to account for the chemistries of WDW No. 3 Rose Run fluids. This hypothetical waste would have to have a relatively concentrated organic constituent content, acidic pH, high sulfate concentration, and essentially no capacity to dilute the natural Rose Run formation water. By adding a waste such as this to the Rose Run, it would be possible to create the observed conditions in the Rose Run at WDW No. 3 wherein pH is relatively neutral, organic constituents are present in relatively high concentrations, and the inorganic chemistry remains similar to 1968 Rose Run concentrations.

Although one can "build" an appropriate third-party case, the bulk of the chemical data indicate that the material in the WDW No. 3 Rose Run fluid was derived from Aristech injectate. For example, upon first comparison, it appears that the occurrence of 2,2- and 4,4-methylenebisphenols in the Mt. Simon and Rose Run, but not in the injectate, could be attributable to third-party influence. As stated in Section III, the likelihood that these compounds could be created via biodegradation is low. However, facility representatives indicate that formaldehyde has been present as an intermediate in the process and/or wastestream, and because of the presence of this compound in facility operations, it is possible that phenol-formaldehyde reactions creating these compounds occurred at the plant some time during the past.

Upon initial examination, it also appears that inorganic constituent concentrations within the Rose Run have not changed since 1968, but careful observation indicates that this is not the case. 1989 Rose Run fluids show minor alteration or dilution of inorganic constituent concentration relative to 1968 values, negating the necessity of a third-party source that would add organics without altering inorganic constituent concentration.

The variability in injectate concentration and minor constituent composition through time relative to organic and inorganic constituents adds uncertainty to any conclusions drawn from "known" injectate chemistry. Additionally, as discussed in previous sections and presented in Appendix M, mixing calculations indicate that the 1989 Rose Run Formation fluid chemistry at the WDW No. 3 intercept could be the result of a number of mixing combinations; hence, there is no reason to believe that a third party created the observed WDW No. 3 Rose Run fluid chemistries.

### C.5.4 Conclusion

In summary, a third party source for constituents in the Copper Ridge and Rose Run is highly improbable. Although it is possible to construct a third-party source for some of the constituents within the Rose Run and Mt. Simon, the bulk of the evidence does not support this scenario. Numerous manufacturers that could have created some of the materials of interest were operational near the Aristech area during the relevant time period, and local residents and workers indicate that well disposal of wastes may have occurred in the area. However, no confirmation of local subsurface injection of these materials by a third party has been found. Hydrogeologic and fluid flow modeling indicate a low probability for this scenario, and chemistry mixing data indicate that fluids within the Rose Run at WDW No. 3 are most likely from Aristech injectate.

## C.6 Scenario 6: Microfracture System

Although direct interconnection of the Rose Run, Copper Ridge, and Mt. Simon through a continuous open fracture(s)/fault has been ruled out, the possibility of relatively slower leakage of fluids upward through an extensive network of microfractures must be examined (Figure 15). This scenario is different from Scenario 3 because it assumes that instantaneous interconnection of fluids has not occurred, but instead slower migration in a microfracture system from the Mt. Simon to the Rose Run has taken place, allowing for fluid-rock interaction. It also assumes that this microfracture system locally extends from the Mt. Simon to the Rose Run near the WDW No. 3 intercept (Figure 15), hence explaining the lack of contamination at the Rose Run Test/Monitoring Well location.

### C.6.1 Fluid Transport and Pressure Rise Modeling

If a naturally transmissive microfracture system is present, modeling results alone cannot be used to rule out the possibility of slow upward fluid movement through such a system of microfractures that is close to the downhole Rose Run location of WDW No. 3. As with Scenario 3, modeling indicates that only a low pressure rise would be evident in WDW No. 3 Rose Run if fluid moved slowly upward, and such pressure rise is apparent in WDW No. 3 Rose Run upon comparison of 1968, 1989, and 1991 pressure data.

Even if extensive microfractures are present, many formations throughout the country have naturally-occurring microfractures that normally exist in a totally closed configuration due to lithostatic or naturally occurring stresses. Modeling and core data indicate it is highly probable that the Mt. Simon and Lower Rome are naturally fractured at WDW No. 3 (injection-induced fractures do not extend to this location), and these fractures are closed, even during injection. The natural microfractures at WDW No. 3 can begin to open when the threshold pressure between 3200 psi and 3400 psi is reached (at a depth of 5416 feet below ground level [BGL]), which corresponds to a fracture opening pressure gradient between 0.59 psi/foot and 0.63 psi/foot. This gradient has been confirmed through step-rate

Figure 15

testing performed in March 1991 (Appendix G4). (The step rate test data collected at WDW 3 indicates fracture opening at a gradient of ≈0.59-0.63 psi/foot, which is consistent with data observed in the Mt. Simon at WDW Nos. 1 and 2 and implies that stresses in the Mt. Simon in all three wells are similar.) Above this gradient range, pre-existing natural fractures will open in the Mt. Simon.

Based on these data, pressure rise in the Mt. Simon at WDW No. 3 has not reached the requisite 600 psi above original formation pressure that is required to open such fractures in the Mt. Simon. Furthermore, a pressure rise of at least 800 to 900 psi would be required to open fractures in the overlying Rome Formation. Data, therefore, indicate that the natural fractures in the Mt. Simon at WDW No. 3 are currently closed, even with ongoing injection.

This microfracture network is not apparent in WDW No. 3 core above the Lower Rome, but even if a microfracture network occurs in the vicinity of WDW No. 3 from the Rome to the Rose Run, it is highly likely that native horizontal in-situ stresses present in the subsurface at WDW No. 3 would be sufficient to close the fractures. Even if it is assumed that an extensive microfracture system is present and open (particularly near WDW No. 3), the rock column would have to be under stress conditions that are significantly different from those measured in the Test/Monitoring Well, and there is no evidence to suggest that in-situ stresses in the formation are significantly different from the Test/Monitoring Well to WDW No. 3. Therefore, unless major differences in formation stress characteristics are present between the Test/Monitoring Well and WDW No. 3 due to features such as previously unidentified flexure or fold, it is unlikely that a hypothetical microfracture system is present in an open configuration that could provide a transmissive pathway from the Mt. Simon to the Rose Run.

## C.6.2 Geological and Geophysical Evidence

Geological and geophysical data show that no large-scale faulting is present in the Aristech area. Comparison of seismic and surface lineament data indicate that there is no direct correspondence between surface lineaments and identified subsurface faults at or immediately near the Haverhill plant. Envirocorp (Appendix F) concluded that a general lineament trend to the north-northwest was apparent in the Haverhill area, and stated "the surface evidence of common, non-random linear trends suggests the presence of fractures in the sedimentary section." However, it is probable that many surface lineaments do not necessarily indicate microfracturing in the subsurface, but instead correspond to bedrock outcrop, etc. Seismic data has a vertical resolution of approximately 30 feet, and therefore may not detect microfracture zones. Based on the above evidence, the occurrence of micro-fractures in the general Haverhill area cannot be ruled out based on seismic and lineament evidence, although seismic data confirmed the laterally continuous nature of beds within the area and did not identify any major disruptions.

Core data from the Test/Monitoring Well indicate that some healed fractures are present in the subsurface. However, almost all of the cored intervals in the Test/Monitoring Well were relatively unfractured, even to within approximately 70 feet of the Mt. Simon formation. Core examined at WDW No. 1 indicate that extensive microfractures were not naturally present in the Rose Run, Rome, and Mt. Simon Formations at this specific location, although fracture records are ambiguous concerning the possibility of fractures in the general vicinity of WDW No. 1. The Mt. Simon and Lower Rome were fractured at WDW No. 3, as evidenced by core data from these intervals, but the Upper Rome at WDW No. 3 was not extensively fractured. Geophysical log analyses tend to confirm core data, although the resolution of geophysical logs relative to microfracture detection is limited and based on the type of log. Therefore, the core data provide strong evidence that the rock column at Haverhill is not extensively and universally fractured above the Mt. Simon such that fluids could everywhere exit the Mt. Simon and flow upward toward the Rose Run Formation.

