ATLANTIC COAST PIPELINE, LLC
ATLANTIC COAST PIPELINE

and

DOMINION ENERGY TRANSMISSION, INC.
SUPPLY HEADER PROJECT

Implementation Plan

EC26 Attachment 1

Fracture Analysis and Dye Trace Report

Fracture Analysis and Dye Trace Report

Dominion ACP

Augusta, Bath and Highland Counties, Virginia & Pocahontas and Randolph Counties, West Virginia

August 30, 2017

GeoConcepts Engineering, Inc.

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August 30, 2017

Colin Olness, PE
Contractor
Atlantic Coast Pipeline - Construction
99 Edmiston Way
Buckhannon, WV 26201

Subject: **Fracture Analysis and Dye Trace Report Dominion ACP, Augusta, Bath and Highland Counties, Virginia & Pocahontas and Randolph Counties, West Virginia (GeoConcepts Project No. 11002.04)**

Dear Mr. Olness:

GeoConcepts Engineering, Inc. (GeoConcepts) is pleased to present this fracture analysis and existing dye trace report for the proposed Atlantic Coast Pipeline.

Sincerely,

GEOCONCEPTS ENGINEERING, INC.

AMERICAN INSTITUTE OF PROFESSIONAL GEOLOGISTS
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Executive Summary

GeoConcepts conducted a fracture trace analysis and summary of existing dye traces of the proposed alignment of the Atlantic Coast Pipeline[1] (ACP) natural gas pipeline located in Augusta, Bath and Highland counties in Virginia, and Pocahontas and Randolph counties in West Virginia. The results of the fracture trace and the existing dye traces were compared and correlated with structures related to the deformation and development of the regional structural geology (e.g. anticlines, synclines, faults, etc.), documented spring locations, and the geologic stratigraphy and varying rock competency.

The fracture trace analysis was conducted within an approximate 2-mile corridor along either side of the proposed pipeline. In some cases, the fracture trace was extended out several miles beyond the 2-mile corridor to follow the trajectory of completed dye traces. The fracture trace analysis encompassed the entirety of the ACP mapped as underlain by karst forming bedrock. Bedrock fractures often manifest themselves on the surface as straight stream segments, long linear erosional structures, linear depressions in the ground surface, and as linear areas of more vigorous vegetation growth. To locate possible bedrock fractures, topographic maps, aerial photographs, and field reconnaissance data were used.

Fracture trace analysis of the ACP corridor indicated the presence of several fracture traces which align with the regional strike, fault surfaces, and documented structural features. The existing dye traces indicate a complex network of sinkholes, caves, and springs which are connected via structures that mimic the lineaments expressed on the surface of the landscape. The structure of the passages of the mapped caves near the ACP alignment had a similar orientation to the strike of the valleys and ridges and the strike-slip faults and ramps perpendicular to the bulk compression direction. It is evident that the movement of subsurface flow and the distribution of springs is strongly controlled by the preexisting structures, faults and fractures, as well as the lithology along the ACP.

Introduction

Based on the National Karst Map (Weary and Doctor, 2014) and landscape feature analysis, the ACP route is planned to cross approximately 71.3 miles of karst terrain, characterized by the presence of closed depressions, sinkholes, caves, sinking streams, and large springs. Karst is a known geohazard, and any infrastructure development in karst terrain must be carefully planned and managed. In addition, the karst environment often provides habitat for rare, threatened and endangered species, and is an important source of drinking water for municipalities and private landowners. In order to conserve this important natural resource, and also to protect the integrity of the pipeline, in June 2017 Dominion Transmission Incorporated (DTI) staff contracted GeoConcepts to conduct a fracture trace and existing dye trace review along the proposed Atlantic Coast Pipeline (ACP).

This report summarizes the methods and procedures used to conduct the fracture analysis, detailed descriptions of the regional and local geology, and a summary of findings based on the fracture trace and data review.

Scope of Services

The ACP project involves the proposed installation of a gas pipeline extending through West Virginia and Virginia. Referencing the currently proposed pipeline construction alignment information sent to us (hereinafter referred to as "the alignment"), we estimated that the route currently being considered for the pipeline crosses approximately 71.3 miles of terrain underlain by karst-forming bedrock located in Randolph and Pocahontas counties in West Virginia, and Highland, Bath and Augusta counties in Virginia, based on regional geological mapping.

Specifically, GeoConcepts provided the following services and deliverables:

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[1]ACP is owned by Atlantic Coast Pipeline, LLC (Atlantic). Atlantic has contracted with Dominion Transmission Inc., a subsidiary of Dominion Resources, Inc. to construct and operate the ACP on the behalf of Atlantic.

- Conducted a fracture trace analysis along the proposed alignment of the ACP where it crosses karst forming bedrock.
- Reviewed existing dye trace data along the ACP alignment and correlated the results with the fracture trace study.
- Developed this report summarizing the methods and findings of the assessment.

Methodology

The above scope of services was accomplished by the following means:

Existing Dye Trace Review – GeoConcepts conducted a review and summary of existing dye traces which receive or have the possibility of receiving drainage from the pipeline. The dye trace information was available from the following sources:

1. Karst Hydrology Atlas of West Virginia (Jones, 1997);
2. Springs Of West Virginia (McColloch, 1986);
3. The spring database of the Virginia Department of Environmental Quality (VDEQ)
4. Existing dye trace data provided by the Virginia Division of Conservation & Recreation – Natural Heritage Program (VaDCR-NHP) Karst Program
5. Proprietary dye trace data provided by the Virginia Speleological Survey (VSS)

Fracture Trace – GeoConcepts completed a fracture trace within a 2-mile corridor along either side of the proposed pipeline. In some cases the fracture trace was extended out several miles to follow the trajectory of completed dye traces. Throughout the remainder of this report, the fracture and lineament orientations are reported as strike, which is an azimuthal measurement (0° – 360°) where 0° is north (e.g. 45° = Northeast and 315° = Northwest). The fracture trace utilized existing geologic and geographic data sets including:

1. Caves of Virginia (Douglass, 1964);
2. Caverns of West Virginia (Davies, 1958);
3. Two-foot and 4-foot contour interval maps derived from county level digital terrain models (DTMs), and 1- and 3-meter contour maps derived from state level digital elevation models (DEMs);
4. Aerial photographs (both recent and historical);
5. USGS Topographic 7.5-minute topographic quadrangles;
6. Sinkhole and depression locations available from the USDA-NRCS soil studies for the counties through which the project will pass; and
7. LIDAR data (where available).

In addition, the fracture locations were correlated and summarized with the existing dye traces, caves, and karst features mapped in the Karst Survey Report. Each karst feature was assigned a *unique identifier* based on the parcel number and an integer as shown in the following example:

E083-001
where
"E083" = Parcel Number and
"001" = the first feature identified within that parcel.

Geological Overview of the Karst Terrain Sections of the Proposed ACP

Overview of regional karst terrain within the project area

The term “karst” refers to a type of landform or terrain, just like “desert”, “marsh”, “tundra”, “steppe” or “montane”. It was named for a province in Slovenia where it was first described in the late 17th and early 18th century by geologists of the former Austro-Hungarian Empire. Simply stated, karst terrain is characterized or diagnosed by the presence of sinkholes, caverns, an irregular “pinnacled” bedrock surface, and many large springs; however, the development of karst terrain is a result of the presence of soluble bedrock such as limestone, dolomite, marble or gypsum. Any landscape that is underlain by soluble bedrock has the potential to develop a karst terrain landform.

As in any region where soluble bedrock is present, a karst landform regime has developed in three known regions of the proposed ACP/SHP. Folding and faulting of the local carbonate rocks has opened up numerous fractures both parallel with the axis of the geologic structures, as well as perpendicular to them. Surface fractures and joints weather differentially, producing a pinnacled or “saw-tooth” profile at the bedrock/soil interface (referred to as the “epikarst” zone). In contrast, rock-enclosed fractures can be secondarily enlarged by the action of carbon dioxide charged groundwater, in some cases forming water-filled or air-filled conduits. As the regional terrain is “mature” karst, nearly all the fractures have undergone successive cycles of sediment filling and flushing. In areas such as the ACP project area, where there is little topographic relief and a relatively minimal groundwater gradient, the great majority of solution fissures are sediment-filled.

The most prevalent type of karst features in the project area are dolines or sinkholes, and these features comprise the greatest potential geohazard risk to any type of construction in karst terrain. Sinkholes fall into two broad categories, “vault-collapse” sinkholes, and “cover-collapse” sinkholes. Vault-collapse type sinkholes (i.e., where a cavern “vault” or roof has failed catastrophically) are rare in the ACP/SHP Project area (Campbell, et al., 2006). Cover-collapse sinkholes, which are common in the ACP project area, develop by the raveling of fines from the soil overburden into solution channels within the bedrock mass, in which water is the transport medium for the movement of the soil fines. The natural raveling process is generally a very slow one, such that sinkhole development generally occurs over a very long time span. However, various changes at a site can sometimes lead to the very sudden development of sinkholes. The most common changes that will exacerbate sinkhole development are:

1. Increase or redirection of overland or subsurface water flow paths, which accelerates the raveling of soil fines;
2. Removal of vegetation cover and topsoil (i.e., stripping and grubbing), which can reduce the cohesive strength of the soils overlying a conduit; and
3. Sudden changes in the elevation of the water table (such as drought, over-pumping of wells, or quarry dewatering), which removes the neutral buoyancy of the water supporting a conduit’s soil plug, and can often result in rapid and catastrophic soil collapse.

Geological Setting

The proposed ACP/SHP will cross three distinct regional provinces of karst geology, from east to west:

1. The **Great Valley subsection of the Valley and Ridge physiographic province**, encompassing the portion of Augusta County, Virginia from the Blue Ridge on the east to Little North Mountain on the west.
2. The **Folded Appalachian subsection of the Ridge and Valley province**, encompassing the westernmost section of Augusta County, and all of Bath County and Highland County, Virginia and extending from the North Mountain area on the east to the Allegheny Mountain on the west.

3. The **Allegheny Front and Appalachian Plateau** provinces of West Virginia, encompassing Pocahontas and Randolph counties in West Virginia, and the karst section of the SHP located in Westmoreland County, Pennsylvania.

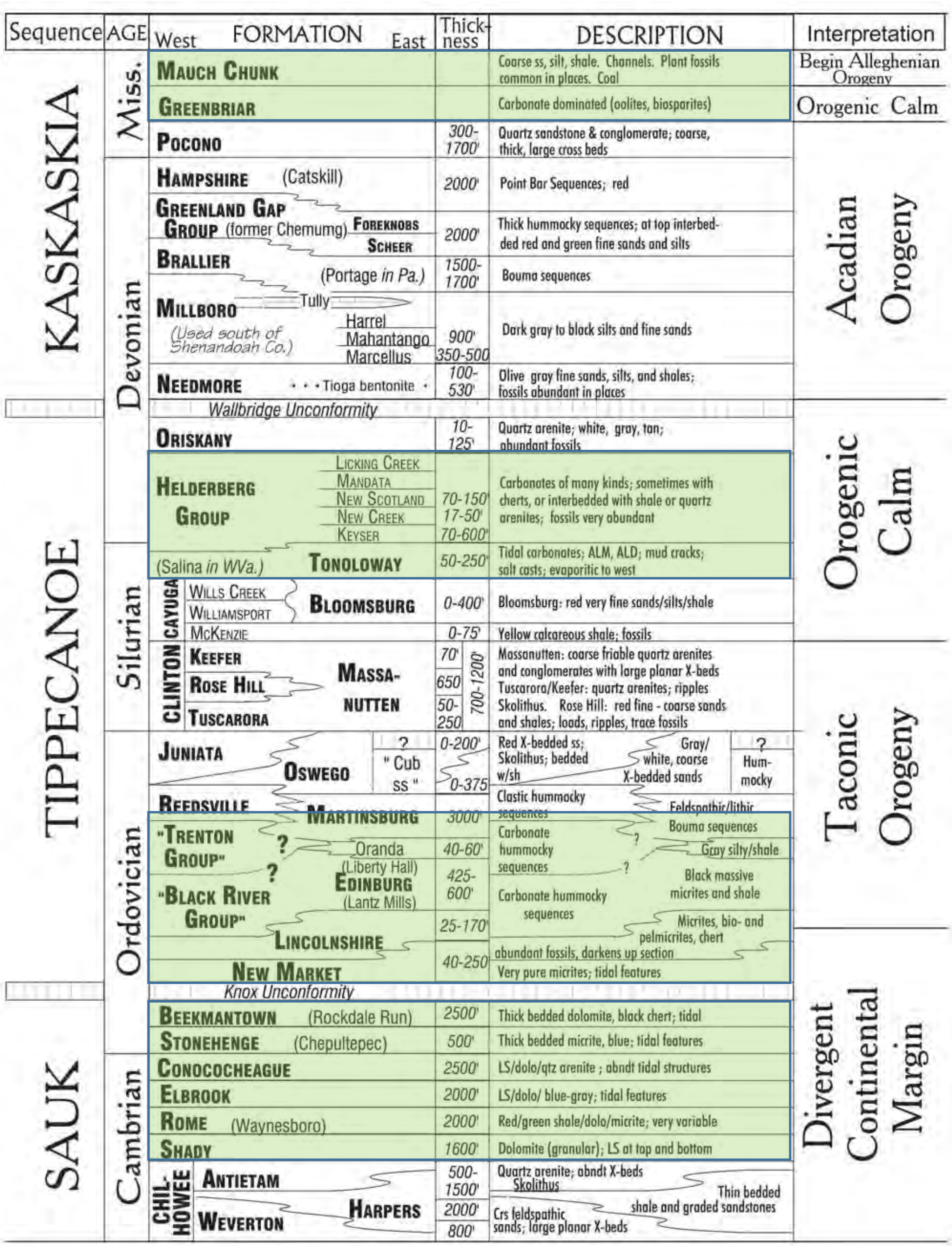

Figure 1. Stratigraphic Column of the central Virginia Great Valley, Folded Appalachians, and eastern Allegheny Front of west central Virginia and eastern West Virginia (Fichter, 2010). (The karst forming units are highlighted in green.)

The Great Valley (Augusta County, VA)

The Great Valley section is a generally downwarped trough (synclinorium) of Paleozoic limestones, shales, and sandstones that lie between the Blue Ridge Massif on the east and the Allegheny Mountains to the west. The

Valley extends between the two mountain uplands from northeast to southwest, parallel with the average strike of the bedrock.

The karst terrain of the Great Valley section of the ACP project area is characterized by numerous circular to oval-shaped sinkholes, ranging in size from a few feet to several hundred feet in diameter, the majority of which are completely vegetated and lack any opening to the subsurface ("throat") at their base. Sinkhole depths can vary, but are usually controlled by the angle of repose of the sediments lining their walls. Steep, rock-walled sinkholes are rare in this section, but generally occur in the small hills and uplands that are erosional remnants of the prior valley floor.

The Great Valley section contains large karst springs in the region. It is also characterized by sinkholes called "estavelles", which are insurgences for water during dry periods, and flood or act as springs (resurgences) during wet seasons. There are also numerous caves (i.e., air-filled voids large enough to permit the entry of a human being and that have an entrance to the surface) and subsurface caverns (air-filled voids large enough for human entry with no connection to the surface) in the region. Most of the caves and caverns range in length from a few feet to several miles; however, the average length rarely exceeds 2,500 feet. This is in contrast to the Folded Appalachian and Appalachian Plateau provinces to the west, where some of the longest caves in the region have been surveyed, many of which are more than 10 miles in length. Nevertheless, though not of great length, some of the most voluminous underground chambers in the region occur in the Great Valley section.

A unique type of karst terrain has developed in the eastern portion of Augusta County along the base of the Blue Ridge Mountains. Here, the characteristic karst terrain has been buried beneath a mantle of alluvial material which was shed off the mountains to the east. This alluvium ranges in age from less than 1 million years (Quaternary Period) to over 50 million years (Paleogene Period). The alluvium thins towards the west, and disappears completely west of Waynesboro, Virginia. Although the primary karst terrain is mantled by the alluvium, numerous shallow broad sinkholes are present and indicate the presence of large karst features in the underlying bedrock.

Bedrock Geology

Specifically, the proposed ACP project area in the Great Valley section has been extensively studied and mapped as being underlain by a series of karst-forming carbonate and calcareous clastic rocks (Campbell et al., 2006; DMME, 1993; Rader & Gathright, 2001; Rader & Wilkes, 2001; Hubbard, 1988; Southworth, et al., 2009) ranging in age from the Lower Cambrian to Middle Ordovician geological periods as follows:

Ordovician Period

Martinsburg Formation (Om)

The upper 100 to 200 feet of this formation is a brown, medium-to coarse-grained, fossiliferous sandstone. An olive-green silty shale and dark-gray siltstone comprises the middle portion of this formation, along with a medium- to coarse-grained, locally pebbly sandstone. The Stickley Run Member exists as the lower 400 to 900 feet of the formation. This is a medium-gray to grayish-black, very fine-grained (aphanitic), very thin- to thin-bedded, argillaceous limestone with interbedded medium- to dark-gray, calcareous shale.

