

CASSVILLE #1 STRATIGRAPHIC TEST BOREHOLE

BARTOW COUNTY, GA

Prepared for:
Georgia Power Company
Atlanta, GA

Under Contract:
U.S. Department of Energy
Cooperative Agreement No. DE-FE0031830

Southern States Energy Board
Southeast Regional Carbon Utilization and Storage Partnership
SECARB USA 931-ARI-2020-001

Prepared by:
Mr. David Riestenberg, Vice President
ADVANCED RESOURCES INTERNATIONAL, INC.
Knoxville, TX

Dr. Jack Pashin, Pashin Geoscience, LLC
Dr. Randall Kath, Petrologic Solutions, Inc.

March 14, 2022

Advanced Resources International, Inc.

Disclaimer

The material in this report is intended for general information only. Any use of this material in relation to any specific application should be based on independent examination and verification of its unrestricted applicability for such use and on a determination of suitability for the application by professionally qualified personnel. No license under any Advanced Resources International, Inc., patents or other proprietary interest is implied by the publication of this report. Those making use of or relying upon the material assume all risks and liability arising from such use or reliance.

Table of Contents

INTRODUCTION **1**

Narrative on Cassville Georgia Strat Test Operations 2

WELL LOG, CORE ANALYSIS, AND X-RAY DIFFRACTION ANALYSIS **6**

Introduction 6

Geophysical Well Logs: Triple Combo 7

FMI Log 11

FMI images 11

Structural interpretation 20

Core Analysis 25

X-Ray Diffraction and thin section Analysis 31

Conclusions 46

GEOLOGIC AND STRUCTURAL SUMMARY **48**

Introduction and Site Selection 48

Regional Geology 50

Regional Stratigraphy 51

Regional Structural Geology 54

Cassville Site Geologic Conditions 56

Borehole Site Stratigraphy 58

Structural Interpretation Based on Borehole Stratigraphy 61

Discussion 62

Assessment 64

REFERENCES **67**

List of Figures

Figure 1: Annotated Drilling Curve, Cassville #1 5

Figure 2: Geophysical well logs and stratigraphic interpretation of the Cassville #1 Borehole 8

Figure 3: Geophysical well log showing results of core analysis in the Rome Formation, Cassville #1 Borehole 9

Figure 4: Distribution of dip measurements and shear zones relative to the stratigraphic section in the Cassville #1 borehole 12

Figure 5: FMI image showing bedding and fracturing in the Pumpkin Valley Shale 13

Figure 6: FMI image showing bedding and dipping shear fractures in the Pumpkin Valley Shale. 14

Figure 7: FMI image showing high-angle fractures in the Rutledge Limestone..... 16

Figure 8: FMI image showing abundant shear fractures in the Maynardville Limestone..... 17

Figure 9: FMI image showing shear zones in the Rutledge Limestone..... 18

Figure 10: FMI image showing a shear zone in dolomite of the Rome Formation. 19

Figure 11: FMI Image showing faulting in the Pumpkin Valley Formation. 21

Figure 12: FMI Image showing folding in the Nolichucky Shale..... 22

Figure 13: Stereoplot of poles to planes of shear fractures imaged in the Cassville #1 borehole. Note clustering of data in the SE quadrant and broad distribution of data in the other quadrants. 25

Figure 14: Porosity-depth profile in the Cassville #1 borehole. Porosity values higher than 7% are restricted to upper Rome porous dolomite..... 26

Figure 15: Permeability-depth profile in the Cassville #1 borehole. Permeability values higher than 1 mD are restricted to upper Rome porous dolomite. 28

Figure 16: Cross-plot of porosity and permeability in the Cassville #1 borehole. Porosity values higher than 7% are restricted to upper Rome porous dolomite..... 29

Figure 17: Oil saturation-depth profile in the Cassville #1 borehole. Oil saturation values higher than 10% are in the upper Rome porous dolomite..... 30

Figure 18: Charts showing the proportions of minerals identified by x-ray diffraction analysis of sidewall core samples from the Cassville #1 well. The shallowest sample is from the Pumpkin Valley Shale, and the remainder are from the Rome Formation. 33

Figure 19: Thin section photomicrograph of arkosic sandstone from the lower Pumpkin Valley Shale (3,508 ft). Note vuggy pores with sparry calcite fill (red stain) and dark, clay-lined pressure solution seams traversing the sample..... 34

Figure 20: Thin section photomicrograph of porous dolomite from the upper Rome Formation (3,713 ft). Note vuggy porosity (blue epoxy) and dispersed detrital quartz and feldspar grains (white)..... 35

Figure 21: Photomicrograph of porous dolomicrite from the upper Rome Formation (3,746 ft). Note vuggy pores (blue epoxy) lined by quartz grains (white) and with sparry calcite cement (red stain)..... 37

Figure 22: Photomicrograph of finely crystalline porous dolomite in the upper Rome Formation. Abundant porosity (blue epoxy) includes intergranular, vuggy, and fracture pores. Quartz grains (white) are dispersed in the sample, and sparry calcite cement (red stain)..... 38

Figure 23: Photomicrograph of porous conglomeratic dolomite from the upper Rome Formation (3,799 ft). Note interparticle and vuggy pores (blue epoxy), quartz grains between clasts (white), and sparry calcite cement (red stain)..... 39

Figure 24: Photomicrograph of fractured and porous dolomite in the upper Rome Formation..... 41

Figure 25: Photomicrograph of intensely veined dolomite in the upper Rome Formation (3,814 ft). Note localized pores (blue epoxy) in large vein cross-cutting specimen and quartz veins developed along small, irregular fractures (white)..... 42

Figure 26: Photomicrograph of gypsum in the upper Rome Formation (3,867 ft). Note dolomite bodies (brown), abundant quartz grains (white), and porosity (blue epoxy) between fibrous gypsum crystals. 43

Figure 27: Photomicrograph of fractured dolomite in the upper Rome Formation (3,894 ft). Note large vein crossing image containing fibrous gypsum (brown), sparry calcite (red stain), and porosity that is restricted to a fracture running along the vein (blue epoxy). 45

Figure 28: Geologic cross section (Panel 2) from Thomas and Bayona (2005) showing Cassville test boring. 56

Figure 29: Modified geologic cross section from Whisner (2010). 56

Figure 30. Geologic cross section from Rome, GA (A) to east of Cartersville., GA (A'). Surface geologic mapping data from the Rome South, Wax, Kingston, Cartersville, and Allatoona Dam Georgia 7.5-minute geologic quadrangles. (Zc- Corbin Meta-Granite; Zou- Ocoee Group undifferentiated; Cchu- Chilhowee Group undifferentiated; Cs- Shady Dolomite; Cr- Rome Formation, Cc- Conasauga Group undifferentiated; OCk- Knox Group undifferentiated) 64

List of Tables

Table 1: Results of routine core analysis in the Cassville #1 borehole. 27

Table 2: Whole rock mineralogy based on x-ray diffraction analysis of sidewall core samples from the Cassville #1 borehole. 32

Table 3: Clay mineralogy based on x-ray diffraction analysis of sidewall core samples from the Cassville #1 borehole. 32

Table 4: General Stratigraphic breaks based on mud logging by SLG Resources. 59

Table 5: Detailed stratigraphic descriptions based on mud logging by SLG Resources. 60

INTRODUCTION

The Cassville #1 Stratigraphic Test Borehole was drilled in the Valley and Ridge geologic province on Bartow County, Georgia, to explore the potential for geologic storage of carbon dioxide proximal to Plant Bowen and Plant Hammond. Located on a flood plain at -84°54'21" W, 34°14'22" N, the borehole was drilled at an elevation of 719 feet. Total depth of 6,030 feet below ground surface was reached on 9/3/2021, but logging was conducted from 5,000 feet to 100 feet below ground surface due to operational issues caused by the regional structure and detailed in the report sections below. Georgia Power contracted Advanced Resources International to drill the test boring location, collect well logs and sidewall core samples, and analyze the collected data.



This report presents in the following sections a description of the drilling, logging, log analysis, regional geology, and geologic structure. Characteristics of a potential target

would include a reservoir pore space in which to sequester the carbon dioxide, an impermeable and continuous caprock to prevent migration of fluids into underground sources of drinking water, and sufficient reservoir permeability to inject the captured CO_2. The Rome formation beneath the Cassville site appears to meet these screening criteria. The report on well log, core analysis, and x-ray diffraction analysis has been written by Dr. Jack Pashin of Pashin Geoscience and the report on the geologic and structure was written by Dr. Randall Kath of Petrologic Solutions.

Narrative on Cassville Georgia Strat Test Operations

The Cassville #1 Stratigraphic Test Borehole was drilled in Bartow County, Georgia to explore the potential for geologic storage of carbon dioxide proximal to Plant Bowen and Plant Hammond. Located on a flood plain at -84°54’21” W, 34°14’22” N, the borehole was drilled at an elevation of 719 feet. The Cassville Georgia deep geologic borehole is drilled in Kingston, Georgia within Bartow County. Its purpose is to collect lithologic, stratigraphic, and petrophysical data on the subsurface geology to determine the feasibility of CO_2 storage in northwestern Georgia. The borehole was spud on August 10th, 2021, following site preparation and mobilization of the drill rig to Kingston, Georgia. Conductor casing was set at 40 feet below ground surface (BGS), where hard rock was quickly encountered. Initially, the near-surface bedrocks consisted of limestone, dolostone, and chert. Because of the lack of pore space, highly cemented hard crystalline lithologies, and chert content, the drilling rate averaged approximately 2 feet per hour for the first portion of drilling with a 12 1/4” bit. Immediately after commencing drilling, natural fractures were encountered at a depth of 65 feet. The drilling mud was lost to the formation, and operations stopped until a cement truck arrived on location to spot cement and seal off the fractures to prevent further loss of drilling mud and contamination.

After allowing the cement to set, drilling continued with a slow Rate of Penetration (ROP) between 2 and 4 feet per hour until another network of fractures was encountered at 261 feet on August 14th. Drilling mud was lost, and two slugs of Lost Circulation Material (LCM) were pumped to develop a mud cake and seal off the fractures. These efforts proved unsuccessful, and cement was called back to location to fully seal the

fractures. The first slug of cement was absorbed into the highly fractured formation, and a second batch of cement was mixed and pumped into the borehole. After the cement had set, the borehole was drilled out until new hole could be made below the now-sealed fractures. As the drill pipe reached greater depths, the drill string weight increased which allowed more weight to be put on the bit and subsequent incremental increases in ROP. However, the increased weight on bit coupled with the hard rock wore out drill bits faster, so they were changed frequently as necessary to maximize efficiency and maintain improved ROP.

Circulation of the drilling mud was lost at a depth of 607 feet. With surface casing on location, the decision was made to set surface casing to a depth of 606 feet, one foot above total depth. The surface casing was prepared, welded, and run in the hole. The Blowout Preventer (BOP) was welded to the casing, providing a safety measure to maintain borehole control. Cement was pumped through surface casing and into the annular space between the surface casing and the open borehole. Due to the formation fractures, the cement level slowly fell from surface, and additional cement was placed in the annulus from surface. After allowing the cement to set, a Cement Bond Log (CBL) was deployed on wireline and determined adequate coverage behind surface casing. Afterward, the BOP was nippled up and successfully pressure tested to ensure operational safety during continued drilling.

The larger 12 1/4” bit was swapped for a smaller 8 3/4” bit to fit through the surface casing, which enabled higher drilling rates. With shallower geologic zones isolated by surface casing and a BOP in place, rotary rotation was increased along with mud circulation rates. Once out of the hard rock formations at a depth of approximately 825 feet, the tri-cone bit was swapped for a PDC bit, to improve drilling in the limestone and shale intervals. At this depth, chert was no longer encountered, suggesting a stratigraphic transition from the Knox Group into the Conasauga Group. The combination of these factors increased the drilling rate to 30 feet per hour, with periods exceeding 60 feet per hour. Drilling continued at this increased speed to a depth of approximately 1,600 feet and the borehole was noted to have a slight deviation.

The deviation of the borehole was an anticipated complexity. Geologic beds in this area are steeply dipping, which creates an operational challenge to maintain a vertical borehole trajectory. In preparation for the steeply dipping beds, the Bottomhole Assembly (BHA) was packed with stabilizers to help maintain a straight hole and was equipped with a Teledrift tool which surveys the inclination of the borehole. Once the inclination was measured above 4 degrees, Weight on Bit (WOB) was decreased, and the stabilizers were placed further away from the bit. These efforts decreased the drilling rate, and a directional drilling crew was brought to site to straighten the borehole and return the borehole to a vertical trajectory. Once rigged up, the directional drillers straightened the borehole while maintaining ROPs averaging around or above 30 feet per hour. At a depth of approximately 2,435 feet, clastic rocks were encountered in the form of siltstone. This transitioned to sandstone starting at a depth of 2,580 feet. For another 700 feet, the sandstone package continued until shale and limestone was encountered at a depth of 3,280 feet. Shale dominates the section until 3,500 feet, after which sandstone and siltstone dominate the lithology with shale and limestone. Shale becomes the dominant lithology starting at 4,820 feet with a minor component of sandstone. Limestone and sandstone return at a depth of approximately 5,720 feet, and slate is encountered around and below the target depth of 6,000 feet. The borehole reached a Total Depth (TD) of 6,030 feet.

After the borehole was drilled, logging tools were trucked to location and run in the hole by Schlumberger. First, a triple combo was run in, which consists of resistivity measurements, gamma ray, spontaneous potential (SP), and porosity. The SP measurements encountered issues while logging and was not re-run to correct. Afterwards, the sonic tool and Formation Micro-Imager (FMI) tool were run together. Locations were selected for sidewall coring based on the triple combo suite, and the sidewall coring tool was run. Of the 25 samples attempted, 17 remained in suitable condition and were sent to Schlumberger's laboratory for Routine Core Analysis (RCA).

With the targeted information collected from the borehole, cement was mixed and pumped into the open hole to plug and abandon the borehole. Cement was pumped in 500-foot sections, allowing 2 hours between plugs to allow the cement to set. Once the

entire borehole was filled with cement, it was allowed to set overnight. If necessary, more cement could be added from the surface if the cement level dropped. Once cement was set, a 1/2" thick steel plate was welded 5 feet below ground surface and the borehole was buried. The site equipment was trucked off location and the worksite reclaimed. Shown below is an annotated drilling curve highlighting key moments in the drilling of the borehole. **Figure 1** shows a drilling curve for the Cassville #1 borehole.

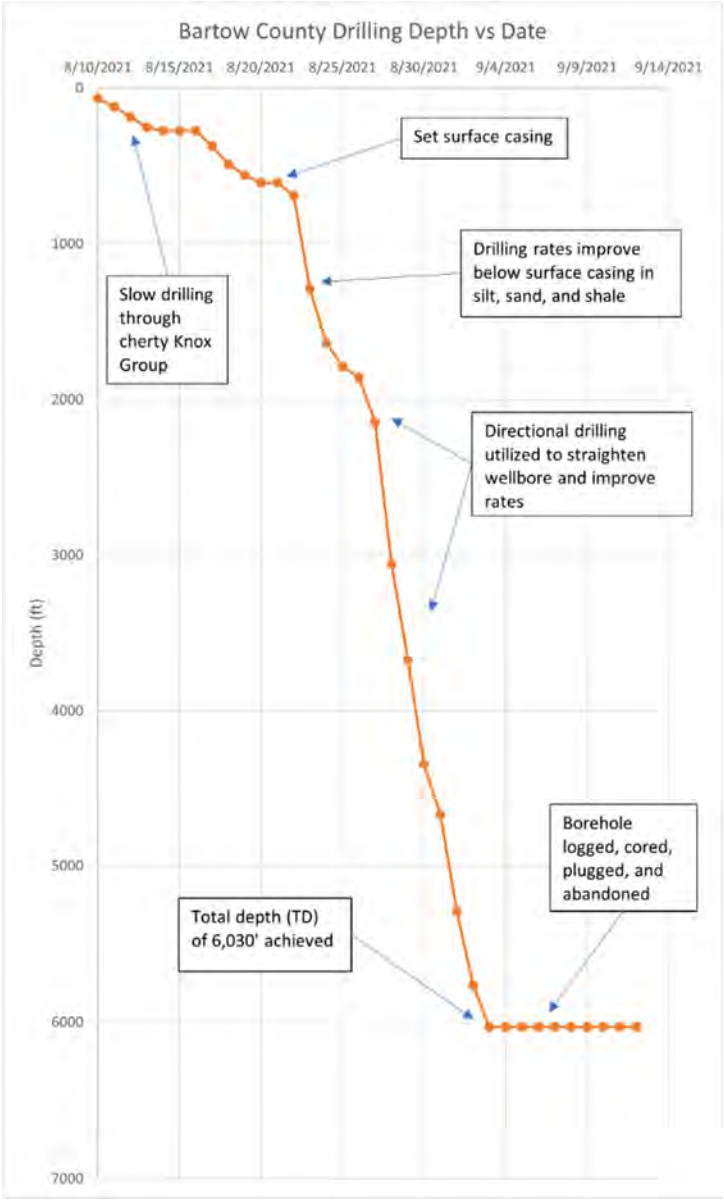


Figure 1: Annotated Drilling Curve, Cassville #1.

WELL LOG, CORE ANALYSIS, AND X-RAY DIFFRACTION ANALYSIS

By: Dr. Jack Pashin, Pashin Geoscience, LLC

Introduction

The Cassville #1 well was drilled in the southern Appalachian thrust belt near Cassville, Georgia to explore for potential geologic CO_2 sinks in Cambrian strata. The location of the well is -84°54'21" W, 34°14'22" N. The well was drilled at a surface elevation of 719 ft and reached a total depth of 6,030 ft. The lower section of the well is tortuous because of structural deformation, and so the well was logged from a depth of 5,000 ft to a near-surface depth of 100 ft. The mud log and geophysical well logs record a thick succession of Cambrian-Ordovician carbonate and siliciclastic strata, including the Rome Formation, Conasauga Group, and the basal part of the Knox Group (Copper Ridge Dolomite). Surface casing was set at to a depth of 606 ft, in the Maynardville Limestone, which forms the top of the Conasauga Group, and the log suite includes SP, resistivity, density, density and neutron porosity, sonic, and FMI logs and records a broad range of rock properties between 4,980 and 606 ft. After logging, 18 sidewall cores were recovered from depths ranging from 4,421 to 2,234 ft. Routine core analysis was performed to determine basic reservoir properties (porosity, permeability, fluid saturation), and X-ray diffraction analysis was performed to determine the mineralogy of selected samples.

This report summarizes the results of geophysical log analysis and core analysis and focuses on geologic interpretation of these results. The report begins with a discussion of the geophysical well logs, including interpretation of rock types, rock properties, stratigraphic interpretation, and structural interpretation. The FMI log was critical for structural interpretation and yields high-quality borehole images in most intervals, as well as data on structural dip and natural fracture systems. Routine core analysis was performed by the Dean-Stark method by Schlumberger, and this report presents and interprets the results of this analysis. X-ray diffraction results, and thin section analysis also are discussed, and the report concludes with interpretation of the CO_2 storage potential of the Cassville area based on the drilling and analytical results.

Geophysical Well Logs: Triple Combo

Interpretation of the deepest part of the geophysical well log is complicated by heterogeneous stratigraphy and wellbore expansion beyond a depth of 4,180 ft. The basal part of the well contains interbedded limestone and shale, which may be part of the Nolichucky Shale, which is in the upper part of the Conasauga Group (**Figure 2**). A major thrust fault may be present at a depth of about 4,780 ft that places the Rome Formation (Lower Cambrian) on top of the Nolichucky Shale (Upper Cambrian). Above this, the geophysical well logs appear to record a normal stratigraphic section in proper succession from the Rome Formation to the upper part of the Conasauga Group.

The lower part of the Rome Formation is dominated by interbedded shale, limestone and perhaps some dolostone (**Figure 2**). Interpretation is complicated by caving and expansion of the borehole as indicated by the caliper tool, which resulted in inconsistent contact between the logging tools and the wall of the borehole. Accordingly, examination of well cuttings helps provide support for the lithologic interpretation, which is based primarily on the geophysical well logs. The upper part of the Rome Formation consists mainly of dolomite and shale with some interbeds of limestone. The mud log records principally sandstone and limestone in this interval, but analysis of well logs and cuttings indicate that dolomite and dolomitic shale are the dominant rock types in this interval. A thick dolomite section (198 ft) is present between 4,090 and 3,892 ft and appears nonporous except at the very top. Dolomite beds tend to thin upward in the upper part of the Rome section, ranging in thickness from 2-32 ft. Most of the mudstone in the Rome Formation is dark gray, and mudstone with reddish hues is present in the upper 300 ft of the formation. The porosity logs indicate that some of the dolomite units in the upper Rome have porosity between 5 and 15% (**Figure 3**).

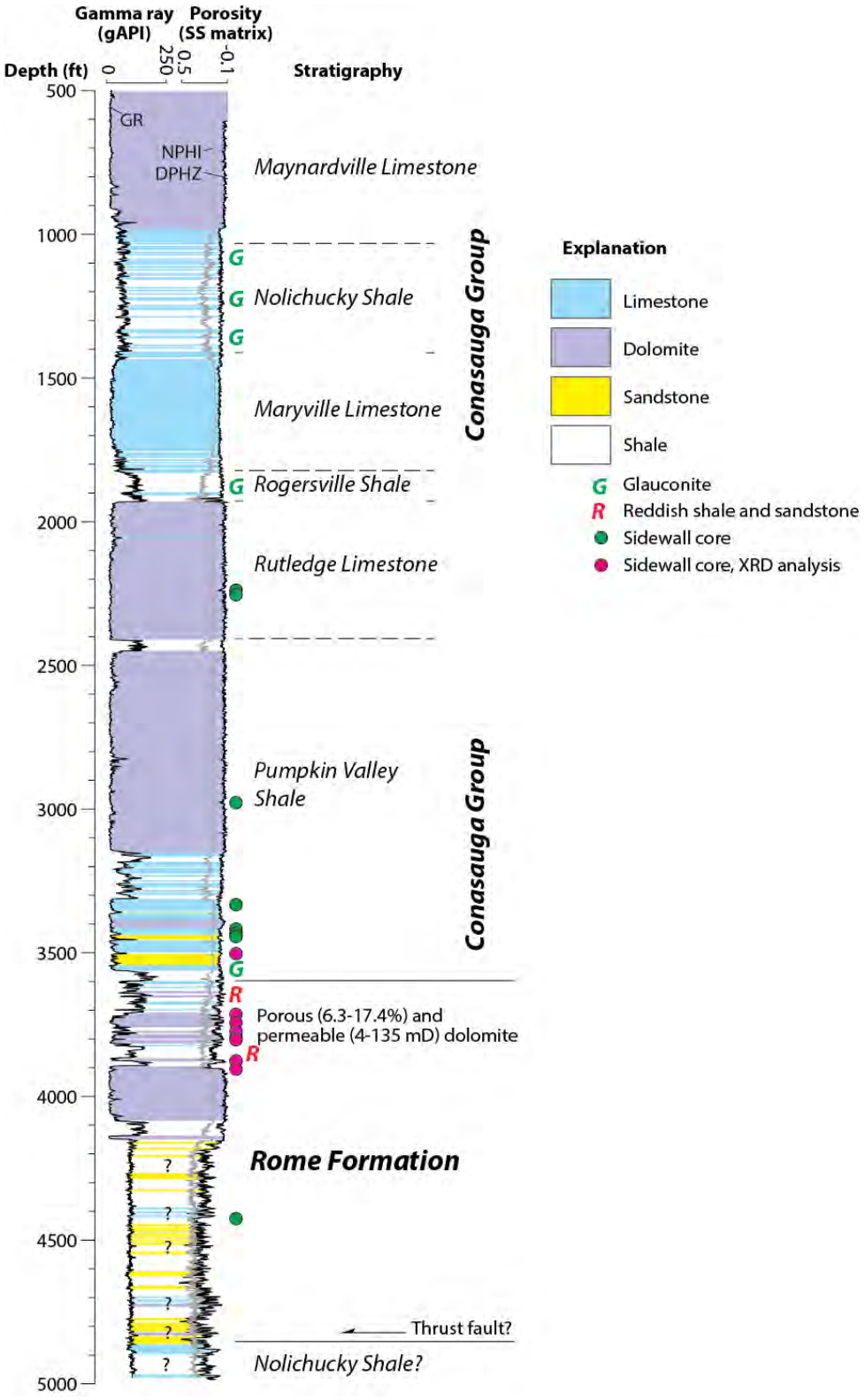


Figure 2: Geophysical well logs and stratigraphic interpretation of the Cassville #1 Borehole.