If a microfracture system was present that allowed upward migration of liquids, the fluid migration rates would be relatively slow (when compared to some aspects of Scenarios 2 and 3), allowing for fluid-rock interaction. Also, the microfracture pathway must also be in relatively close proximity to the WDW No. 3 Rose Run intercept, because natural groundwater flow velocities within the Rose Run are likely so slow that lateral migration of fluids due to natural groundwater movement in the Rose Run would likely be minimal.

In conclusion, core data do not support this scenario, although WDW No. 3 core in the Mt. Simon and Lower Rome was naturally fractured. However, for this scenario to be plausible the microfracture system would not be present near the Test/Monitoring Well, which is confirmed by core data and inferred by Rose Run Formation fluid sample analyses.

### C.6.3 Fluid Chemistry and Fluid Mixing

Mixing calculations indicate that fluid present at the WDW No. 3 Rose Run intercept could not be the result of mixing of 1989 Mt. Simon fluids with 1968 Rose Run fluids. However, mixing calculations (based on comparison of a limited number of constituents) indicate that if a mixture of an average injectate/1968 Mt. Simon fluids moved up a microfracture system and displaced rather than mixed with 1968 Rose Run fluids, this could also produce the observed WDW No. 3 Rose Run fluid chemistry. Displacement or mixing of Copper Ridge injectate combinations were not considered under this scenario.

1989 Rose Run fluids did not contain aniline, which was added to injectate in 1981. Because this constituent is not present in 1989 Rose Run fluid this can be used in support of slow upward-migration of fluids through a microfracture system. However, dilution and injectate compositional variations could account for this discrepancy, and therefore fluid composition does not confirm or refute this scenario.

### C.6.4 Conclusion

Geologic core data indicate that only WDW No. 3 Mt. Simon was fractured at the time of drilling, and formations above the Mt. Simon at WDW Nos. 1, and 3, and the Test/ Monitoring Well do not show development of pervasive microfracture systems. Geophysical data indicate that strata in the area are continuous with no major disruptions visible within the resolution of the seismic data, but can neither confirm nor refute the occurrence of microfracture systems that may be undetectable because of the 30-foot resolution limit of the seismic data.

Stress test data indicate the regional horizontal stresses are sufficient to close natural microfractures, particularly near WDW No. 3. Also, there is no evidence that sufficient injection-related pressure rise has occurred in a regional perspective to open fractures, especially near WDW No. 3. Modeling of pressure rise and flow transport data can neither confirm nor deny the scenario if a naturally transmissive pervasive microfracture system is assumed to exist (contrary to stress test and geologic evidence). Chemistry data indicate that Rose Run Chemistry could be the result of displacement of Rose Run fluids by Mt. Simon-injectate mixtures.

No data absolutely confirm that this scenario is possible, and other recently acquired Test/ Monitoring Well data indicate that the scenario is unlikely. Therefore, because of the new Test/Monitoring Well data relative to site geology, the scenario is unlikely.

## C.7 Scenario 7: Incorrect Sampling of the Rose Run Formation at WDW No. 3

The formation fluid chemistries in the Rose Run at WDW No. 3 and the Copper Ridge at the Test/Monitoring Well indicate that both formations contain injectate in various percentages. The question then arises whether the sampled interval in WDW No. 3 at the Rose Run horizon was correct (Figure 16).

Figure 16

The Rose Run was sampled twice during drilling of WDW No. 3: once during the drilling process before the Copper Ridge was drilled into, and once (via straddle pack test) after the Copper Ridge was encountered. If an error was made concerning drilling depth when the first Rose Run sample was collected, it is possible that this sample could have been taken from a deeper formation, such as the Copper Ridge. Available data indicate that the sampled interval was correct, and that the Copper Ridge was not sampled at WDW No. 3. Daily drilling records and personnel on-site during drilling of WDW No. 3 indicate that no errors were made (i.e., during pipe tally) to such a degree that an interval approximately 200 feet below the Rose Run was accidentally sampled.

Scenario 7 is not plausible because available data indicate that the Rose Run, not Copper Ridge, was sampled in WDW No. 3.

APPENDIX M

ASSESSMENT OF HAVERHILL FLUID CHEMISTRY
(BY DR. DONALD LANGMUIR, 1991)

P4-91

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Box 37

# Assessment of Haverhill Fluid Chemistry

by

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## 1. Injectate Chemistry

The more general composition of injectate through time is given in Tables 1a and 1b. Data for several organic and inorganic species are available beginning in 1981. Because of the relatively high phenol levels in injectate up to 1984, and much lower and declining phenol concentrations in post-1984 injectate, the data in Table 1 have been analyzed in two different ways. The 1981 to 1984 data are averaged in Table 1a, while the overall data averages for 1981 to 1989 are listed in Table 1b.

Mean concentrations in the injectate based on the data in Table 1, are summarized in Table 2. Only a few values are available for certain species such as Na, Cl, $SO_4$, and formic acid, for example. In addition, the variability of existing data, as evident from its standard deviation, is usually quite large. Nevertheless, several tentative conclusions seem reasonable. First, TDS, and Na, Ca, and $SO_4$ are relatively constant between 1981 and 1989. The data for Cl suggest that values may have increased through time, however, given that only four analyses are available, such a conclusion cannot be argued with confidence.

Table 1a

Injectate Composition Through Time
(in parts per million)

| Species | 4/12/81 | 7/9/81 | 1/4/83 | 1/20/83 | 9/26/83 | 10/1/84 | 10/22/84 | 10/29/84 | 11/15/84 | No. of Samples Through 11/15/84 | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Na | - | - | 9000 | 10000 | - | - | - | - | - | 2 | 9500 | 707 |
| Ca | - | - | 28 | 13 | - | - | - | - | - | 2 | 21 | 11 |
| Cl | - | - | 640 | 1170 | - | - | - | - | - | 2 | 905 | 375 |
| $SO_4$ | - | - | 9100 | 10250 | - | - | - | - | - | 2 | 9680 | 813 |
| $NH_3$-H | 600 | - | 800 | 1600 | - | 27 | 1400 | 900 | 1000 | - | - | - |
| TDS | - | - | 21000 | 23000 | - | 18000 | 21000 | 12000 | 18000 | 6 | 18800 | 3870 |
| SpC | - | - | - | - | - | - | - | - | - | | | |
| SpG | - | - | - | - | 1.02 | - | - | - | - | | | |
| pH | - | 9.5 | 10.3 | 10.5 | - | 10.2 | 7.2 | 6.9 | 10.5 | - | - | - |
| Acetic Acid | - | - | - | - | - | 970 | 620 | 500 | 580 | 4 | 668 | 208 |
| Acetone | 306 | 540 | 700 | 1000 | 380 | 300 | 900 | 270 | 800 | 9 | 577 | 281 |
| Acetophenone | 350 | 1140 | - | 120 | 240 | 150 | 240 | 390 | 120 | 8 | 344 | 337 |
| Aniline | 350 | - | - | 54 | 20 | 30 | 80 | 250 | 80 | 7 | 123 | 126 |
| Formic Acid | - | - | - | - | - | - | 1100 | 950 | 980 | 3 | 1010 | 79 |
| Phenol | 4220 | 6600 | - | 2540 | 4500 | 2565 | 4200 | 4400 | 2400 | 8 | 3930 | 1410 |