Edinburg Formation (Oeln)

A black, fine-grained to aphanitic limestone with layered black shale that commonly contains pyrite, and medium- to light-gray, fine- to coarse-grained, nodular limestone with thin partings of black shale. This formation lies in thicknesses ranging from 450 to 1,000 feet throughout the three subject areas.

Lincolnshire Limestone (Oeln)

Gradational contact with the overlying Edinburg. A light- to very dark-gray, fine- to coarse-grained, medium- to very thick-bedded limestone with black chert nodules. The Murat Limestone Member, generally found at the top of the formation, is a light colored, coarse-grained limestone composed of fossil fragments. Thicknesses throughout the subject areas range from 50 to 250 feet.

New Market Limestone (Oeln)

Unconformable upper contact with the Lincolnshire. The upper unit of this formation is a medium-gray, aphanitic, thick-bedded, limestone with scattered calcite crystals. The lower unit is a medium- to dark-gray, fine-grained, thin-bedded, argillaceous, bioturbated limestone that is dolomitic in parts, with its base being a carbonate pebble conglomerate. Formation thicknesses throughout the subject areas range from 100 to 250 feet.

Beekmantown Group (Ob)

The Beekmantown Group consists of three distinct formations in the Great Valley, from youngest to oldest: the Pinesburg Station Dolomite; Rockdale Run Formation; and Stonehenge Limestone. Further west in the folded Appalachians the Beekmantown is undivided, and is referred to as the Beekmantown Formation.

The Pinesburg Station Dolomite is a medium- to light gray, fine-grained, medium- to thick-bedded dolomite rock, with sparse fossils. When weathered, this dolomite is very light-gray, and exhibits a "butcher-block" structure. A medium-gray, fine-grained limestone exists as the base of this unit. The formation's average thickness is 400 feet. It overlies the Rockdale Run Formation**,** and its contact with it is unconformable.

The Rockdale Run Formation is comprised of a medium-gray, fine-grained, fossiliferous limestone and a light- to medium-gray, fine-grained, laminated dolomitic limestone and dolostone with mottled beds. Thin lenses of gray chert are common near the base of the formation. Formation thickness ranges from 1,500 to 2,400 feet.

The oldest and lowermost member of the group is the Stonehenge Limestone. Its upper contact with the Rockdale Run Formation is gradational. The upper 400 to 500 feet of the Stonehenge is comprised of a medium- to dark-gray and black, fine- to medium-grained limestone, with thin beds of macerated fossil debris. The lower 50 to 150 feet (Stoufferstown Member) is a dark-gray to black, fine-grained limestone with thin sheet-like, crinkly partings due to cleavage, and thin beds of coarse-grained, bioclastic limestone.

Cambrian Period

Conococheague Formation (OCco)

The upper contact with the Stonehenge Limestone of the Beekmantown Group is unconformable. The upper 2,000 feet of this formation is a light- to dark-gray, fine-grained, laminated limestone, dolomitic limestone, and dolostone with flat-pebble conglomerate beds. Some cross laminated sandstone beds occur in the uppermost part of this unit. The Lower 200 to 500 feet (Big Spring Station Member) consists of a light-gray, fine-grained dolostone, medium- to dark-gray, fine-grained laminated limestone and dolomitic limestone, and gray, coarse-grained sandstone and dolomitic sandstone. Beds of flat-pebble conglomerate occur in the dolomite.

Elbrook Formation (Ce)

This unit's thickness ranges from 2,000 to 2,500 feet. The formation is a dark- to medium-gray, fine- to medium-grained limestone, dolomitic limestone, dolostone, and dolomitic shale. These lithologies commonly occur as erosion-surface-bounded sequences of algal limestone overlain by laminated dolomite. Decalcified, ocherous shale-like chips on the ground surface characterize this unit. The lower 300 to 400 feet is green to greenish-gray, fine-grained dolostone, dolomitic limestone, and shale.

Waynesboro Formation (Cw)

The upper contact with the Elbrook Formation is gradational. A dusky-red to olive-gray, fine- to medium-grained sandstone and dusky-red to gray shale exists as the upper 300 feet. The middle 400 feet is a medium- to dark-gray, saccharoidal dolomite and fine-grained limestone. The lower 500 feet is dusky-red, olive-gray, and dark-gray shale and dusky-red to brownish-gray, fine- to medium-grained sandstone. Overall thickness is approximately 1,200 feet.

Tomstown Dolomite/Shady Dolomite (Ct/Cs)

The upper 600 feet is light- to dark-gray, fine- to coarse-grained, medium- to thick-bedded, locally laminated dolostone with white chert rosettes and nodules in the upper 50 feet. The middle unit (about 210 feet) is very light- to medium-gray, medium-grained, very thick-bedded dolostone and high-magnesium dolostone. The lower unit (about 325 feet) is dark-gray to black, very fine-grained, thin- to very thin-bedded limestone and dolomitic limestone with argillaceous laminations. The overall unit thickness ranges from 1,100 to 1,200 feet. The Shady Dolomite is the homologous unit in the southeastern Great Valley at the base of the western edge of the Blue Ridge Mountains.

The Folded Appalachians (Augusta County, Bath County, Highland County, VA and Eastern Pocahontas County, WV)

The western edge of the Great Valley is demarcated by the North Mountain Fault, and the ridges of Little North and Great North Mountain. The rocks underlying this section are younger than those of the Great Valley, dating primarily from the Late Ordovician through the Devonian periods in age. In general, the mountain ridges are underlain by sandstone and siltstone, clastic rocks which are insoluble and not prone to karst terrain development. In contrast, the intervening deep valleys are often floored by carbonate rocks, and a characteristic karst landscape characterized by sinkholes, caves and springs has developed in many cases along the axis and flanks of these valleys (Hubbard, 1988; Rader & Wilkes, 2001; DMME, 1993).

In many areas of this province, the development of karst terrain has been influenced by the effects of relatively acidic surface and groundwater originating from acid-forming bedrock, and acting upon adjacent carbonate units (*see definitions*: Allogenic Recharge). The primary regional acid-forming rocks are the middle Paleozoic shales, in particular the Ordovician age Martinsburg Formation (pyritic only in specific areas), and the Devonian age shales of the Hamilton Group (includes the Mahantango, Marcellus and Needmore formations all of which can be pyritic). The only place where these shales occur along the ACP in West Virginia near the carbonate units is in eastern Pocahontas County, on the eastern slope of Michael Mountain, and they are at a lower elevation than the Devonian and Silurian carbonate units further up the slope. Thus, the drainage would be away from the carbonates and towards the acid-forming shales.

Bedrock Geology

The regional geology of the Folded Appalachians in the project area has been mapped (DMME, 1993) as being underlain by a series of karst-forming carbonate rocks ranging in age from the Lower Ordovician to Lower Devonian geological periods as follows:

Devonian – Silurian Periods

Helderberg Group (Dh)

This group consists of thick- to massive-bedded, dark gray/black micritic limestone with reef structures. The limestone shows some degree of recrystallization. The uppermost Helderberg is typically silicified near its contact with the overlying Oriskany sandstone. In many areas the Helderberg gives off a distinct petroliferous odor when freshly broken. The contact with the overlying Oriskany Sandstone is poorly exposed regionally, but the contact with the underlying Tonoloway Formation is distinct and often unconformable, where the massive bedding of the Helderberg gives way to the thin-bedding of the Tonoloway Formation. The contact can be identified in places by a lag deposit consisting of flat, packstone rip-ups and pebble conglomerate.

The group is a major cave forming unit of the Folded Appalachian section, however, it is of note that the stratigraphy of this unit has been the subject of a much detailed study in recent years (Haynes, et al., 2014). The Helderberg Group consists of a series of individual formations, from oldest to youngest, respectively: the Keyser Limestone, New Creek Limestone, Corriganville Limestone, and Licking Creek Limestone formations. Although the Helderberg was originally considered strictly Devonian in age, based on biostratigraphic analysis the Keyser Limestone, the basal formation of the Helderberg Group, has been shown to straddle the boundary of the Silurian and Devonian periods (Denkler and Harris, 1988a).

The entire Helderberg Group varies regionally, ranging from 85 feet to over 400 feet in thickness. The Keyser is considered the thickest of the individual formations comprising the group, ranging from 50 to 230 feet in thickness.

Silurian Period

Tonoloway Limestone (Sto)

This formation consists of extremely thin-bedded (0.5 inches or less) dark gray micritic limestone interbedded with fissile, calcareous shale. The formation gives off a distinct petroliferous odor when freshly broken. The contact with the overlying Keyser Limestone is distinct; however, it grades into the underlying Wills Creek Limestone. The Tonoloway Formation varies from 150 to 600 feet in thickness.

Wills Creek Limestone (Swc)

This formation consists of thin-bedded (less than 5 inches) dark gray calcareous shale and fossiliferous micrite, which is poorly exposed in the ACP project area. The thickness is variable, ranging from 3 feet to 230 feet.

Ordovician Period

Juniata, Oswego, Reedsville, Dolly Ridge, and Eggleston Formations (Oun)

Karst forming unit present only in the westernmost Valley and Ridge section of the ACP alignment (Highland and Bath counties). The Dolly Ridge and Eggleston Formations are the only karst-forming units and consist of a medium-gray, fine-grained, thin-bedded, argillaceous limestone with interbedded olive-gray calcareous claystone, silt argillaceous limestone, gray shale, and K-bentonite beds. Thickness is about 400 feet in Bath and Highland counties. The unit is laterally equivalent to the Middle Ordovician ("Trenton Group") limestones and part of the lower Martinsburg Formation.

Middle Ordovician Limestones, Undivided (Olm)

These limestones consist of the Edinburg Formation, the Lincolnshire Formation, and the New Market Limestone. The Edinburg is a black, fine-grained to aphanitic limestone with layered black shale that commonly contains pyrite, and medium- to light-gray, fine- to coarse-grained, nodular limestone with thin partings of black shale. Thickness is 400 feet to 500 feet. The Edinburg grades downward into the Lincolnshire Formation, a light- to very dark-gray, fine- to coarse-grained, medium- to very thick-bedded limestone with black chert nodules. Thicknesses throughout the ACP project area range from 25 to 250 feet. This unit is underlain by the New Market Limestone. The upper contact with the Lincolnshire is generally unconformable. The upper unit of this formation is a medium-gray, aphanitic, thick-bedded, limestone with scattered calcite crystals. The lower unit is a medium- to dark-gray, fine-grained, thin-bedded, argillaceous, bioturbated limestone that is dolomitic in parts, with its base being a carbonate pebble conglomerate. Formation thicknesses throughout the ACP project area range from 0 to 150 feet.

Beekmantown Formation (Ob)

This formation is a medium- to light-gray, fine-grained, medium- to thick-bedded dolostone, with sparse fossils. When weathered, this dolomite is very light-gray, and exhibits a "butcher-block" structure. A medium-gray, fine-grained limestone exists as the base of this unit. This formation is comprised of a medium-gray, fine-grained, fossiliferous limestone and a light- to medium-gray, fine-grained, laminated dolomitic limestone and dolostone with mottled beds. Thin lenses of gray chert are common near the base of the formation. Formation thickness ranges from 1,500 to 2,400 feet. The Beekmantown Formation typically consists of three members, which although distinct in the Great Valley region are hard to distinguish in the Folded Appalachian province.

The Allegheny Front & Appalachian Plateau (Pocahontas County and Randolph County, WV)

The last section of the folded Appalachian karst is located in eastern Pocahontas County. To the west occurs the relatively flat-bedded geology of the Allegheny Front and Appalachian Plateau provinces. The karst terrain in this area is formed almost exclusively by the carbonate rocks of the Mauch Chunk and Greenbrier Groups.

In general, the Mauch Chunk and Greenbrier Group carbonates exhibit a high density of caves relative to the other two karst sections along the pipeline. There are several factors that contribute to this, the main one being that the units act as a drain system for groundwater infiltrating downward through the fractured clastic rocks above them. Where they are exposed along the mountain flanks, the steep groundwater gradients have enhanced this cavern development. In many places surface water plunges directly into the carbonates via steep-walled, open throat sinkholes (swallets). Most of the caves are linear networks, and exhibit conduit flow, capturing surface streams upgradient which then emerge as springs at the downgradient end.

Bedrock Geology

The Appalachian Plateau section has been mapped (Cardwell, et al., 1968; Davies, 1958) as being underlain by the karst-forming carbonate rocks of the Greenbrier and Mauch Chunk Groups, exclusively. The geology is described from youngest to oldest as follows:

Mississippian Period

Mauch Chunk Group – Includes the Bluestone and Princeton Formations (Mbp), Hinton Formation (Mh), and Bluefield Formation (Mbf). The group is predominantly red, green and medium-gray shale and sandstone, with a few thin limestone lenses in each formation. Although the limestone strata in the unit are considered secondary, the topographic position of the Mauch Chunk along the edges of the eroded upland of the Allegheny Plateau where there is a relatively steep downward hydraulic gradient has enhanced water flow through the carbonate lenses, forming karst conduit networks with high transmissivity (Kozar & Mathes, 2001), thus from a karst hydrology viewpoint this unit is significant.

Greenbrier Group (Mg) – In the project area the Greenbrier Group (or “Big Lime” as it is known locally) is up to 400 feet in thickness. It is primarily a gray to dark gray, massively bedded marine limestone, with interbeds of red and green marine and nonmarine shale and thin discontinuous beds of sandstone. The Group is divided into six stratigraphic units; from oldest to youngest they are: the Denmar Limestone, Taggard Shale, Pickaway Limestone, Union Limestone, Greenville Shale, and Alderson Limestone. The principle cave forming units are the Pickaway and Union limestones.

Survey Results and Discussion

The fracture trace analysis encompasses the entirety of the ACP that is mapped as underlain by karst forming bedrock. Bedrock fractures often manifest themselves on the surface as straight stream segments, long linear erosional structures, linear depressions in the ground surface, and as linear areas of more vigorous vegetation growth. To locate possible bedrock fractures, topographic maps, aerial photographs, and field reconnaissance data are used. Fracture trace analysis of the ACP corridor indicates the presence of several fracture traces which align with the strike of the regional bedding, fault surfaces, and known structural features. The results are summarized below by each major tectonostratigraphic region in Virginia.

The Great Valley (Figure 2)

The Great Valley section is located in Augusta County and contains two sensitive locations, which are shown as areas 1 and 2 in Figure 2. Area 1 is a set of springs situated around a "high risk" karst feature, located in Stuart's Draft and Area 2 is the Wellhead Protection Area (WHPA) for Gardner Spring, which was delineated by Wiley & Wilson, Inc., and Emery & Garrett Groundwater Investigations (EGGI).