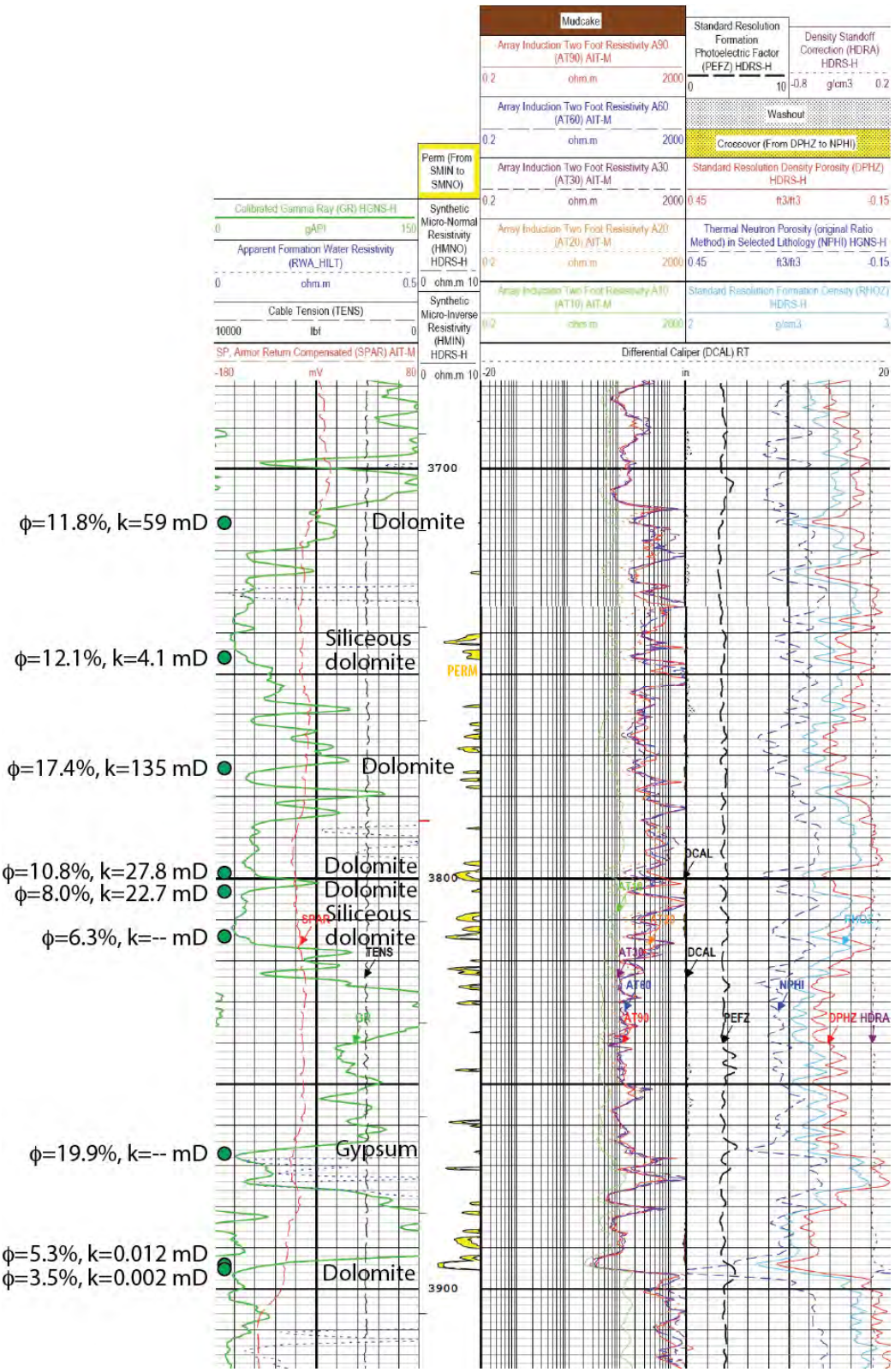


Figure 3: Geophysical well log showing results of core analysis in the Rome Formation, Cassville #1 Borehole.

A radioactive shale marker (>150 GAPI) at 3,598-3,563 ft is interpreted to mark the base of the Pumpkin Valley Shale, which is the basal unit of the Conasauga Group (**Figure 2**). The shale is dolomitic and also contains glauconite. Above the shale is 252 ft 3,563-3,311 ft of thickly interbedded limestone, sandstone, and dolomite that may contain some thin, porous zones. This interval is overlain by 163 ft (3,311-3,148 ft) of interbedded limestone and shale. The upper part of the Pumpkin Valley includes a massive dolomite section that spans almost 700 ft (3,148-2,450 ft) and is capped by another radioactive shale marker between depths of 2,450-2,412 ft.

The Rutledge Limestone overlies the Pumpkin Valley radioactive shale marker and is 482 ft thick (1,930-2,412 ft) (**Figure 2**). Although the mud log indicates limestone, the Rutledge is composed primarily of dolomite based on the well samples and geophysical logs. This type discrepancy between the mud logs and the other logs is typical of the dolomite sections in the Cassville well and indicates an error in the mud logs.

The Rogersville Shale is another radioactive shale unit and overlies the Rutledge Limestone. The Rogersville is 100 ft thick (1,930-1,830 ft), is dolomitic, and contains glauconite (**Figure 2**). The Rogersville Shale grades upward into the Maryville Limestone, which is 423 ft thick, ranging between depths of 1,830 and 1,407 ft and is logged as limestone in both the geophysical logs and the mud log. The Maryville is overlain gradationally by the Nolichucky Shale, which is 428 ft thick and is composed of interbedded limestone and glauconitic shale. The top of the Nolichucky is picked at 979 ft at the base of a thick dolomite section that forms the upper part of the well log. This dolomite is assigned to the Maynardville Limestone, which is the youngest formation of the Conasauga Group. Based on the mud log, the top of the Maynardville is at a depth of 160 ft and is thus about 820 ft thick. The shallowest 160 ft of the well section is in the Copper Ridge Dolomite of the Knox Group, which is composed of limestone, dolomite, and chert.

FMI Log

The imaging quality of the FMI log is exceptional throughout most of the wellbore. Bedding is generally shown clearly, and numerous fracture and fault systems are imaged. Imaging problems were encountered mainly in zones of borehole expansion, particularly in the lower Rome section. Plotting the azimuth and dip of bedding against the gamma ray and porosity logs shows the major patterns of bedding attitude in the Cassville #1 well (**Figure 4**). Shear zones with abundant fractures are common in the wellbore, and most of the fractures have low resistivity fills, suggestive of clay or fluid fill. Many fractures in the region are filled with carbonate, and these types of veins are difficult to image in FMI logs because of low resistivity contrast with the host rocks, which are dominated by carbonate.

FMI images

An FMI image showing well-bedded dolomite and shale in the upper part of the Pumpkin Valley Shale (2,481-2,508 ft) shows bedding that generally dips <10° and is gently folded, with dip generally oriented NE and SW (**Figure 5**). Two fracture zones are shown in the image that consist of abundant short-length high-angle fractures generally dipping between 71 and 83° N-NE and S-SW. The fractures commonly cross-cut, defining a conjugate shear system.

Another image from the upper part of the Pumpkin Valley Shale (2,822-2848 ft) shows a higher proportion of dolomite (**Figure 6**). Shear fractures dipping 60-80° increase in abundance downward in the image and dip dominantly N-NE with dip magnitude ranging from 60-80°. Bedding is gently folded, and bedding dip is generally <10° and dip direction in the upper part of the changes from S-SW to S-SE in the upper part of the image. In the lower part of the image, shear fractures swarm around a fold hinge in which dip changes from about 5° toward the E to about 20° toward the NW.

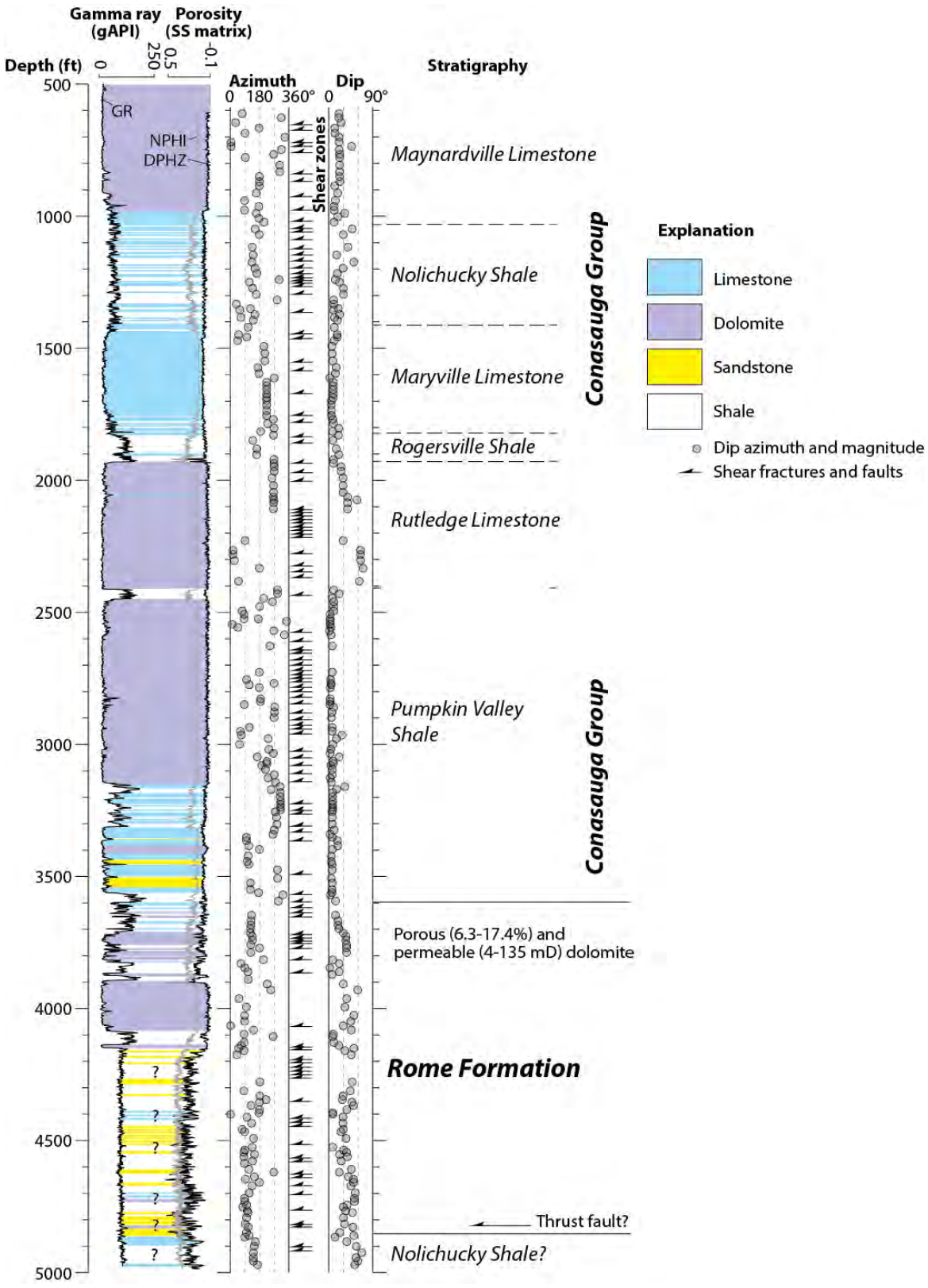


Figure 4: Distribution of dip measurements and shear zones relative to the stratigraphic section in the Cassville #1 borehole.

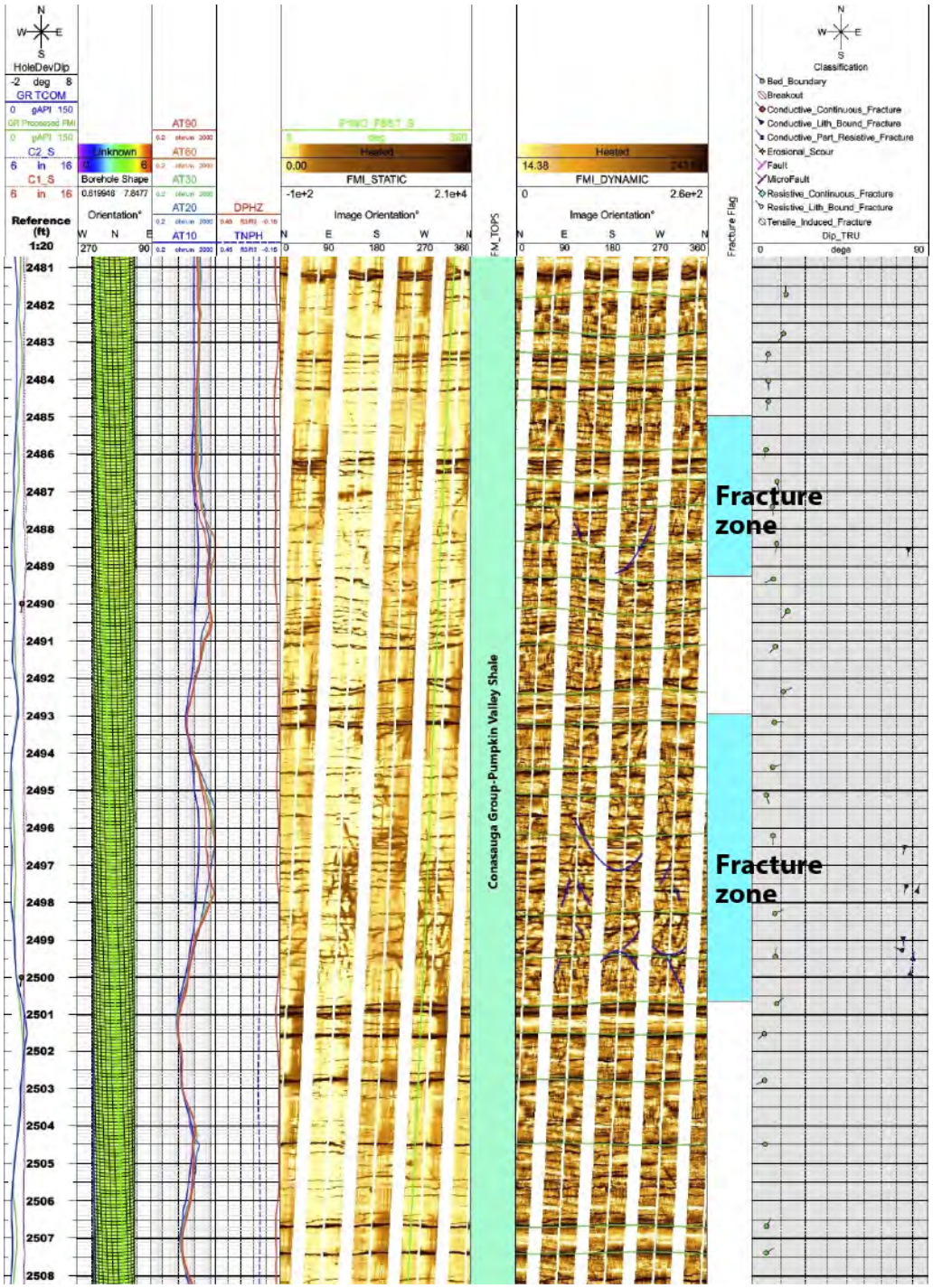


Figure 5: FMI image showing bedding and fracturing in the Pumpkin Valley Shale.

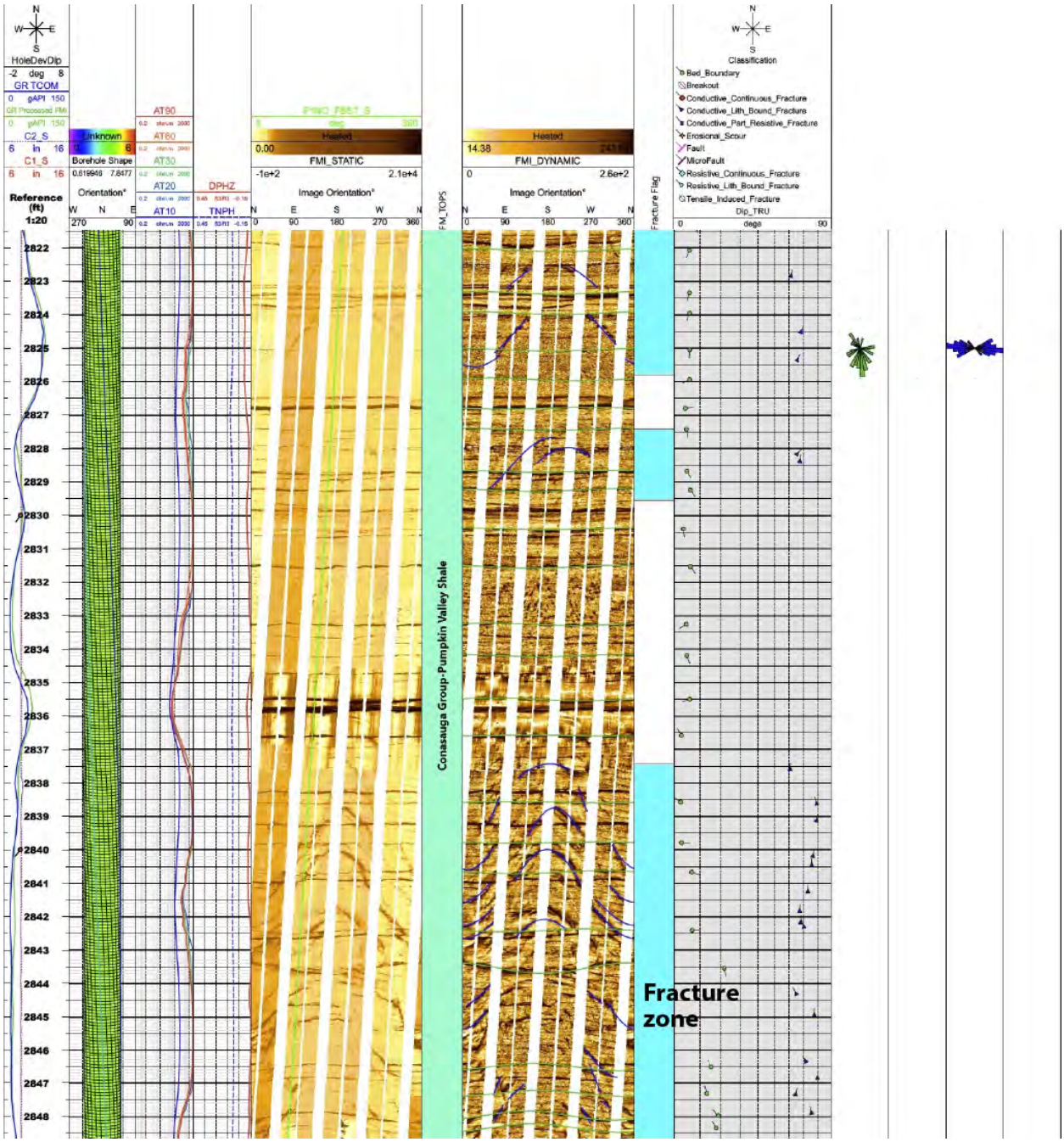


Figure 6: FMI image showing bedding and dipping shear fractures in the Pumpkin Valley Shale.

Low-resistivity, high-angle fractures are well imaged in a section of dolomite in the Rutledge Limestone (1971-1995 ft) (**Figure 7**). Bedding dips between 15 and 30° toward the W-SW. Fractures in the middle and upper part of the image traverse up to 6 ft of section and dip N-NE steeper than 80°. Abundant fractures define a shear zone in the lower part of the image (1989-1995 ft) and have variable dip direction and appear mutually cross-cutting.

Shear zones containing complex networks of fractures are distributed through much of the wellbore (**Figure 4**). The fractures tend to dip between 50 and 80°, and in most zones dip direction is highly variable. An image of dolomite in the Maynardville Limestone (658-695 ft) shows the complexity of the fracture networks, which cross-cut bedding and form complex, mutually cross-cutting conjugate fracture systems (**Figure 8**). In this image, bedding generally dips 10-30° S-SE and N-NW, and cross-cutting shear fractures are distributed throughout the image, in places making bedding difficult to discern.

A similar zone from the dolomite of the Rutledge Limestone (2,113-2,140 ft) shows intense shear fracturing (**Figure 9**). Bedding is difficult to identify in much of the image and locally dips as steep as 55° toward the W. Continuous shear fractures dip with a northward component, and numerous short-length fractures and faults are imaged. Conjugate faults dipping 20° SE and 30° W are present in the upper part of the image.

An image from the upper Rome Formation (4,129-4,152 ft) shows a pervasive shear zone that is developed in a resistive dolomite bed from 4,137-4,149 ft (**Figure 10**). Bedding of the shale above the dolomite dips about 20° NE, whereas that below the dolomite dips >40° NE. Traceable shear fractures dip 35-70° NW and SE and form a complex conjugate shear system in a hinge where bedding dip decreases above the shear zone. This configuration is suggestive of an intensely sheared fold hinge.