Table 1b

Injectate Composition Through Time (con't)
(in parts per million)

| Species | 1/3/85 | 2/23/87 | 4/20/87 | 12/7/87 | 3/1/88 | 6/13/88 | 8/22/88 | 12/5/88 | 2/20/89 | 6/5/89 | 6/15/89 | 11/20/89 | 3/28/90 | No. of Samples Through 3/28/90 | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Na | - | - | - | - | - | - | - | - | - | - | 5080 | 11000 | - | 4 | 8770 | 2590 |
| Ca | - | 49 | 12.4 | 26 | 23 | 20 | 19 | - | 17 | 30 | 21 | 38 | - | 12 | 25 | 11 |
| Cl | - | - | - | - | - | - | - | - | - | - | 2790 | 1900 | - | 4 | 1625 | 933 |
| $SO_4$ | - | - | - | - | - | - | - | - | - | - | 1790 | 14000 | - | 4 | 8790 | 5100 |
| $NH_3$-H | 190 | 818 | - | 1590 | 563 | 640 | - | - | 1000 | 570 | 81 | 560 | - | - | - | - |
| TDS | 19000 | - | 25000(?) | 36000 | 25000 | 25000 | 19000 | 25000 | 14000 | - | - | - | - | 14 | 21500 | 5850 |
| SpC | - | - | 20000 | 24000 | 22450 | 22500 | 15000 | 24000 | 20000 | - | - | - | - | - | - | - |
| SpG | - | - | 1015 | - | 1.0158 | 1.0174 | 1.0085 | 1.0172 | - | - | 1.01 | - | - | - | - | - |
| pH | 10.6 | - | 10.3 | 10.1 | 10.5 | 10.9 | 10.6 | 10.7 | 10.7 | - | 12.4 | 11.56 | - | - | - | - |
| T(C) | - | - | 28.3 | 24.8 | 24 | 25 | 25 | 26 | 27 | - | - | - | - | - | - | - |
| Acetic Acid | 320 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Acetone | 420 | 410 | 1500 | 2000 | 2700 | 500 | 82 | - | 1300 | 880 | - | 600 | 770 | 20 | 818 | 641 |
| Acetophenone | 80 | 200 | 70 | 140 | 130 | 110 | 110 | - | 22 | 190 | 94 | - | - | 12 | 216 | 249 |
| Aniline | 140 | 110 | 45 | - | 78 | 58 | 26 | - | 40 | 54 | 18.8 | - | - | 16 | 90 | 90 |
| Formic Acid | 1100 | - | - | - | - | - | - | - | 1800 | 3900 | 1681(?) | - | - | 7 | 1430 | 1190 |
| Phenol | 4000 | 97 | 520 | 2300 | 3600 | 1200 | 1100 | - | 1200 | 2000 | 1300 | 250 | - | 19 | 2580 | 1755 |

Table 2

Mean concentrations of species in the injectate used in mixing calculations in ppm. (See discussion of phenol in the footnote). SD denotes one standard deviation of the mean. Mean injectate concentrations were computed from all the available data for the period 1981-1989. Mean concentrations of species in the injectate samples obtained during the period 1981-1984 are also shown separately because of their relatively high phenol concentrations. (See Table 1 and Fig. 1).

| | 1981-1984 | | | 1981-1989 | | | |
|---|---|---|---|---|---|---|---|
| Species | No. of Anals. | Mean | SD | No. of Anals. | Mean | SD | Remarks |
| Na | 2 | 9500 | 707 | 4 | 8770 | 2590 | Inorganics probably relatively constant 81-89' |
| Ca | 2 | 21 | 11 | 12 | 25 | 11 | |
| Cl | 2 | 905 | 375 | 4 | 1625 | 933 | " |
| $SO_4$ | 2 | 9680 | 813 | 4 | 8790 | 5100 | " |
| TDS | 6 | 18800 | 3870 | 14 | 21500 | 5850 | " |
| Acetone | 9 | 577 | 281 | 20 | 818 | 641 | Incr. 84-89' (?) |
| Acetophenone | 8 | 344 | 337 | 18 | 216 | 249 | Decr. 84-89' (?) |
| Analine | 7 | 123 | 126 | 16 | 90 | 90 | Decr. 84-89' (?) |
| Formic Acid | 3 | 1010 | 79 | 7 | 1430 | 1190 | Slight incr. after 1984 (?) |
| Phenol* | 8 | 3930 | 1410 | 19 | 2580 | 1755 | Decr. 84-89' |

*Based on the graph of phenol in injectate with time in Fig. 1, the 'grand' average from 1978-1984 is 5800 ± 1900 ppm, and from 1974-1984 is 5100 ± 2100 ppm. The latter figure has been used in all mixing calculations.

Although data variability is large, the data for phenol in Table 2 suggests that its concentrations decreased after 1984, consistent with the plot in Figure 1. Because the number of phenol analyses used to derive the mean values plotted in Figure 1 greatly exceeds the number in Table 1, mean phenol concentrations based on Figure 1 data are considered the more representative, and an average 1981-1989 value of 5100+2100 ppm for phenol in the injectate is assumed in subsequent mixing calculations.

## 2. Groundwater Geochemistry

Very limited information is available regarding the natural composition of groundwaters underlying the Haverhill Area prior to the start of injection in 1968. What is known is based on drill stem tests conducted in WDW No. 1 in 1968, which collected samples from several formations, including the Mt. Simon and Rose Run. Sampling from the Berea sand under the site at a depth of 713-733 ft, indicated that the water was brackish with Na, Cl and TDS concentrations of 1730, 3480 and 6600 ppm, respectively. Evidence discussed in Section D.2.4.2 of this report indicates that these concentrations were lower than actually present in the formation, and had been diluted by drilling-mud fluids. Based upon the same 1968 sampling effort, the Lockport (Newburg) Formation at 1795-1835 ft contained brines with respective Na, Ca, Cl $SO_4$, and TDS concentrations of 46,900, 39,600, 170,000, and 266,000 ppm. These Lockport concentrations differ little from values for the same

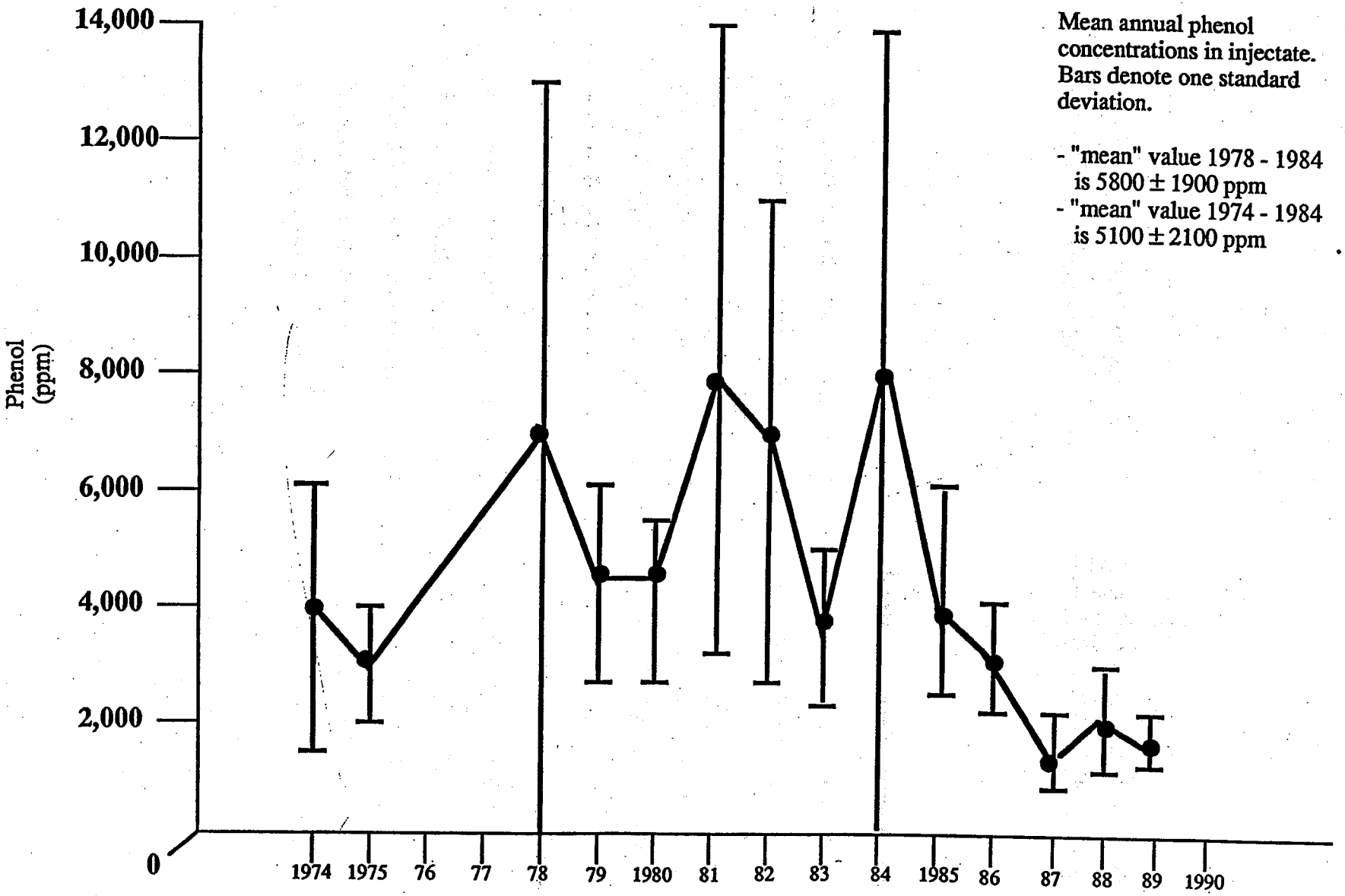


Figure 1. Mean Annual Phenol Concentrations in Injectate with Standard Deviations from 1974 to 1989