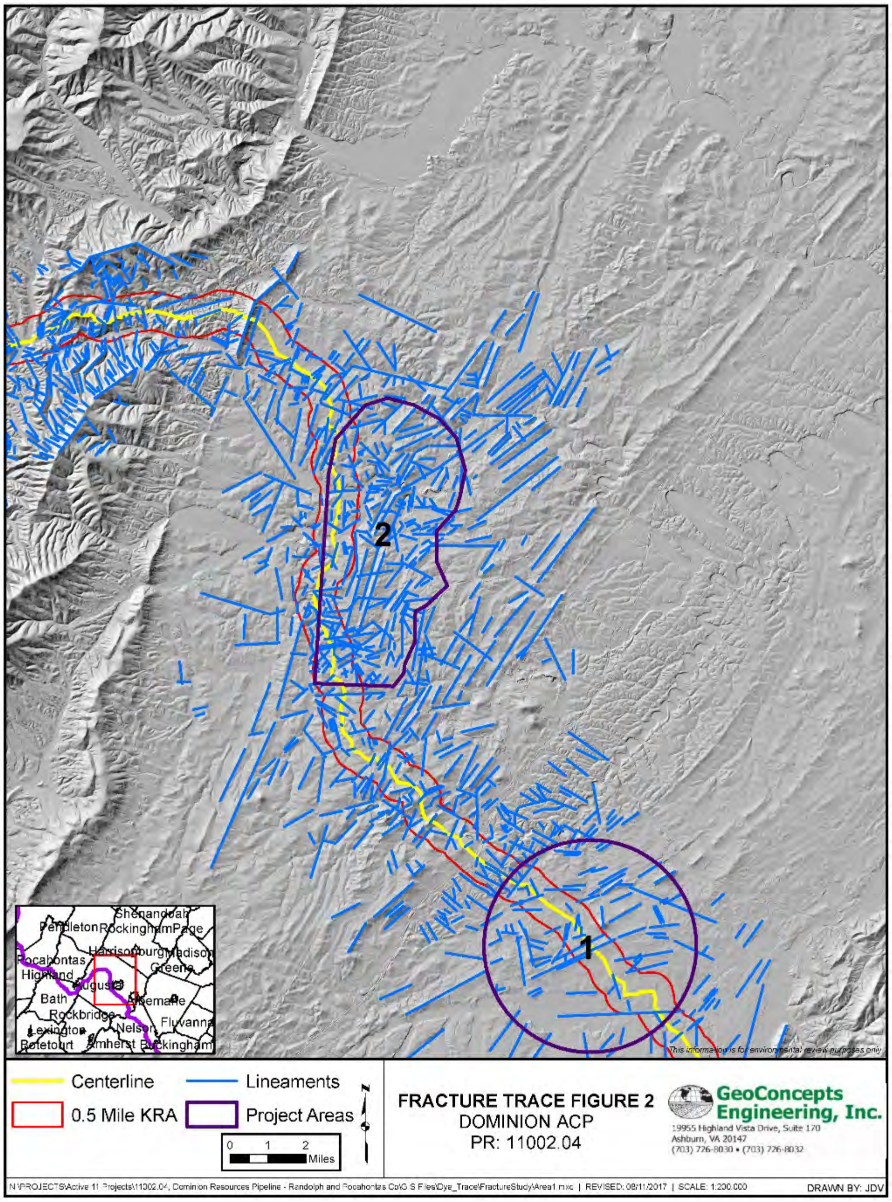

Figure 2. The Great Valley region fracture trace along the ACP revealing a complex system of lineaments. Both areas underwent a detailed fracture trace analysis as requested by the VA-DEQ. Area 1 = Stuart's Draft, Area 2 = Gardner Spring WHPA

Stuart's Draft (Area 1) – This region is situated along the western foot of the colluvial apron, which mantles the pediment of the Blue Ridge Mountains to the southeast, extending several miles to the west into the Great Valley proper. The karst forming limestone bedrock is buried by the colluvial mantle, and thus sinkholes in this region tend to be broad, shallow and rarely contain open throats or cave entrances. The site is located on the eastern limb of the Massanutten Synclinorium which strikes northeast (Fig. 1, Appendix B). A cluster of features near State Route 340, are classified as "high risk" because there is evidence of an open throat at the base one of the largest sinkholes. This karst feature is surrounded by springs to the north and east within a mile, and may contribute to the groundwater recharge in the area.

The Great Valley region is typified by a radial type of subsurface flow (Jones, 1997), where the sinks may connect to several springs in all directions. The purple circle away from this cluster of features includes springs which may receive subsurface flow from this point (Fig. 2).

The fracture trends in this region are oriented NE/SW (50°- 75°) and N/S (355°- 0°) and are composed of 89 lineaments (Fig. 1, Appendix A). The strongest northeast trend of lineaments correlates with the axis of the Massanutten Synclinorium and the overall strike of the rock units. The secondary north orientation may be related to tributaries and rivers flowing down the slopes of the Blue Ridge Mountains, from south to north.

There are two clusters of karst features, situated in the Elbrook Formation, which correlate well with the lineaments mapped during the fracture analysis. Karst features A159.AR-1 to A159.AR-3 are clustered along a northeast striking ridge and the A162 and A165 karst feature sets form a line which corresponds with a northwest striking lineament to the south (Fig. 1, Appendix A).

Gardner Spring WHPA (Area 2) – The Gardner Spring WHPA is located in the western edge of the "Great Valley" portion of the Valley and Ridge province. The general structure of the region is represented by valleys and ridges striking from northeast. Gardner Spring is located near the contact between the Beekmantown Formation and New Market Limestone (Knox Unconformity), on the east limb of an unnamed anticline (Fig. 2 Appendix B). Several small, right lateral faults strike northwest and slightly north of the spring and a series of Mesozoic dikes strike north-northeast.

The fracture trends in this region are oriented NNE/SSW (15°- 30°), NE/SW (55°- 65°), and NW/SE (325°- 335°) and are composed of 231 lineaments (Fig. 2, Appendix A). The spring itself is located close to the end of the longest lineament in the area oriented northeast. The plot shows a broad range of orientations, generally striking northeast and northwest, which follow the strike of the ridges. The intersection of the Long Glade Syncline and the northwest striking right lateral faults may account for the upwelling of groundwater at Gardner Spring. Although Gardner Spring is not located directly on the northwest striking faults, it is likely that there are subsurface fractures related to a fault zone in the area. The fracture trace results show that lineaments related to the northwest striking faults and the Long Glade Syncline dominate the surficial local structure. In addition, the north-northeast and northwest striking Mesozoic dikes correlate with the third strong lineament orientation.

There are many karst features located along the proposed pipeline within the Gardner Spring WHPA, which have formed near the contact with the Beekmantown Group and the Conococheague Formation. The majority of these features correlate with a lineament or lineament intersection on the high ridges and uplands in the region. Specifically, karst features A083-1 and A084-1 occur on a northeast striking lineament which intersects a complex area of smaller northwest striking fractures (Fig. 2, Appendix A).

Folded Appalachians (Figure 3)

The folded Appalachian locations are located in western Augusta, Bath and Highland counties. These regions have either undergone successful dye tracing or are VA-DEQ proposed locations for future dye traces.

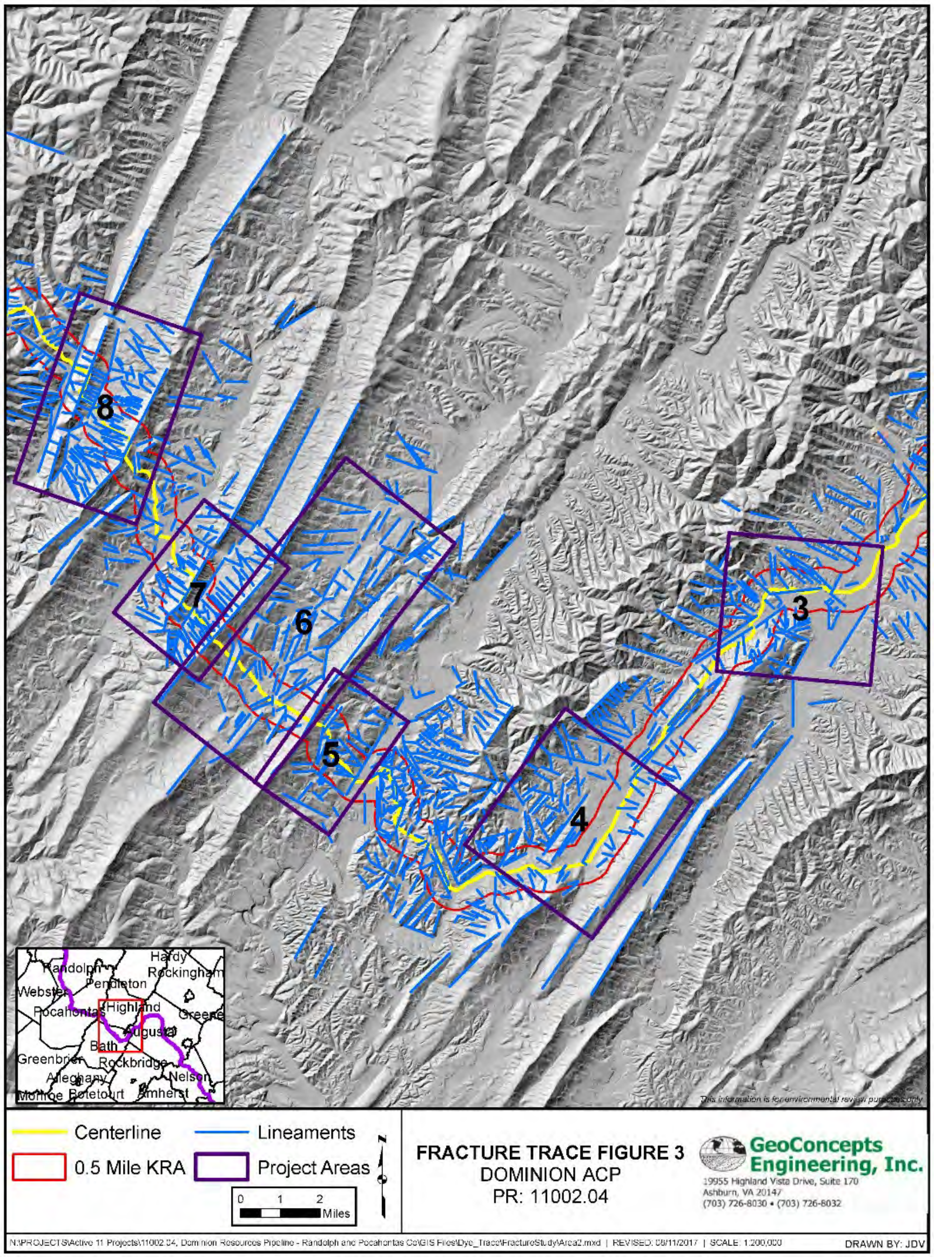

Figure 3. The folded Appalachian section contains several locations which require a detailed fracture trace analysis. Area 3 = Deerfield, Area 4 = Brushy Ridge, Area 5 = Fort Lewis, Area 6 = Burnsville Cove, Area 7 = Little Valley, Area 8 = Valley Center

Deerfield (Area 3) – The Deerfield Valley region is located at the northern end of Walker Mountain which is formed on the Deerfield Anticline that plunges to the northeast. There is a sinking stream section of the Hamilton Branch, which is located on the contact of the clastic rocks of the Needmore Formation and the Helderberg Group carbonates and sandstones (Fig. 3, Appendix B).

The fracture trends in this region are oriented N/S (0°- 10°) and NW/SE (300°- 315°) and are composed of 85 lineaments (Fig. 3, Appendix A). Although few in number, the longest lineaments correlate with the northeast orientation of the mountain ridges and valleys. The strongest trend is northwest, which correlates with the linear tributaries along the slopes of Walker Mountain and Shenandoah Mountain (McClung Syncline). Small ridges of Needmore Formation in Deerfield Valley, which are not covered with Quaternary alluvium, also depict a strong northwest orientation. Finally, the lineaments which are oriented north-south appear to occur near the tip of the plunging anticline where the streams form at the end of the mountain.

There are no identified karst features in the town of Deerfield or along the ACP Alignment with the exception of the sinking stream section of the Hamilton Branch. The sinking stream is upstream of Deerfield, and is oriented northeast to southwest and follows a very distinct lineament along the contact of the Needmore Formation and Helderberg Group (Fig. 3, Appendix A).

Brushy Ridge (Area 4) – The Brushy Ridge site is located a few miles to the southwest of Deerfield along Walker Mountain (Fig. 5, Appendix B). Unlike Deerfield, there is a second and smaller syncline/anticline pair along the western side of Walker Mountain (Fig. 4, Appendix B). The anticline is named Brushy Ridge, which is composed of the limestone bearing Helderberg Group. The major springs in the valley occur on the northeast trending contact with Helderberg Group and the Needmore Formation. The general structure of the region is represented by valleys and ridges oriented northeast.

The fracture trends in this region are oriented NE/SW (30°- 50°), NW/SE (315°- 330°), and WNW/ESE (285°- 290°) and are composed of 108 lineaments (Fig. 4, Appendix A). The longest and most numerous lineaments in the valley are oriented northeast to southwest along the axis of the anticlines and synclines between Walker Mountain and Shenandoah Mountain. Rock competency differences may play a role in the development of the two approximate northwest oriented lineament sets (Figure 4, Appendix A).

The karst features in this region occur on top of Brushy Ridge, which is underlain by the Helderberg Group rocks, and the remaining features are present in the alluvium alongside Walker Mountain. The four features along Brushy Ridge follow a very distinct set of northeast oriented lineaments, while the features in lower Deerfield Valley do not align with any lineaments (Fig. 4, Appendix A). It is possible that the features in the lower valley have formed in the hyporheic zone of the Mill Creek channel and floodplain, and do not correspond with fracture trace patterns in the region.

Fort Lewis (Area 5) – The Fort Lewis transect is located just north of the town of Fort Lewis along the eastern slope of Tower Hill Mountain (Fig. 5, Appendix B). Existing dye traces on the ridge link up two sinking streams on either side of the proposed pipeline, which lead to Fort Lewis Spring. The spring was originally domestic, but has since been abandoned for a more prolific spring higher up the slope and outside of the pipeline KRA. The Fort Lewis Spring is located on the Helderberg Group and Ridgely sandstone contact (Fig. 5, Appendix B). Tower Hill Mountain is an anticline which strikes to the northeast. The region is underlain by the Tower Hill thrust fault which is poorly exposed in the outcrop along the northwest face of Tower Hill Mountain (Bick, 1962). More recent work in the area (Swezey et al., 2015) did not observe any clear evidence of the Tower Hill thrust fault and instead noted minor thrust faulting and folding along the ridge. During the karst field survey, several features were discovered in the Helderberg Group rocks on the southeastern face of Tower Hill Mountain. The entrance to Jewel Box Cave was located during the survey, and a short passage was shown striking northeast with subsidiary passages to the northwest.

The fracture trends in this region are oriented NE/SW (30°- 45°) and NW/SE (280°- 310°) and are composed of 43 lineaments (Fig. 5, Appendix A). The strongest lineament trend is northeast, which corresponds with the axis of the Tower Hill Mountain anticline. A smaller set of fractures striking northwest are oriented perpendicular to the axis of the anticline. The lineament orientations correspond with the passages of Jewel Box Cave.

Karst features along the proposed pipeline route in the Fort Lewis region are concentrated on a northeast striking subordinate ridge below the crest of the mountain in the Helderberg Group rocks (Fig.5, Appendix A). These features are located near a prominent northeast striking lineament denoted by the ridgeline and are on the same horizon as the injection points for the previously completed dye traces.

Burnsville Cove (Area 6) – The Burnsville valley is a structurally complex series of anticlines and synclines which are bounded to the north by Jack Mountain and to the south by Tower Hill Mountain (Fig. 6, Appendix B). The general structure of the region is represented by anticlines and synclines which trend northeast. The structure in the center of the valley from east to west is comprised of a series of synclines and anticlines, including the Sinking Creek Syncline, the Chestnut Ridge Anticline, and the White Oak Syncline, respectively. Burnsville Cove contains several very large cave systems such as Chestnut Ridge (21 mi), Butler Cave (16.7 mi), and Breathing Cave (6.1 mi), and approximately a hundred additional smaller cave systems. All of the water in these cave systems exit the valley into the Bull Pasture River through Aqua (aka: Gorge Spring), Cathedral, and Blue Springs. These cave systems follow the axis of the synclines and anticlines in the valley. The caves are formed primarily in the lower Tonoloway Formation carbonates, and the Lower Helderberg Group limestones, between alternating sandstones and thick limestone units. The subsurface flow in this region has been thoroughly characterized by dye tracing, as shown in Figure 5.

The fracture trends in this region are oriented NE/SW (30°- 40°) and NW/SE (305°- 310°) and are composed of 113 lineaments (Fig. 6, Appendix A). The longest lineaments in the region follow the orientation of the axis of the synclines and anticlines, striking to the northeast. Smaller cross fractures have an orientation of northwest and are perpendicular to the large structural folds in the valley. Based on the maps of the caves in the region, the smaller side passage typically follow the cross fractures in the limbs of the folds and the large trunk passages follow the axis of the folds. The numerous dye traces support this structural relationship and show that all subsurface flow goes generally northeast towards the three major springs on the Bull Pasture River.

Two karst features were identified where the proposed pipeline crosses the Burnsville Cove region (Figure 5). Although the features do not align with any of the lineaments from the fracture trace both of them form where there is a break in slope at the base of hillsides (Fig. 6, Appendix A). This topographic break may represent a fracture which is obscured by the flat laying material in the fields. The karst features were topographically connected with Laurel Run, which is comprised of a set of surface streams that drain into Dry Run to the south west.

Little Valley (Area 7) – The Little Valley resides in the axis of the breached Bolar Anticline, which is bordered to the southeast by Jack Mountain and to the northwest by Little Mountain (Fig. 7, Appendix B). The karst bearing units in the valley include the Ordovician Moccasin and Bays formations which are present along the central portion of the axis of the anticline, and the overlying Dolly Ridge and Eggleston Formations which are the western equivalents of the Lower Martinsburg and Edinburg Formations. The narrow strip of karst is oriented northeast and is marked by a series of broad mature sinkholes. Springs are present along the upper slopes of Jack Mountain, roughly half way up the slope. The outfall from these springs flows down to the base of the valley along the fold axis and eventually drains to the northwest into the Bolar Run. Bolar Spring is located in the village of Bolar. The temperature of the water is approximately 73° F year round, which implies that the source of the water is old and deep. The anticline is on strike with the Warm Springs Anticline to the south, in which occurs the majority of thermal springs in the state, including the Jefferson Pools (95° F.) and the Hot Springs at the Homestead (106° F), respectively (Waring and Blankenship, 1965).