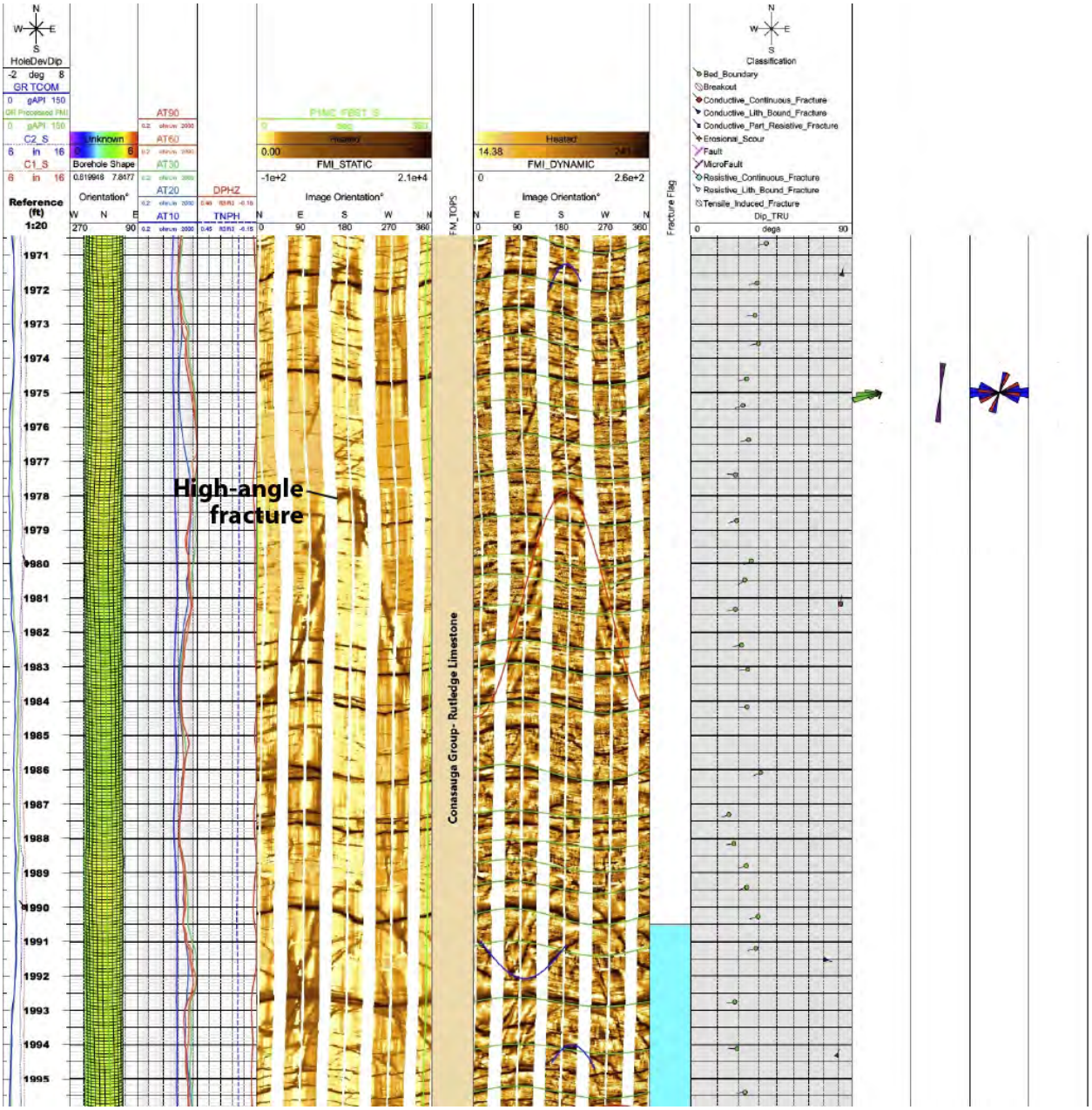


Figure 7: FMI image showing high-angle fractures in the Rutledge Limestone.

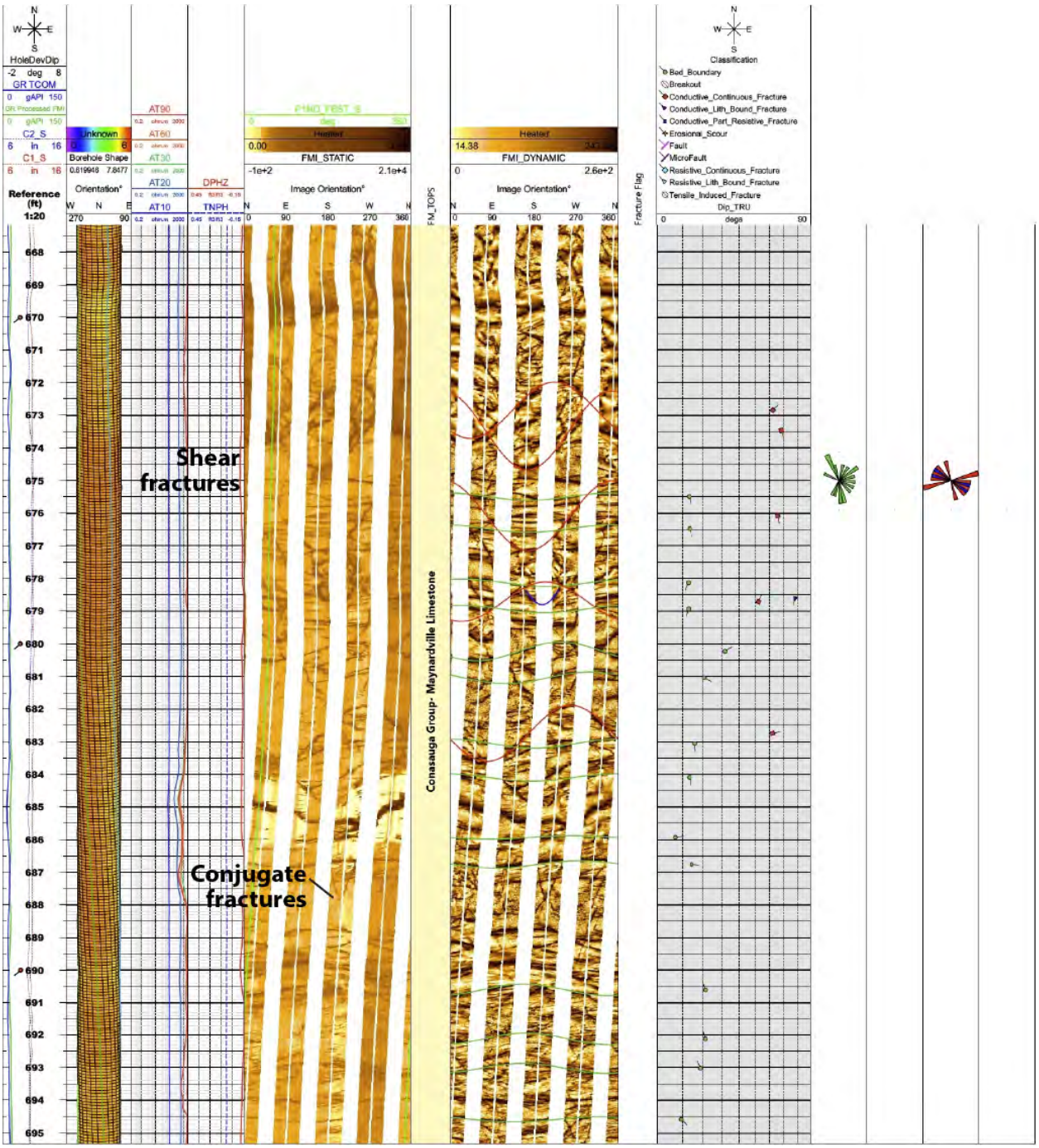


Figure 8: FMI image showing abundant shear fractures in the Maynardville Limestone.

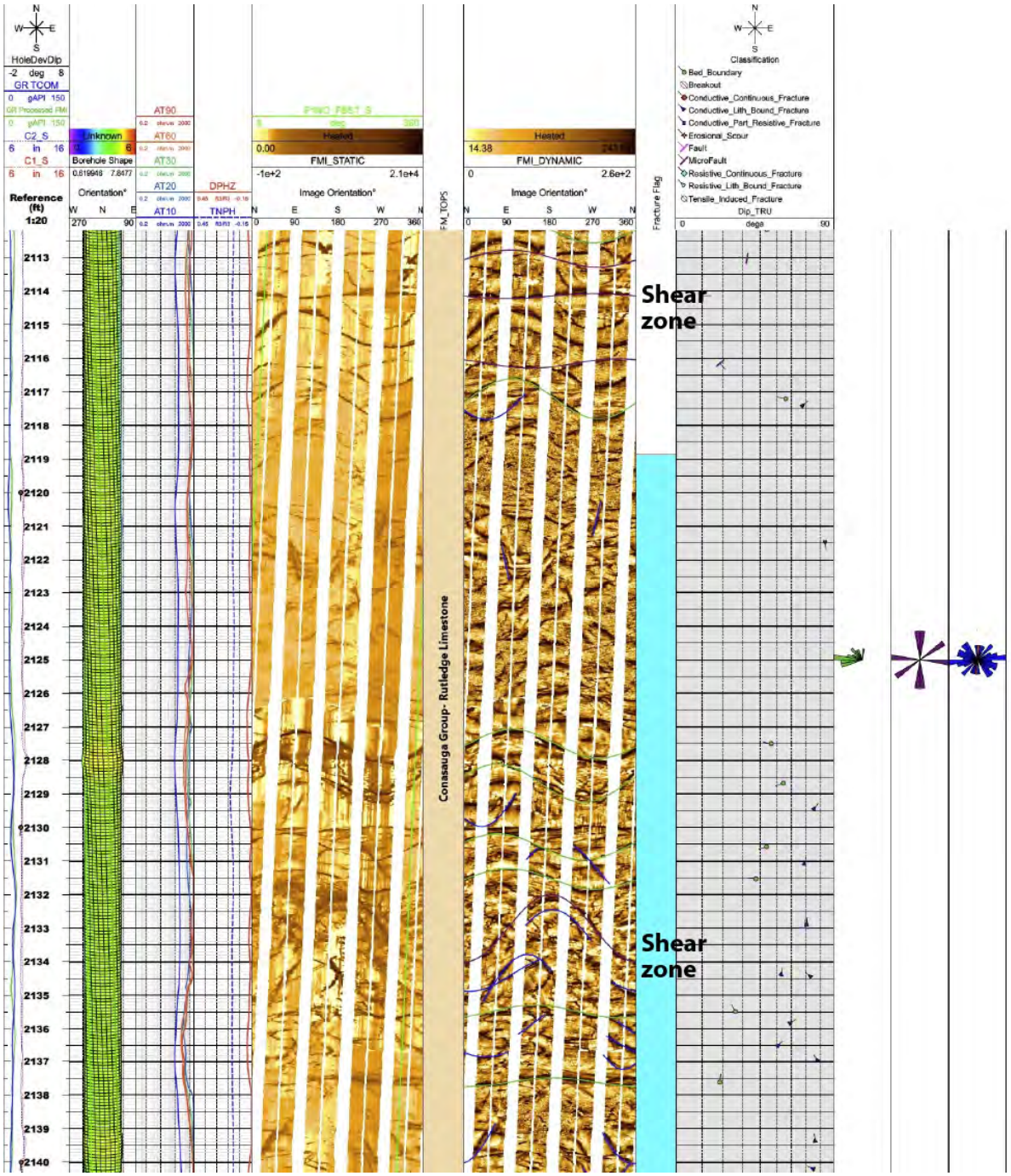


Figure 9: FMI image showing shear zones in the Rutledge Limestone.

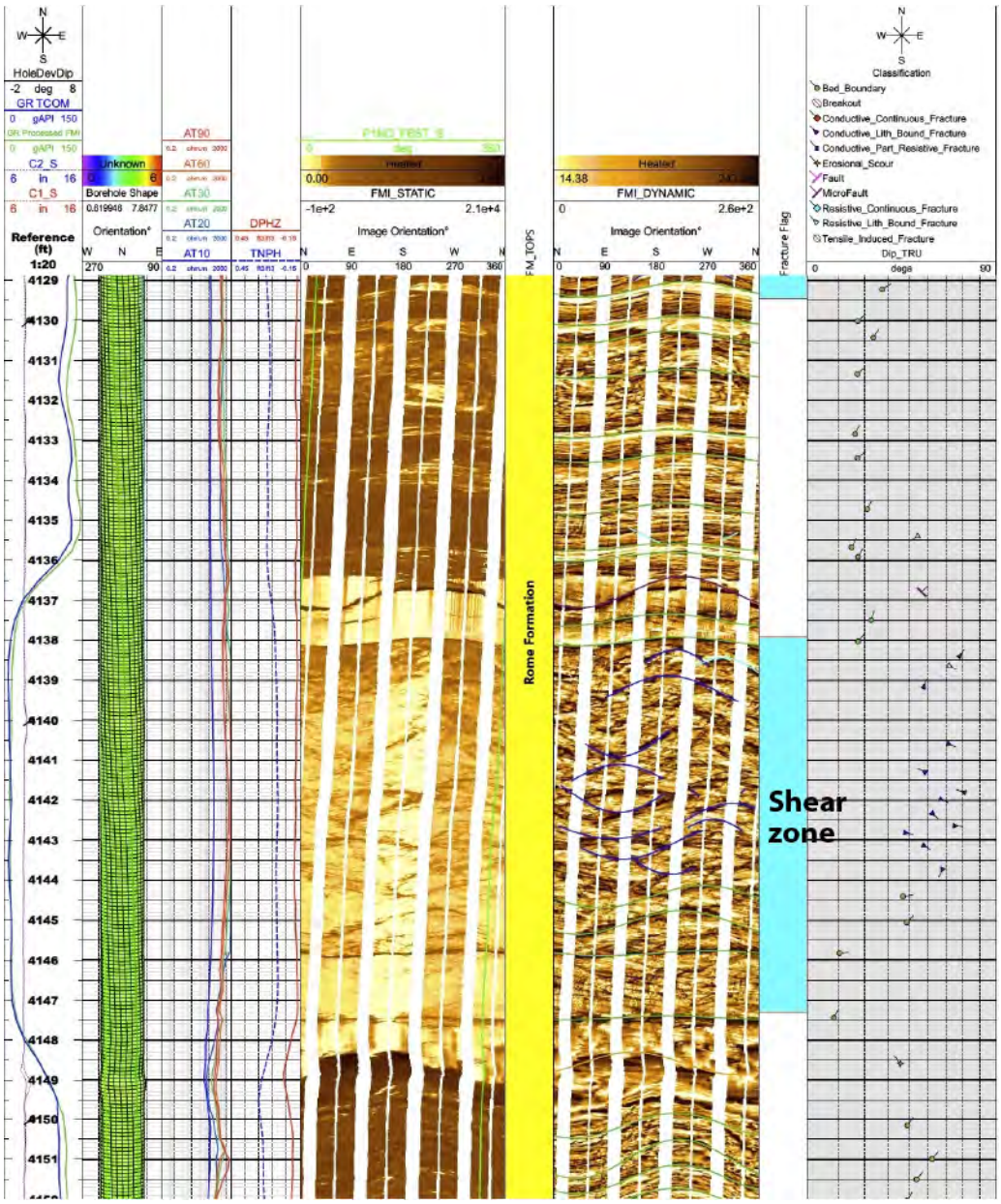


Figure 10: FMI image showing a shear zone in dolomite of the Rome Formation.

Faults are commonly expressed in the FMI log as discontinuities in dip and bedding across shear fractures and shear zones. Faults are especially well imaged in the lower part of the Pumpkin Valley Shale from 3,303-3,330 ft (**Figure 11**). A prominent fault dipping 70° toward the NE is imaged at 3,312 ft where a low-resistivity shale is juxtaposed with high-resistivity limestone. A satellite fault at 3,309 ft dipping 51° toward the NE is imaged faintly in the static FMI image and is distinctly shown by bedding discontinuities in the high-contrast dynamic image. Bedding dip, however, has a distinct westward component and ranges between 3 and 20° throughout the image.

Fold hinges typically are characterized by dip changes in the FMI log and are most distinct where they contain abundant shear fractures; many of the hinges appear faulted. A simple fold nose is imaged near the top of the Nolichucky Shale (984-997 ft) (**Figure 12**). The fold nose images distinctly at 990 ft and may contain overturned bedding in one of the limbs. Strata below the nose dip about 10° toward the SE, whereas strata above the nose dip up to 40° S-SW, suggesting that the fold has a conical kink-band geometry.

Structural interpretation

Plotting dip azimuth, dip magnitude, and the positions of shear zones adjacent to the stratigraphic section reveals some of the major structural trends in the Cassville #1 well (**Figure 4**). In the apparent Nolichucky Shale section at the bottom of the well, strata dip > 50° toward the SE. Above the interpreted thrust fault that places the lower Rome Formation above the Nolichucky (4,700-4,870 ft), strata dip erratically between 15 and 50° toward the E-NE, indicating complex folding and faulting above the main thrust fault. From 4,700-4,250 ft, dip magnitude in the lower Rome varies greatly from ~10-50°, and dip azimuth also is variable, indicating even more complex folding and faulting. Strata are pervasively sheared between depths of 4,200 and 4,300 ft, and bedding dip is difficult to detect.

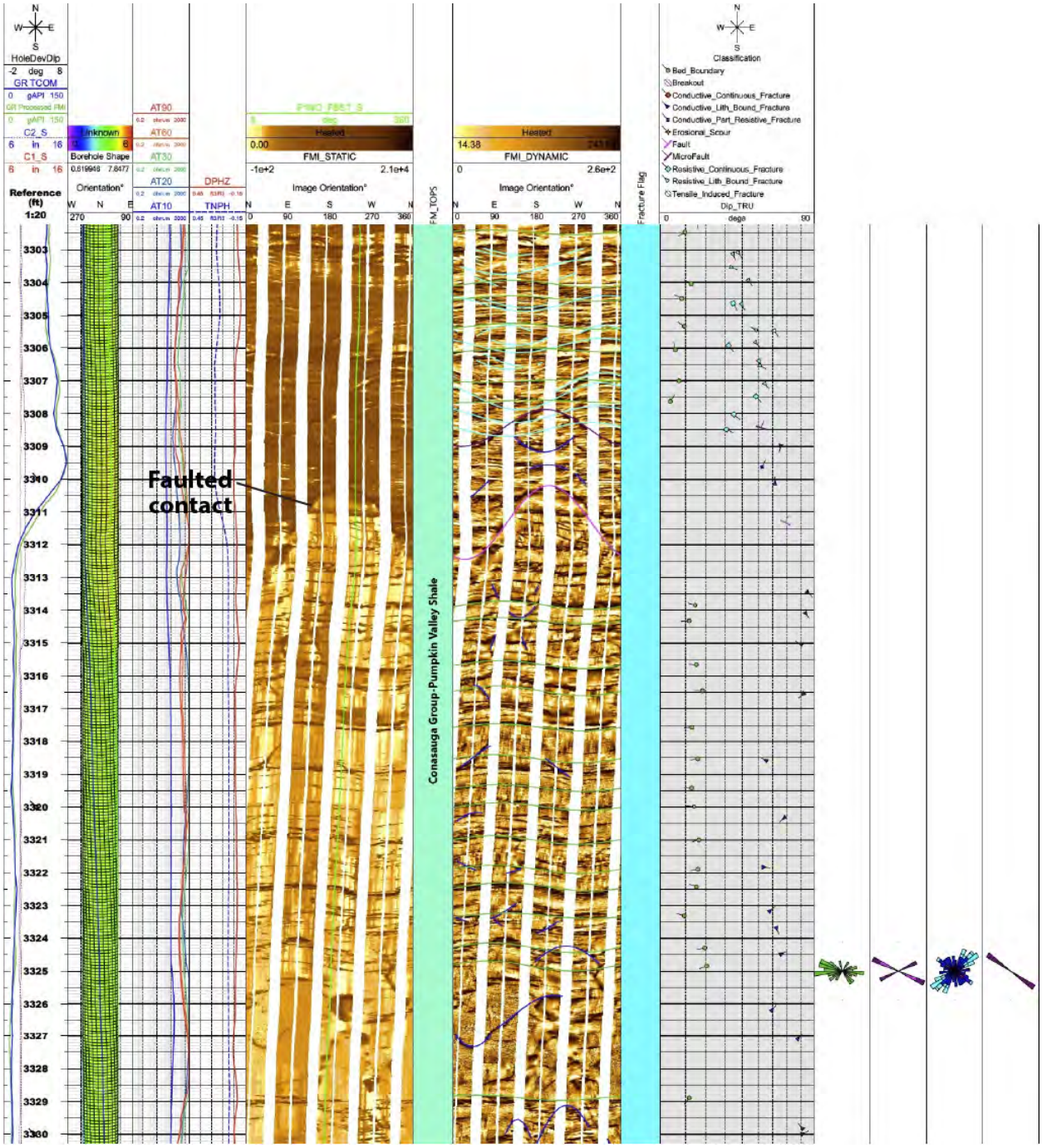


Figure 11: FMI Image showing faulting in the Pumpkin Valley Formation.

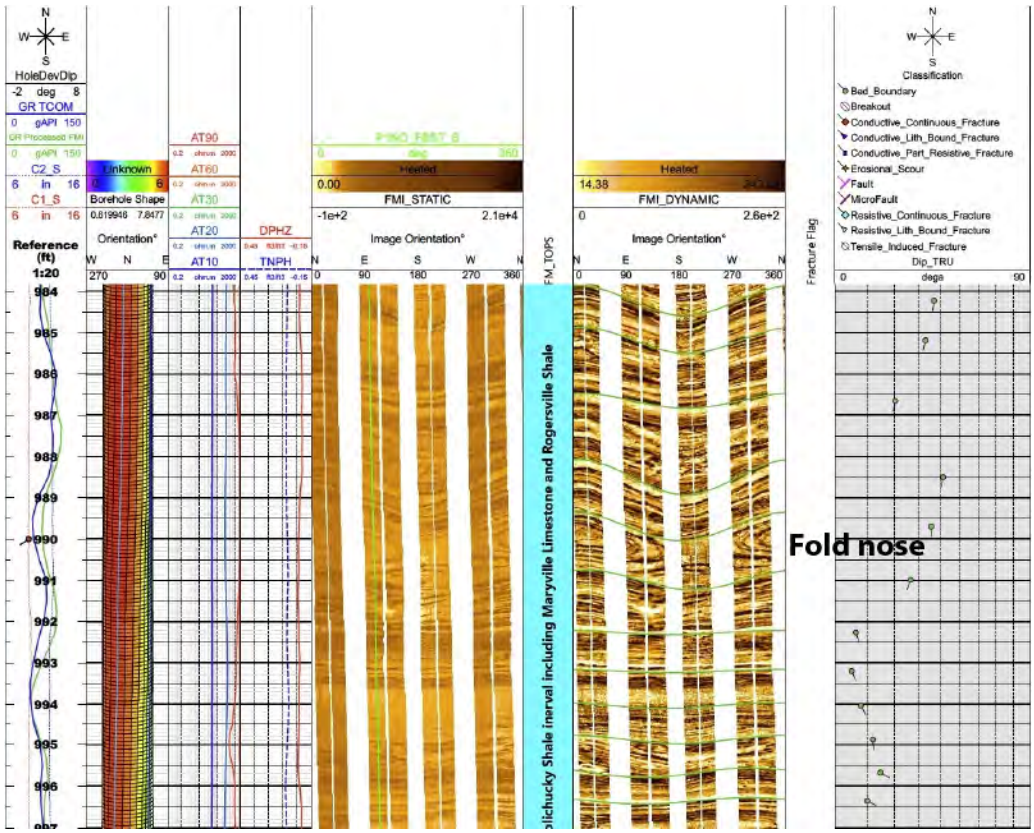


Figure 12: FMI Image showing folding in the Nolichucky Shale.

Dip decreases from >45° to ~10° across the lower boundary of the dolomitic upper Rome Formation, defining a large, curved fold limb, and dip direction is dominantly toward the E (**Figure 4**). Within the thick upper Rome dolomite unit (4,086-3,893 ft), shear zones are not readily apparent, and strata are folded with dip magnitude ranging between 30 and 60°. Dip direction in the lower part of the dolomite is dominantly E and near the top is SW. In the shaly section above the dolomite, dip magnitude ranges from ~5-20° and swings upward from E-SE to NE. Above this, in the porous dolomite interval (3,817-3,708 ft), dip is about 40° toward the SE. In the uppermost part of the Rome Formation, which contains mainly interbedded limestone and shale, dip gradually decreases upward from ~40-15°, defining a curved SE-dipping fold limb.