Table 3

Compositions of waters used in mixing calculations involving the 1968 and 1989 Mt Simon and Rose Run Formations, in ppm. Average injectate concentrations of organic species are for the period 1981-1984 (see Table 2) unless otherwise indicated. Uncertainties are one standard deviation of the mean. See Table 2 for the number of injectate sample analyses used in the averages. When June 15, 1989 analyses of Rose Run No. 1 and No. 2 wells were reported for a given species, the two analyses have been averaged. Average Mg and Br in the injectate are estimates.

| Species | Mt. Simon | | Rose Run | | Average Injectate |
|---|---|---|---|---|---|
| | 1968 | 1989 | 1968 | 1989 | |
| Na | 58,300 | 14,000 | 54,100 | 45,600±1340 | 8770±2590 |
| Mg | 7080 | 424 | 7610 | 5490±830 | 10 (est) |
| Ca | 50,600 | 2850 | 39,800 | 38,500 | 25±11 |
| Cl | 200,000 | 21,200 | 176,000 | 165,000±7070 | 1630±933 |
| Br | 2160 | 200 | 1950 | 1630 | 5 (est) |
| $SO_4$ | 140 | 2490 | 74 | 355±35 | 8790±5100 |
| TDS | 316,000 | 48,400 | 278,000 | 279,000±12,000 | 21,500±5850 |
| Acetone | - | 800 | - | 141±98 | 577±281 (81-84) 818±641 (81-89) |
| Acetophenone | - | 35 | - | 6.3±0.4 | 344±337 |
| Analine | - | 3.1 | - | - | 123±126 |
| Formic Acid | - | 1335 | - | 175±8 | 1010±79 (81-84) 1430±1190 (81-89) |
| Phenol | - | 940 | - | 460±85 | 5100±2100 (74-84) |

No chemical analyses to determine the presence of dissolved organic species in the Mt. Simon, Rose Run and other groundwaters was performed on the samples collected in 1968. Consequently, the possible existence of anthropogenically derived organic substances in these formation prior to injection is unknown. However, concentrations of natural organic substances in these brines, which are not associated with petroleum deposits, are unlikely to have exceeded 15 ppm, and were probably below 2 ppm (cf. p. 14, in Thurman, E. M., 1985, Organic Geochemistry of Natural Waters, Martinus Nijhoff/Dr. W. Junk Publishers, Boston. 497 pp).

The remarkable chemical similarity of brines in the Newburg, Beekmantown (Upper Knox), Rose Run, Copper Ridge (Lower Knox) and Mt. Simon Formations, which span a total vertical depth of from about 1800 to 5600 ft., indicates that these groundwaters are either interconnected or have similar histories of evolution. Hydrogeologic data suggests that vertical interconnection is highly unlikely given the presence of several low permeability shale horizons separating these formations in the stratigraphic column. More likely is a similar evolutionary history for these groundwaters. The practically identical stable oxygen and deuterium isotope compositions of Beekmantown, Rose Run and Copper Ridge groundwaters, which have an average delta-$^{18}O$ of $-0.9\pm0.3$ per mil, and delta-deuterium of $-28.8\pm1.3$ per mil, indicates that these waters have a very similar origin.

Examination of Figure 3 in the text, the Generalized Stratigraphic Column, Haverhill Area, shows that between the Lockport and Mt. Simon Formations, the geology is comprised of interbedded carbonates (limestone and dolomite), with minor shales and sandstones. Petrographic data in Table 1 of the text, indicate the presence of anhydrite ($CaSO_4$) in the Precambrian basement and overlying Mt. Simon and Rome Formations. If anhydrite saturation limits Ca and $SO_4$, concentrations, then the molal product of these species should remain roughly constant, regardless of changes in their relative concentrations, in brines of roughly the same salinity. Thus, in 1968 Mt. Simon groundwaters, in which Ca = 50,600 ppm and $SO_4$ = 140 mg/l, the molal product $(mCa)(mSO_4)$ = (1.26)(8.33E-4) = 1.8E-3. In 1989 Mt. Simon groundwaters, which have been altered by mixing with injectate (see Table 3), Ca and $SO_4$ concentrations are 2850 and 2490 ppm, respectively, but the molal product $(mCa)(mSO_4)$ still equals 1.8E-3, indicating that Ca and $SO_4$ concentrations are limited by anhydrite saturation. The anhydrite molal product equals 0.8E-3 in 1968 Rose Run groundwaters, suggesting undersaturation with respect to anhydrite, consistent with the lack of anhydrite reported in the Rose Run. However, 1989 Rose Run groundwater, which has a slightly elevated $SO_4$ concentration, probably because of mixing with sulfate-rich injectate, has an anhydrite molal product of 3.6E-3, at or just above anhydrite saturation.

Because of anhydrite saturation in 1968 and 1989 Mt. Simon groundwaters and in 1989 Rose Run groundwater, it is clear that neither Ca, $SO_4$, nor TDS concentrations can be assumed conserved in mixtures of these waters. Thus, although mixing calculations involving TDS are shown in Tables 4 and 6, the results are not used in arguments regarding hypothetical mixing proportions. The ubiquitousness of limestone ($CaCO_3$) in the stratigraphic column with which all the groundwaters must therefore be at saturation, also limits Ca concentrations, and argues against the use of Ca as a groundwater tracer.

Although Mg is also considered in the mixing calculations summarized in Tables 4 and 5, it too is a poor groundwater tracer. This is because of its tendency to coprecipitate with $CaCO_3$, and to be adsorbed as pH increases when low pH groundwater mixes with high pH injectate.

All the groundwaters are substantially undersaturated with respect to halite (NaCl), and at these high ionic strengths, Na is unlikely to be significantly involved in adsorption reactions. For such reasons Na is a good groundwater tracer. Also for reasons of non-reactivity, Cl and Br are excellent groundwater tracers. Based upon the above discussion, the species given the most weight in mixing discussions are Na, Cl and Br.

Table 4a

Simple dilution of 1989 Mt. Simon groundwater composition relative to its 1968 composition is given in Column 2. Column 3 lists the volume ratios ($R_V$) of average injectate to 1968 Mt. Simon that would produce the 1989 chemical analyses of the groundwater, shown in Column 4. Column 5 gives concentrations of the listed species that would be present in 1989 groundwater if the average $R_V$ value of 9.2 ± 0.8 (± 97%) for the relatively unreactive species Na, Cl and Br are assumed for all species.

| Species | Dilution 68' to 89' | $R_V$ | Mt. Simon 89'Conc. | Average Conc. if $R_V$ = 9.2 |
|---|---|---|---|---|
| Na | 4.2 | 8.5 | 14,000 | 13,600 |
| Mg | 17 | 16 | 424 | 703 |
| Cl | 9.4 | 9.1 | 21,200 | 21,100 |
| Br | 10.8 | 10 | 200 | 217 |
| TDS | 6.5 | 9.9 | 48,400 | 50,300 |
| Acetone | - | undefined (see text) | 800 | 520 (81-84)<br>737 (81-89) |
| Acetophenone | - | 0.11 | 35 | 310 |
| Analine | - | 0.03 | 3.1 | 111 |
| Formic Acid | - | undefined (see text) | 1335 | 910 (81-84)<br>1288 (81-89) |
| Phenol | - | 0.23 | 940 | 4600 |