The fracture trends in this region are oriented NW/SE (310°-320°) and E/W (265°-270°) and are composed of 97 lineaments (Fig. 7, Appendix A). The northwest lineament orientation is the most prevalent, and is perpendicular with the axis of the anticline. The longest lineaments in the region are oriented northeast and correspond with the axis of the Bolar anticline and the adjacent valleys and ridges.

Several karst features were identified near the base of Little Valley upstream of Bolar Run in the Moccasin and Bays Formations. The features formed in a series of lineaments following the strike of the rock units and the northeast orientation of the mapped fractures (Fig. 7, Appendix A).

Valley Center (Area 8) – The Valley Center region is located along the axis of the breached Hightown Anticline, which strikes northeast. The anticline is bounded by Back Creek Mountain to the southeast and Little Mountain (different than the little mountain adjacent to Little Valley) to the northwest (Fig. 8, Appendix B). There is a thrust fault located along the northwest slope of Little Mountain which dips to the southeast and a smaller thrust on Back Creek Mountain which dips to the northwest. The karst bearing unit in the valley is the Ordovician Moccasin and Bays Formations which is present along the axis of the anticline. Preexisting dye traces in the region have clearly denoted the subsurface flow paths lead to Apple Jack Spring and Devore Spring near the proposed pipeline alignment.

The major fracture trend in this region is oriented NW/SE (285°- 300°) and a minor set is oriented NE/SW (30°- 45°) and are composed of 110 (Fig. 8, Appendix A). The northwest lineament orientation is the most prevalent, and is perpendicular with the axis of the anticline. The longest lineaments in the region are oriented northeast and correspond with the axis of the Hightown anticline and the adjacent valleys and ridges.

There are many karst features, including sinkholes and caves, present in Valley Center, which have formed in the Moccasin and Bays Formations. The largest group of features is situated near the long northeast striking lineament at the center of the valley, which leads to the Devore and Apple Jack springs. Karst features C011-1 and C011-2 are both located on a northwest striking ridge which intersects the spring locations and the northeast striking lineaments at the base of the valley (Fig. 8, Appendix A).

Appalachian Plateau (Figure 4)

The Appalachian Plateau section resides in Pocahontas and Randolph counties in West Virginia, and includes several large cave systems and sinking stream sections (e.g. Elk River). The karst systems in this region have been previously dye traced, with the majority of subsurface water flowing into the Elk River system.

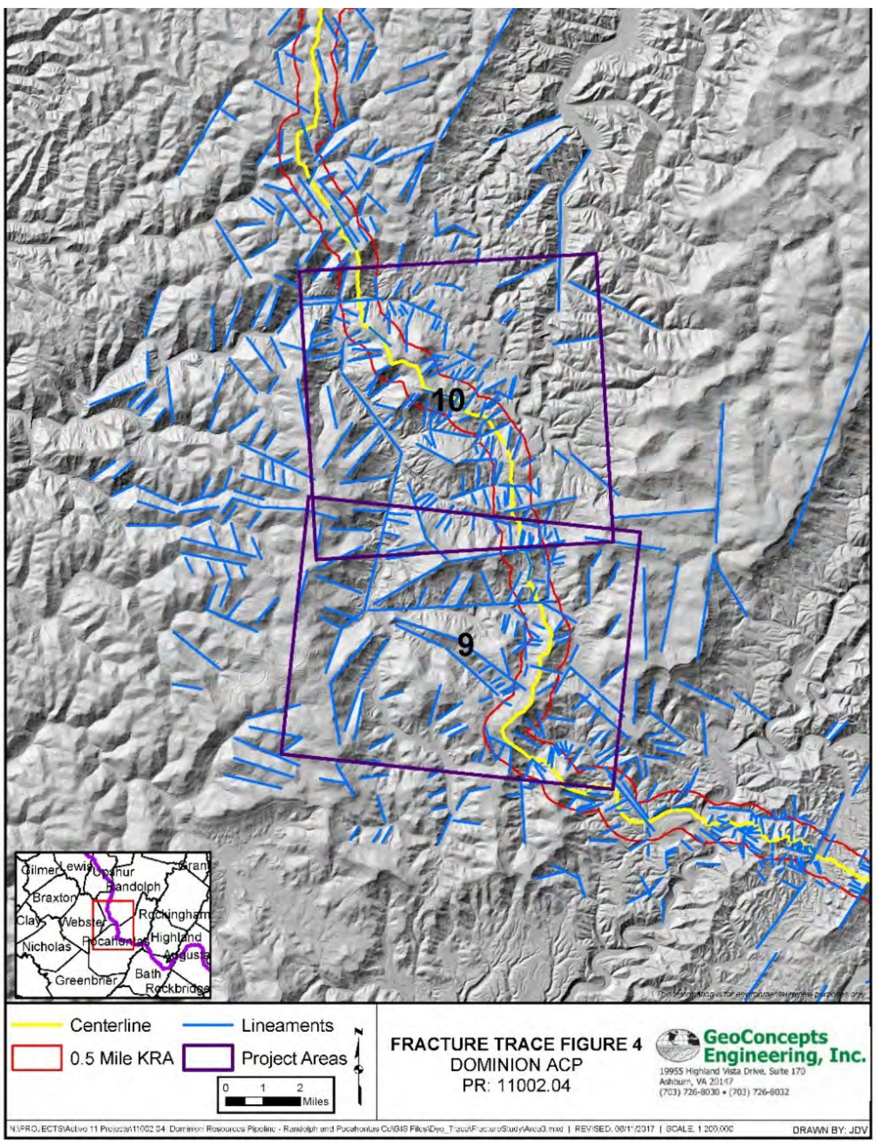

Figure 4. The proposed pipeline alignment crosses two regions of intense karstification and cave development in the Appalachian Plateau. Area 9 = Snow Show, Area 10 = Simmons Mingo

Snow Shoe (Area 9) – The regional structure is comprised of a large syncline/anticline system to the east of the field locations, with younger subhorizontal layers draped on top of the features to the west (Fig. 9, Appendix B). The North Potomac Syncline is oriented northeast and forms Cheat Mountain, which is the highest point in the region. Tygart Valley is a breached anticline which strikes northeast along the side of Cheat Mountain. The region that is crossed by the proposed pipeline is underlain by subhorizontal (gently dipping) strata which cover the synclines and anticlines and is characterized by a dendritic drainage pattern. Existing dye traces in the area show that all subsurface flow eventually leads to the Elk River system. The upper headwaters of the Elk River in this region are known to sink into a complex karst network which connects the majority of the caves in the region (Dasher, 1998). The area includes Tapp's Trap and Jacob's Waterfall Cave, which are small structurally controlled caves that have passages oriented roughly northeast and northwest.

The fracture trends in this region are oriented NNE/SSW (15°- 30°), NE/SW (60°- 75°), and E/W (270°- 285°) and are composed of 172 lineaments (Fig. 9, Appendix A). The longest lineaments correlate with the northeast striking syncline and anticline system located to the northeast. Smaller subsets of northwest and west striking lineaments appear to not follow any major structural trends in the region. The dendritic drainage landscape yielded more ambiguous fracture orientations since the surficial structures and lineaments are less obviously derived from the regional deformation. The passages of Tapp's Trap and Jacob's Waterfall Caves roughly correlate with the lineaments mapped on the surface.

Nearly every karst feature and spring identified along the proposed pipeline correlates with a lineament mapped in the fracture trace analysis. The karst features occur in the Green Briar and Mauch Chunk Groups, and typically follow either a northeast or northwest oriented lineament. Specifically, the E091 karst feature group all occur along a lineament oriented northeast and the E086 feature group follow a similar orientation along the ridge to the north (Fig. 9, Appendix A).

Simmons Mingo (Area 10) – The regional structure is comprised of a large syncline/anticline system to the east of the field locations, with younger subhorizontal layers draped on top of the features to the west (Fig. 9, Appendix B). The North Potomac Syncline is oriented northeast and forms Cheat Mountain, which is the highest point in the region. Tygart Valley is a breached anticline which strikes northeast along the side of Cheat Mountain. The region that is crossed by the proposed pipeline is underlain by subhorizontal strata which cover the synclines and anticlines and is characterized by a dendritic drainage pattern. Existing dye traces in the region show that all subsurface flow eventually leads to the Elk River system. The upper headwaters of the Elk River in this region are known to sink into a complex karst network which connects the majority of the caves in the region (Dasher, 1998). The Simmons Mingo and My Cave system is located underneath Mingo Knob, and has been dye traced, demonstrating that all subsurface flow leads to the Elk River cave system and eventually emerges at WV Elk Spring. The Falling Spring Cave is located within Elk Mountain and the subsurface flow of this cave also leads to the WV Elk Spring.

The fracture trends in this region are oriented NE/SW (0°- 45°) and WNW/ESE (270°- 285°) and are composed of 194 lineaments (Fig. 10, Appendix A). The longest lineaments in this region strike northwest, but the greatest number of lineaments are striking northeast. The lineaments in this region correlate well with the orientation of the cave passages in Simmons Mingo, My Cave, and Falling Spring Caves.

In this region, the karst features are located on the ridges which do not typically follow a consistent fracture trace. Karst features B025-15 through B025-18 are grouped along a straight northwest oriented section of the ridgeline and B074-1 and B074-5 follow a deep northeast oriented valley (Fig. 10, Appendix A).

Summary of Findings

Based on the current analysis of existing dye traces and fracture traces along the ACP in Augusta, Bath, Highland, Pocahontas, and Randolph counties our findings are as follows:

- In the Great Valley area the overall fracture trends were along strike from NE to SW, and a secondary set of fractures perpendicular to the main set. However, there are numerous chaotically oriented fracture sets which complicate the analysis of patterns and trends. Although no dye traces have been conducted in the area impacted by the ACP, prior studies throughout the Great Valley suggest radial subsurface flow, with both a conduit flow and a diffuse flow pattern (Jones, 1997).
- In the Folded Appalachian Region, the primary trend of the fractures was NE to SW, with a NW trending secondary set of conjugate fractures. Dye traces in this region suggest subsurface flow is primarily conduit-based and controlled by the fracture patterns.
- In the Appalachian Plateau Region, there is a general NE to SW trend of fractures, however the surface drainage pattern does not closely reflect the fracture orientation as it does in the nearby Folded Appalachians. Nevertheless, regional dye trace studies suggest that conduit flow dominates the subsurface drainage pattern, in some cases over relatively long distances, and this pattern closely follow the fracture orientations.

Conclusions

The synopsis of the existing dye traces and the fracture trace analysis demonstrate that many of the karst features within or receiving drainage from the 300-foot corridor along the ACP, are located inside of and/or may lead to the watersheds of nearby springs. The greatest potential impact to groundwater is from features which allow surface water to plunge into the subsurface such as caves, sinkholes with open, rock-bound throats, and sinking or losing streams. The features and their ranking relative to potential impact to groundwater are summarized in the Karst Survey Report. During construction, it is critical that the protocols in the Karst Terrain Assessment, Construction, Monitoring and Mitigation Plan be followed to limit the potential for groundwater to be impacted by the ACP construction activities.

General Limitations

Findings contained in this report are based upon the data obtained from the data review and field survey services detailed herein. It is essential that on-site observations and monitoring in accordance with the Karst Survey and Mitigation Plan be performed during the construction period to confirm the subsurface conditions indicated herein, and to address any karst related issues that occur during construction.

This report was prepared in accordance with generally accepted geologic and geotechnical engineering practices. No warranties, expressed or implied, are made as to the professional services included in this report.

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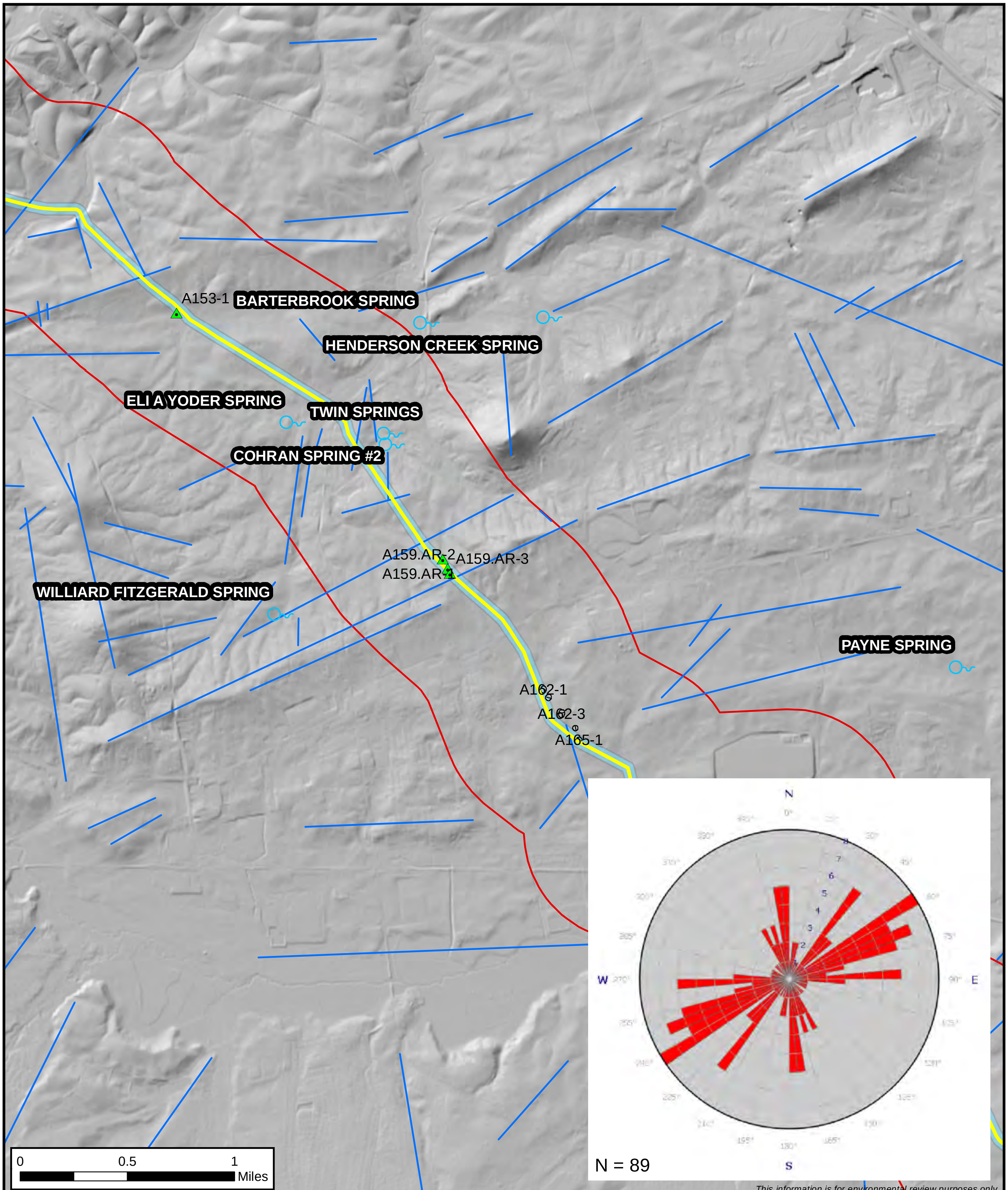
APPENDIX A
Fracture Trace Maps



Centerline	VDEQ Springs
300' Corridor	Fracture Trace
0.5 Mile KRA	Point Features
	Area Features