Structural dip in the Pumpkin Valley Shale is typically 10° or less, save for a few zones where dip reaches a maximum value of 32° (**Figure 4**). Dip direction clusters in the NE and NW quadrants in the interbedded limestone, sandstone, and shale succession near the base of the formation. In the shale-limestone interval between 3,151 and 3,311 ft, strata tend to dip NW. The thick dolomite interval in the upper part of the Pumpkin Valley exhibits highly variable dip direction indicating that the strata are broadly folded and undulatory; numerous shear zones are present and commonly separate dipping panels. The shale forming the top of the Pumpkin Valley Formation is strongly sheared in places.

The basal part of the dolomite unit constituting the Rutledge Limestone contains strata dipping steeper than 60°, and dip direction is variable but most commonly N-NE (**Figure 4**). The middle part of the limestone is intensely sheared between 2,100 and 2,200 ft, and it is difficult to distinguish between bedding and shear fracture networks. Strata in the upper part of the Rutledge, however, dip westward, and dip decreases upward from about 40-25°.

Structural dip remains low in the Rogersville Shale and Maryville Limestone. Rogersville strata dip between 10 and 20°, whereas Maryville strata commonly dip <10° (**Figure 4**). Dip direction in the Rogersville is generally NE to S., whereas that in the Maryville is typically SW, although NE values are common near the top of the limestone. In the basal part of the Nolichucky Shale, dip is generally <20°, and dip values are concentrated in the NE and SE quadrants, indicating significant folding. Shear zones are abundant near the middle of the Nolichucky, and dip is variable in the middle and upper Nolichucky, reaching maximum values around 50°. In the Maynardville Limestone, Dip is commonly on the order of 20°, and dip direction is variable, with measurements clustering in the NE and NW quadrants.

Results of structural analysis based on the FMI log indicate that the Rome Formation is a structurally weak layer that was prone to folding and shearing, as indicated by dip values commonly exceeding 30° (**Figure 4**). Overall, the section above subthrust strata appear to be largely in proper stratigraphic order, indicating most of the thrust

deformation is intraformational and is related to widespread layer-parallel slip and formation of shear duplexes that may have limited areal extent. Indeed, the large gently dipping structural panel in the Pumpkin Valley Shale contains numerous shear zones, which are interpreted to the be product of layer-parallel slip and shortening. The contrast in dip magnitude between the Rome and Pumpkin Valley strata further suggests that a significant structural discontinuity, such as a detachment zone, exists in the shaly zone above the thick dolomite unit in the Rome at a depth of ~3,850 ft.

High structural dip in the lower part of the Rutledge Limestone indicates significant deformation at this level, perhaps related to increased shortening along slip planes in the radioactive shale at the top of the Pumpkin Valley Formation. Dip returns to low values in the Maryville Limestone and the lower part of the Nolichucky Shale. However, variable dip in the upper Nolichucky indicates that this shaly unit behaved as a structurally weak layer between brittle strata of the Maryville Limestone and Maynardville Limestone. Deformation of the Nolichucky apparently contributed to the relatively steep dip of about 20° in near-surface strata of the Maynardville Limestone. Variable dip directions and common shear zones in the Maynardville reflect the same type of shear deformation that is developed deeper in the section and indicates that tectonic forces were strong enough to deform both weak shale and stiff carbonate layers throughout the section.

Plotting poles to the planes of the shear fractures demonstrates that dip values are most concentrated in the SE quadrant around an azimuth of 150° (**Figure 13**). This reflects shear associated with northwestward thrust translation and associated deformation. Fracture orientations are broadly distributed in the other quadrants, the dip of all imaged fractures is highly variable, suggesting that many of the fractures may have been rotated during regional deformation.

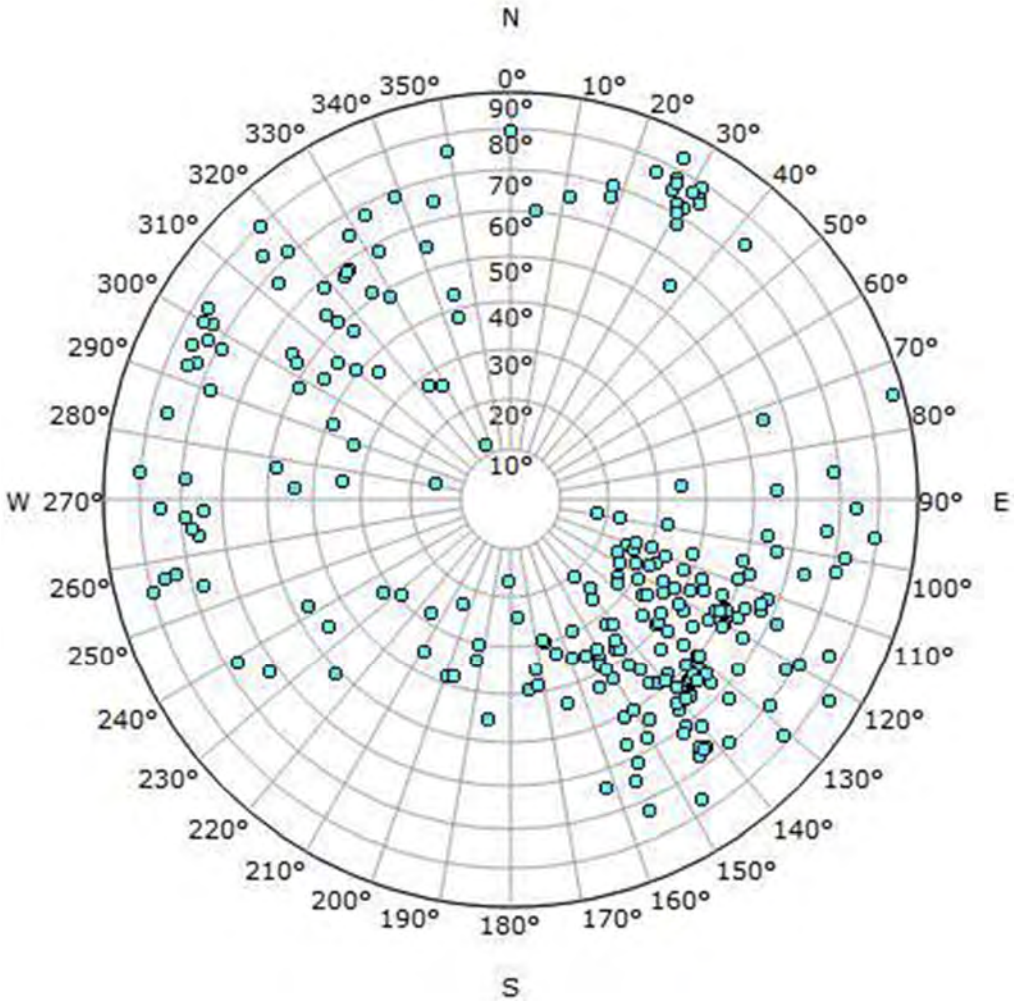


Figure 13: Stereoplot of poles to planes of shear fractures imaged in the Cassville #1 borehole. Note clustering of data in the SE quadrant and broad distribution of data in the other quadrants.

Core Analysis

Core analysis was performed on sidewall core plugs retrieved between depths of 4,421 and 2,234 ft (**Table 1**). The samples retrieved are mainly dolomite and include sandstone (3,508 ft) and gypsum (3,867 ft). Porosity values range from 0.6-19.9%, and values higher than 10.0% are restricted to dolomite in the upper Rome Formation (3,713-3,798 ft) (**Figure 3, 14; Table 1**).

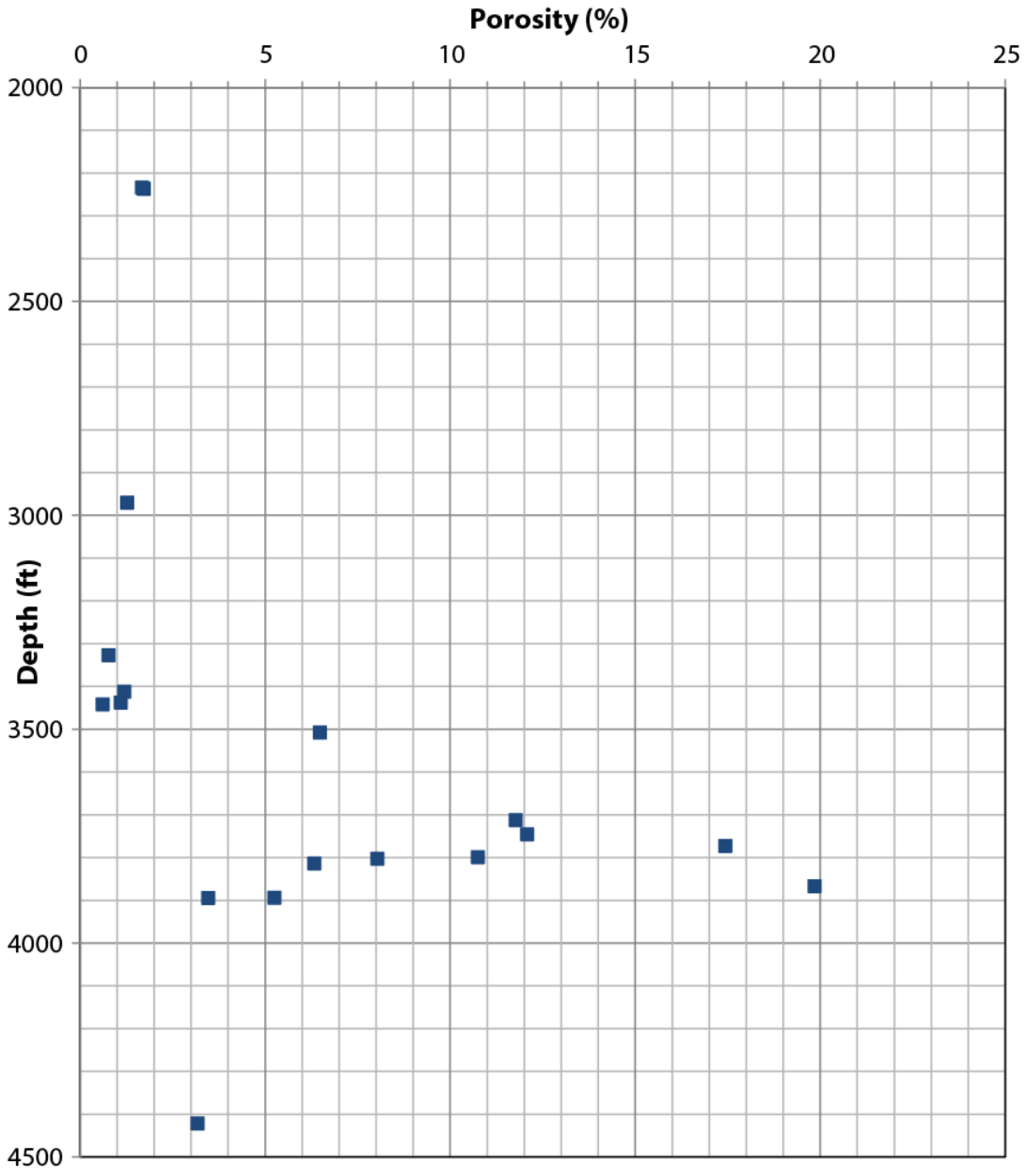


Figure 14: Porosity-depth profile in the Cassville #1 borehole. Porosity values higher than 7% are restricted to upper Rome porous dolomite.

Table 1: Results of routine core analysis in the Cassville #1 borehole.

					800 psi confining			Saturation		
Sample ID	Depth (ft)	Length (cm)	Diameter (cm)	Grain Density (g/cm3)	Helium Porosity (%)	Nitrogen Permeability (mD)	Klinkenberg Permeability (mD)	Oil (% PV)	Water (%PV)	Comments
29	2233.99	1.840	2.316	2.83	1.7	-	-	**	**	Short
27	2236.95	1.633	2.315	2.83	1.7	-	-	**	**	Short
26	2970.88	1.803	2.317	2.71	1.3	-	-	**	**	Short
25	3326.92	2.718	2.312	2.72	0.8	0.021	0.004	**	**	
24	3412.02	3.762	2.317	2.72	1.2	0.007	0.001	**	**	
23	3437.92	3.384	2.319	2.72	1.1	0.019	0.004	**	**	
21	3442.02	2.934	2.318	2.74	0.6	0.017	0.003	**	**	
20	3508.01	2.093	2.319	2.66	6.5	0.096	0.029	4.3	70.7	
19	3713.02	2.807	2.321	2.84	11.8	65.0	59.0	12.9	57.6	
15	3745.94	3.522	2.323	2.78	12.1	5.44	4.12	8.4	67.2	
14	3772.98	3.585	2.323	2.85	17.4	165	135	7.0	76.0	
13	3798.99	3.268	2.319	2.85	10.8	36.1	27.8	36.8	34.0	
12	3803.03	2.748	2.316	2.78	8.0	36.8	22.7	-	-	
10	3814.01	1.972	2.309	2.85	6.3	-	-	48.8	9.7	Short
9	3866.97	1.822	2.326	2.58	19.9	-	-	-	-	Short, ##
8	3894.02	2.354	2.313	2.82	5.3	0.050	0.012	68.3	0.0	
7	3894.93	2.799	2.311	2.83	3.5	0.010	0.002	**	**	
3	4421.45	1.943	2.317	2.77	3.2	-	-	**	**	Short

** The pore volume is less than 0.5 cc. The percent error for oil and water saturations could be ±50%. Percent error improves as the pore volume increases.
The sample lost grains during cleaning causing the inaccurate saturations.

-Assumptions for saturation calculations: Water salinity 25,000 ppm NaCl with a 1.015 g/cc water density. Oil density 0.85 g/cc.

Some of the core plugs are too short to accurately measure permeability, including a gypsum sample with 19.9% porosity (3,867 ft), and so Klinkenberg permeability was determined on 12 of the samples. Klinkenberg permeability ranges from 0.001-0.029 mD in samples from depths of 3,327-3,508 ft and is 0.050 and 0.010 in the samples from 3,894 and 3,895 ft, respectively. Within the porous dolomite, however, permeability ranges from 54.1-135 mD (**Figures 4, 15; Table 1**). Accordingly, this dolomite unit was the only significantly porous and permeable unit encountered in the Cassville #1 well.

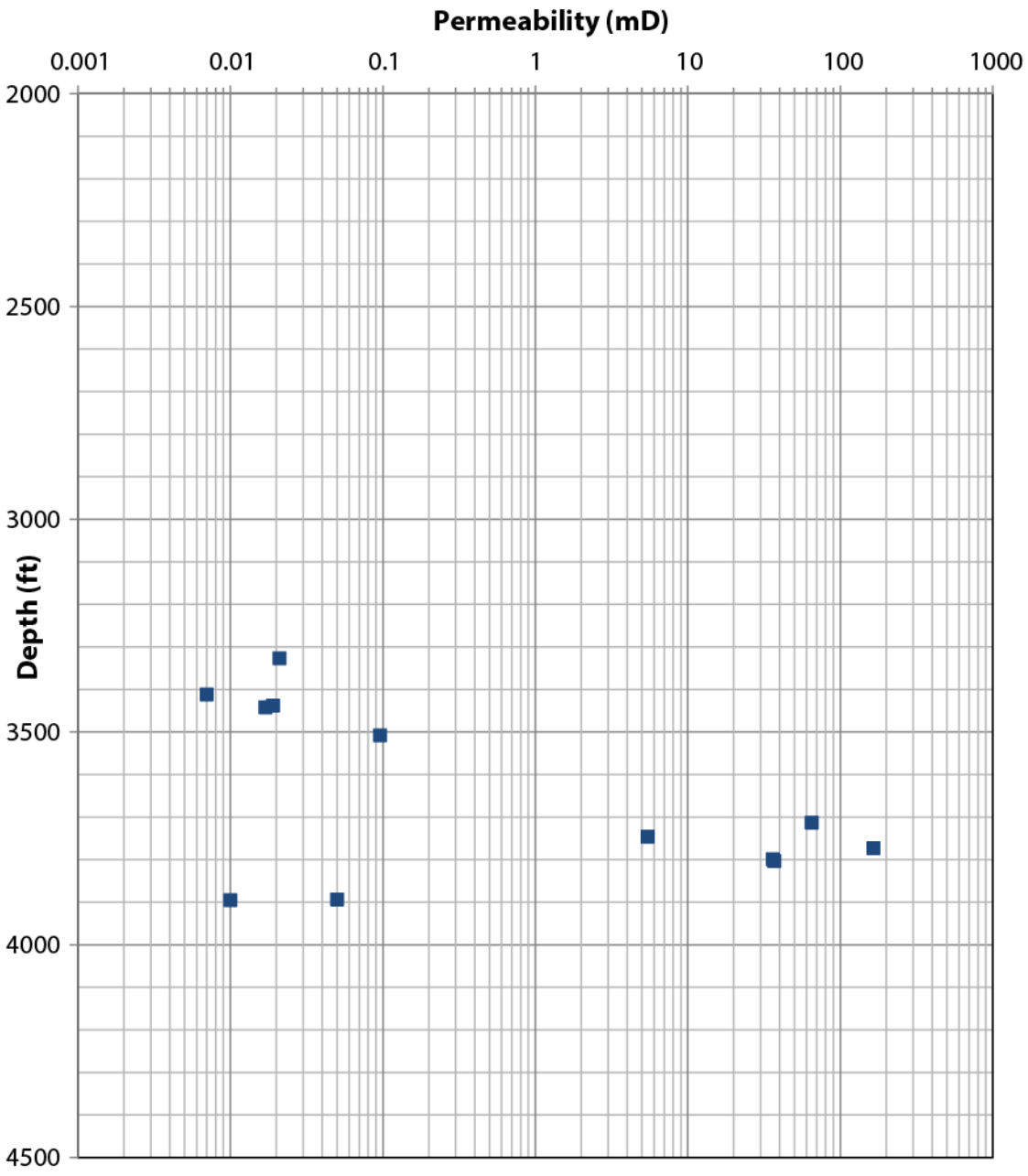


Figure 15: Permeability-depth profile in the Cassville #1 borehole. Permeability values higher than 1 mD are restricted to upper Rome porous dolomite.

Cross-plotting porosity and Klinkenberg permeability indicates an exceptionally strong relationship (**Figure 16**). The coefficient of regression is 0.90, and samples with porosity < 7.0% have permeability lower than 0.03 mD. Samples with higher porosity have permeability ranging between 4 and 135 mD and, again, are restricted to the upper Rome porous dolomite interval (**Figure 3**).

Fluid saturation was determined on 7 of the sidewall core samples, which are at depths ranging from 3,508-3,894 ft (**Table 1, Figure 17**). Error in the fluid saturation values may be as high as 50% because the pore volume is less than 0.5 cm^3, although the accuracy improves as the porosity of the sample increases. Water saturation values range from 0.0- 76.0% and are higher than 34% in the porous dolomite. Oil saturation was measured in the Rome Formation and ranges from 4.3-68.3%. The highest value comes from the top of the thick upper Rome dolomite unit, and values in the porous dolomite interval range from 4.3-48.8%. Although there may be error in the estimates, results indicate that an oil resource may exist in porous upper Rome dolomite.

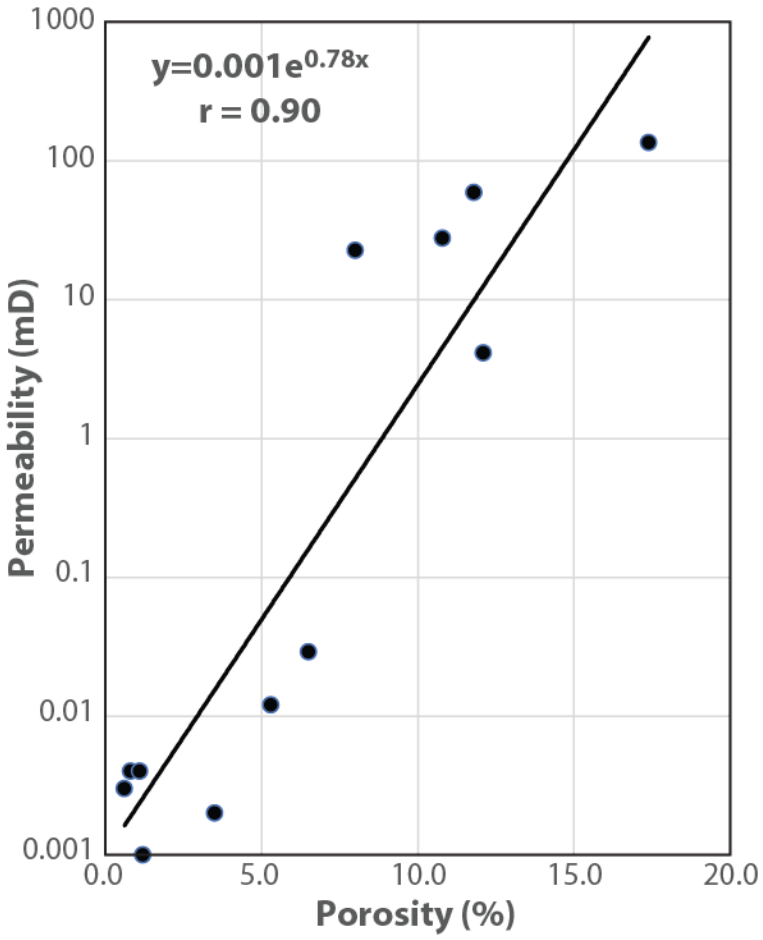


Figure 16: Cross-plot of porosity and permeability in the Cassville #1 borehole. Porosity values higher than 7% are restricted to upper Rome porous dolomite.

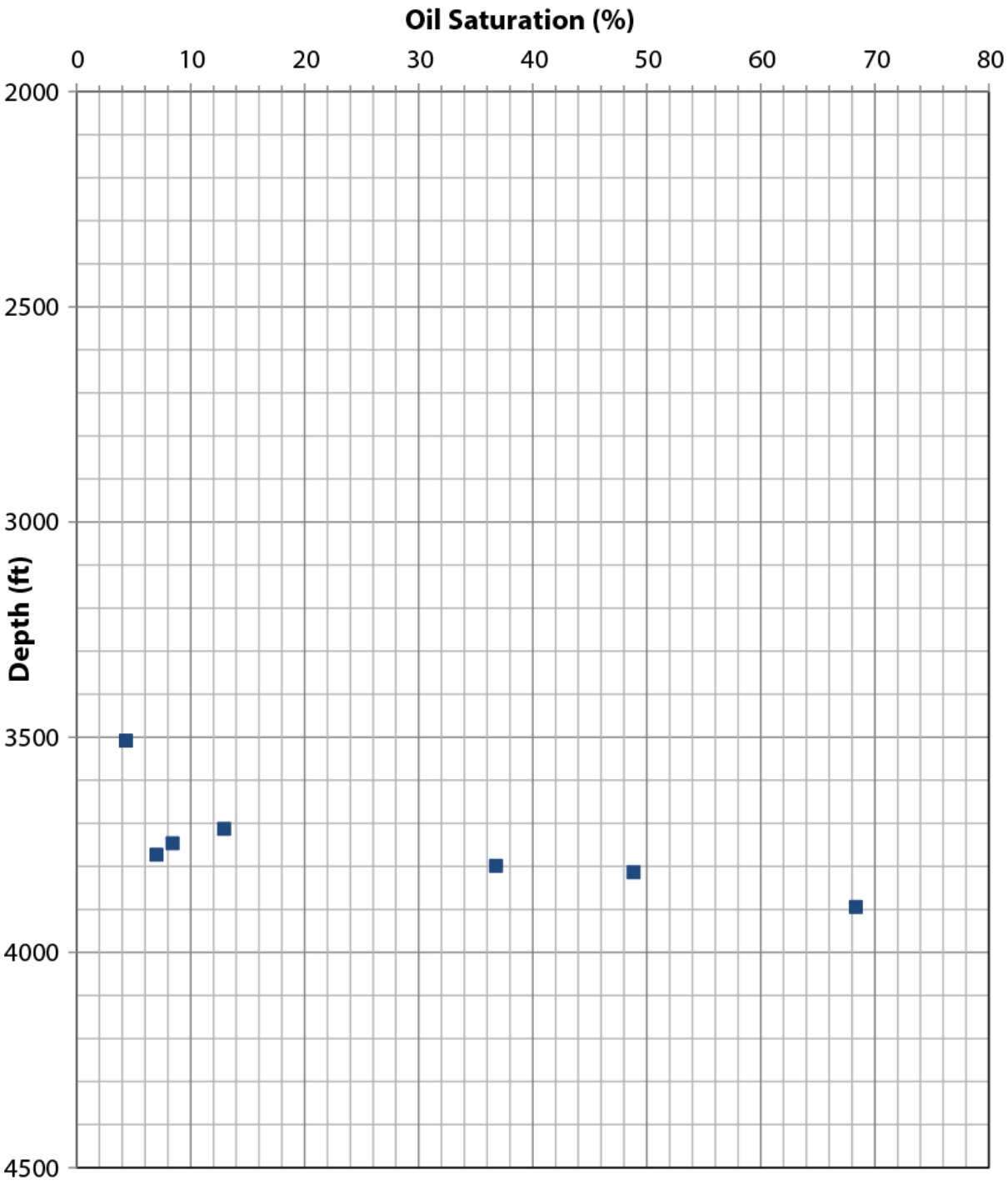


Figure 17: Oil saturation-depth profile in the Cassville #1 borehole. Oil saturation values higher than 10% are in the upper Rome porous dolomite.