Table 4b

Simple dilution of 1989 Rose Run groundwater composition relative to its 1968 composition is given in Column 2. Column 3 lists the volume ratios ($R_v$) of average injectate to 1968 Rose Run groundwater that would produce the 1989 chemical analyses of the groundwater shown in Column 4. Column 5 gives concentrations of the listed species that would be present in 1989 groundwater if the average $R_v$ value of 0.17 ± 0.09 (± 53%) for Na, Cl and Br is assumed for all species. See text.

| Species | Dilution 68′ to 89′ | $R_v$ | Rose Run 89′ Conc. | Average Conc. if $R_v$ = 0.17 |
|---|---|---|---|---|
| Na | 1.19 | 0.23 | 45,600±1340 | 47,300 |
| Mg | 1.39 | 0.39 | 549±830 | 6470 |
| Cl | 1.07 | 0.07 | 165,000±7070 | 150,000 |
| Br | 1.20 | 0.20 | 1630 | 1660 |
| TDS | 1.00 | undefined | 279,000±12000 | 240,000 |
| Acetone | - | 0.32 | 141±98 | 87 or 123 |
| Acetophenone | - | 0.02 | 6.3±0.4 | 52 |
| Formic Acid | - | 0.14(81-84)<br>0.21(81-89) | 175±8<br>175±8 | 152<br>215 |
| Phenol | - | 0.10 | 460±85 | 765 |

Table 5

Volume ratio ($R_v$) of 1968 Rose Run to 1989 Mt. Simon groundwaters, which would produce the average concentrations of solute species reported in the 1989 Rose Run groundwater analysis given in Column 3, and the average concentrations of the same species expected in 1989 Rose Run groundwaters, assuming $R_v = 0.19 \pm 0.10$ (± 53%), the average of the $R_v$ values for Na, Cl, and Br. Concentrations are in ppm.

| Species | $R_v$ | Rose Run 89'Conc. | Average Conc. if $R_v = 0.19$ |
|---|---|---|---|
| Na | 0.27 | 45,600±1340 | 47,700 |
| Mg | 0.42 | 5490±830 | 6460 |
| Cl | 0.08 | 165,000±7070 | 151,000 |
| Br | 0.22 | 1630 | 1670 |
| Acetone | 0.21 | 141±98 | 128 |
| Acetophenone | 0.21 | 6.32±0.4 | 5.6 |
| Formic Acid | 0.15 | 175±8 | 214 |
| Phenol | 0.96 | 460±85 | 150 |

Table 6

Volume ratio ($R_v$) of 1968 Mt. Simon groundwater to average injectate, which would displace Rose Run groundwaters, producing the average concentrations of solute species reported in the 1989 Rose Run groundwater analysis given in Column 3, and the average concentrations of the same species expected in 1989 Rose Run groundwaters, assuming $R_v = 0.29 \pm 0.07$ ($\pm$ 24%), the average of the $R_v$ values computed for Na, Cl, and Br. Concentrations are in ppm.

| Species | $R_v$ | Rose Run 89'Conc. | Average Conc. if $R_v = 0.34$ |
|---|---|---|---|
| Na | 0.34 | 45,600±1340 | 47,400 |
| Mg | 0.29 | 5490±830 | 5520 |
| Cl | 0.21 | 165,000±7070 | 160,000 |
| Br | 0.33 | 1630 | 1690 |
| TDS | 0.14 | 279,000±12,000 | 251,000 |
| Acetone | 0.32 | 141±9 | 127 (81-84)<br>180 (81-89) |
| Acetophenone | 0.02 | 6.3±0.4 | 76 |
| Formic Acid | 0.21 (81-84)<br>0.14 (81-89) | 175±8 | 222 (81-84)<br>315 (81-89) |
| Phenol | 0.10 | 460±85 | 1120 |

## 3. Mixing of Fluids

### 3.1 Proof of Mixing with Injectate

Proof that mixing or original groundwaters with injectate or with injectate-affected groundwaters has taken place must be based on two observations. First, such a mixture must be more dilute than original groundwaters, and second, it must contain organic substances which are specific to the Aristech injectate, at high enough concentrations to only have been derived from mixing with injectate.

That dilution of inorganic species concentrations will occur upon mixing with injectate, reflects the fact that except for sulfate concentrations, which are high in the injectate, injectate concentrations of inorganic species are much lower than they are in natural groundwaters from the Haverhill area. (Compare the concentration data in Table 6 and Fig. 7 of the text). Thus any mixing of injectate with natural groundwaters will cause dilution in the concentrations of these species in the mixtures. Consequently, if a comparison of chemical analyses from the same formation at different times does not show significant dilution of the inorganics, then mixing with injectate cannot have occurred.

## 3.2 Theoretical Basis

A useful approach to evaluating the possibility that 1989 Mt. Simon and Rose Run groundwaters have resulted from mixing with injectate, is to compare hypothetical mixtures involving the 1968 compositions of these waters, with their 1989 compositions. The comparison is done for individual chemical species or properties whose concentrations are known or can be assumed in each water.

If there are no additions or losses of a chemical species upon mixing of injectate and initial groundwater, that species' concentration in the mixture ($C_M$) is related to its concentration in the injectate ($C_I$) and in the initial groundwater ($C_G$) by the equation:

$$C_M V_M = C_I V_I + C_G V_G \qquad (1)$$

where the V terms are the corresponding volumes. If we assume for simplicity that $V_M = V_I + V_G = 1$, then algebraically we can manipulate equation (1) to solve for the ratio of the volume of injectate that would be mixed with a volume of initial groundwater, to produce the species concentration in the resultant groundwater. Labeling this ratio, $R_V$, we find it equals:

$$R_V = \frac{V_I}{V_G} = \frac{C_G - C_M}{C_M - C_I} \qquad (2)$$

Equation (2) is the basis for calculating the volume ratios ($R_V$ values) in Tables 4-6, which are discussed in following sections of this report.

The uncertainties shown with the $R_V$ values in following text and tables equal one standard deviation of the mean value shown. Following parenthetic values are the percentage uncertainties that those standard deviations represent. In general, those hypothetical mixing processes which have the smallest percentage uncertainties are more likely to have occurred than processes having larger percentage uncertainties.

### 3.3 Assumed Compositions of Injectate, and Mt. Simon, Rose Run and Copper Ridge Groundwaters Used in Mixing Calculations

Calculation of the hypothetical composition of mixtures and of mixing volumes requires that concentrations of certain chemical species in all the waters involved in the calculation be known. Listed in Table 3 are concentrations of those chemical species for which data exist for average injectate, and for 1968 and 1989 Mt. Simon and Rose Run groundwaters. It is assumed in all mixing calculations that concentrations of acetone, acetophenone, analine, formic acid and phenol in the 1968 groundwaters were zero. Even if a few tens of ppm of these species were present before deep well injection, it would not significantly change the results of the mixing calculations.

## 3.4 1989 Mt. Simon Groundwaters

That Mt. Simon groundwaters have been substantially diluted with respect to their inorganic species is evident from the dilution factors listed in column 2 of Table 4a. The dilution factor is the ratio of a species concentration in the 1968 analysis to its concentration in the 1989 analysis in Table 3. The most convincing species to define the extent of dilution are Na, Cl and Br, which are practically inert in this groundwater system.