FRACTURE ANALYSIS AND DYE TRACES 1

DOMINION ACP

Stuart's Draft

PR: 11002.04

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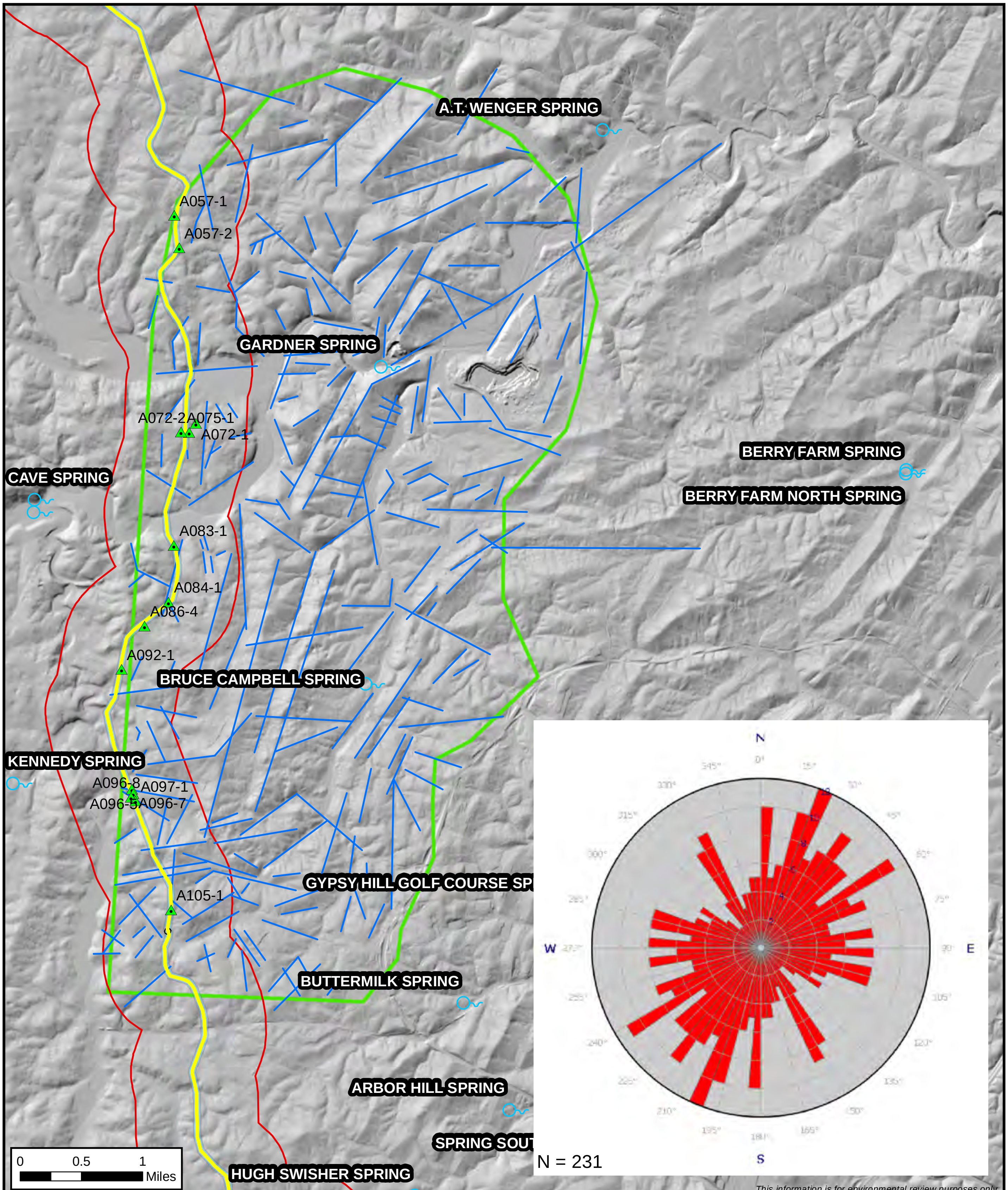

Centerline
300' Corridor
0.5 Mile KRA
VDEQ Springs
Fracture Trace
Gardner WHPA
Point Features
Area Features

FRACTURE ANALYSIS AND DYE TRACES 2
DOMINION ACP
GARDNER SPRING
PR: 11002.04

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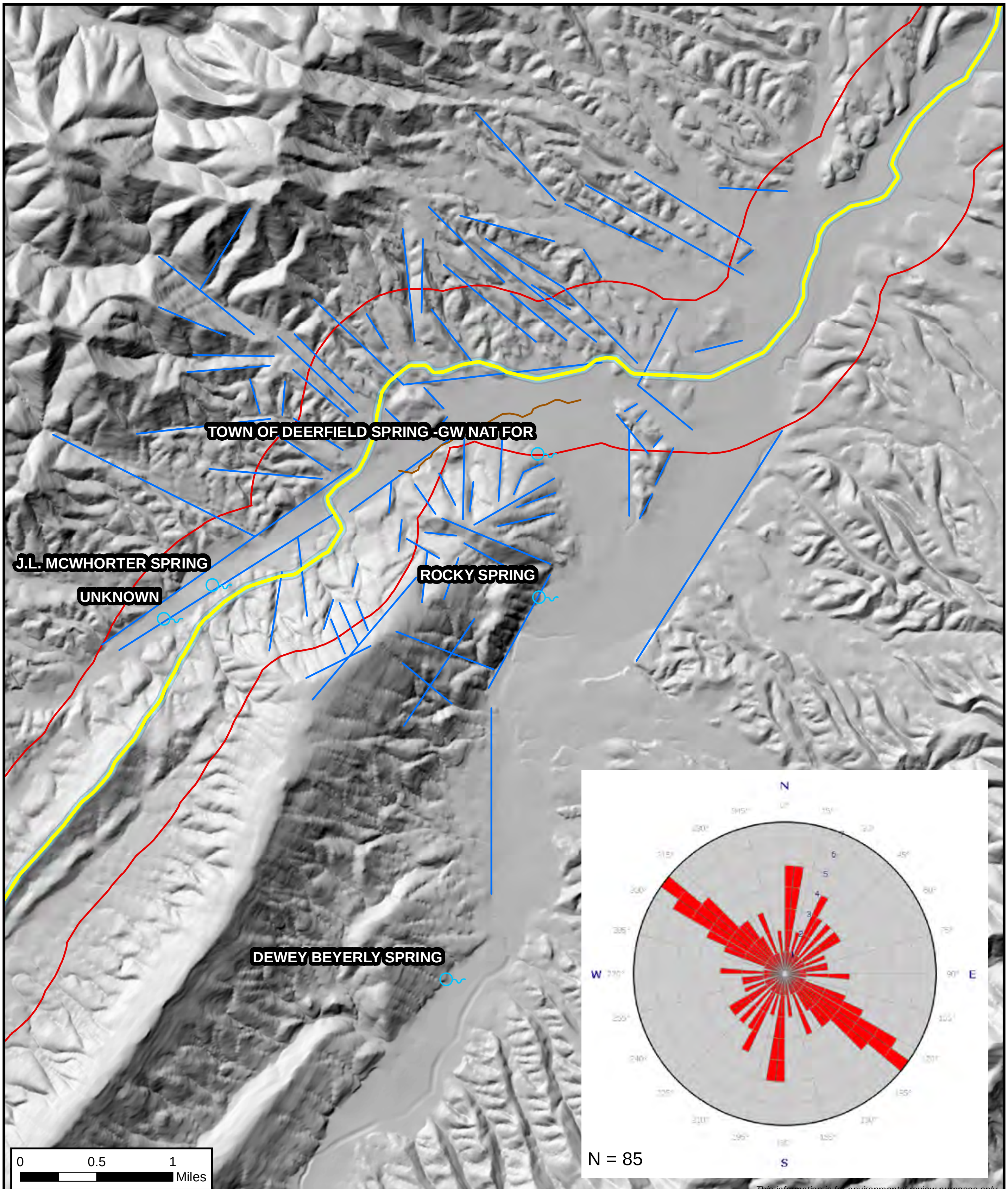

Legend

- Centerline
- 300' Corridor
- 0.5 Mile KRA
- VDEQ Springs
- Fracture Trace
- Sinking Stream

FRACTURE ANALYSIS AND DYE TRACES 3
DOMINION ACP
DEERFIELD
PR: 11002.04

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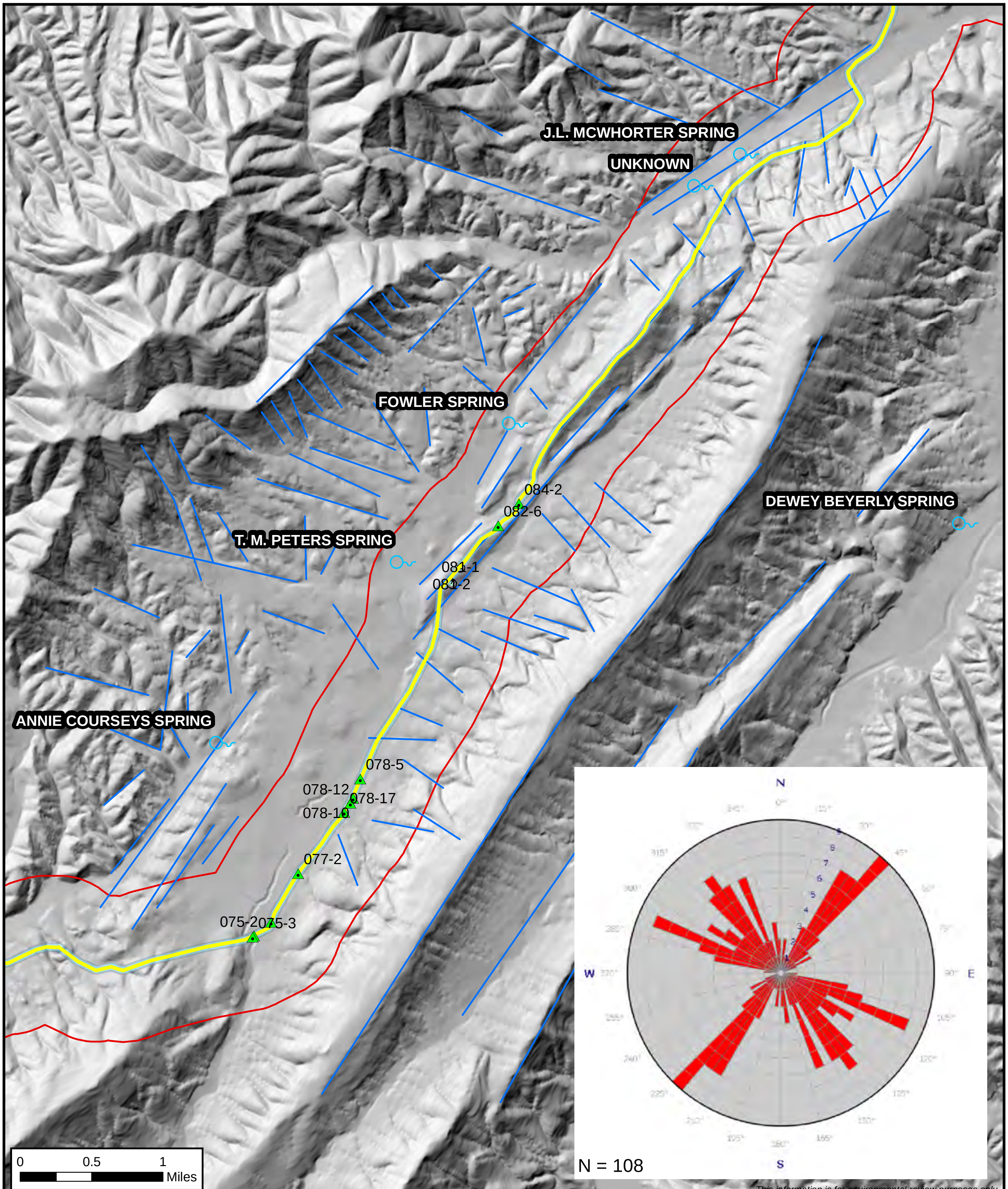

Centerline
Fracture Trace
300' Corridor
Point Features
0.5 Mile KRA
Area Features
VDEQ Springs

N

FRACTURE ANALYSIS AND DYE TRACES 4
DOMINION ACP
BRUSHY RIDGE
PR: 11002.04

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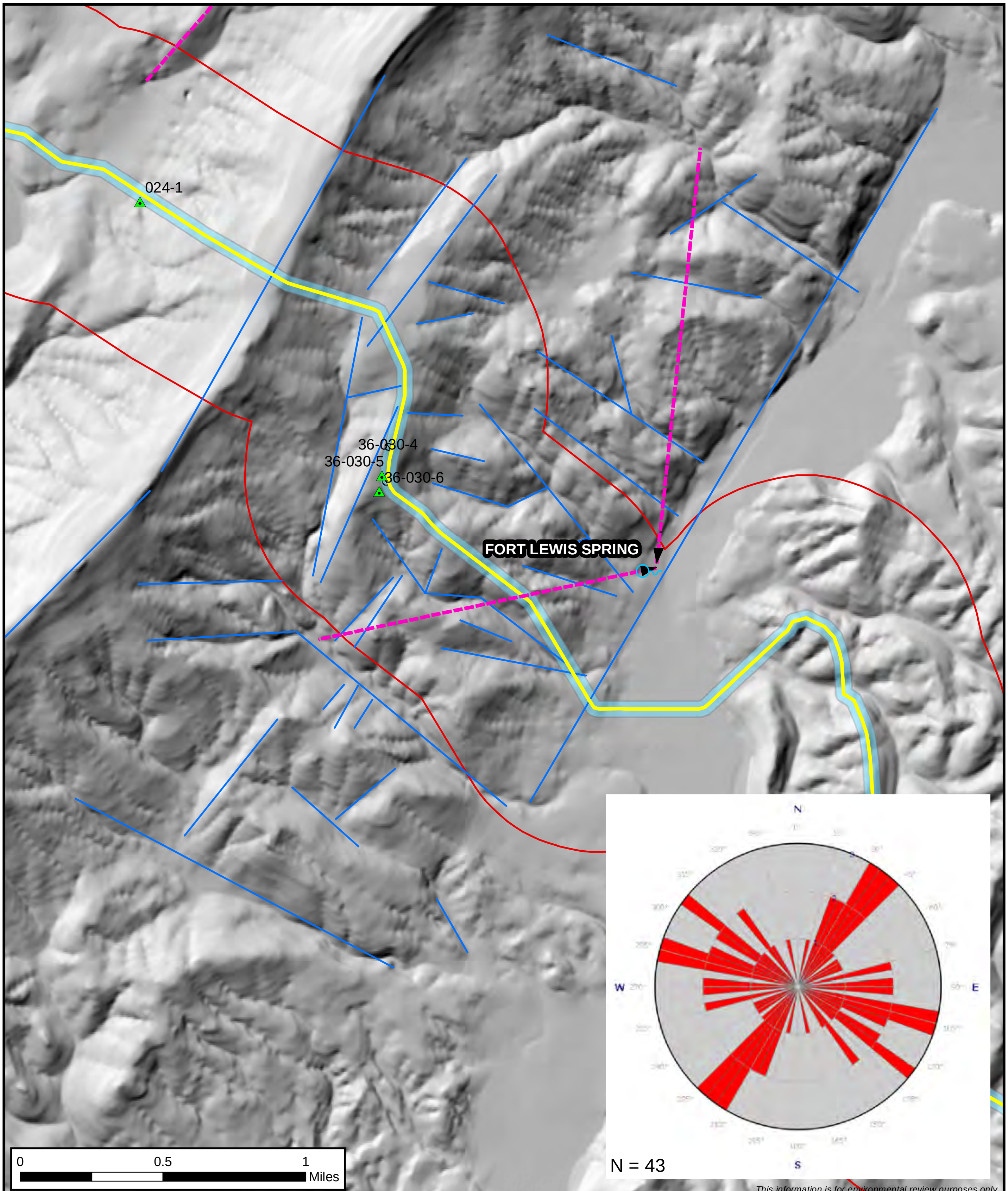