X-Ray Diffraction and thin section Analysis

X-ray diffraction analysis was performed on 9 samples at depths of 3,508-3,894 ft (**Tables 2, 3**). The shallowest sample (3,508 ft) is from near the base of the Pumpkin Valley Shale and is arkosic sandstone with 41% quartz, 21% K-feldspar, 6% calcite, and 11% dolomite (**Table 2; Figure 18**). The sample contains 19% clay minerals, including illite-mica (15%) and kaolinite (4%) (**Table 3**). Quartz and feldspar form the framework of the sandstone, and porosity is present as intergranular and what appears to be vuggy porosity (**Figure 19**). Sand grains are very fine- to fine-grained and angular to subround. Porosity comprises 6.5% of the rock volume; sparry calcite fills the vuggy pores, and dolomite crystals are dispersed in the matrix. Interparticle pores are common in the rock matrix, and many of the voids may be a product of dissolution of feldspar and other labile minerals; kaolinite is probably a product of felspar dissolution. No plagioclase is in the sample, suggesting that it may have been dissolved, thus contributing to interparticle porosity. Clay-filled pressure solution seams also are present in the sandstone. Permeability if the sandstone is only 0.096 mD, indicating poor interconnection of the pores, which reflects the high clay volume.

The remainder of the samples are from the upper part of the Rome Formation, and all but the deepest sample are from the porous dolomite interval (**Figure 2**). A sample from 3,713 ft is dolomite containing 6% quartz, 4% potassium feldspar, 88% dolomite (**Table 2; Figure 18**). Clay forms only 3% of the sample is composed of illite-mica (**Tables 2, 3**). The rock is dominated by finely crystalline dolomite, and detrital quartz and feldspar grains are irregularly distributed in the sample; the grains are mainly supported by the dolomite matrix (**Figure 20**). Interstitial clay also is irregularly distributed in the sample. Porosity of the sample is 11.8%, and the thin section indicates that vuggy porosity dominates and is irregularly distributed. Klinkenberg permeability is 59 mD, indicating that the pore system is well interconnected.

Table 2: Whole rock mineralogy based on x-ray diffraction analysis of sidewall core samples from the Cassville #1 borehole.

SAMPLE ID	Depth (ft)	QUARTZ	K-FELDSPAR	PLAGIOCLASE	CALCITE	DOLOMITE	PYRITE	CELESTINE	BARITE	HEMATITE	ANHYDRITE	GYPSUM	**TOTAL NON-CLAY**	ILLITE+MICA	KAOLINITE	**TOTAL CLAY**	**GRAND TOTAL**	**TOTAL EXPANDABLE CLAY**
20	3508.01	42	21	0	6	11	0	0	0	0	0	0	**81**	15	4	**19**	**100**	0
19	3713.02	6	4	0	0	88	0	0	0	0	0	0	**97**	3	0	**3**	**100**	0
15	3745.94	18	6	0	19	51	0	0	0	0	0	0	**94**	4	1	**6**	**100**	0
14	3772.98	3	3	0	1	91	0	0	0	0	0	0	**98**	2	0	**2**	**100**	0
13	3798.99	1	1	0	5	91	0	0	0	0	0	0	**98**	2	0	**2**	**100**	0
12	3803.03	5	4	0	2	87	0	0	0	0	0	0	**97**	3	0	**3**	**100**	0
10	3814.01	10	0	0	4	81	1	2	0	0	0	0	**98**	2	0	**2**	**100**	0
9	3866.97	7	0	0	0	12	0	0	0	0	1	79	**99**	1	0	**1**	**100**	0
8	3894.02	4	1	0	2	85	0	0	0	0	4	3	**99**	1	0	**1**	**100**	0

Mineralogy values in wt.%

Table 3: Clay mineralogy based on x-ray diffraction analysis of sidewall core samples from the Cassville #1 borehole.

SAMPLE ID	Depth (ft)	ILLITE	KAOLINITE	**TOTAL CLAY**
20	3508.01	57	43	**100**
19	3713.02	79	21	**100**
15	3745.94	36	65	**100**
14	3772.98	58	42	**100**
13	3798.99	100	0	**100**
12	3803.03	84	16	**100**
10	3814.01	78	22	**100**
9	3866.97	89	11	**100**
8	3894.02	100	0	**100**

Relative Clay Abundance (<4 µm size fraction)

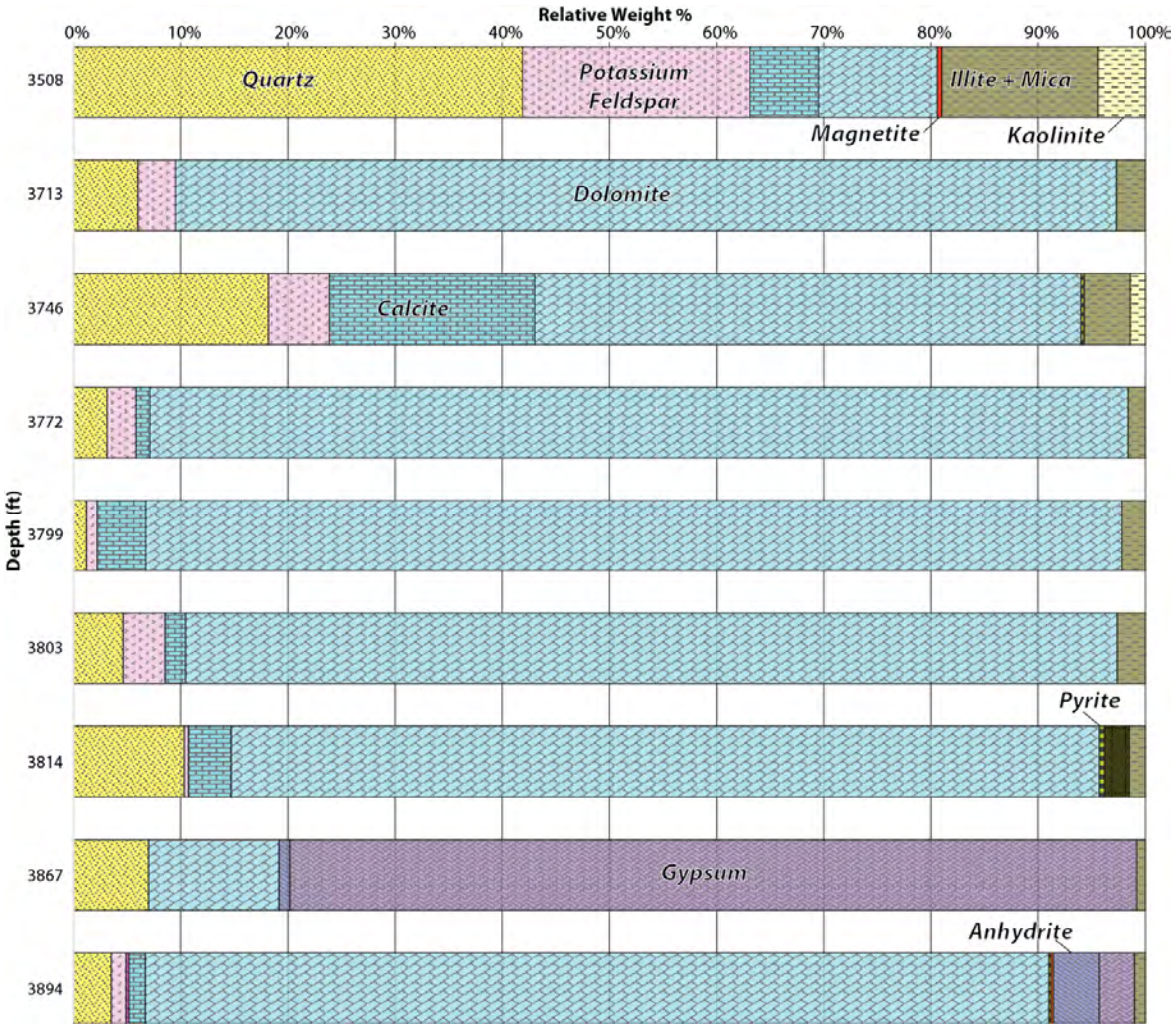


Figure 18: Charts showing the proportions of minerals identified by x-ray diffraction analysis of sidewall core samples from the Cassville #1 well. The shallowest sample is from the Pumpkin Valley Shale, and the remainder are from the Rome Formation.

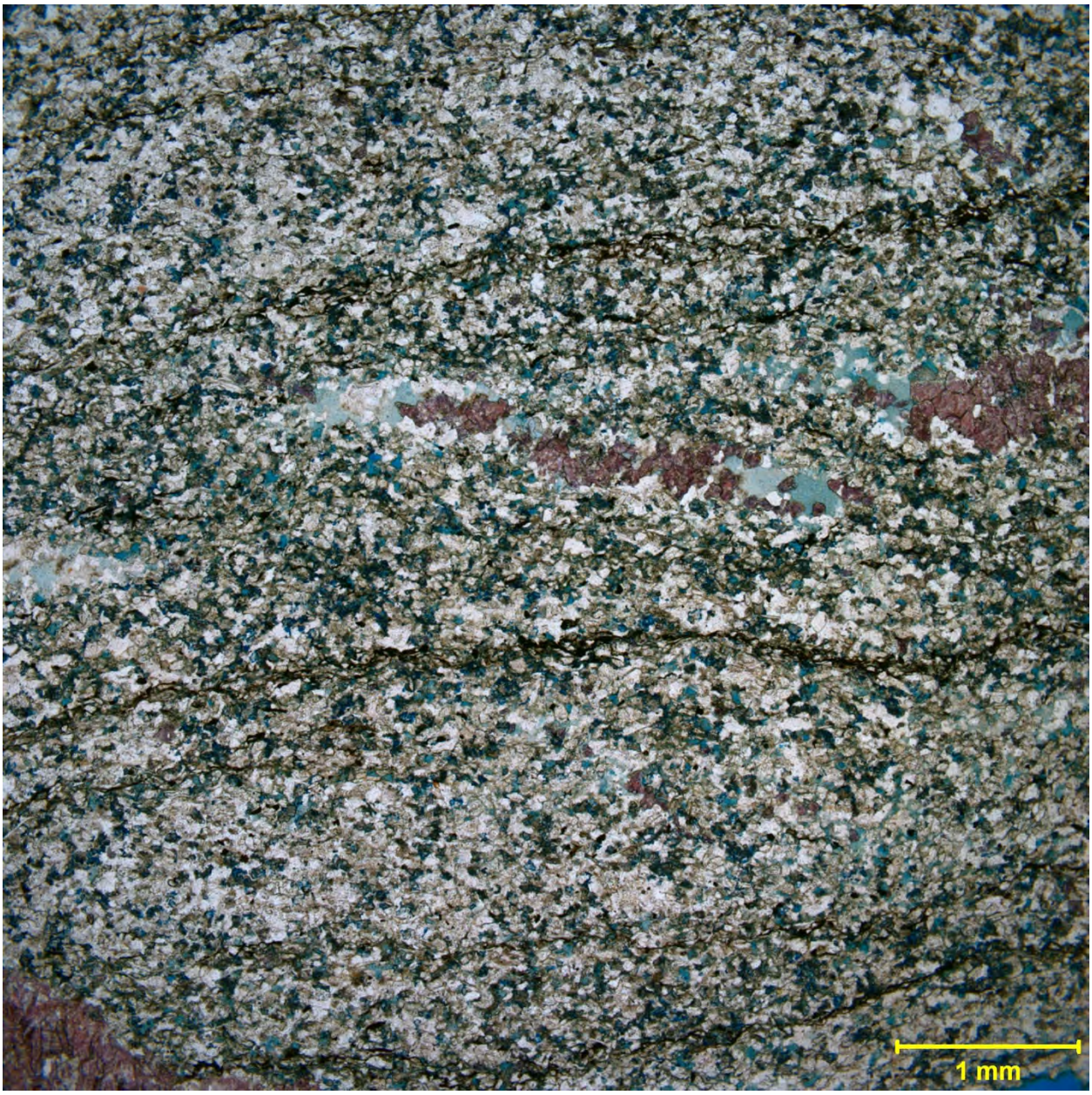


Figure 19: Thin section photomicrograph of arkosic sandstone from the lower Pumpkin Valley Shale (3,508 ft). Note vuggy pores with sparry calcite fill (red stain) and dark, clay-lined pressure solution seams traversing the sample.

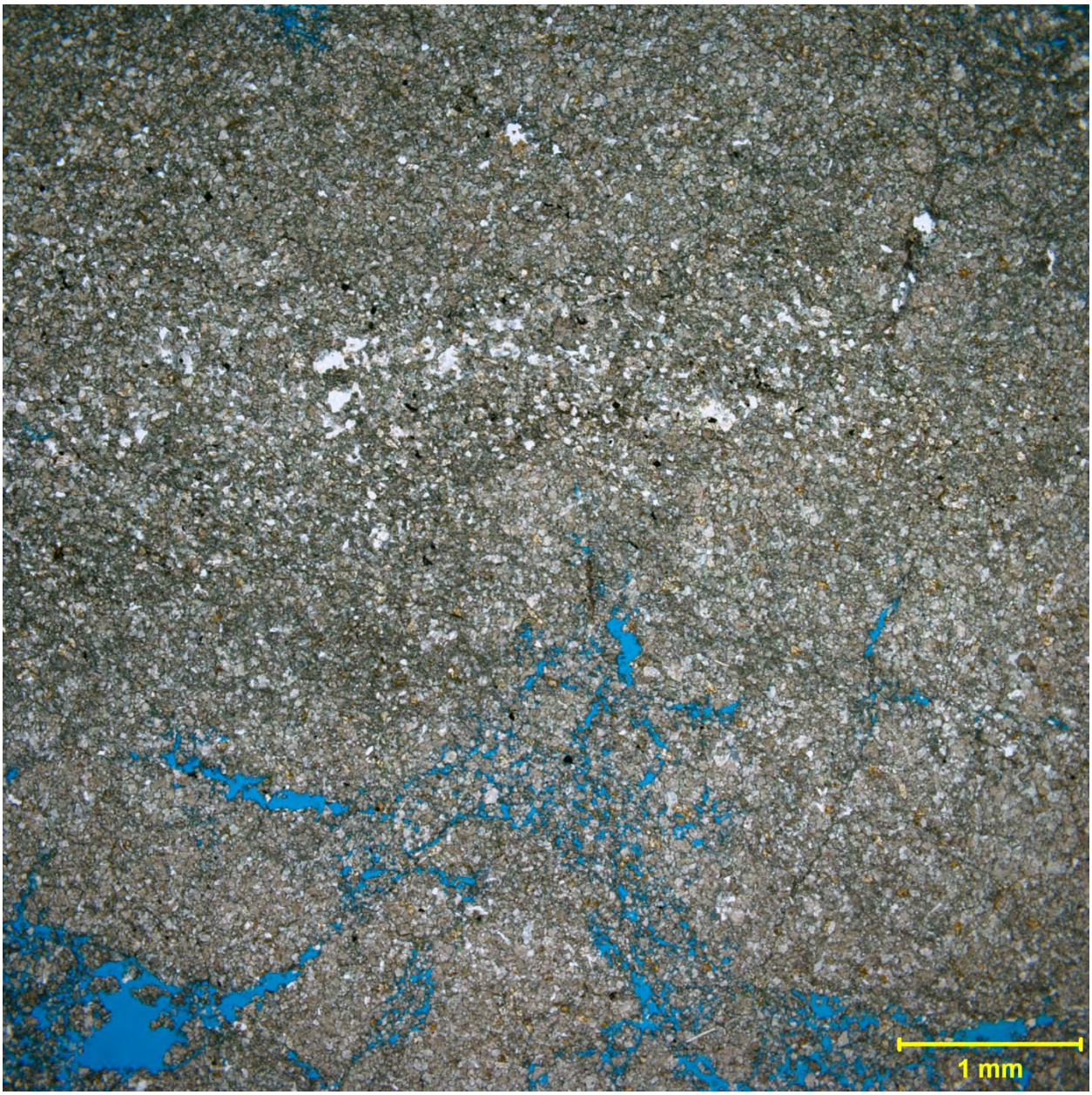


Figure 20: Thin section photomicrograph of porous dolomite from the upper Rome Formation (3,713 ft). Note vuggy porosity (blue epoxy) and dispersed detrital quartz and feldspar grains (white).

A sample of the porous dolomite at 3,746 ft consists of arenaceous dolomite containing 18% quartz, 6% feldspar, 19% calcite, and 55% dolomite (**Table 2; Figure 18**). Clay minerals constitute 6% of the sample and include 4% illite-mica and 1 percent kaolinite; it is not clear what clay minerals form the remaining 1% (**Tables 2, 3**). The sample can be characterized as arenaceous dolomicrite with vuggy porosity. Quartz and feldspar crystals are dispersed irregularly in the rock matrix and commonly line vuggy pores (**Figure 21**). Parts of these pores are filled with fine- to medium-crystalline sparry calcite. Porosity of the sample is 12.1%, and Klinkenberg permeability is 4.12 mD, indicating weak interconnection of the pore system.

At 3,773 ft, the porous dolomite contains 3% quartz, 3% K-feldspar, 1% calcite, and 91% dolomite (**Table 2, Figure 18**). Clay minerals only form 2% of the sample and are composed of illite-mica (**Tables 2, 3**). The dolomite is micritic to finely crystalline and displays a mix of intercrystalline, vuggy, and fracture porosity (**Figure 22**). Sparry calcite is present locally, bridging a curving fracture. Quartz grains are irregularly dispersed in the sample, quartz overgrowths commonly give the grains euhedral faces. Porosity constitutes 17.4% of the rock volume, and Klinkenberg permeability is 135 mD, indicating that the pore system is very well interconnected. Indeed, this is the most permeable sample recovered in this study.

The sample from 3,799 ft is dolomite containing 1% quartz, 1% feldspar, 5% calcite, and 91% dolomite (**Table 2; Figure 18**). As in the previous sample, clay minerals only form 2% of the sample and are composed of illite-mica (**Tables 2, 3**). The rock has a conglomeratic texture and includes clasts of dolomicrite and finely crystalline dolomite (**Figure 23**). Interparticle and fracture porosity dominate, and some vuggy porosity is apparent. Quartz crystals locally line pores, and sparry calcite fills some pores. Porosity in this sample is 10.8%, and Klinkenberg permeability is 27.8 mD, indicating a moderately interconnected pore system.

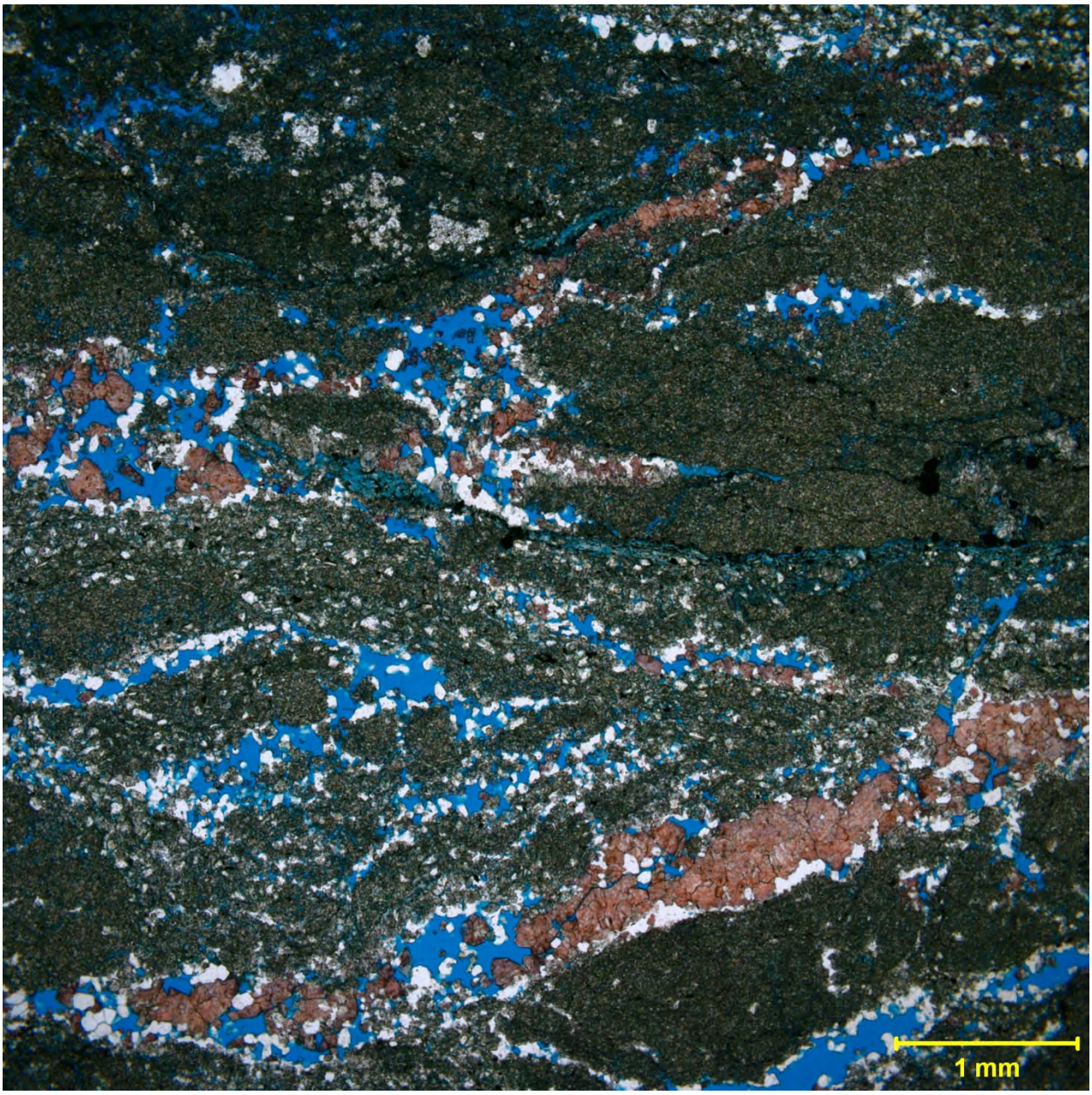


Figure 21: Photomicrograph of porous dolomicrite from the upper Rome Formation (3,746 ft). Note vuggy pores (blue epoxy) lined by quartz grains (white) and with sparry calcite cement (red stain).