A more useful exercise, however, is to compute the volumes of 1968 Mt. Simon groundwater and average injectate, which upon mixing would create 1989 Mt. Simon groundwater. Using the water compositions given in Table 3, and equations from Section C.3.1, we can determine $R_V$, the volume ratio of injectate to 1968 Mt. Simon groundwater that would produce the concentrations of each species found in the 1989 Mt. Simon. The results are shown in column 3 of Table 4a. The inorganic species Cl, Br and Na, are among the least reactive in the groundwater. Their $R_V$ values in Table 4a suggest that 1989 Mt. Simon groundwaters were probably created by the mixing of about 9.2 parts injectate with 1 part initial (1968) groundwater. The $R_V$ value of 9.2 corresponds to the following mixture:

89′ Mt. Simon = 90% (injectate) + 10% (68′ Mt. Simon)

Acetophenone, analine and phenol all have lower $R_v$ values than 9.2, consistent with their attenuation in the groundwater system. The extent of attenuation is suggested by comparing their measured concentrations in 1989 Mt. Simon groundwaters (column 4 of Table 4a) to concentrations predicted assuming they all have an $R_v$ value of 9.2 (column 5 of Table 4a). For TDS, Na, Cl and Br, the predicted values based on $R_v$ = 9.2 are all within analytical uncertainties of measured 1989 concentrations. (The TDS agreement is probably fortuitous. See discussion of anhydrite saturation in the Mt. Simon in Section 2 of this Appendix). Among the organic species, acetone and formic acid concentrations in the 1989 Mt. Simon are slightly higher than predicted assuming the highest injectate concentrations of these species. This suggests that 'average' injectate concentrations of acetone and formic acid contributing to the mixture with Mt. Simon groundwaters, may be somewhat higher than suggested in Table 3. Among the remaining organic species, all have been attenuated relative to their

injectate concentrations, with the extent of attenuation increasing from phenol (80% lost), to acetophenone (89% lost), to analine (97% lost). The logic of these overall results, especially the almost identical $R_V$ values for Na, Cl and Br, is quite consistent with the conclusion that 1989 Mt. Simon groundwaters have been formed by mixing average injectate with the original Mt. Simon groundwater, as sampled in 1968.

One can probably assume that the extent of attenuation of organic substances from the injectate as evidenced by analyses of 1989 Mt. Simon fluids is relatively minimal, given the proximity of these waters to the injection well and their short residence times. One might expect then, that any mixing with injectate which also involved fluid migration and more time in the formations would show equal or greater attenuation of injectate organic compound concentrations that observed in 1989 Mt. Simon fluids.

### 3.5 1989 Rose Run Groundwaters

That 1989 Rose Run groundwaters may have formed by mixing of injectate and original Rose Run waters as sampled in 1968, is less convincing. Table 4b gives the results of such a mixing calculation. The $R_V$ average for Na, Cl, and Br is $0.17 \pm 0.09 (\pm 53\%)$ This corresponds to the following mixture:

89'Rose Run = 15% (injectate) + 85% (68' Rose Run)

The data for Na and Br agree and yield an average $R_v$ value of 0.22. However Cl, which should also be conserved, gives inconsistent mixing results, and greatly exceeds its expected concentration in 1989 groundwater. This may, however, reflect an inaccurate chloride analysis of the 1968 Rose Run fluid. Consistent with the above injectate/Mt. Simon mixing calculation, acetone and formic acid show little or no evidence of attenuation upon mixing, whereas the mixing results suggest increasing attenuation of phenol (50% lost) and acetophenone (90% lost).

Calculations can also be performed to test whether 1989 Rose Run groundwaters could have been formed by mixing of 1989 Mt. Simon and original (1968) Rose Run groundwaters. The results of such an exercise are given in Table 5. The resultant average $R_v$ value of $0.19 \pm 0.10 (\pm 53\%)$ corresponds to the following mixture:

89' Rose Run = 16% (89' Mt. Simon) + 84% (68' Rose Run)

Again, the $R_v$ values for Na and Br are consistent with such a

possibility. However, the Cl and phenol data are not. Concentrations of these species in the 1989 groundwater are too high to be explained by such a simple origin, although as noted above the chloride mismatch may reflect an error in the chloride analysis of the 1968 Rose Run groundwater.

If injectate mixed with 1968 (pre-injectate) Mt. Simon groundwaters has displaced preexistent Rose Run groundwaters, then this mixture should approach the composition of 1989 Rose Run groundwaters. A test of this possibility is shown in Table 6. As with the previous hypothetical mixture, $R_v$ values for Na and Br are practically identical. Assuming an average $R_v = 0.29 \pm 0.07 (\pm 24\%)$, concentrations of Cl, Mg, and acetone are also consistent with such an origin for 1989 Rose Run groundwater. This $R_v$ is equivalent to the following mixture:

89' Rose run = 22% (injectate) + 78% (68' Mt. Simon)

## 3.6 1991 Copper Ridge Groundwaters

Organic species concentrations found in groundwaters from the Copper Ridge member of the Lower Knox Formation in the Test/Monitoring Well in 1991, indicate that small amounts of Aristech injectate have found their way into the Copper Ridge. Because Copper Ridge groundwaters have not been previously sampled and analyzed, there is no information to determine the composition of these waters prior to their mixing with injectate. However, the

similarity in composition of groundwaters from the Copper Ridge and the overlying, uncontaminated Rose Run Formation in the test well, suggested that the latter might be considered as a proxy for the pre-injection Copper Ridge. Mixing calculations based upon this assumption are given in Table 7. The average $R_v = 18$ computed from the values for Na, Cl, and Br, is also consistent with the values

Table 7

Mixing calculations to test whether the slightly contaminated groundwater collected in 1991 from the Copper Ridge Member of the Knox Formation at the Test/Monitoring Well could have been formed by mixing of uncontaminated Copper Ridge groundwater and average injectate. Lacking data on the composition of the uncontaminated Copper Ridge, it is assumed in the calculation that the uncontaminated Rose Run groundwaters collected from the test well in 1991 have the same composition as the uncontaminated Copper Ridge. Chemical analytical concentrations are in ppm. $R_v$ is the ratio of volumes of uncontaminated Copper Ridge (91' Rose Run) to average injectate needed to form the 91' Copper Ridge. $R_v = 18 \pm 3$ is the average of the values for the Na, Cl, and Br. Based upon this value, the 91' Copper Ridge = 5% injectate + 95% uncontaminated Copper Ridge.

| Species | $R_v$ Assuming 91' Rose Run + Injectate Produced the Copper Ridge | 91' Copper Ridge | 91' Copper Ridge Less Injectate ($R_v = 18$) | 91' Rose Run |
|---|---|---|---|---|
| Na | 14 | 48,200 | 50,300 | 51,000 |
| Ca | 17.5 | 35,000 | 36,900 | 37,000 |
| Cl | 20.6 | 208,000 | 219,000 | 218,000 |
| Br | 19 | 2090 | 2180 | 2200 |
| TDS | 16.9 | 293,000 | 297,000 | 309,000 |
| Acetone | 6.4 | 110 | 82 | 0 |
| Phenol | 20.2 | 240 | 0 | 0 |

for TDS and phenol. However, the elevated acetone value in the Copper Ridge suggests that the injectate reaching that formation contained much more acetone than the 818 ppm assumed present in the injectate.

Also shown in Table 7 is a back-calculated composition of the original Copper Ridge groundwater, assuming $R_v = 18$. Its remarkable similarity to the 1991 Rose Run at the Test Well, for Ca, TDS and phenol, as well as (as expected) for Na, Cl and Br, supports the original assumption that 1991 Rose Run fluids are a good analog for original Copper Ridge groundwater. The computed presence of acetone in back-calculated original Copper Ridge, again suggests that injectate acetone concentrations may have exceed the average value assumed in the mixing calculations.

### 3.7 1989 Rose Run Groundwaters from Mixing of Injectate with Original Copper Ridge Groundwaters

The mixing calculations discussed in Section 3.6 suggest a fourth possible origin of contamination in 1989 Rose Run fluids, involving the mixing of injectate with original (computed) Copper Ridge groundwaters. Results of such a mixing calculation are given in Table 8. The average $R_v = 0.29 \pm 0.15 (\pm 52\%)$ corresponds to the following mixture:

89' Rose Run = 22% (injectate) + 78% (original Copper Ridge)

The large scatter of $R_v$ values for Na, Cl and Br, cast further doubt on this mixing origin for 1989 Rose Run fluids. Back-

Table 8

Mixing calculations to test whether 1989 Rose Run Groundwaters could have formed by mixing of average injectate with original Copper Ridge groundwaters (91' Copper Ridge less injectate; see text and Table 7). The resultant average $R_v$ based on the values for Na, Cl and Br, is 0.29±0.15(±52%).

| Species | $R_v$ | Rose Run 89' Conc. | Average Conc. if $R_v$ = 0.29 |
|---|---|---|---|
| Na | 0.13 | 45,600±1340 | 41,000 |
| Cl | 0.33 | 165,000±7070 | 170,000 |
| Br | 0.42 | 1630 | 1690 |
| TDS | 0.07 | 279,000±12,000 | 235,000 |
| Acetone | 0.21 | 141±98 | 184 |
| Phenol | 0.10 | 460±85 | 1150 |

calculation indicates that acetone and phenol concentrations in 1989 Rose Run fluids are 23% and 60% lower than would be predicted from such a mixture. However, such attenuation would seem possible. In summary, given that the composition of the original Copper Ridge has itself been estimated, drawing conclusions from this mixing result is obviously rather tenuous.