FRACTURE ANALYSIS AND DYE TRACES 5
DOMINION ACP
FORT LEWIS
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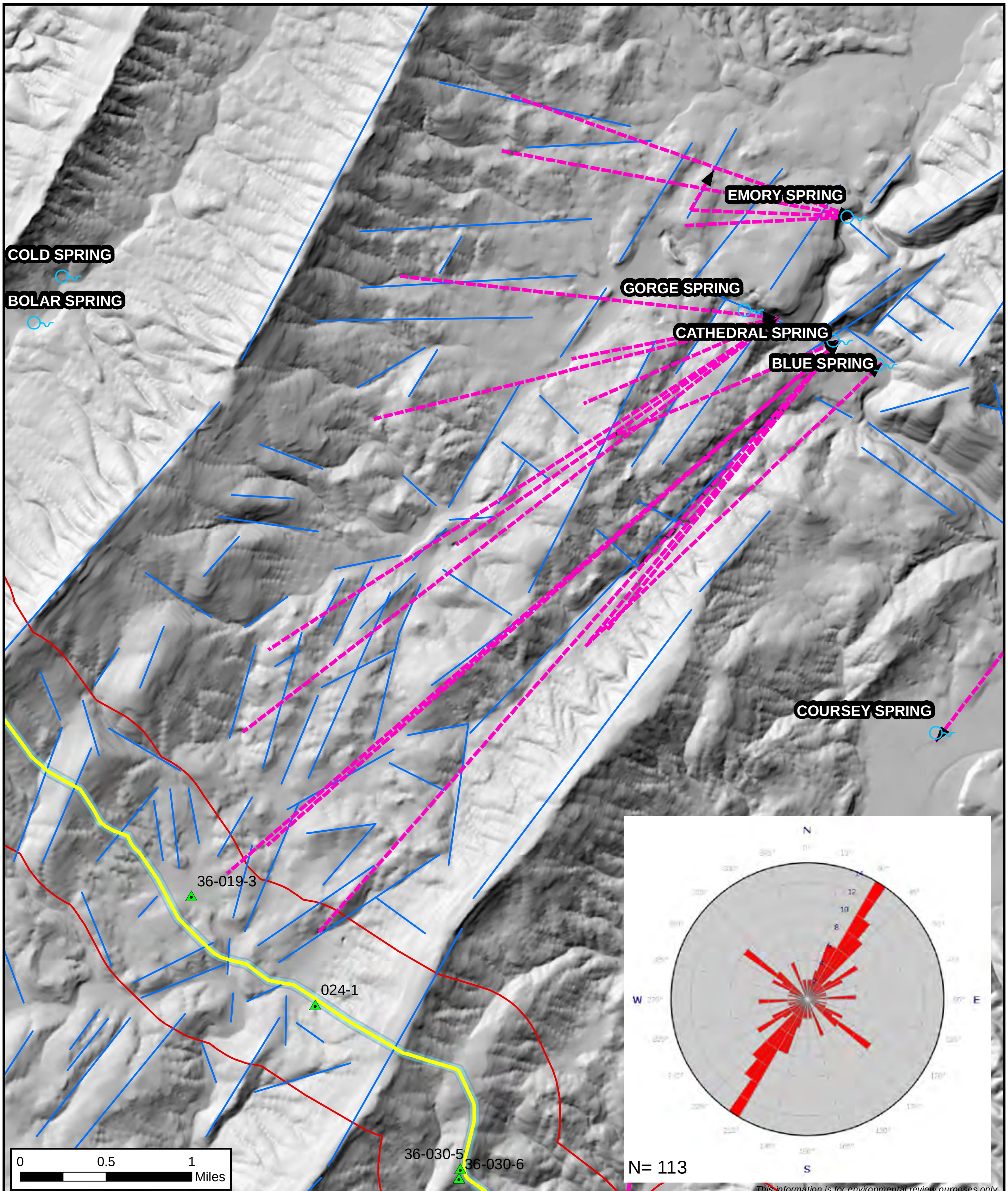

Centerline	VDEQ Springs
300' Corridor	Dye Traces
0.5 Mile KRA	Area Features
Fracture Trace	Point Features

FRACTURE ANALYSIS AND DYE TRACES 6
DOMINION ACP
BURNSVILLE COVE
PR: 11002.04

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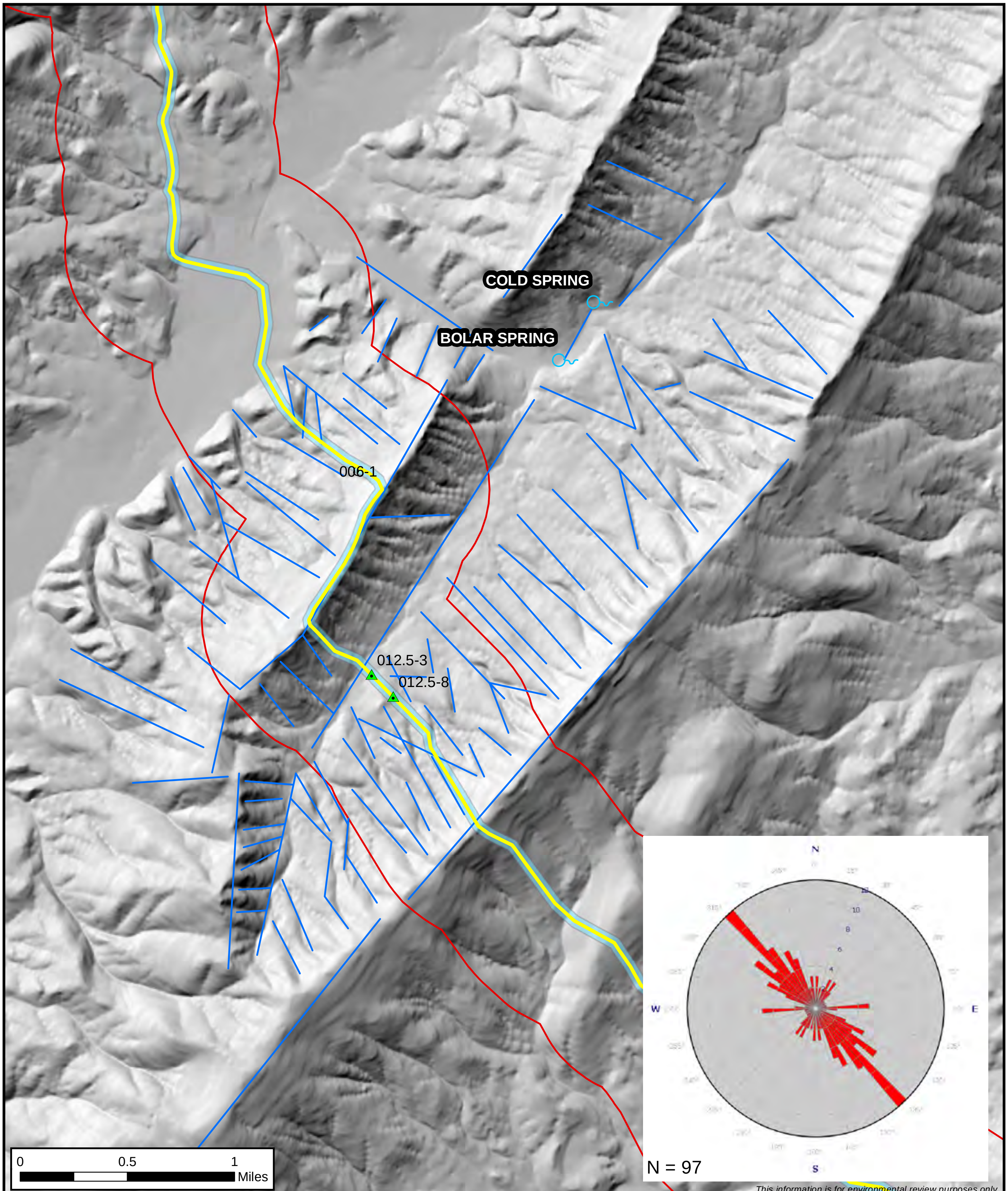

Centerline
300' Corridor
0.5 Mile KRA
VDEQ Springs
Fracture Trace
Area Features
Point Features

FRACTURE ANALYSIS AND DYE TRACES 7
DOMINION ACP
LITTLE VALLEY
PR: 11002.04

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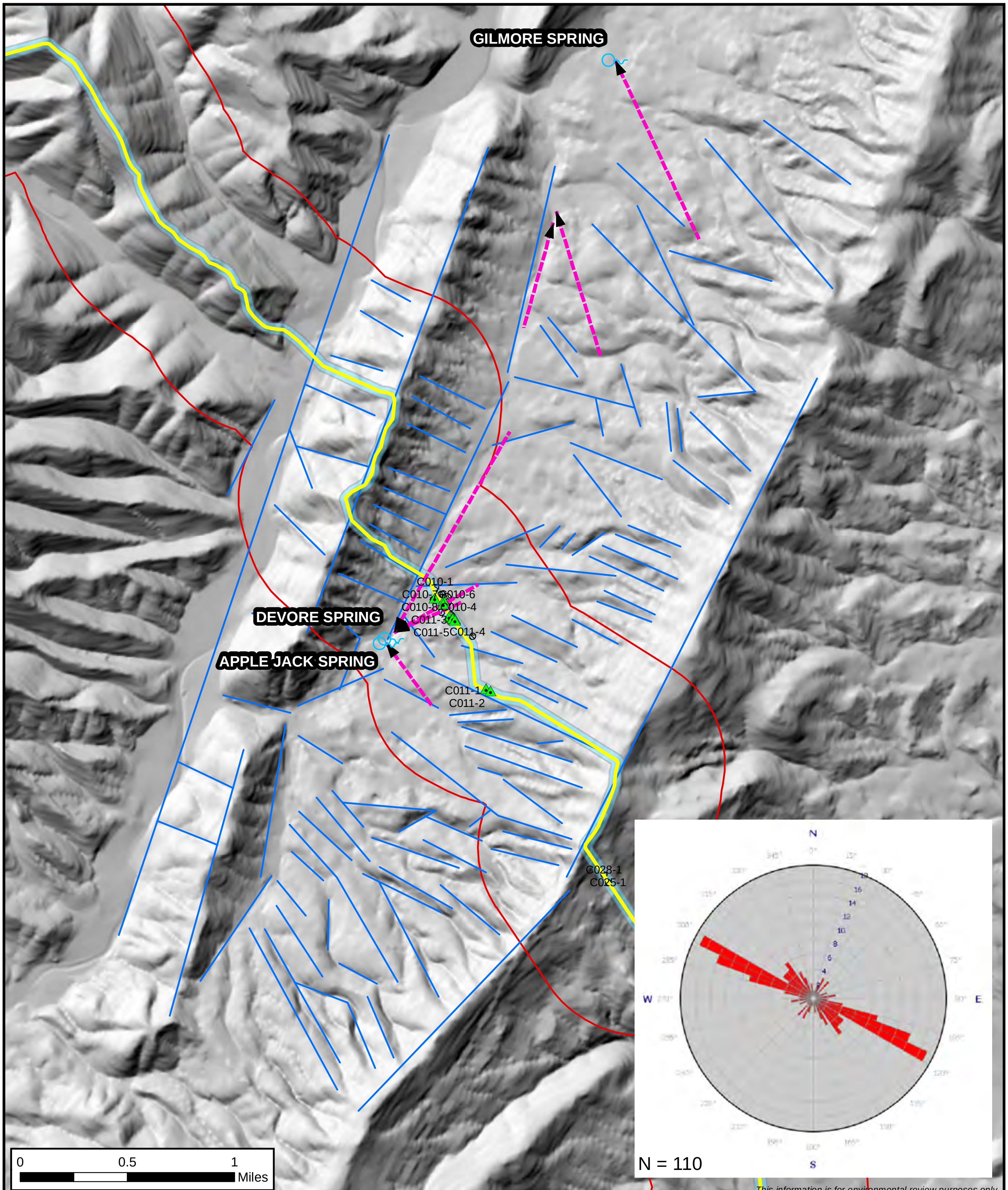

Centerline
300' Corridor
0.5 Mile KRA
Dye Traces
VDEQ Springs
Fracture Trace
Area Features
Point Features

FRACTURE ANALYSIS AND DYE TRACES 8
DOMINION ACP
VALLEY CENTER
PR: 11002.04

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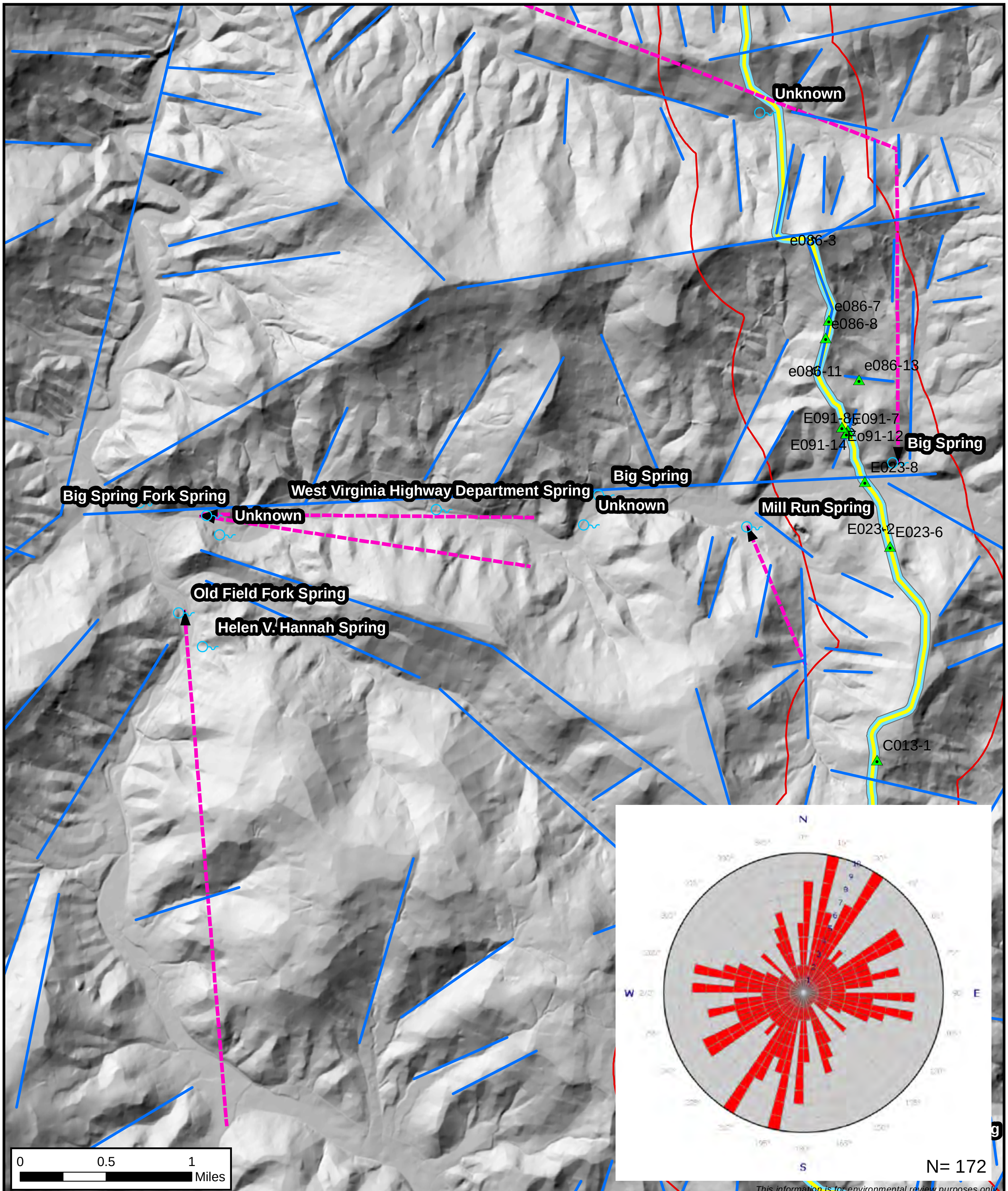

Centerline
300' Corridor
0.5 Mile KRA
WVsprings
Fracture Trace
Dye_traces
Area Features
Point Features

FRACTURE ANALYSIS AND DYE TRACES 9
DOMINION ACP
SNOWSHOE AREA
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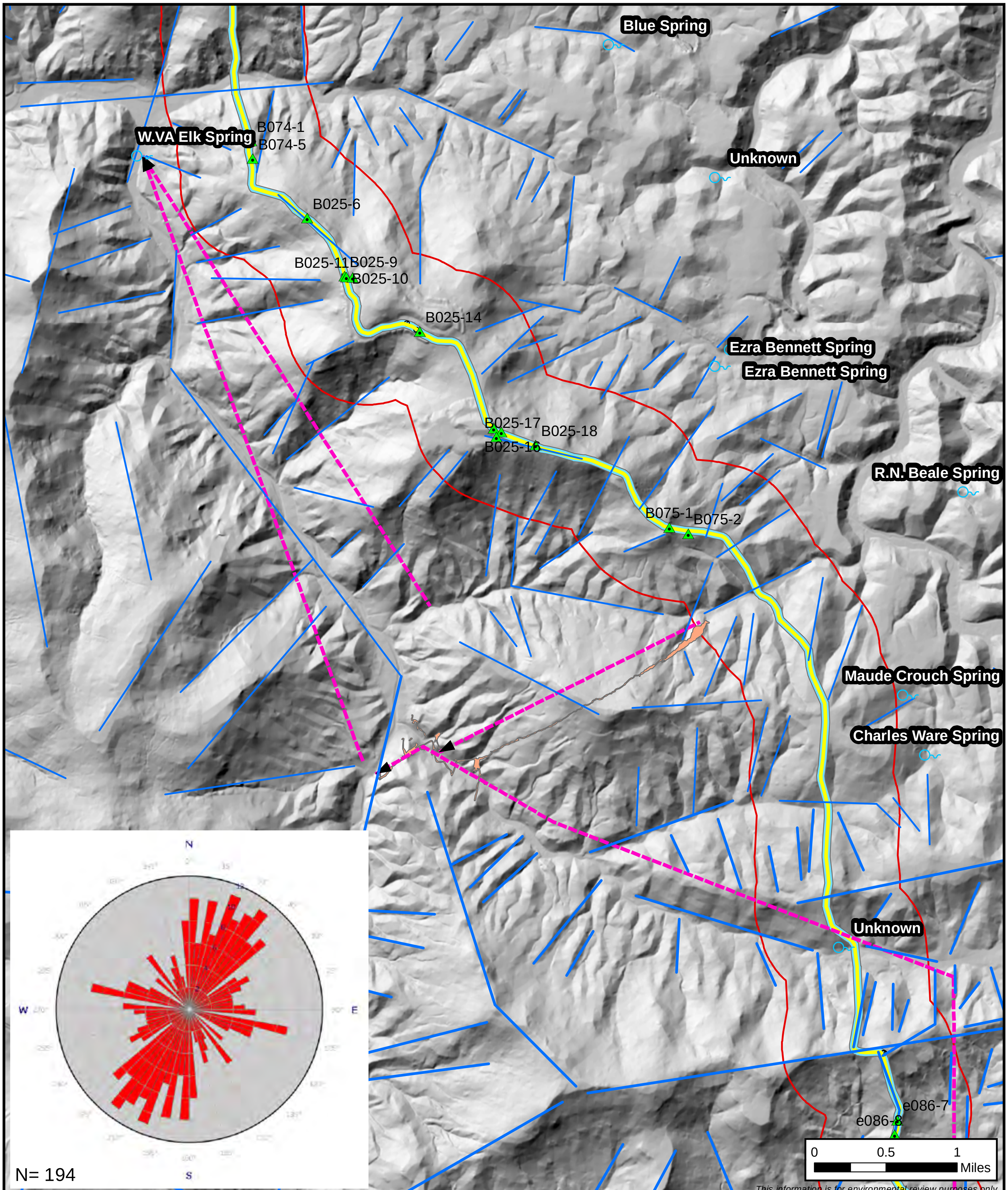