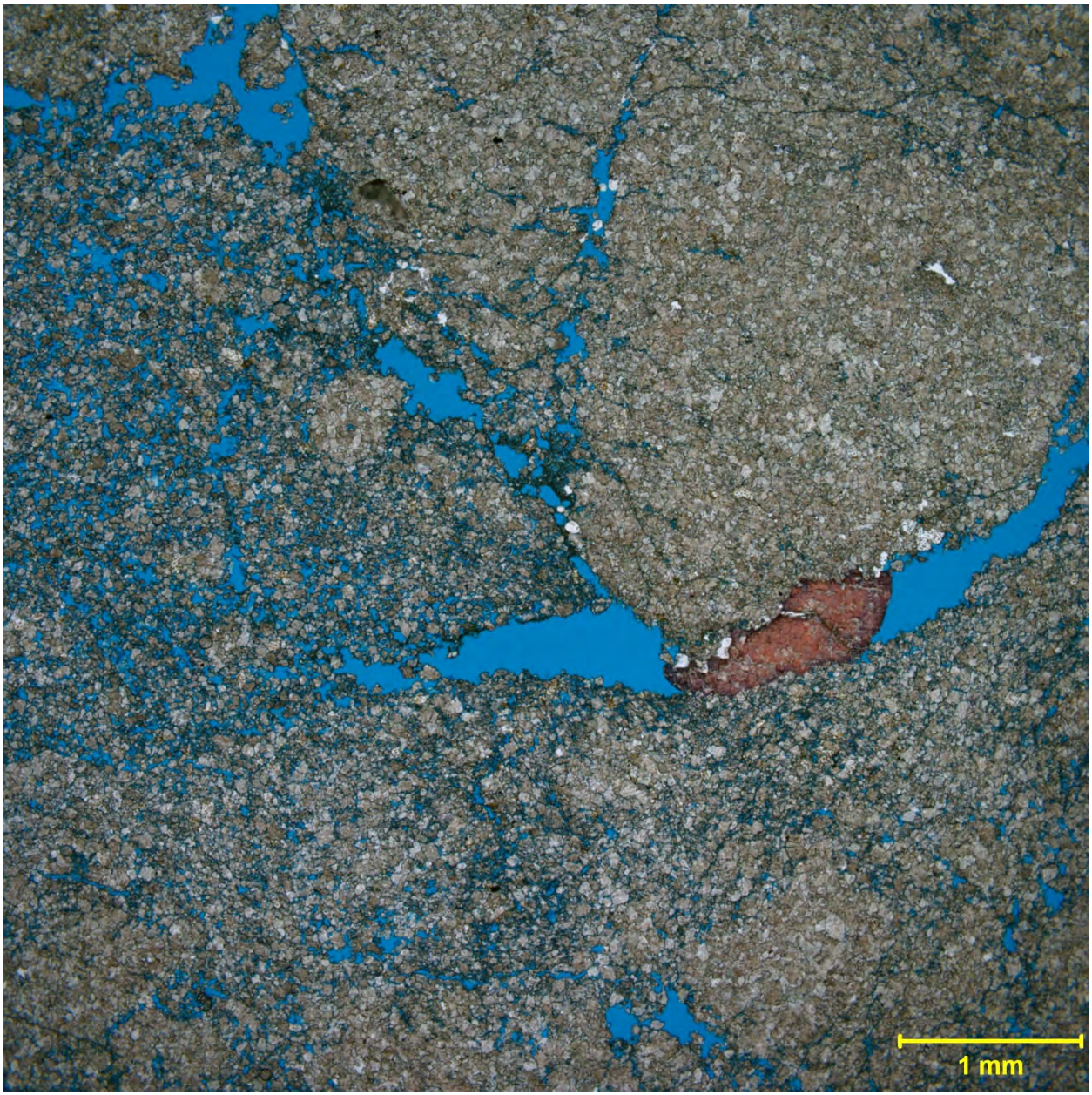


Figure 22: Photomicrograph of finely crystalline porous dolomite in the upper Rome Formation. Abundant porosity (blue epoxy) includes intergranular, vuggy, and fracture pores. Quartz grains (white) are dispersed in the sample, and sparry calcite cement (red stain).

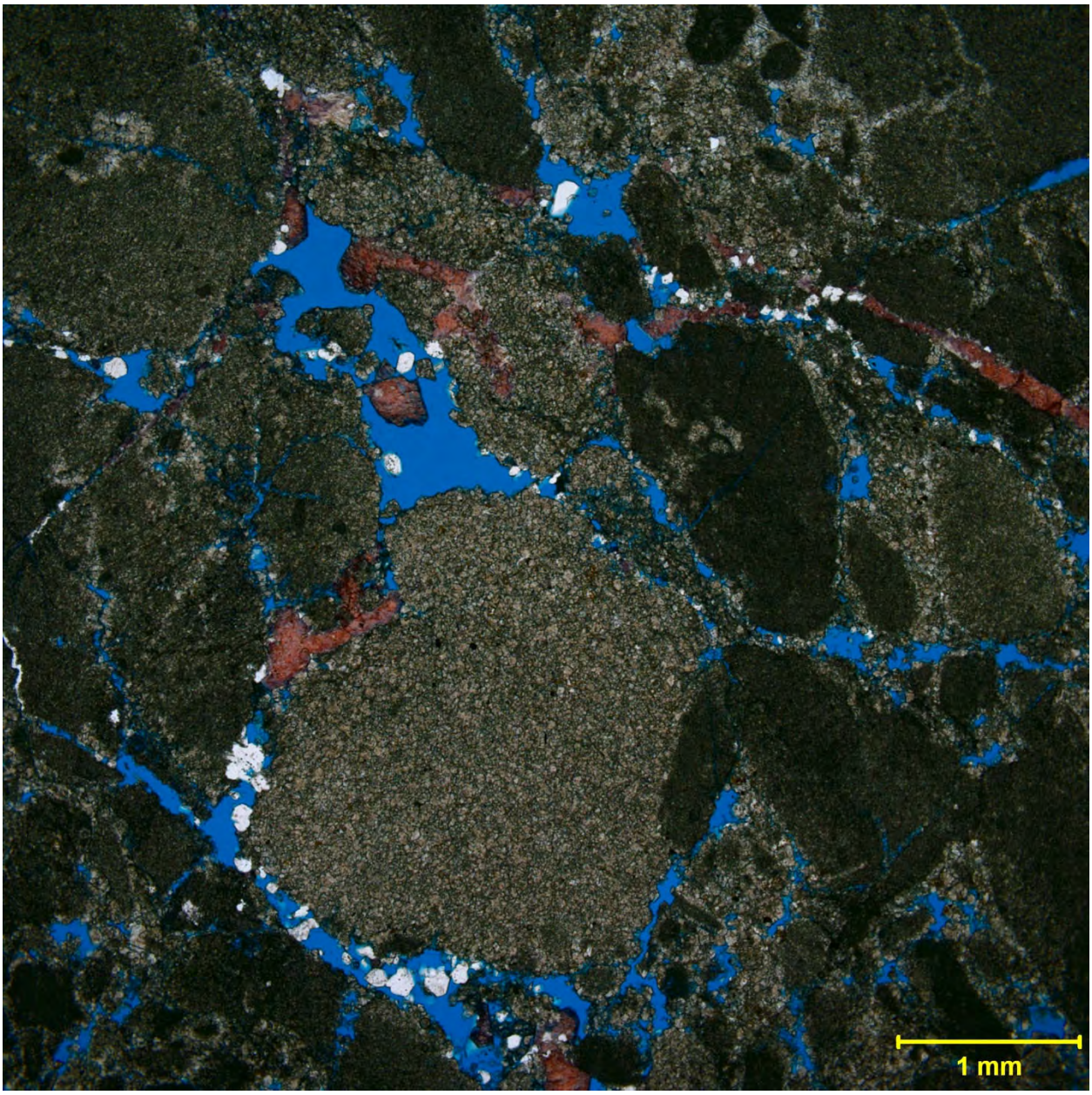


Figure 23: Photomicrograph of porous conglomeratic dolomite from the upper Rome Formation (3,799 ft). Note interparticle and vuggy pores (blue epoxy), quartz grains between clasts (white), and sparry calcite cement (red stain).

Porous dolomite at 3,803 ft is composed of 5% quartz, 4% K-feldspar, 4% calcite, and 87% dolomite (**Table 2; Figure 18**). Clay minerals are illite-mica and compose only 3% of the sample (**Tables 2, 3**). The rock is composed of finely crystalline dolomite, and quartz grains are confined to a lamina (**Figure 24**). Fracture, vuggy, and interparticle porosity is concentrated along the quartz- bearing lamina, and clay lines fracture surfaces in the sample. A clay bridge traversing a large pore appears to outline dissolved labile grains, which were probably feldspar. Porosity in this sample is 8.3%, and Klinkenberg permeability of 22.7 mD suggests that the pore network is moderately interconnected, as is the case in the previous sample.

At 3,814, the sidewall core contains siliceous dolomite containing 10% quartz, 4% calcite, 81% dolomite, 1% pyrite, and 2% celestine (strontium sulfate) (**Table 2; Figure 18**). Illite-mica forms the clay fraction, which composes only 2% of the rock (**Tables 2, 3**). The thin section shows that the rock is highly veined (**Figure 25**). The rock matrix is micritic to finely crystalline dolomite, and the fractures are filled with dolomite, quartz, and calcite. Porosity is restricted to a large sparry vein traversing the center of the sample and appears to be intercrystalline dissolution porosity on the basis of corroded sparry crystal margins. The sample contains only 6.3% porosity, and permeability was not determined but appears to be low based on the thin section, which contains abundant veins.

An unusual sample at 3,867 contains abundant gypsum. The mineralogy of the sample consists of 7% quartz, 12% dolomite, 1% anhydrite, and 79% gypsum (**Table 2; Figure 18**). Clay minerals make up only 1% of the sample and are illite-mica (**Tables 2, 3**). Fibrous gypsum forms most of the rock, which also includes clasts and irregular bodies of dolomicrite and quartz (**Figure 26**). Most of the quartz grains are floating in matrix. Porosity of the sample is 19.9%, which is the highest value measured in the Cassville #1 well, but permeability was not determined because of short sidewall core length. Porosity is intercrystalline and is developed mainly between fibrous gypsum crystals.

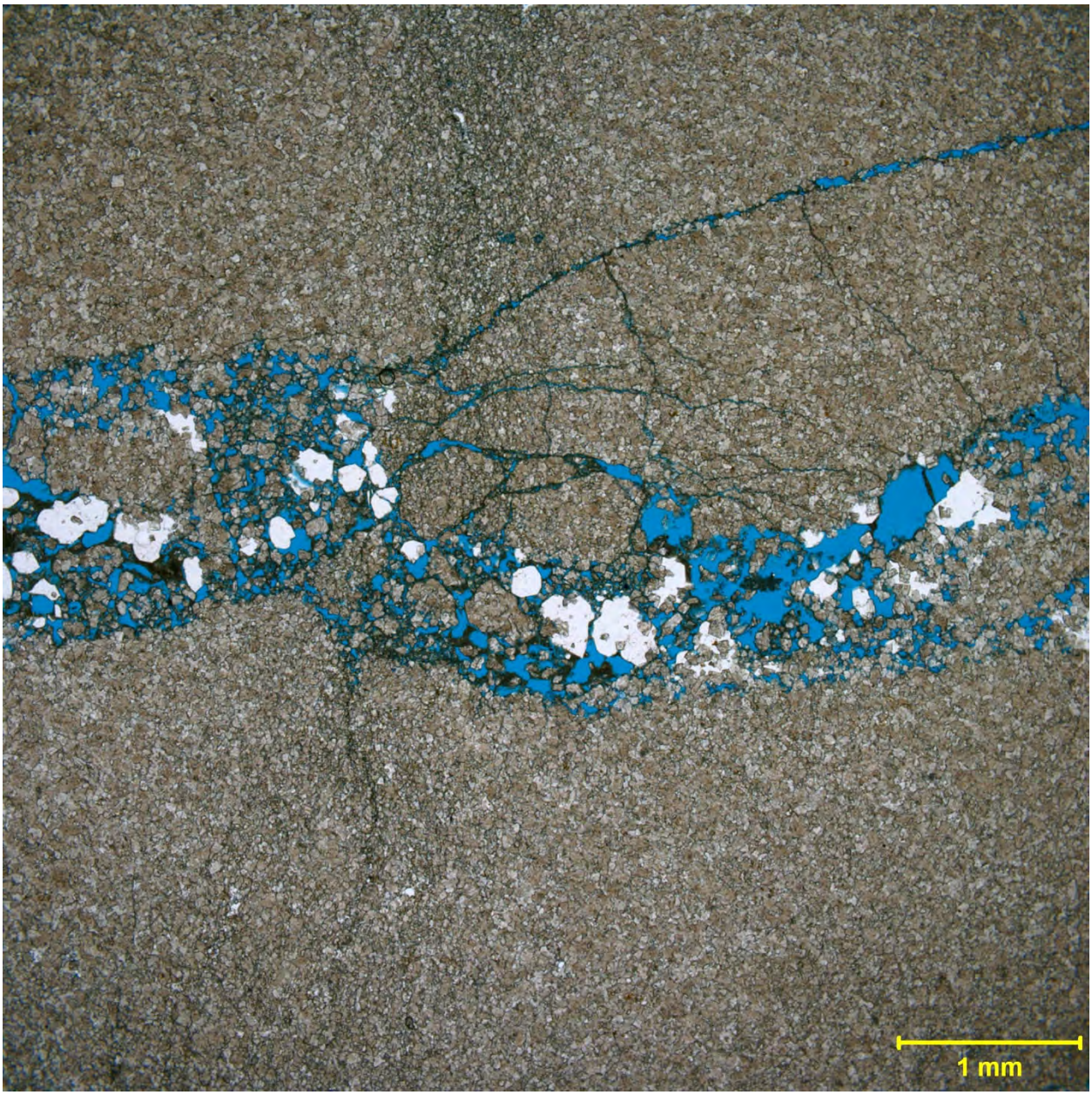


Figure 24: Photomicrograph of fractured and porous dolomite in the upper Rome Formation.

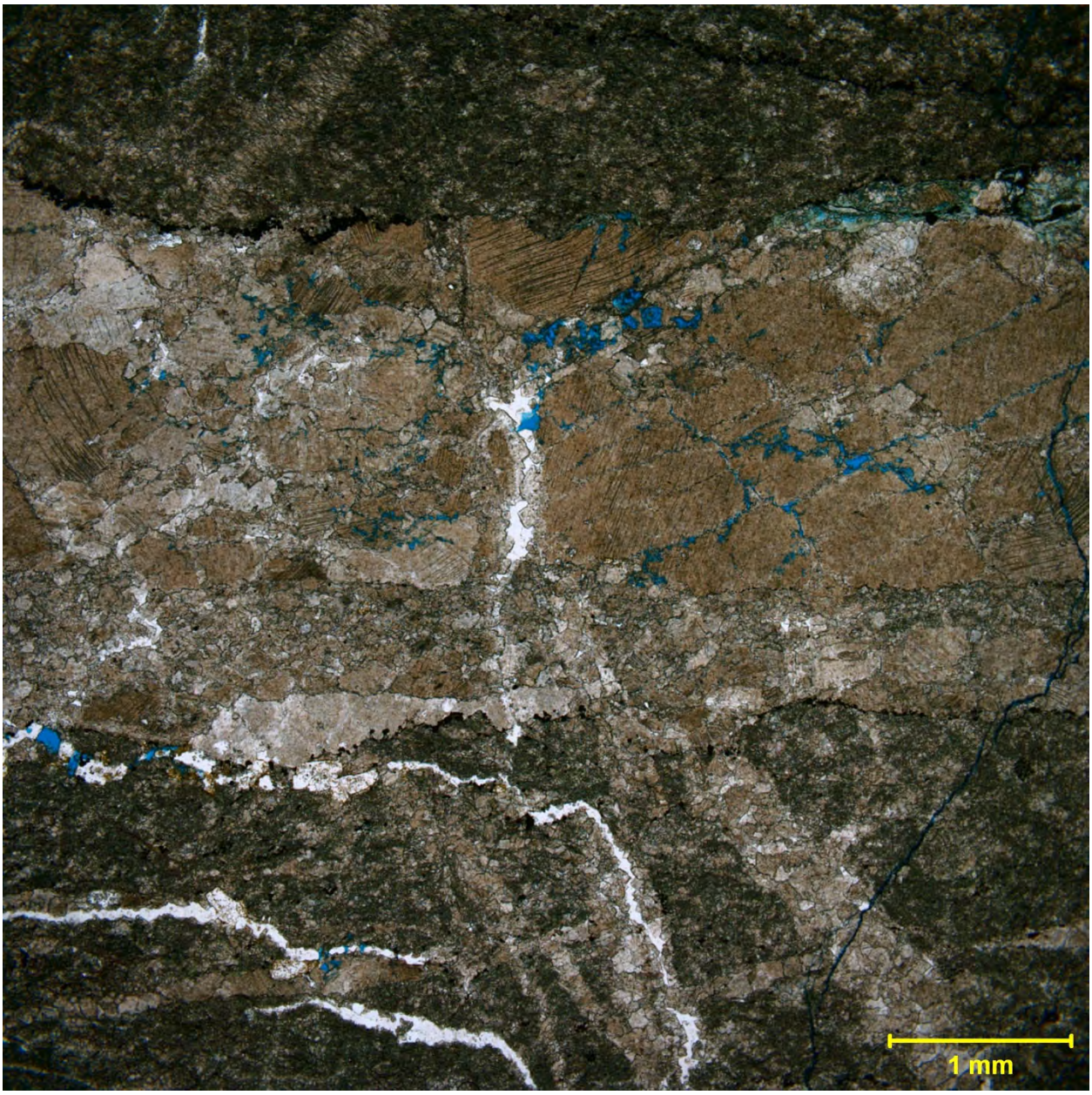


Figure 25: Photomicrograph of intensely veined dolomite in the upper Rome Formation (3,814 ft). Note localized pores (blue epoxy) in large vein cross-cutting specimen and quartz veins developed along small, irregular fractures (white).

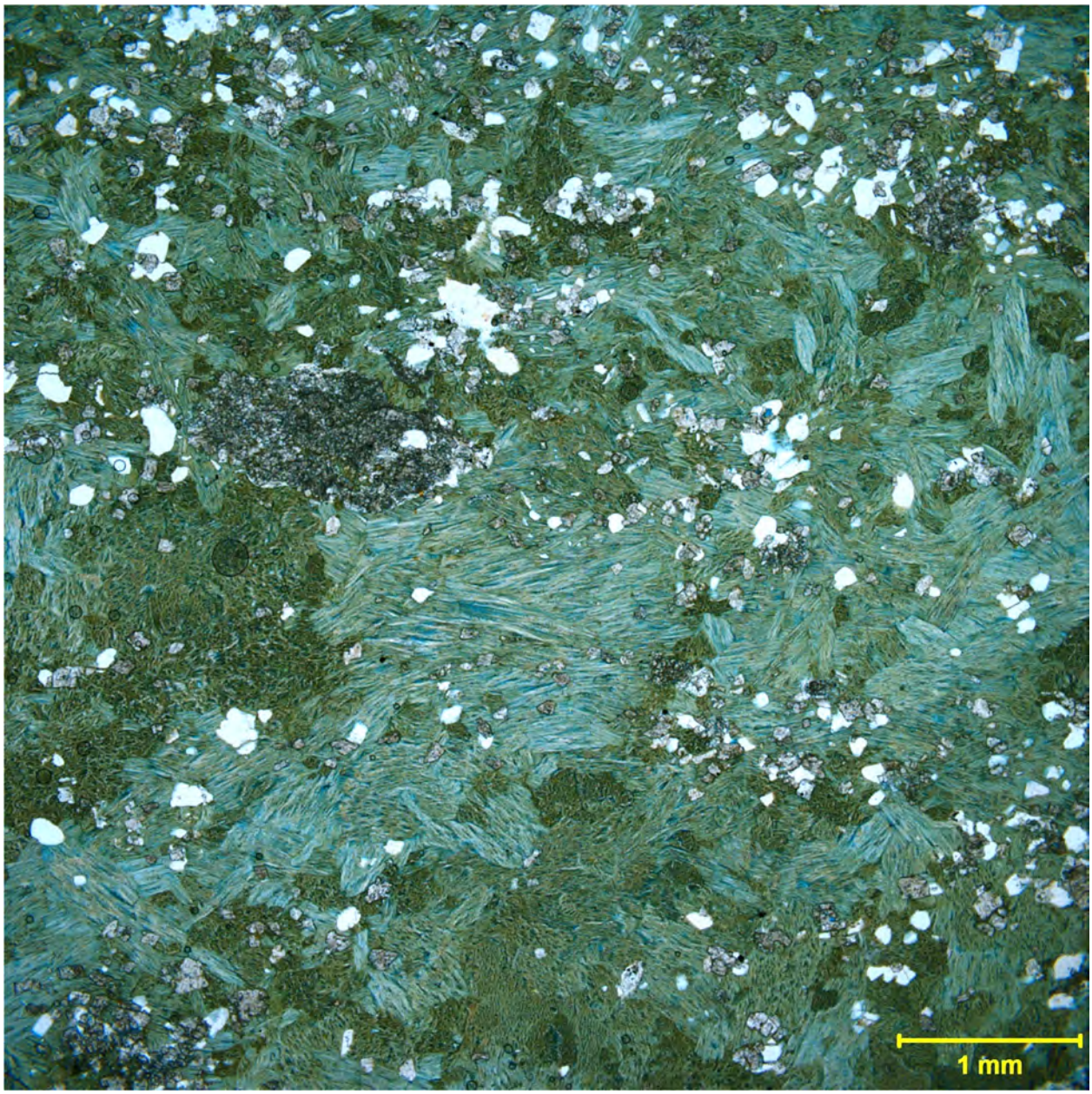


Figure 26: Photomicrograph of gypsum in the upper Rome Formation (3,867 ft). Note dolomite bodies (brown), abundant quartz grains (white), and porosity (blue epoxy) between fibrous gypsum crystals.

The deepest sidewall core sample recovered is from 3,894 ft and is from the top of the thickest upper Rome dolomite unit. Mineralogy of the sample is 4% quartz, 1% K-feldspar, 2% calcite, 85% dolomite, and 3% gypsum. The sample is composed of micritic to finely crystalline dolomite that is highly fractures (**Figure 27**). Vuggy pores and fractures contain isolated quartz grains and are filled with dolomite, gypsum, and sparry calcite cement. Porosity in the sample is restricted to a large vein that traverses the specimen. Porosity of the sample is only 5.3%, and Klinkenberg permeability is only 0.012 mD indicating that the fracture pores are poorly interconnected.