In spite of the large uncertainties in results of three of the four mixing approaches considered to form 1989 Rose Run fluids, the four approaches lead to a similar conclusion: 1989 Rose Run fluids are comprise of a mixture of 14-22% injectate with an original formation groundwater. (See Table 9 in the text). The lower uncertainty (±24%) associated with the injectate plus 68' Mt. Simon origin for the 89' Rose Run suggests that this origin is the most likely of the four

# INTER-OFFICE MEMORANDUM

W1-08 1508 58
002640

**To** Mr. John Fitzpatrick
USS Chemicals

**Date** June 15, 1968

**From** W. J. Turner

**Subject** Haverhill Drilling Report No. 9

June 2 — Coring Mt. Simon sand. Drilled top of Mt. Simon at 5528, Commenced coring at 5532.

June 3 — Core No. 6: 5532 to 5562 recovered 30 feet. Twenty-seven feet clean white hard sandstone; 3 feet shaly, fine grain hard silty sandstone.

Core No. 7: 5563 to 5573 recovered 10 feet of fine grained, tight silty sandstone, very hard and dense, poor permeability, bleeding salt water.

June 4 — Reamed core hole and drilled from 5573 to 5595. Probable top of Granite wash zone at 5589 indicated by increased penetration rate and granite material in cuttings. Preparing to run drill stem test No. 4 in Mt. Simon sand.

June 5 — DST No. 4 - 5520 to 5565, Mt. Simon sand. Open one hour, recovered 1895 feet (978 gallons) of salt water, specific gravity 1.215. Average flow rate 16.3 gpm. Pressures as follows:

| | Hydrostatic | Flowing | Shut-in |
|---|---|---|---|
| Initial | 2667 | 130 to 714 | 2533 |
| Final | 2623 | 736 to 1072 | 2545 |

June 6 — Core No. 8: 5595 to 5617 recovered 22 feet of granite, no apparent porosity. DST No. 5 - 5575 to 5617 (granite zone) open one hour, recovered two feet of drilling mud; pressures as follows:

| | Hydrostatic | Flowing | Shut-in |
|---|---|---|---|
| Initial | 2699 | 30 to 30 | 2347 |
| Final | 2677 | 30 to 30 | 2210 |

Results indicate permeability too low in granite to be practical for disposal. Schlumberger checked resistivity of water samples recovered from DST's as follows:

| DST No. | Zone | Depth | Sample Temp °F | $R_w$ Ohm-meters |
|---|---|---|---|---|
| 2 | Newburg | 1795-1835 | 71 | .051 |
| 3 | Rose Run | 4220-4265 | 71 | .072 |
| 4 | Mt. Simon | 5520-5565 | 73 | .076 |

June 7 Completed running Schlumberger electric logs at 2:00 a.m. Waiting on delivery of casing hanger.

June 8 Waiting on casing hanger part of well head.

June 9 Still waiting.

June 10 Still waiting. Ran drill pipe in hole to circulate and condition mud in preparation for laying down drill pipe and running casing.

June 11 Laid down drill pipe. Casing hanger arrived on location at noon. Ran 5603.47 feet of 7-inch casing landed at 5600 feet below kelly bushing. Used Baker guide shoe on bottom and Baker insert float valve one joint above bottom. Ran sand coated joints of casing opposite Mt. Simon sand and Rose Run sand. Installed Halliburton DV stage cementing packer collar below Rose Run sand.

Attempted first stage cement job at 11:50 p.m. with 200 sacks of cement. First stage cementing plug failed to seat properly. Continued pumping water after plug until 650 barrels were pumped and tanks were empty. Cement circulated out of hole. Ran wire line measure in hole and found plug at 5325 feet, indicating it had passed through DV collar ok but had failed to seat at bottom. Continuity of circulation indicated possibility that either plug had torn up or casing had a hole in it at about 5325. After circulation was shut down, reverse flow from casing indicated that Baker insert float valve was not functioning.

Cementing attempt was witnessed by State Inspector Harry Smith. After failure of cement job, Inspector Smith was informed that casing would be pulled to investigate cause of failure and that an estimated 36 hours would be required to pull casing, correct the malfunction, re-run it and be ready to cement again.

June 12 Pulled casing to investigate cause of failure. Found two-inch hose adapter nipple with union flange in casing on top of insert float valve. This nipple prevented cementing plug from seating properly. It had accidentally come loose from the end of a two-inch hose which had been used for filling the casing in lieu of the automatic fill-up tube. Pulling the casing destroyed the Baker metal petal basket and also the packer rubber on the Halliburton DV stage cementing packer. Casing was re-run using a Halliburton guide shoe and float collar to replace the Baker equipment which had malfunctioned. It was decided to re-cement in one stage since the packer rubber of the stage collar had been destroyed.

June 13 Completed re-running casing and started pumping single stage cement at 8:25 a.m. Total time lost 32-1/2 hours as a result of foreign object in casing. Cementing completed with 1350 sacks of cement at 9:30 a.m. Cement did not circulate to surface.

Ran total of 5607.38 feet of casing landed at 5605 feet, K.B. Float collar at 5570 or ten feet below bottom of Mt. Simon sand. Hung entire weight of casing on well head casing hanger with internal pressure released. Released rotary rig and waiting on cement to set.

June 14 Ran Schlumberger Temperature Log 13 hours after cementing. Results showed top of cement behind 7-inch casing at 1935 feet, K.B. Cooling anomaly at 1833 to 1838 indicates probable source of salt water and gas flow coming up between 7-inch casing and 10-3/4 inch surface casing. This is the Newburg dolomite zone which was cored and tested.

Failure of primary cement job to circulate to surface was probably caused by excess hole cavings during waiting time for casing hanger and pulling and re-running casing. Cement volume had been calculated on the basis of caliper log run prior to these events. It will be necessary to repair cement job by squeeze cementing after cable tool completion rig moves on.

No rig time was charged to USS Chemicals after June 11 since contractor assumed responsibility for failure of first attempt to cement casing.

WJT bw
cc - Mr. H. L. Hosmer
Mr. J. P. Gravenstreter

# INTER-OFFICE MEMORANDUM

To Mr. John Fitzpatrick
USS Chemicals

Date July 1, 1968

From W. J. Turner

Subject Haverhill Drilling Report No. 10

June 17 Earl Schilling and Son, Contractor excavating cellar and welding 10-3/4" casing head.

June 18 Laid reinforcing bars in 12" lattice and poured 8 inches of 5000 psi concrete for cellar floor.

June 19 Setting forms and 12" reinforcing lattice for cellar walls.

June 20 Finished wall forms and reinforcing. Poured 8" of 5000 psi concrete.

June 21 Removed forms and backfilled around walls.

June 22 Waiting for concrete to cure.

June 23 Moving in Carter Well Service rig.

June 24 Rigged up Carter Well Service and ran 5571 feet of 2-3/8" EUE tubing with 6-1/8" bit and drilled cement plug to 5561 G.L. = 5572 K.B. After reaching desired depth, circulating pump malfunctioned, bit plugged and tubing stuck. Operator pulled too hard on tubing and collapsed mast of Carter's single pole well service unit.

June 25 Moved in Halliburton to circulate well. Broke circulation with 4000 psi pump pressure. Circulated hole clean. Released Carter well service rig.

June 26 Moved in Eastern Well Service rig and pulled 2-3/8" tubing. Ran McCullough Correlation Gamma Ray Log and Cement Bond Log. Bond Log good up to top of cement at 1962 feet K.B.