Centerline
300' Corridor
0.5 Mile KRA
WVsprings
Fracture Trace
Dye_traces
Simmons Mingo
Area Features
Point Features

FRACTURE ANALYSIS AND DYE TRACES 10
DOMINION ACP
SIMMONS MINGO
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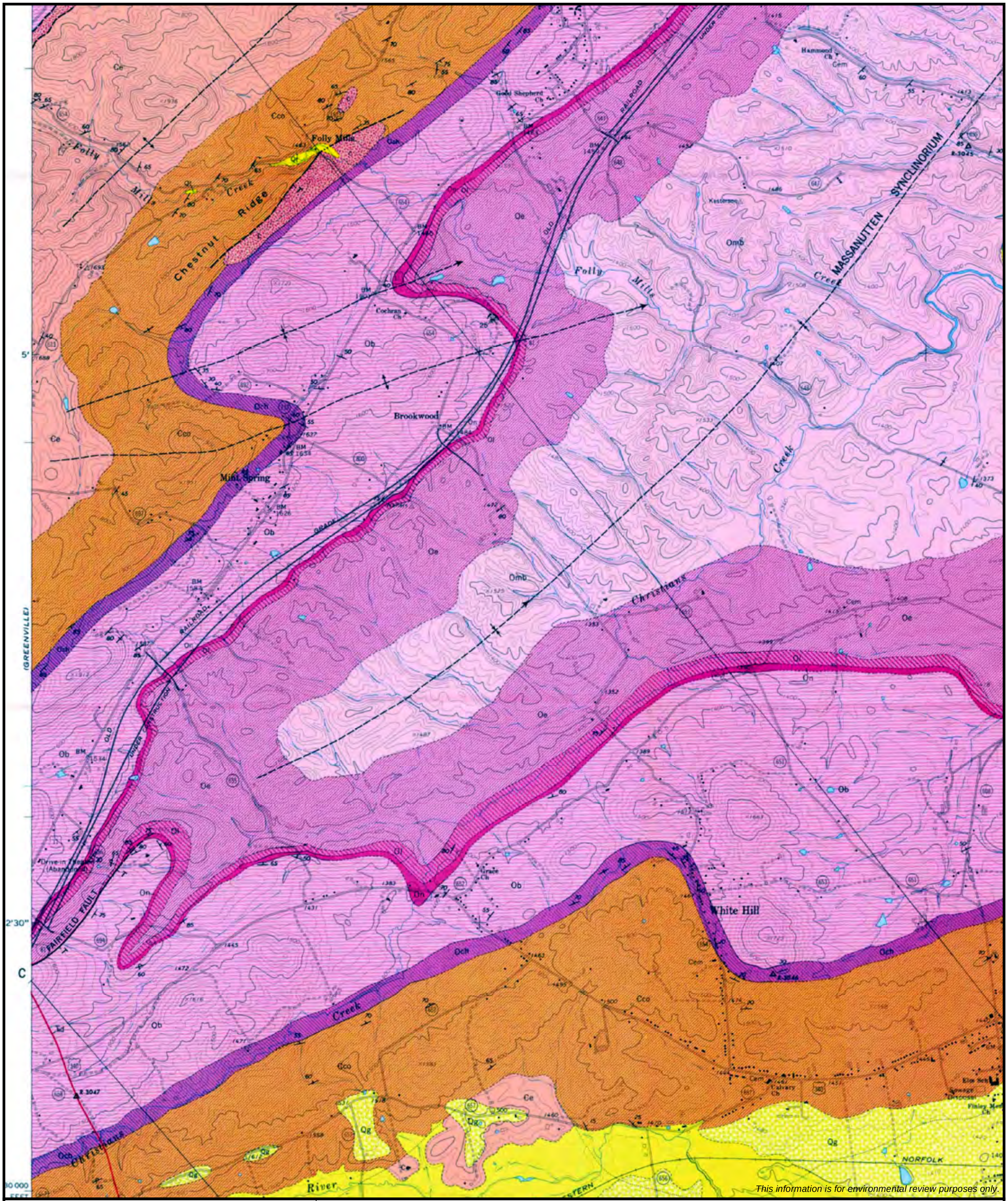
APPENDIX B

Geologic Maps



0 — 1 mi

N

GEOLOGY MAP FIG. 1
DOMINION ACP FRACTURE STUDY
STUART'S DRAFT
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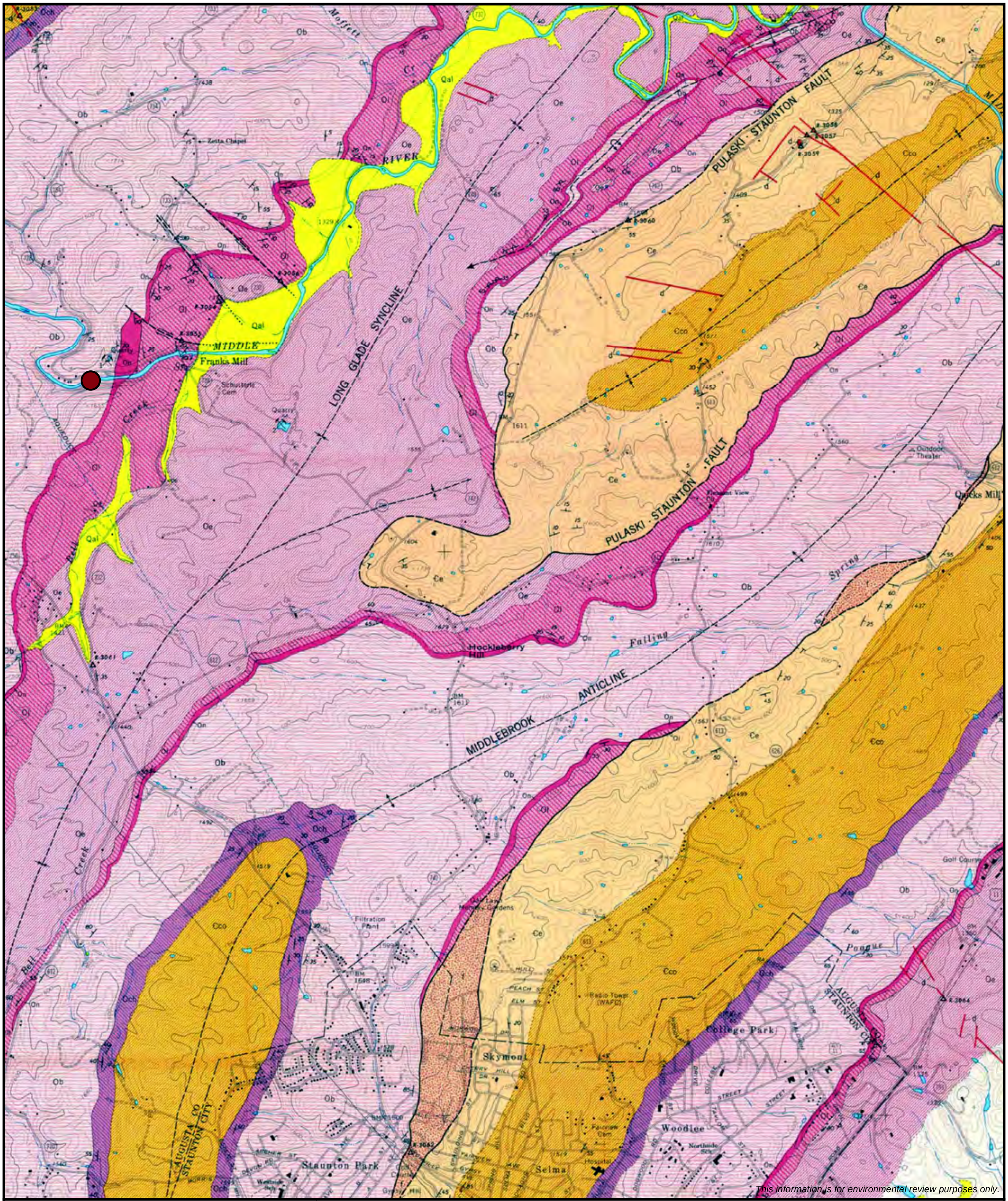

Legend

GardnerSpring

0 — 1 mi

N

GEOLOGY MAP FIG. 2
DOMINION ACP FRACTURE STUDY
GARDNER SPRING
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0 1 mi

N

GEOLOGY MAP FIG. 3

DOMINION ACP FRACTURE STUDY

DEERFIELD

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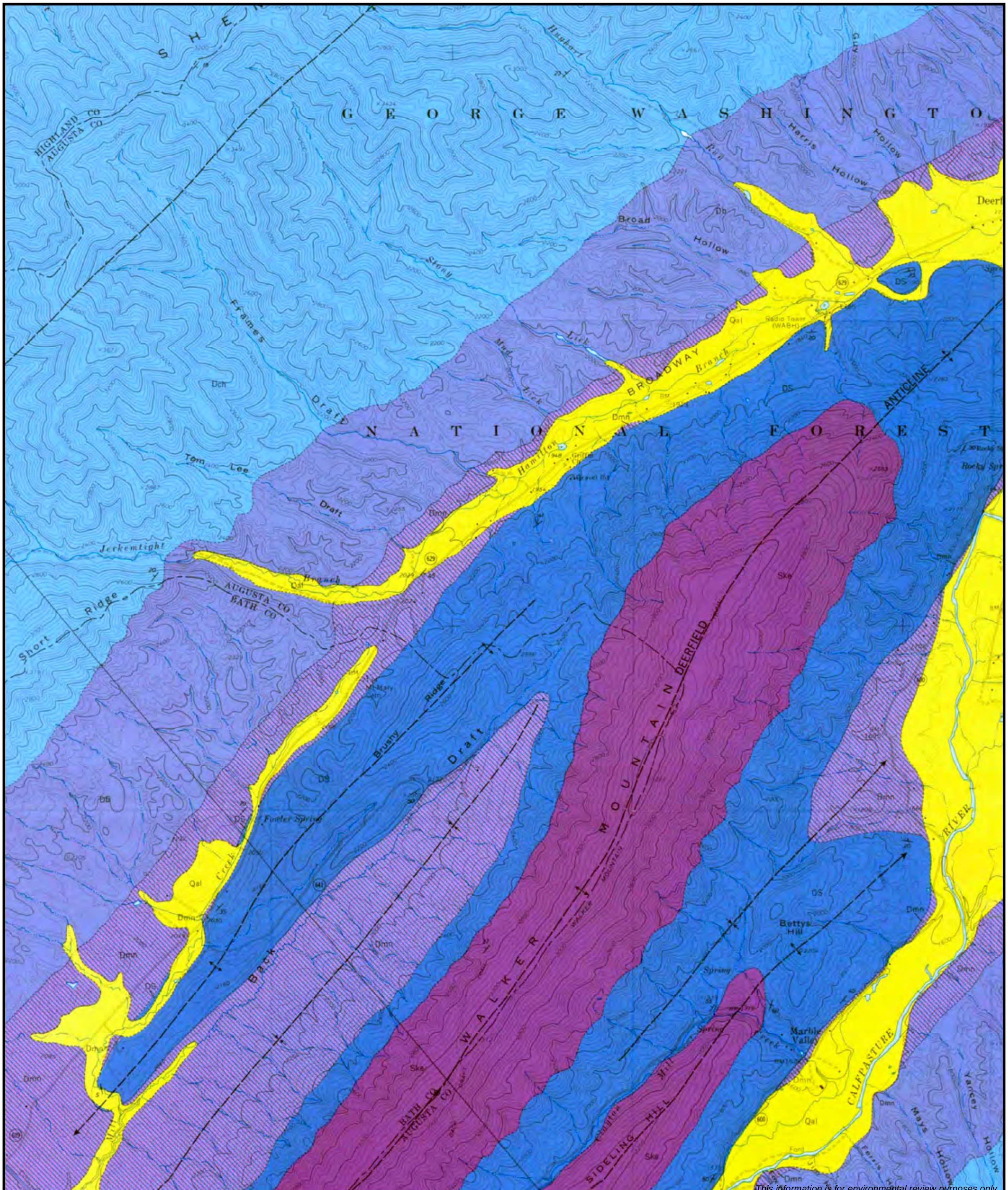

0 1 mi

N

GEOLOGY MAP FIG. 4

DOMINION ACP FRACTURE STUDY
BRUSHY RIDGE
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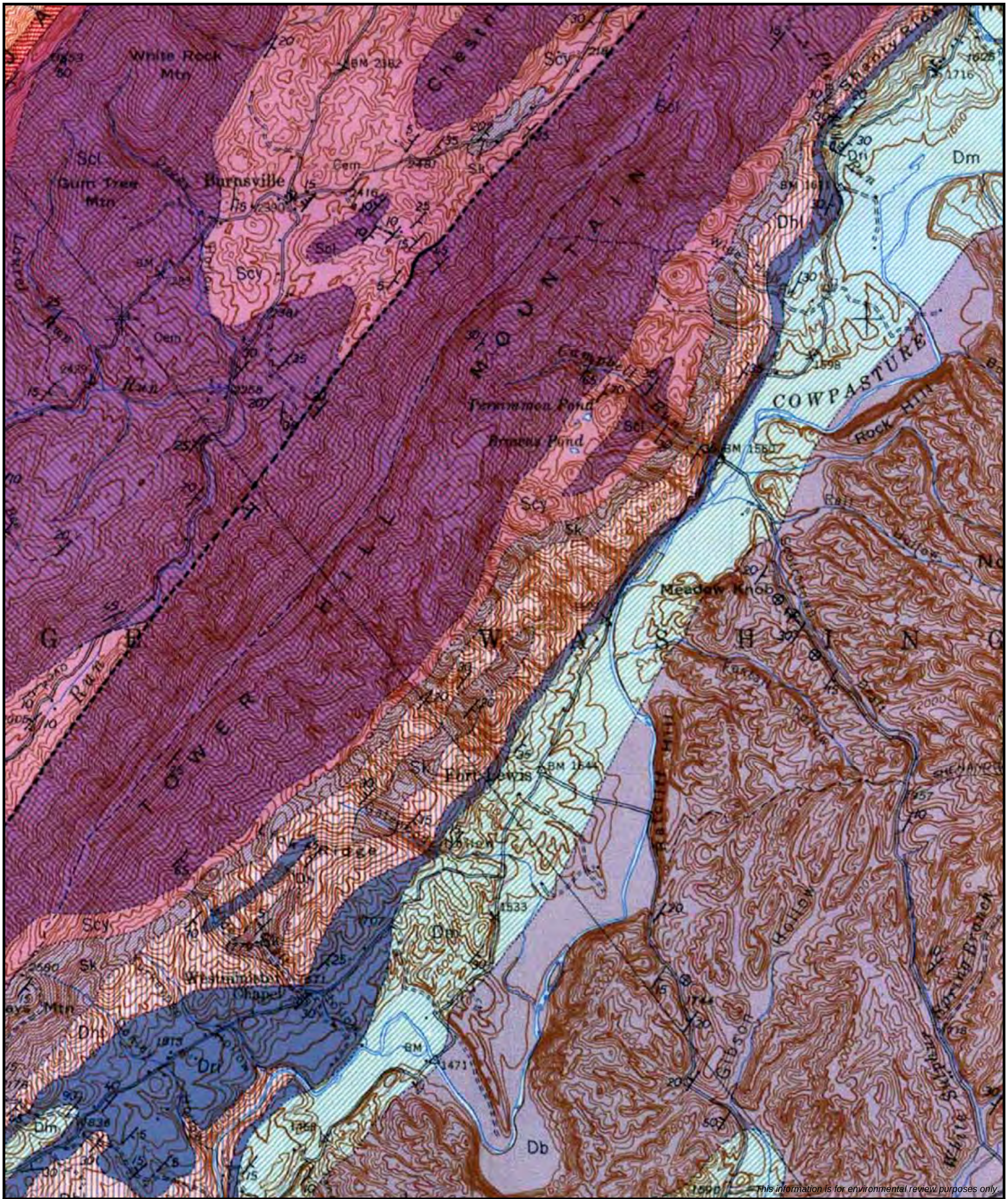