Results of XRD and thin section analysis indicate that dolomite is the dominant rock type in the intervals where sidewall cores were recovered. The arkosic nature of the lower Pumpkin Valley sandstone indicates a basement uplift origin, and the high clay content that is at least in part a product of feldspar dissolution resulted in a poorly interconnected pore system. Dolomite in the upper Rome Formation is predominantly finely crystalline to micritic, and porosity reflects a combination of dissolution and fracturing. The occurrence of gypsum in the upper Rome Formation is surprising, and association with anhydrite suggests that the gypsum formed diagenetically by hydration of anhydrite during regional deformation and fluid expulsion associated with thrust belt development.

Importantly, the only significantly porous and permeable strata found in the Cassville #1 well are in the porous dolomite of the upper Rome between depths of 3,710 and 3,867 ft. Accordingly, this interval appears to be the only candidate identified that may be viable for geologic CO_2 storage, but high structural dip (~40°) and unknown lateral continuity in the structurally weak Rome Formation raise questions that can be answered through additional research, including seismic exploration.

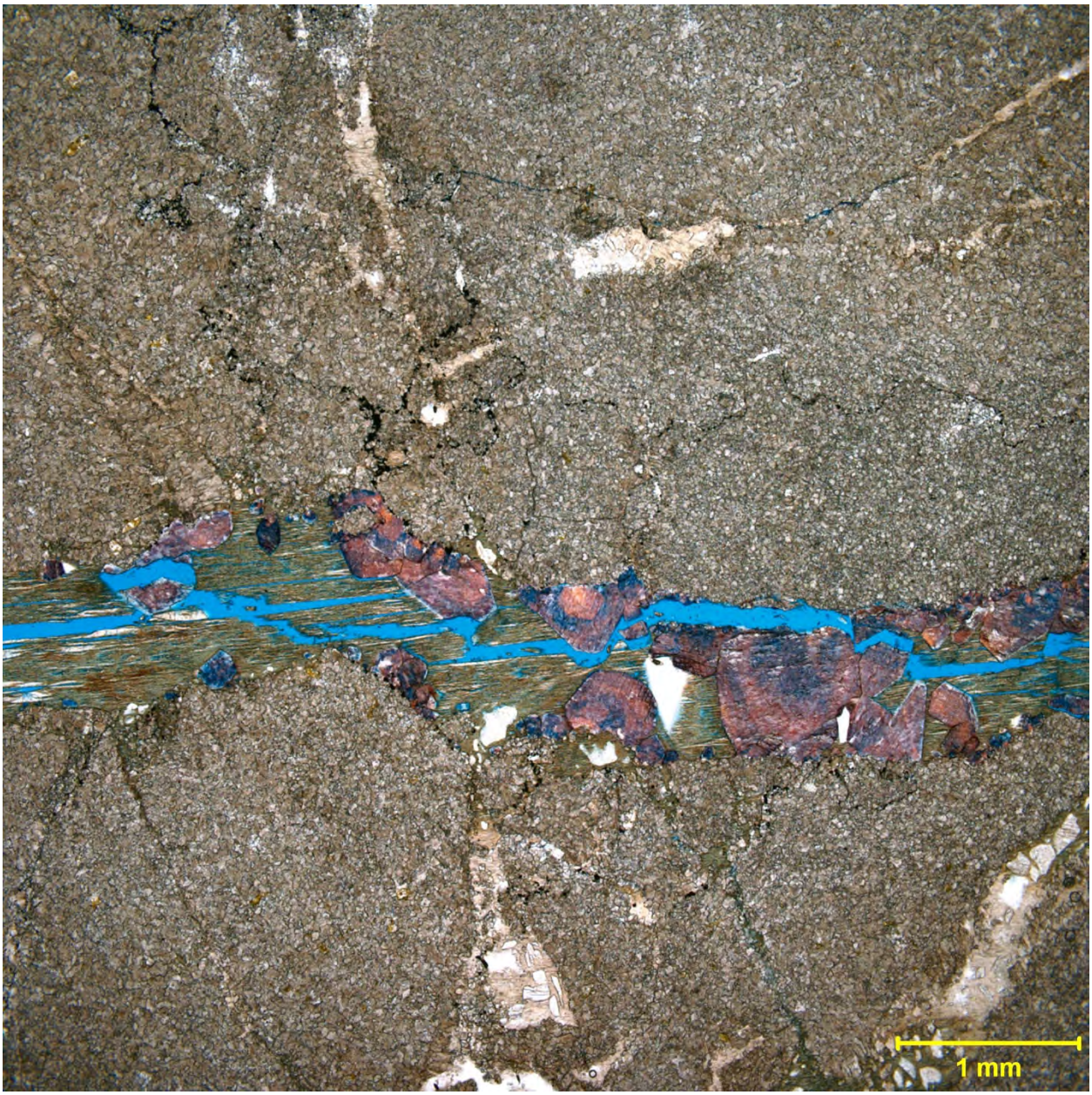


Figure 27: Photomicrograph of fractured dolomite in the upper Rome Formation (3,894 ft). Note large vein crossing image containing fibrous gypsum (brown), sparry calcite (red stain), and porosity that is restricted to a fracture running along the vein (blue epoxy).

Conclusions

The Cassville #1 well was drilled into a thick succession of Cambrian strata in the Appalachian thrust belt of Bartow County, Georgia that includes the Rome Formation, the Conasauga Group, and the basal Knox Group. Geophysical well logs record rock properties in Rome and Conasauga strata. The lower Rome Formation contains mainly interbedded shale, sandstone, and limestone, whereas the upper Rome is dominated by dolomite and shale. The Pumpkin Valley Shale forms the base of the Conasauga Group and is composed mainly of carbonate rocks at this location. The lower Pumpkin Valley contains interbedded limestone, sandstone, shale, and dolomite, whereas the upper part of the Pumpkin Valley contains a thick dolomite unit that is overlain by a thin radioactive shale interval. Above the Pumpkin Valley is the Rutledge Limestone, which is composed mainly of dolomite. The Rutledge is overlain by glauconitic Rogersville Shale, which is in turn overlain by the Maryville Limestone and interbedded shale and limestone of the Nolichucky Shale. The Nolichucky is overlain by a thick dolomite unit assigned to the Maynardville Limestone, which is in turn overlain chert-bearing limestone and dolomite that is characteristic of the Copper Ridge Dolomite of the Knox Group.

The bottom of the well apparently penetrated the Nolichucky Shale below a significant thrust fault (~3.870 ft) that may be a thrust ramp or upper-level detachment that is developed above imbricated Cambrian-Ordovician carbonate rocks. Above the Nolichucky, Rome-Conasauga units appear to be in normal stratigraphic order. However, FMI imaging and interpretation indicate that this section is internally structurally complex. Strata in the Rome Formation are complexly folded and sheared, commonly dipping steeper than 50°, establishing the Rome as a structurally weak layer. Structural dip is generally <10° in the Pumpkin Valley Shale, and abundant shear zones and variable dip direction indicate significant internal deformation including layer-parallel shear. The basal part of the Rutledge Limestone dips steeper than 60°, indicating a significant structural discontinuity, such as a detachment at the base. Dip decreases upward in the Rutledge, and the Rogersville-Maryville section forms a gently dipping structural panel similar to that in the Pumpkin Valley Shale. Strata in the Nolichucky Shale are complexly folded and sheared, with dip up to 50°, constituting an upper-level weak layer that is in some respects

similar to the lower Rome. Above this deformation zone, Maynardville and younger strata dip ~20°with variable dip direction, and shear zones are distributed throughout the section, underscoring the complexity of internal deformation in the Cambrian section. Shear related fractures have variable orientations but tend to cluster in the SE quadrant, reflecting northwestward translation of strata in the thrust belt.

Core analysis and geophysical log analysis reveal the development of significant porosity and permeability in the upper Rome dolomite section between depths of 3,713 and 3,803 ft. Porosity is developed principally in dolomite and is locally as high as 19.9%. Porosity values in candidate reservoir dolomite range from 8.0-17.4%, and Klinkenberg permeability ranges from 4.1-135 mD. Water saturation in the candidate reservoir zone ranges from 34.0-67.2%. Oil saturation varies from 7.0-36.8%, but there are significant errors in determination of fluid saturations because of limited sample pore volume. Regardless, some hydrocarbon production potential may exist in the upper Rome porous dolomite interval.

X-ray diffraction and thin section analysis were used to establish rock composition, rock fabric, and the nature of upper Rome pore systems. Upper Rome strata can be classified principally as dolomite and siliceous dolomite, and some evaporitic strata were identified that contain gypsum and anhydrite. Pore systems include vuggy porosity, fracture porosity, and intercrystalline porosity, and Klinkenberg permeability values ranging from 4-135 mD indicate a moderately connected to well-connected pore system. The porous dolomite interval has structural dip of about 40°, and relatively little is known about the overall geometry and continuity of these strata. Accordingly, additional investigation including seismic exploration is recommended to better understand and predict reservoir properties and structural continuity in the Rome Formation.

GEOLOGIC AND STRUCTURAL SUMMARY

By: Dr. Randall Kath, Petrologic Solutions, Inc.

Introduction and Site Selection

Advanced Resources International (ARI) is working on a project to assess the potential for carbon sequestration in the lower Cambrian stratigraphy of northwest Georgia. ARI subcontracted Petrologic Solutions Inc. (Petrologic) in December 2020 to help identify potential sites for drilling a stratigraphic test boring to evaluate the presence of suitable host rock. ARI provided the following criteria to Petrologic for siting the test boring:

- Proximity to and accessibility to Plant Bowen and Plant Hammond, both of which are large producers of CO_2;
- A potentially porous reservoir (most likely sandstone and/or siltstone of the Rome Formation and/or Chilhowee Group that have the potential for primary and secondary permeability and porosity);
- An impermeable cap rock (most likely shale of the Conasauga Group);
- Well site should avoid protracted drilling in the Knox Group that overlies the Conasauga because of the high chert content of the Knox lithologies;
- Have limited up dip connection to ground surface to avoid leakage the porous reservoir;
- The target unit should be overlain by at least 2500 feet (760 meters) of stratigraphy to avoid the potential for hydrofracking the rock; and,
- The property should preferably be owned by either Southern Company Services (SCS) or Georgia Power.

Based on Petrologic's professional knowledge and geologic experience in northwest Georgia, three target test boring areas were initially identified that most likely complied with the geologic siting criteria specified above. Upon review of these locations, ARI and SCS indicated that two of the test boring areas did not meet some of the logistical criteria for siting; consequently, Petrologic was instructed to focus their evaluation on the third area identified. The geologic target for this location, located near Kingston, Georgia, included stratigraphic inliers of the Conasauga Group within the Knox terrane.

ARI requested that Petrologic conduct detailed mapping on two properties at the third test boring area. The mapping was conducted to better understand the site-specific geology and confirm suitability based on the siting criteria established by ARI. The two properties, both owned by Georgia Power, were identified. One property is located at the southeastern side of the intersection of GA Hwy 20/411 and Hardin Bridge Road (referred to as the Kingston site), and the other property is located at a power substation between Kingston and Cassville, Georgia (referred to as the Cassville site).

Detailed geologic mapping indicated that the Kingston site is underlain by carbonate rocks of the Knox Group. Using chert morphology and the presence of thin sandstone beds, this property is interpreted to be directly underlain by the lower-most units in the Knox: the Chepultepec Dolomite and the Copper Ridge Dolomite. Although the thickness of this stratigraphic section of the Knox Group is unknown in this part of northwest Georgia, Petrologic estimates based on nearby outcrops in the Etowah River that there could be up to 2500 feet of cherty Knox Group rocks that would require penetration to reach the underlying geologic formations, which are the ultimate target of the stratigraphic test boring. Additionally, a moderately-sized closed depression was also observed during the geologic mapping that drained to a central area on the property. The morphology of this features suggested a sinkhole was present in this area which might be problematic for stability of the drilling platform foundation.

Because the Kingston site was interpreted to have a thick sequence of Knox lithologies overlying the target formations, and due to the potential ground instability related to the occurrence of a sinkhole, the Cassville site was also investigated. Detailed

geologic mapping of the Cassville site indicated that it is directly underlain by limestones and dolostones of the upper Conasauga Group. Immediately west of the property, several ridges are held up by cherty residuum of the Knox, further supporting the site being underlain by upper Conasauga stratigraphy. Given the preferable geologic conditions observed, the Cassville site was selected for advancement of the deep stratigraphic test boring, which was drilled in western Bartow County near the town of Cassville, Georgia.

Regional Geology

Bartow County is located within the Blue Ridge and Valley and Ridge physiographic provinces with the southeastern portion of Bartow County occurring in the Blue Ridge. The oldest exposed rocks in this area occur within the Corbin Massif (Corbin Granite, Rowland Springs Formation and Red Top Mountain Formation), which is a complex of Proterozoic aged rocks. Rocks within Corbin Massif occur within the hanging wall of the Great Smoky Fault. The Great Smoky Fault represents the structural boundary between the Blue Ridge and Valley and Ridge physiographic provinces, with the Valley and Ridge occupying much of the west/northwest portions of the County.

Valley and Ridge rocks of the Chilhowee Group, Shady Dolomite, and Conasauga Group are exposed west of the Great Smoky Fault in a series of imbricate thrust faults, including the Cloverleaf, White and Cassville faults (Kath et al., 2015). These Paleozoic-age sedimentary rocks have been folded into a series of anticlines and synclines broken by numerous thrust (reverse) faults and lateral strike-slip faults. The ridges are primarily held up by layers of sedimentary rock more resistant to weathering, such as sandstone, whereas the valleys are underlain by shale and limestone that readily weathers.

The area within and around Cassville is primarily underlain by rocks of the middle to upper Cambrian Conasauga Group and Cambro-Ordovician Knox Group. The oldest sedimentary rocks exposed near the site occur within the middle and upper Conasauga Group. The Conasauga Group consists primarily of sandstone and siltstone near the base (lower) which grades upward into calcareous shale and limestone/dolostone (middle and upper). The overlying Knox Group is comprised of variably cherty dolostone,

dolomitic limestone and limestone. Due to the calcareous nature of these rocks, they are prone to both physical and chemical weathering, which can develop a karstic terrain.

Based on knowledge of the regional structure and stratigraphy, the Knox and Conasauga Groups near the Cassville site are interpreted to be underlain by sedimentary rocks related to the stratigraphically older Chilhowee Group, Shady Dolomite, and Rome Formation units.

Regional Stratigraphy

A brief description of the relevant stratigraphy anticipated to occur beneath the Cassville site is presented below. The descriptions provided are a summary of numerous geologic publications in the region.

Valley and Ridge

Lower Cambrian Chilhowee Group-

Early workers mapped the Lower Cambrian clastic rocks below the Shady Dolomite as a single unit referred to as the Weisner Formation and named for Mount Weisner, the type area in southern Cherokee County, Alabama. These rocks have since been correlated with the Chilhowee Group (Mack, 1980; Bearce, 1977, 1985), and consequently are referred to as such in this summary.

The Chilhowee Group clastics comprise the oldest sediments deposited on the southeast margin of the North American craton (Laurentian margin) at the beginning of the Cambrian transgression. Mack (1980) observed this sequence of clastics in the Indian Mountain area in exposures east of Piedmont, Alabama, through Maxwell Gap near Borden Springs, Alabama, and subdivided the exposure of Chilhowee in Maxwell Gap into four formations based on the occurrence of depositional facies. Total thickness of the Chilhowee in this section was measured to be 2165 ft (660 m); the base of the Chilhowee is not present in this exposure, however, indicating that the Chilhowee is thicker than reported. The four formations delineated by Mack (1980) include (from oldest to youngest):

1. Cochran Formation- poorly sorted feldspathic sandstone and conglomerate interbedded with greenish siltstone and mudstone, interpreted as braided-stream alluvium. Mack (1980) observed this unit to be isolated by faulting west of the Borden Springs quadrangle, grading upward into shale of the Nichols Formation west of Maxwell Gap.

2. Nichols Formation- greenish gray to black, micaceous mudstone with minor interbeds of siltstone and very fine sandstone. This unit includes some calcareous shale and limestone in southeastern belts and is interpreted as an offshore shelf facies which records maximum flooding during the Cambrian transgression. This Formation grades upward into the overlying Wilson Ridge Formation.

3. Wilson Ridge Formation- gray to black silty mudstones with current ripple lamination, flaser bedding, mudcracks and burrows encasing lenticular fine- to coarse-grained, quartz arenites, with channel structures, crossbeds, wave and current ripples. The Wilson Ridge grades upward into the overlying Weisner Formation.

4. Weisner Formation- conglomeratic, cross bedded, rippled to laminated quartz arenites with Skolithus burrows which are interpreted as high energy shoreface-beach facies.

Lower Cambrian Shady Dolomite-

The Shady Dolomite was named by Keith (1903) for exposures in Shady Valley, Tennessee. East of the drill site near Cartersville, Georgia, the Shady Dolomite is poorly exposed in natural outcrops. However, the Shady is well exposed in mine pits in the Cartersville Mining District. Where exposed, the Shady is light-gray to light-bluish gray to medium dark-gray, thick- to massive-bedded dolostone and dolomitic limestone. The Shady is locally siliceous and weathers to an umber- or ocher-colored “chocolate brown” clay residuum which is often associated with iron oxide deposits. Because of intense silicification associated with mineralization, weathering of the Shady commonly yields jasperiod, also closely associated with iron ore deposits of the Shady.

West of the study area in Floyd County, Georgia, the Shady is exposed in the north bank of Big Cedar Creek about 300 ft (90 m) east of the bridge on Spout Springs Road on the Livingston quadrangle and along the west side of Walker Mountain on Park Avenue on the Rome South quadrangle (Cressler, 1970). The Shady is also exposed along a north-south strike belt on the east side of the Cedartown West quadrangle (Kath and Crawford, 2006; Cressler, 1970). In these two exposures, the Shady is mainly a medium- to dark-gray, thick bedded, fine- to medium-crystalline dolostone. Based on the structural interpretation of these two exposures, the Shady has a minimum thickness between 320 and 490 ft (100 and 150m).

Lower Cambrian Rome Formation-

The Rome Formation was named by Hayes (1891) for exposures on Walker Mountain in Floyd County, Georgia, near Rome, Georgia, and has been assigned to the lower and middle Cambrian. The Rome consists of gray silty clay shale that weathers to a characteristic tan, orange, pink or maroon color and commonly displays a distinctive silvery sheen. Silty shale beds are commonly dolomitic, and in fresh exposures they have the appearance of massive dolostone. Thin to thick layers of gray, purple, white, pale-red, and green siltstone and sandstone beds, some of which are dolomitic, are also scattered throughout the shale, particularly in the upper part of the formation. The Rome is relatively resistant to weathering and generally forms low-relief ridges. Where present in the exposures, the red and green siltstones and sandstones are characteristic. Cressler (1970) estimates the Rome to be between 490 and 985 ft thick (150 to 300m).

Middle and Upper Cambrian Conasauga Group-

Hayes (1891) named the Conasauga Formation for exposures along the Conasauga River in Whitfield and Murray Counties, Georgia. The Conasauga has been given group status and is comprised of Maynardville Limestone, Nolichucky Shale, Maryville Limestone, Rogersville Shale, Rutledge Limestone and Pumpkin Valley Shale in Tennessee. Cressler (1970) divided the Conasauga into an eastern and western belt in Floyd County and Polk County, Georgia. Lithologically, the two belts differ significantly; the eastern belt consists of limestone and shale in nearly equal proportions, whereas the

western belt contains shale and medium-grained sandstone. Based on Cressler's descriptions of the different lithologic belts, the Cassville drill site appears to be within the easter belt.

Cressler describes the lower unit of the eastern belt, east and southeast of the Coosa Fault, as up to 98 ft (30 m) of medium-gray massive limestone. The middle part of the unit includes thick discontinuous layers of massively bedded limestone (oolitic and nonoolitic) that grades into and is interbedded with olive tan shale. The upper part of the unit consists of nearly 330 ft (100 m) of calcareous olive-gray and tan shale interbedded with thick sections of massive bedded blue-gray ribboned limestone and some gray dolostone.

Middle Cambrian and Lower Ordovician Knox Group-

The Knox Group has been divided into three formations (from oldest to youngest): Copper Ridge Dolomite, Chepultepec Dolomite, and Longview Limestone. Thin- to massive-bedded dolostones, primarily brown or tan in the lower part and medium- to light-gray in the middle and upper parts, have a maximum thickness estimated at approximately 3500 ft (1065 m). Gray limestone beds are interlayered with the dolostone in the upper part. The carbonates are highly siliceous, with abundant masses and nodules of chert; weathering produces a cherty, silty, clay-rich residuum up to 195 ft (60(+)m) thick.

Regional Structural Geology

Published geologic maps around Cassville (Croft, 1963; Cressler, 1970; Georgia State Geologic Map, 1976; Kath and Crawford, 2009) show that the area is underlain by the Knox Group and various lithologies of the Conasauga Group. Croft (1963) subdivided the Conasauga Group into lower, middle, and upper stratigraphy, which is also reflected on the 1976 State Geologic Map. The lower unit is mainly dolostone with some interbedded limestone and shale; the middle units is mainly shale and calcareous shale; and the upper unit is mainly interbedded shale and limestone. Cressler (1970) and Kath and Crawford (2009) show the Conasauga Group rocks mostly comprised of three lithologies. The lower most lithology is mainly thin- to thick-bedded gray limestone; the

middle unit is dominantly greenish, gray and slightly purplish shale that contains lenses of limestone; and the upper unit is thinly to massively bedded gray dolostone that contains dark-gray, clayey limestone which locally contain chert. All of the published geologic maps show undifferentiated Knox Group to the west of the site.

The structural interpretations of the areal distribution of lithologic units in the Cassville area are variable. Croft (1963) shows the site to be near the axis of an overturned anticline with an overturned syncline immediately to the east of the site. Cressler (1970) and Kath and Crawford (2009) show the site to be near the western end of either a normal stratigraphic inlier and/or a gently westward plunging anticline.

Subsurface investigations were conducted by Thomas and Bayona (2005) and Whisner (2010). Thomas and Bayona generated 18 balanced geologic cross sections along lines that are generally perpendicular to regional geologic strike. The cross sections are based on outcrop geometry, bedding attitudes, stratigraphic thicknesses, seismic reflection profiles, and deep wells. For development of the balanced cross sections, the Paleozoic stratigraphic was divided based on the mechanical behavior or rheology of the different rock units. Unit 1 in the cross sections, shown by the magenta color, are mechanically weak rocks near the base of the Paleozoic section. Unit 1 consists of the Chilhowee Group, Shady Dolomite, Rome Formation and Conasauga Group lithologies. This package of lithologies is dominantly comprised of interlayered shale, sandstone, and carbonate. Unit 2 is a mechanically stiff layer and is comprised of the Knox Group carbonates.

Geologic cross section 2 of Thomas and Bayona (2005) is in close proximity to the drill site, **Figure 28**. Based on this panel, the basement is between 9,000 and 11,000 ft (2750 to 3350 m) below the ground surface. Their subsurface interpretation in the vicinity of the site shows that Unit 1 is repeated at least two times along flat-on-flat thrust faults.