June 27 Finished logging and perforated Mt. Simon sand with 36 - 80 gram jet shots from 5541 to 5559 K.B. with 2 shots per foot. Swabbed hole down. Fluid rose in casing at rate of approximately 300 to 400 feet per hour. Rate not accurate because of drive chain on rig breaking frequently during swabbing. Swabbed hole down in preparation for 25,000 gallon fracture treatment. Halliburton dumped 1000 gallons of Mod 202 acid on bottom and loaded hole with water. Shut down because of darkness for safety reasons.

June 28 Air trapped in casing escaped overnight allowing fluid level in well to fall. Halliburton finished loading hole and began pumping water at 8:50 a.m. to break down formation with acid. After loading hole, pumped 1620 gallons between 8:54 a.m. and 10:26 a.m. at average rate of 17.7 gpm. Pressure at start was 4000 psi. Gradually increased pressure to 7000 psi. Failed to get breakdown of formation. Perforated additional holes from 5517 to 5541 K.B. with 3 - 80 gram jet shots per foot. Total of 72 shots in 24 feet. Perforations now open extend from 5517 to 5559. Halliburton pressured up on casing again in effort to break down formation. Began pumping at 7:55 p.m. at average rate 23 gpm at 6700 psi. Raised pressure to 7000 psi at 8:10 p.m. and 3" side valve connection on 10-3/4" x 7" spool blew off. Released Halliburton.

June 29 Removed christmas tree to re-weld broken part. Swabbed hole to clean up and test productivity. Recovered substantial quantity of unspent acid from casing. No gauge of productivity because of difficulty in swabbing. Swab rubbers were damaged by tight spot or obstruction in casing at approximate depth of 4100 feet. Ran McCullough collar locater log and Caliper to evaluate possible casing damage. Logs indicated no apparent severe damage. Collar log indicated all perforations to be at correct location and no other holes in casing were detected. Caliper indicated I.D. of casing to be correct within tolerance. Concluded that obstruction may be a piece of perforating carrier strip caught in a collar. Fourteen feet of sheet metal carrier strip was lost in hole on last perforating job.

June 30 Sunday, shut down.

WJT bw
cc - Mr. H. L. Hosmer
Mr. J. P. Gravenstreter

# INTER-OFFICE MEMORANDUM

To Mr. John Fitzpatrick
USS Chemicals

Date July 9, 1968

From W. J. Turner

Subject Haverhill Drilling Report No. 11

July 1 Re-installed casing head after repair and swabbed from bottom recovering salt water and some sand and perforating debris. Fill-up rate estimated at approximately 50 feet per hour. Shut down at 7:30 p.m.

July 2 Had approximately 600 feet of fill-up in casing overnight (12 hours). Swabbed hole to bottom then swabbed and bailed 18.72 bbl in 3-1/2 hours. Ran tubing with Halliburton Hydro-Jet notching tool on bottom. Tool rigged with four jets 90° apart in horizontal plane.

July 3 Cut notches at 5545, 5541, and 5538 pumping sand and water mixture at rate of 6 to 10 bbl per minute with 5000 psi pump pressure. Circulated hole clean to plug depth of 5566. Pulled tubing to remove notching tool.

July 4 Re-ran 2-3/8" tubing with Halliburton RTTS packer with 3 joints of tail pipe below packer. Spotted 500 gallons of 6% HF acid and 9% HCl over perforations and notches. Set packer and pressured up to 4500 psi and formation broke down. Pumped at average rate of 334 gpm at 3000 to 4500 psi after break down. Instantaneous pressure after shut down was 1200 psi indicating 1800 to 3300 psi friction pressure in tubing. Lower friction pressure was with gel mixed in water and higher friction pressure was with water only. Pulled tubing and installed christmas tree. At 7:30 p.m. well was flowing back fresh water at 3.8 gpm = 132 bpd. At 8:30 p.m. shut well in and measured 100 psi shut-in pressure.

At 9:35 p.m. began fracture treatment by pumping 500 gallons of 6% HF and 9% HCl acid ahead of treatment. Pumped 25,000 gallons of gelled water and 30,000 lbs of 20-40 mesh Ottawa sand at rates up to 43 bbl/min (1810 gpm) average treating pressure 2000 psi. Tailed in with 200 lbs 12-20 mesh UCAR props (Union Carbide glass beads). Treatment complete at 9:58 p.m. Instantaneous shut-in pressure 1350 psi. Pressure declined as follows:

| | Time | Pressure |
|---|---|---|
| July 4 | 9:58 pm | 1350 |
| | 11:30 pm | 700 |
| July 5 | 12:30 am | 600 |
| | 1:00 am | 585 |
| | 9:30 am | 340 |
| | 10:30 am | 330 |

July 5 Ran injection test pumping 15 minutes at each rate as follows:

| Injection Rate | | Pressure, |
|---|---|---|
| Bbl/Min | Gal/Min | psi |
| 0.5 | 21 | 389 |
| 1.0 | 42 | 430 |
| 1.5 | 63 | 490 |
| 2.0 | 84 | 540 |
| 2.5 | 105 | 590 |
| 3.0 | 126 | 635 |
| 3.5 | 147 | 690 |
| 4.0 | 168 | 750 |
| 4.5 | 189 | 800 |
| 5.0 | 210 | 880 |
| 5.5 | 231 | 930 |
| 6.0 | 252 | 990 |

Above rates and pressures were measured at the end of the respective 15 minute injection periods. Recorded pressure fall-off after injection test as follows:

| Time After Shut-in, Min | Well Head Pressure, psi |
|---|---|
| 0 | 990 |
| 5 | 640 |
| 6 | 610 |
| 15 | 605 |
| 20 | 600 |
| 25 | 590 |
| 30 | 585 |
| 35 | 580 |
| 40 | 570 |
| 45 | 565 |
| 50 | 560 |
| 55 | 555 |
| 60 | 550 |

Released remaining pressure by flowing well to pit for approximately 2-1/2 hours. Removed christmas tree and McCullough set Baker wire line model N cast iron bridge plug in casing at 1975 feet, K.B. Perforated with four 0.63 inch holes from 1946 to 1952 feet, K.B. State inspector Gilbert Archer witnessed setting of bridge plug and perforating.

July 6 Ran 2-3/8" tubing with Halliburton RTTS packer set at 1800 feet, K.B. Mixed and pumped 500 sacks of regular cement into perforations at 1946 to 1952. Added 2% $CaCl_2$ to last 25 sacks of cement. Had good circulation returns until about half of cement in the returns ceased. Cleared packer and perforations with water. Cementing witnessed by State inspector Gilbert Archer.

Waited 12 hours for cement to set. For second stage cementing of perforations 1946 to 1952, mixed and pumped 225 sacks of light cement with Flocele flakes and 15 lbs of Gilsonite added per sack. Final pressure reached was 450 psi but pressure did not hold. Cleared perforations with water. Second stage squeeze witnessed by State inspector David Edgar.

July 7 Third stage squeeze of perforations 1946 to 1952 started at 10:30 a.m. twelve hours after second stage. During third stage squeezed 85 sacks of light cement with Flocele and Gilsonite added. Used 2% $CaCl_2$ in last 25 sacks. Cleared packer and repeated squeeze pressures for two hours until attaining 3500 psi which held constant. Left 57 feet of cement in casing above perforations. Third stage cement squeeze witnessed by State inspector David Edgar.

July 8 Waiting for cement to set.

July 9 McCullough ran Cement Bond Log from 720 to 1886 feet, K.B. Top of cement indicated at 852. Perforated two 0.63-inch holes at 846. Halliburton pumped 310 sacks of cement down casing with same mixture as on previous squeeze jobs. Followed cement with rubber cementing plug. Pumped plug down to 746 feet leaving approximately 80 feet of cement and 20 feet of water in casing between plug and perforations. Plug down at 8:00 p.m. Waiting on cement to set. Had good circulation return all during job and circulated good cement to surface. Cementing witnessed by State inspector David Edgar.

WJT bw
cc - Mr. H. L. Hosmer
Mr. J. P. Gravenstreter