0 1 mi N

GEOLOGY MAP FIG. 5
DOMINION ACP FRACTURE STUDY
FORT LEWIS
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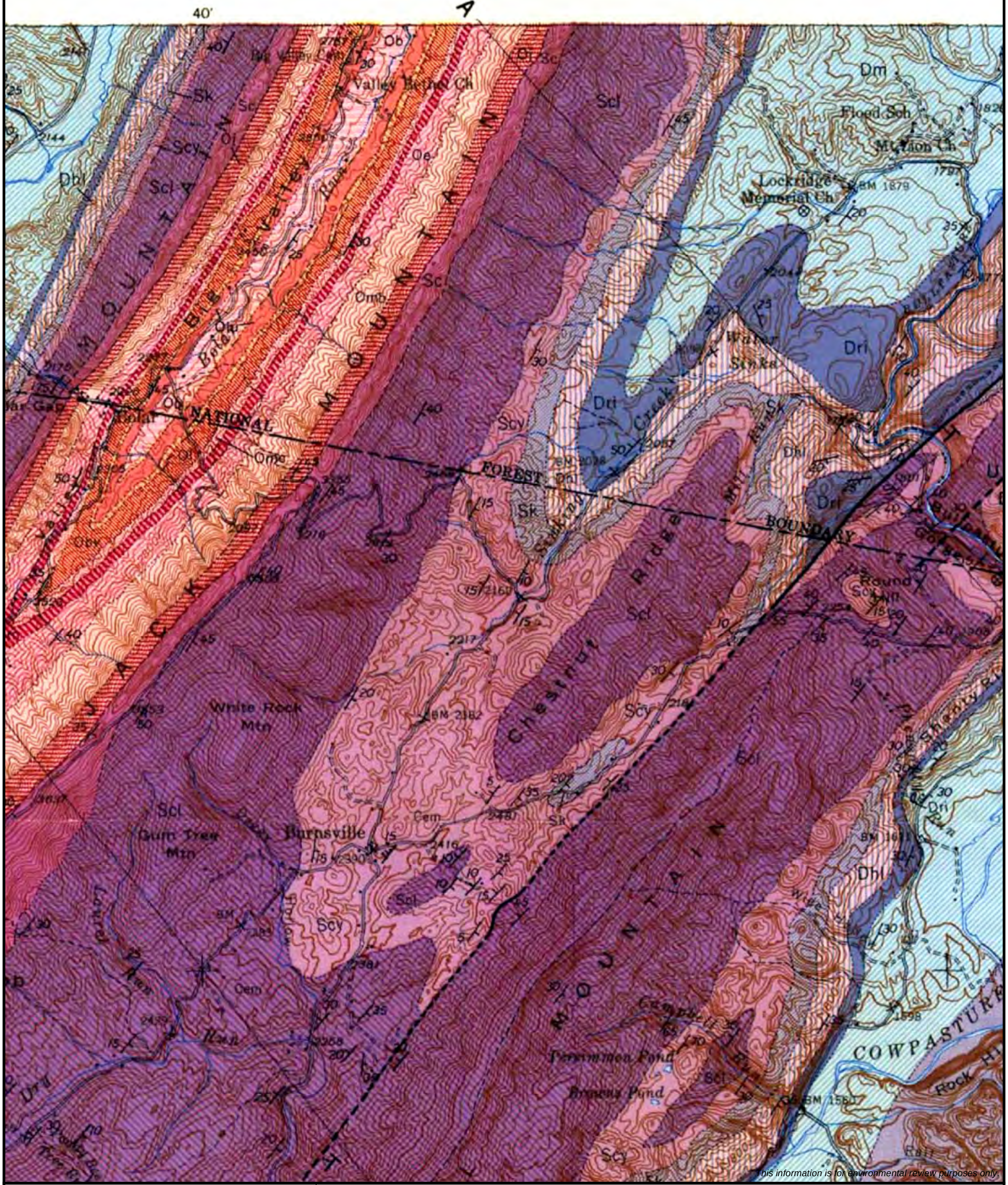

GEOLOGY MAP FIG. 6

DOMINION ACP FRACTURE STUDY
BURNSVILLE COVE
PR: 11002.04

0 1 mi

N

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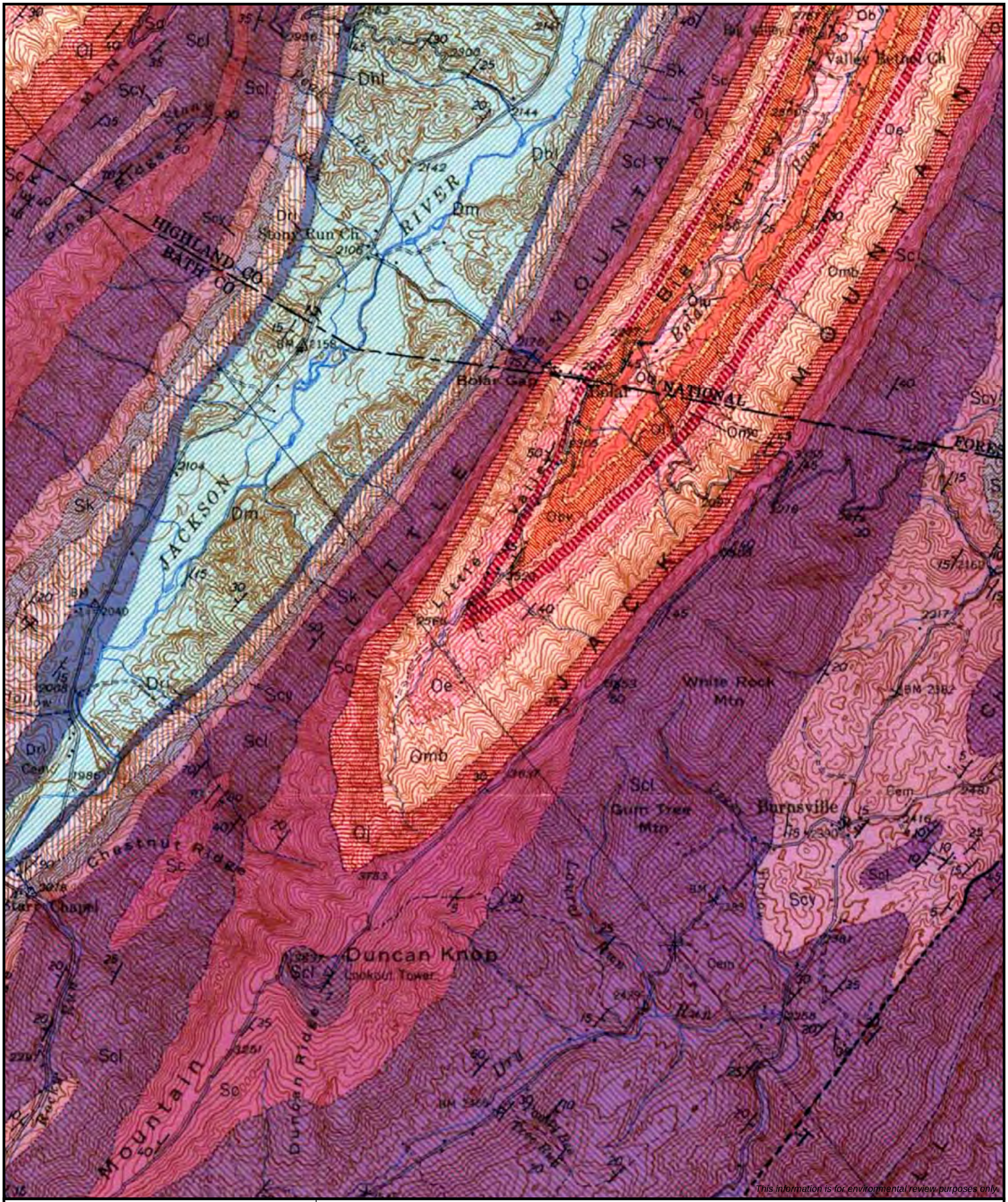

0 1.5 mi

N

GEOLOGY MAP FIG. 7

DOMINION ACP FRACTURE STUDY
LITTLE VALLEY
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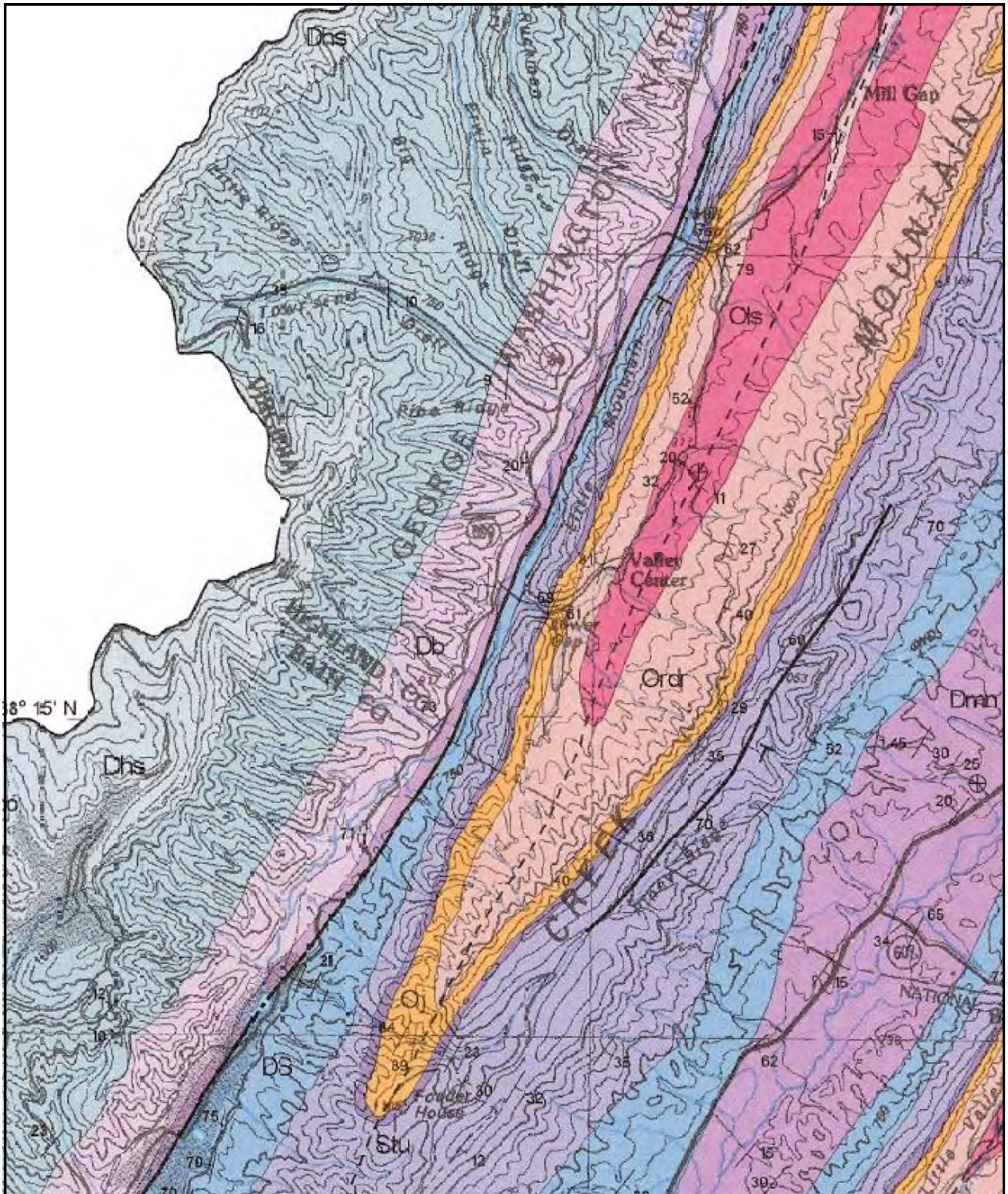

0 1 mi

GEOLOGY MAP FIG. 8
DOMINION ACP FRACTURE STUDY
VALLEY CENTER
PR: 11002.04

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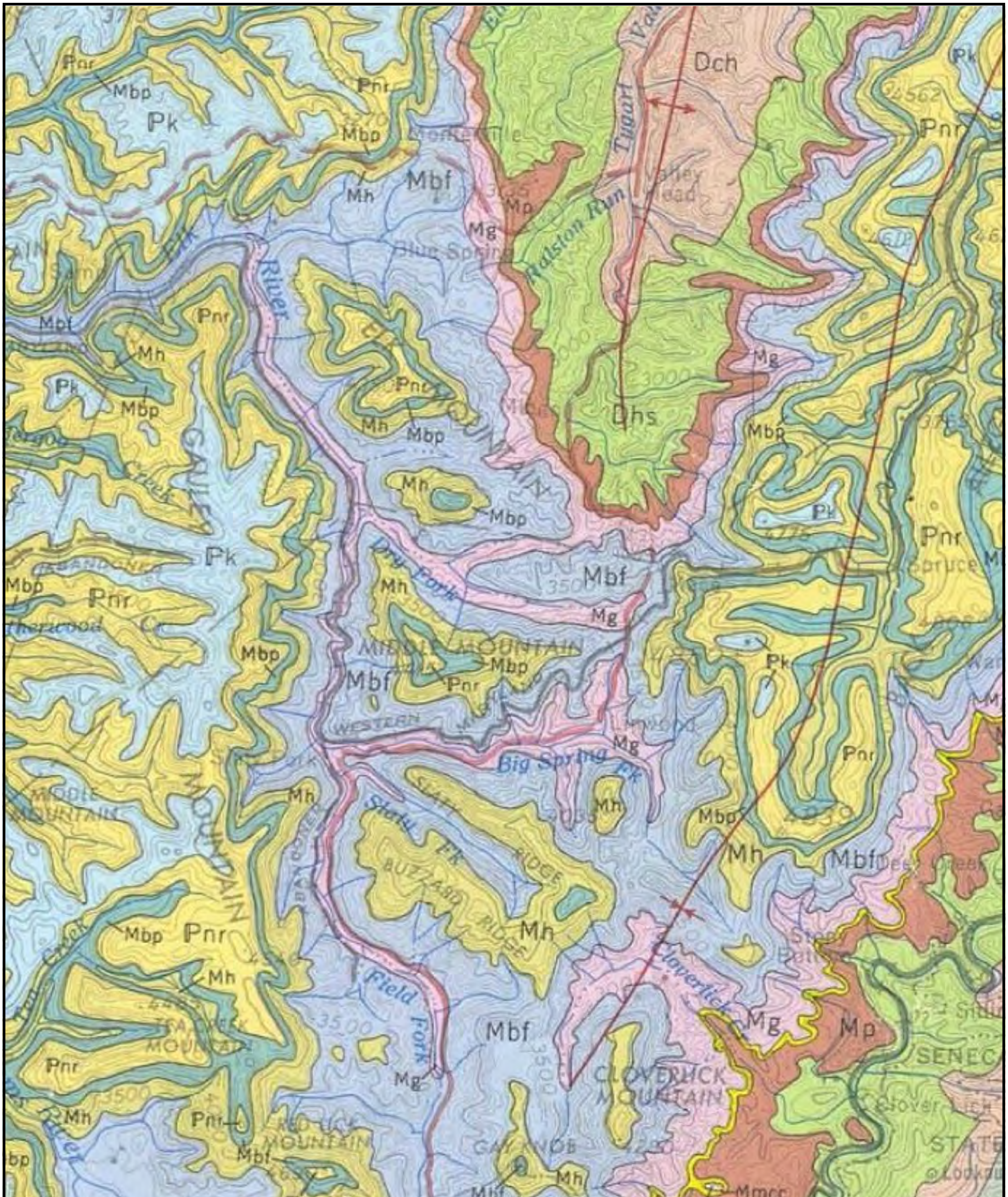

0 3 mi

N

GEOLOGY MAP FIG. 9

DOMINION ACP FRACTURE STUDY

WV LOCATIONS

PR: 11002.04

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