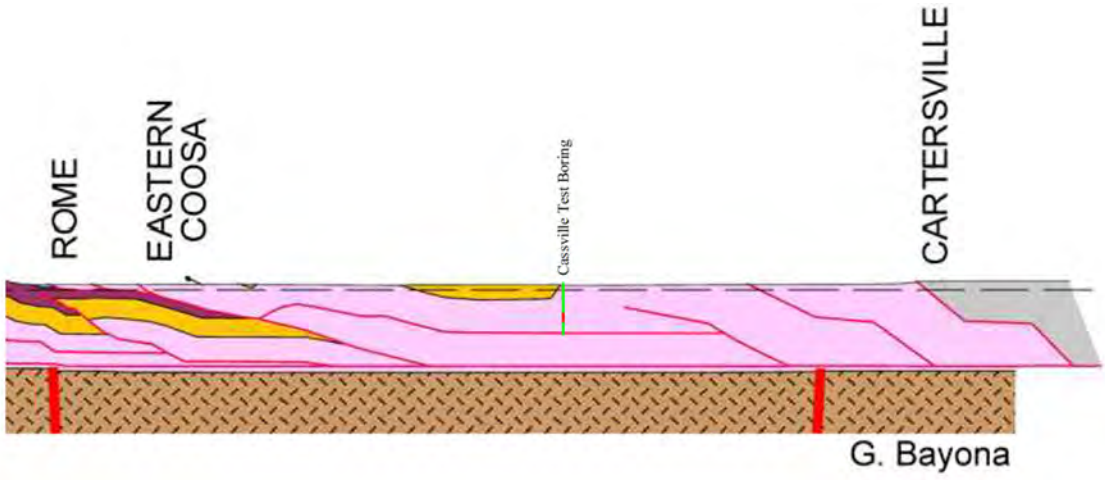


Figure 28: Geologic cross section (Panel 2) from Thomas and Bayona (2005) showing Cassville test boring.
(green part of boring represents Conasauga Group, whereas red part of boring represents Rome Formation).

Whisner (2010) further modified cross section 2 of Thomas and Bayona by subdividing Unit 1 to show the Rome Formation, **Figure 29**. In **Figure 29** (Panel 15), Whisner interprets the Rome Formation to be structurally thickened in the lower thrust sheet and repeated in an upper thrust sheet. Similar to Thomas and Bayona, Whisner shows the general structure to be a flat-on-flat thrust geometry.

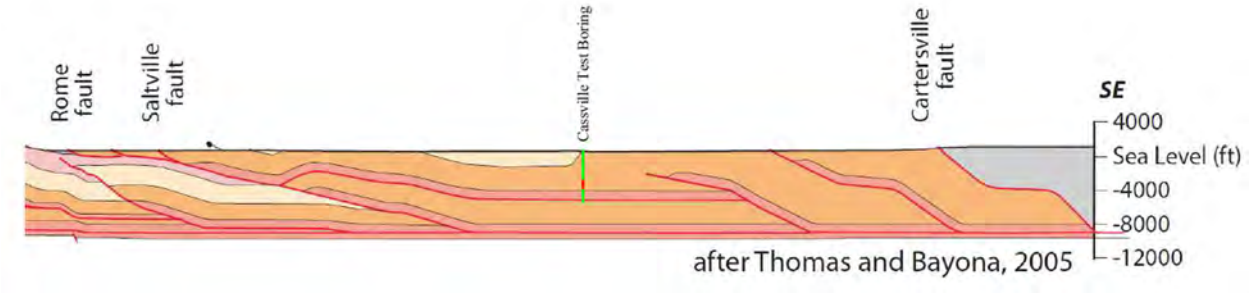


Figure 29: Modified geologic cross section from Whisner (2010).
(green part of the boring represents Conasauga Group, whereas red part of boring represents Rome Formation).

Cassville Site Geologic Conditions

The detailed geologic mapping was performed within and around the site on April 14, 2021, and April 16, 2021 using the Kingston, GA USGS 7.5-minute topographic quadrangle as a base map. In general, the mapping was focused on geologic features exposed on and around the substation property. Information recorded at each map station includes: lithology and mineralogy; orientation and characteristics of structural

discontinuities including, faulting, jointing, cleavage, and compositional layering; and depth and type of weathering characteristics of the rock. Map station locations were recorded using a hand-held, Wide Area Augmentation System (WAAS)-enabled Global Positioning System (GPS) and the Avenza Maps application.

The Cassville site occurs within the Valley and Ridge physiographic province, which occupies most of the county and is characterized by a series of long, narrow northeast/southwest-trending ridges separated by wide parallel valleys. Topographic relief within this province is about 800 to 1000 feet, with topographic lows of about 650 to 700 feet above mean sea level (ft. msl) occurring in the river valleys and topographic highs up to 1,600 ft. msl on nearby ridges.

Contacts between three different geologic units were observed during the geologic mapping. Two mappable lithologic units associated with the Conasauga Group were observed in the central and eastern portions of the site. The central unit, at and west of the drill site, is comprised primarily of calcareous and silty shale that is generally characterized as being deeply weathered, fine-grained, and locally fissile. Due to the structural complexity and deeply to completely weathered nature of this shale, no structural data was obtained during mapping.

A Conasauga limestone unit occurs at and east of the drill site and is in stratigraphic contact with the Conasauga shale. This unit is characterized by relatively fresh, coarsely crystalline, very pure, limestone and dolomitic limestone that is exposed along the banks and in the stream bed of Two Run Creek and associated tributaries, as well as in cuts along the railroad south of the drill site.

The Knox Group underlies the site west of the Conasauga shale units. Due to physical and chemical weathering, the Knox typically weathers deeply and heterogeneously, leaving a variably thick horizon of residual soil and locally, a transitionally weathered zone between the residual soils and fresh bedrock. No exposures of the Knox Group rocks were found in the immediate vicinity of the drill site.

The only observed exposures of the Knox Group was along Highway 293 west of downtown Kingston. This exposure is near the Knox/Conasauga contact and is therefore assumed to be within Copper Ridge Dolomite unit of the Lower Knox Group. This unit is characterized by fresh, finely-crystalline, moderately-well bedded and jointed, cherty dolostone that locally contains fine-grained, cross stratified, thin sandstone beds (quartz arenite). Consequently, this exposure of relatively unweathered Knox is highly unusual in the Valley and Ridge of Georgia.

Borehole Site Stratigraphy

Geologic logging of drill cuttings from the borehole, referred to as Cassville #1, was conducted by SLG Resources, who electronically transmitted daily drilling reports to Petrologic. Based on the geologic logging combined with site visits to inspect the cuttings, Petrologic interpreted the stratigraphy encountered during drilling.

In general, the upper 3610 ft (1100 m) below the ground surface (ft. BGS) of the boring encountered lithologies that are consistent with the Maynardville Limestone, Nolichucky Shale, Rutledge Limestone and Pumpkin Valley Shale (upper, middle and lower Conasauga Group rocks using the Tennessee stratigraphy nomenclature). At approximately 3610 ft. BGS (1100 m), red colored lithologies consistent with the Rome Formation were encountered. These lithologies included sandstone, siltstone, and shale that locally contain thin beds of finely-crystalline limestone/dolostone. Below 4740 ft.BGS (1445 m), the lithologies become less sandy and contain white calcite-filled fractures that is characteristic of natural exposures of the Conasauga throughout northwest Georgia.

The general stratigraphy interpreted by Petrologic is shown in **Table 4**, whereas the detailed stratigraphy is shown on **Table 5**.

Table 4: General Stratigraphic breaks based on mud logging by SLG Resources.

Cassville Stratigraphic Test Boring (Wildcat No. 1)

Regional Dip 25

From (ft)	To (ft)	Interval (ft)	Corrected Thickness (ft)	Tennessee Stratigraphy	Georgia Stratigraphy
0	160	160	145	Conasauga Group- Maynardville Limestone (cherty)	upper Conasauga Group
160	826	666	604	Conasauga Group- Maynardville Limestone	upper Conasauga Group
826	1928	1102	999	Conasauga Group- Nolichucky Shale interval including Maryville Limestone and Rogersville Shale	middle Conasauga Group
1928	2434	506	459	Conasauga Group- Rutledge Limestone	middle Conasauga Group
2434	3610	1176	1066	Conasauga Group- Pumpkin Valley Shale	lower Conasauga Group
3610	4740	1130	1024	Rome Formation	Rome Formation
4740	5710	970	879	Conasauga Group- Nolichucky Shale interval including Maryville and Rogersville (?)	middle Conasauga Group
5710	6030	320	290	Conasauga Group- Pumpkin Valley Shale (?)	lower Conasauga Group

Table 5: Detailed stratigraphic descriptions based on mud logging by SLG Resources.

From (ft)	To (ft)	Interval (ft)	Corrected Thickness (ft)	General Lithologic Description	Comments	Formation/ Group
0	40	40	40	surface casing; surface geology indicates limestone and dolostone interbedded with shaly limestone and calcareous shale, minor chert, highly folded (chevron folds)		
40	160	120	109	Interbedded limestone and dolostone with discrete zones of chert and minor shale		Conasuaga Group
160	826	666	604	Limestone, fine-grained to micro-crystalline, light gray to white, locally contains intraformational conglomerate (breccia); minor yellowish chert		
826	1928	1102	999	Shale, dary gray, silty, calcareous; interbedded with limestone (10-40%); locally contains traces of dull brown chert	not a strong gamma response until ~960 ft. BGS	
1928	2434	506	459	Limestone, light- to dark-gray, finely crystalline, locally contains traces of pyrite	gamma drop at ~1930 ft. BGS, transition from shale cominated to limestone dominated	
2434	2630	196	178	Siltstone, dark gray to black, calcareous; interbedded with limestone; grading down hole into sandstone		
2630	3280	650	589	Sandstone, tan to white, fine grained, well sorted, silica- and calcareous-cement	~3150 ft. BGS gamma increases then reduces at 3310 ft. BGS	
3280	3610	330	299	Interbedded shale, sandstone, siltstone and limestone	sharp gamma drop at 3310 ft. BGS- possible fault (?)	
3610	3670	60	54	Sandstone, tan to white, trace red to pink, fine-to medium-grained, interbedded with finely crystalline limestone.	top of Rome Formation	Rome Formation
3670	3880	210	190	Sandstone, red to pink and white, fine-to-medium-grained; interbedded with minor shale and limestone	strong gamma drop at 3700 ft. BGS	
3880	4122	242	219	Siltstone, dark gray, shaly, interbedded with sandstone	3880-3890 ft. BGS large increase then decrease in gamma	
4122	4210	88	80	Interbedded sandstone, siltstone and shale		
4210	4340	130	118	Sandstone and siltstone		

From (ft)	To (ft)	Interval (ft)	Corrected Thickness (ft)	General Lithologic Description	Comments	Formation/ Group
4340	4590	250	227	Sandstone, light gray to white, fine- to medium- grained; intebedded with minor amounts of siltstone		
4590	4740	150	136	Sandstone dominated	base of Rome Formation	
4740	4822	82	74	Sandstone and siltstone grading downhole into a shale dominated sequence. All units contain calcite filled fractures that are characteristic of the Conasauga Group		Conasauga Group
4822	5710	888	805	Mostly shale: light- to dark-gray, clacareous, crenulated, with calcite veins; interlayered with varying amounts of sandstone and siltstone		
5710	6030	320	290	Interlayered limestone, silstone and sandstone		

Structural Interpretation Based on Borehole Stratigraphy

The structural interpretations by Thomas and Bayona (2005) and Whisner (2010), presented in the Regional Structural Geology section above, appear to be based on a seismic section that was collected in 1981 along Highway 411/GA-20 from I-75 near Cartersville, Georgia to Centre, Alabama. Although the seismic section does not transect the site, the part of the section near the site runs nearly east-west along Highway 411/GA-20 approximately 1.25 miles south of the site. Given the near proximity to the site, the depth to basement shown in the two cross sections should be relatively accurate. However, the lower Cambrian stratigraphy typically does not show up well in seismic sections, especially the sections using older seismic data where the profiles were collected using thumper trucks. Additionally, the rheologically weaker layers (i.e., shale) are highly strained and deformed and do not show up well on the seismic profiles. In contrast, the rheologically stiffer layers (i.e., Knox Group) show up very well on seismic sections.

Based on the stratigraphic interpretation of the mud logs and regional stratigraphy, the Conasauga Group lithologies that were encountered in the upper part of the test boring (40 to 3610 ft. BGS) are considered to be in a normal stratigraphic contact with the underlaying Rome Formation. The boundary between the Rome Formation and

Conasauga Group was identified at approximately 3610 ft.BGS (1100 m) based on the first occurrence of red beds. However, given the complexity of the Formation Microimager (FMI) logs, this normal stratigraphic contact appears to have been subjected to bedding-parallel slip and associated deformation due to a high rheologic contrast between the different lithologies.

Shale units that were encountered above 3610 ft.BGS (1100 m) appear to be highly contorted. Given that these units are interbedded with thick carbonate units, the rheologic contrast between the shale- and carbonate-dominated units within the Conasauga Group would cause the less competent shale units to be highly contorted and deformed.

Within the Rome Formation, between 3610 and 4740 ft. BGS, there appear to be several highly deformed zones. Given that the Rome Formation is very shaley, there are probably several bedding-parallel faults similar to the imbricates seen within the Rome Formation near Rome, Georgia. Surface geologic mapping west of the drill site shows that these bedding-parallel faults have dissected and structurally thickened and thinned the Rome Formation. Historically, faults in the area that carry Rome Formation lithologies in the hanging wall are associated with the Coosa Fault system.

With the contrast is lithologies between the base on the Rome Formation and the Conasauga Group lithologies encountered between 4740 and 6030 ft. BGS (1840 m), the Rome/Conasauga observed at 4740 ft, BGS is also probably highly sheared. Because of the juxtaposition of the stratigraphy, this contact is interpreted as a major thrust fault, emplacing Rome Formation over the Conasauga Group.

Discussion

As described above, the Cassville site test boring encountered relatively high porosity/high permeability lithologies within the Rome Formation which is considered to be a favorable host rock. ARI has expressed concern regarding the potential for the injected gas to escape to the surface where the target host rock crops out. Based on review of published and unpublished geologic mapping, the Rome Formation is shown to occur at depth between the Great Smoky Fault which is located approximately 9 miles

(14.5 km) to the east and the Coosa Fault which is located approximately 16 miles (26 km) west of the test boring, **Figure 30**.

Based on detailed geologic mapping by Kath et al., (2015) of the Cartersville Mining district, the Rome Formation has been highly imbricated along the Cassville, White and Cloverleaf Faults. Any sequestered carbon injected in the subsurface at the Cassville test site would be trapped in the Rome Formation, east of the site, due to stratigraphic termination of the Rome Formation along the Cassville Fault.

To the west, the Rome Formation is interpreted to crop out along the trace of the Coosa Fault and a smaller fault splay associated with the Coosa Fault. The formation is interpreted to be semi-planar between the test boring and the Coosa Fault, as shown on **Figure 30**; however, there is a high probability that the Rome Formation is dismembered along several possible blind thrusts which are represented at the surface as small asymmetric anticlines bringing the Conasauga lithologies to the surface between Cassville and Rome, GA.

Based on our interpretation of the regional geology, there are several imbricate thrust faults between the Cassville test boring and the area of outcrop near the Coosa Fault, disrupting continuity of any bedding planes within the formation. This, in combination with the significant distance between the test boring and where the host rock is exposed (~16 miles), suggests that it will be highly unlikely for gas to migrate from the test boring location and be released at ground surface near the Coosa Fault.

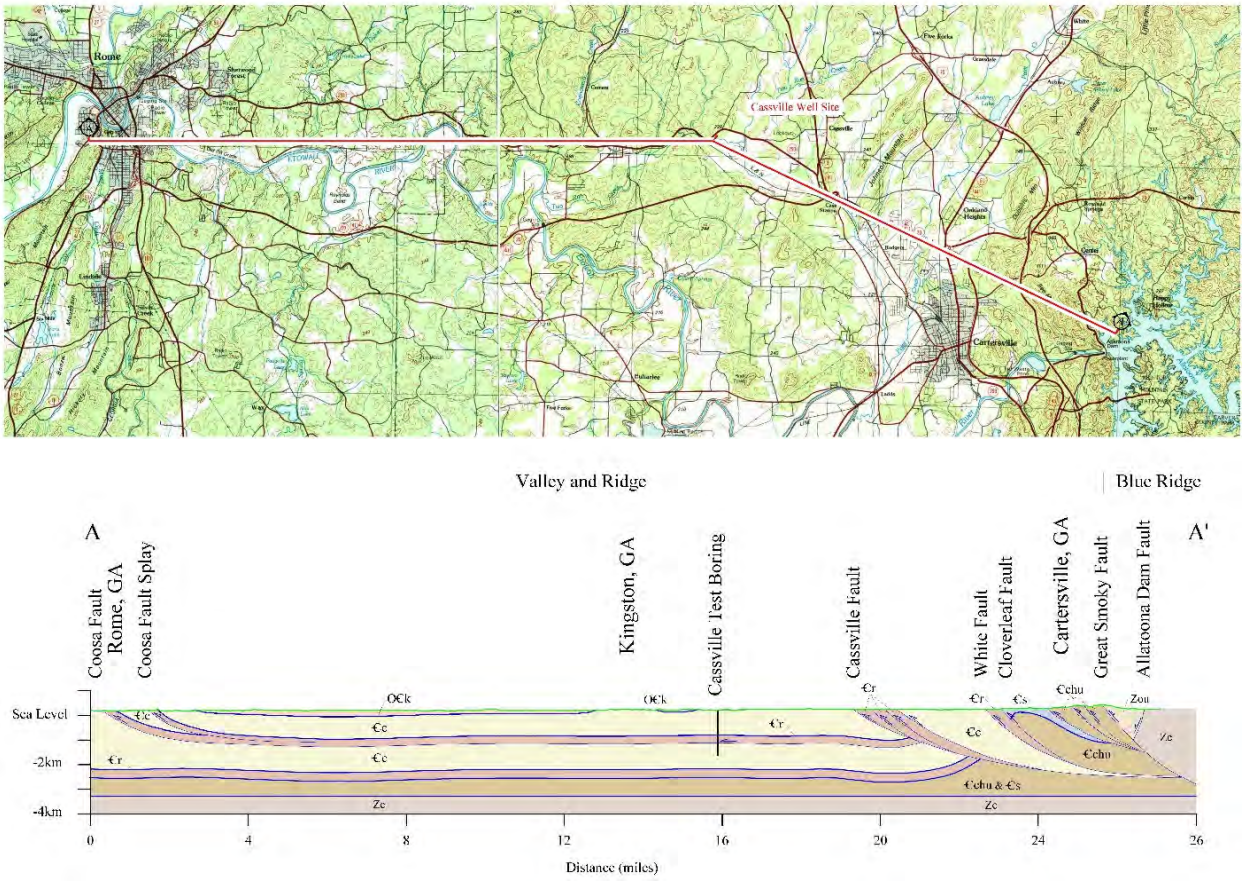


Figure 30. Geologic cross section from Rome, GA (A) to east of Cartersville., GA (A'). Surface geologic mapping data from the Rome South, Wax, Kingston, Cartersville, and Allatoona Dam Georgia 7.5-minute geologic quadrangles. (Zc- Corbin Meta-Granite; Zou- Ocoee Group undifferentiated; Cchu- Chilhowee Group undifferentiated; Cs- Shady Dolomite; Cr- Rome Formation, Cc- Conasauga Group undifferentiated; OCk- Knox Group undifferentiated)

Assessment

Despite the operational challenges encountered while drilling, the results of routine core analysis and log analysis prove encouraging for further investigation of the CO_2 storage potential of northwest Georgia Valley and Ridge province. Specifically, the upper Rome Formation, which may form a duplex beneath the Conasauga Group encountered, demonstrated preferential petrophysical characteristics for CO_2 storage.

Log results record a thick succession of Cambrian-Ordovician carbonate and siliciclastic strata, including the Rome Formation, Conasauga Group, and the basal part

of the Knox Group (Copper Ridge Dolomite), in ascending order. Shear zones containing complex networks of fractures are distributed through much of the wellbore and beds dips are steep, as shown by the FMI log interpretatin. The core analysis summary demonstrated that porosities higher than 10.0% are present in dolomites in the upper Rome Formation (3,713-3,798 ft) and the associated Klinkenberg permeabilities range from 54.1-135 mD. This apparently porous and permeable zone warrants further investigation as a storage interval. The upper Rome section is classified by x-ray diffraction analysis as dolomite and siliceous dolomite, with some evaporitic strata identified to contain gypsum and anhydrite. The permeability values from core analysis indicates a moderately connected to well-connected pore system which is composed of vuggy, fracture, and intercrystalline porosities.

Structural analysis indicates that the area within and around Cassville is primarily underlain by rocks of the middle to upper Cambrian Conasauga Group and Cambro-Ordovician Knox Group. The site is located within the Valley and Ridge physiographic province, which is characterized by long, narrow series of northeast/southwest-trending ridges separated by wide parallel valleys. Structural interpretations of the region are variable, Croft (1963) shows the location of the Cassvile site to be near the axis of an overturned anticline with an overturned syncline immediately east of the site while Cressler (1970) and Crawford (2009) show the site to be near the western end of a normal stratigraphic inlier and/or a westward plunging anticline. The Rome Formation occurs at depth between the Great Smoky Fault which is approximately 9 miles to the east and the Coosa Fault which is located approximately 16 miles west of the test boring. Stratigraphic termination of the Rome Formation along the Cassville Fault east of the site would potentially trap injected CO_2. To the west, the formation is interpreted as semi-planar but there is a high probability it is dismembered along several possible blind thrusts which are represented at surface as small asymmetric anticlines. Based on the interpretation by Petrologic Solutions, there are several imbricated thrust faults between the Cassville test boring site and the area of outcrop near the Coosa fault. The stratigraphic interpretation coupled with the extensive regional distance (~16 miles) suggests a low probability of injected CO_2 to migrate to surface.

The upper Rome Formation contains high regional porosity and permeability, which suggest it may be favorable for the permanent geologic storage of CO_2. The strata overlying the Rome Formation, the Conasauga Group, contains shale likely with low porosity and permeability, which could prevent the migration of CO_2 into overlying formations and into underground sources of drinking water. The structural complexity provides apparent containment to the east by stratigraphic trap, and to the west by lateral distance and imbricated thrust faults. Further structural investigation is recommended to confirm lateral continuity and confinement above the upper Rome Formation. This would require the acquisition and interpretation of several 2D seismic lines. Additionally, more testing is recommended to confirm the injectivity of the discussed potential target of the Rome Formation. Despite the regional geologic complexity of the Valley and Ridge province, the log and core analysis show promising results for the development of a potential CO_2 storage site.

REFERENCES

Cressler, C. W., 1970, Geology and ground-water resources of Floyd and. Polk Counties, Georgia: Georgia Geological Survey Information. Circular 39

Croft, M.G., 1963, Geology and Ground-Water Resources of Bartow County, Georgia, U.S. Geological Survey Water Supply Paper 1619-FF

Kath, R.L., and Crawford, T.J., 2009, Bedrock Geologic Map of the Kingston, 7.5-Minute Quadrangle, Georgia: Georgia Department of Natural Resources Open File Report 09-1

Lawton, D.E., and others, 1976, Geologic Map of Georgia: Georgia Geological Survey, scale = 1:500,000

Thomas, W. A., and G. Bayona, 2005, The Appalachian thrust belt in Alabama and Georgia: thrust-belt structure, basement structure, and palinspastic reconstruction: Geological Survey of Alabama Monograph 16, 48 p., 2 plates.

Whisner, J.K., 2010, Surface and subsurface structures of the western Valley and Ridge in Tennessee and geometry and kinematics that permit reconstruction of the Tennessee salient, southern Appalachians: University of Tennessee Ph.D. Dissertation.