Mountain Valley Pipeline Project

Docket No. CP16-__-000

Resource Report 6 – Geologic Resources

October 2015

Mountain Valley Pipeline Project
Resource Report 6 – Geologic Resources

Resource Report 6 Filing Requirements	
Information	**Location in Resource Report**
Minimum Filing Requirements	
1. Identify the location (by milepost) of mineral resources and any planned or active surface mines crossed by the proposed facilities. (§380.12 (h) (1 & 2)). Describe hazards to the facilities from mining activities, including subsidence, blasting, slumping or landsliding or other ground failure.	Sections 6.3, 6.3.1, 6.3.2, 6.3.3, and 6.3.4
2. Identify any geologic hazards to the proposed facilities. (§380.12 (h) (2)) For the offshore, this information is needed on a mile-by-mile basis and will require completion of geophysical and other surveys before filing.	Section 6.4
3. Discuss the need for and locations where blasting may be necessary in order to construct the proposed facilities. (§380.12 (h) (3))	Section 6.2
4. For LNG Projects in seismic areas, the materials required by "Data Requirements for the Seismic Review of LNG Facilities," NBSIR84-2833. (§380.12 (h) (5))	Not Applicable (not an LNG project)
5. For underground storage facilities, how drilling activity by others within or adjacent to the facilities would be monitored, and how old wells would be located and monitored within the facility boundaries. (§380.12 (h) (6))	Not Applicable (no underground storage proposed)
6. Identify any sensitive paleontological resource areas crossed by the proposed facilities. (Usually only if raised in scoping or required by land-managing agency.)	Section 6.5
7. Briefly summarize the physiography and bedrock geology of the project area	Sections 6.1.1 and 6.1.2
8. If application is for underground storage facilities: • Describe monitoring of potential effects of the operation of adjacent storage or production facilities on the proposed facility, and vice versa; • Describe measures taken to locate and determine the condition of old oil wells within the field and buffer zone and how the applicant would reduce risk from failure of known and undiscovered wells; and • Identify and discuss safety and environmental safeguards required by state and Federal drilling requirements	Not Applicable (no underground storage proposed)

FERC Environmental Information Request for Resource Report 6 Dated March 13, 2015	
Request	**Location in Resource Report**
1. Include a discussion of the Saint Clair fault line. Indicate what impacts the fault may have on the pipeline. Outline measures that would be implemented to avoid, minimize, or mitigate impacts from this fault.	Section 6.4.1.3, p. 6-16; Section 6.6.1.3, p.6-28
2. List, by MPs, areas along the pipeline route that have the potential for landslides. Outline the measures Mountain Valley would implement to avoid, minimize impacts, or mitigate impacts related to landslides.	Section 6.4.3, p.6-22; Table 6.4-6, p. 6-24; Section 6.6.1.2, p. 6-28

FERC Environmental Information Request for Resource Report 6 Dated March 13, 2015	
Request	**Location in Resource Report**
3. List, by MPs, areas along the pipeline route that have karst features or the potential for sinkhole development. Outline measures Mountain Valley would implement to avoid, minimize impacts, or mitigate impacts related to karst features or sinkholes. Document consultations with appropriate local, state, and federal resource agencies regarding karst features and sinkholes.	Section 6.4.2 and Table 6.4-3, p. 6-17; Section 6.6.1.5 p. 6-31
4. List, by MPs, any caves that would be crossed, or would be within 0.5-mile of the pipeline route. For each cave, provide its name (if known), distance (in feet) and direction from the pipeline centerline, depth of the cave, use for recreational purposes, and potential habitat for bats. Include site-specific information on caves identified by stakeholders in comments filed with the FERC, such as: Pig Hole Cave, Smoke Hole Cave, Tawney Cave, Mill Creek Nature Preserve Caves, and Cross Smokehole Cave. Outline measures Mountain Valley would implement to avoid, minimize impacts, or mitigate impacts related to the pipeline crossing or being near a cave. Document consultations with appropriate local, state, and federal resource agencies regarding caves.	Section 6.4.2.2, p. 6-19; Table 6.4-4 p. 6-21
5. List, by MPs, all oil or gas wells within 0.25-mile of the pipeline. The table should provide the name of the well, distance in feet and direction from centerline, and well depth. Also, illustrate the locations of the nearby oil and gas wells in relation to the pipeline route on 7.5-minute U.S. Geological Survey topographic quadrangle maps. Outline measures Mountain Valley would implement to avoid, minimize impacts, or mitigate impacts on those oil and gas wells.	Section 6.3.2 and Table 6.3-2, p.6-11; Appendix 6-C; Section 6.3.5, p. 6-13
6. List, by MPs, any active or abandoned mines, including coal mines and quarries, within 0.25-mile of the pipeline. The table should provide the name of the mine, its distance (in feet) and direction from centerline, type of mine, material quarried or removed, and indicate if the mine is active or abandoned. In particular, identify any underground mine workings that may be crossed. Outline measures Mountain Valley would implement to avoid, minimize impacts, or mitigate impacts on mines that would be crossed or near the pipeline.	Section 6.3 and Table 6.3-1, p. 6-9; Section 6.3.3, p. 6-13

FERC Environmental Information Request for Resource Report 6 Dated August 11, 2015		
	Request	**Location in Resource Report**
1.	Include copies of the reports referenced in the citations for Draper Arden Associates 2015a, b, and c.	Appendices 6-D.1 and 6-D.2.
2.	Revise figures in RR 6 (such as figure 6.4-1 and 6.4-2) to increase the size and clarity of the legend.	Figures 6.4.1 and 6.4-2
3.	Revise RR 6 text and tables to include information regarding geology, mineral resources, and geologic hazards for all aboveground facilities including, compressor stations, meter stations, contractor yards, pipe storage yards, access roads, and extra work spaces.	Section 6.1.3.
4.	Revise section 6.1.1 to include a more detailed discussion of the Blue Ridge and Piedmont Physiographic Provinces such as common geologic features, underlying bedrock, and potential geologic hazards associated with each province.	Section 6.1.1.
5.	Revise section 6.1.2 to include a discussion of surficial geology crossed by the proposed Project.	Section 6.1.2.

FERC Environmental Information Request for Resource Report 6 Dated August 11, 2015		
	Request	**Location in Resource Report**
6.	Update table 6.1-2 to include: a. surficial geology by MP; b. a description of the general surficial geology within each physiographic province; and c. the geology between mileposts 201.09 and 204.70.	Table 6.1-2 and Sections 6.1.1 and 6.1.3.
7.	Revise table 6.3-1 to include all Project components (such as pipeline, compressor stations, meter stations, MLVs, access roads, extra work spaces, pipe storage yards, and contractor yards), the type of mine being crossed (i.e. surface or underground), and the material that is being mined. Explain why many have a status of "unknown."	Table 6.3-1.
8.	Include proposed avoidance, minimization, and mitigation measures for oil and/or gas wells located within 100 feet of the proposed construction work spaces.	Sections 6.3.2 and 6.6.1.
9.	Assess the potential impact of the Project during operation upon future natural gas well drilling sites or lost or impaired mineral rights. Describe any setbacks or other measures that may hamper a landowner's ability to drill a new gas well.	Section 6.3.2.
10.	Section 6.3.3 states "final Project design will include more specific identification of all mines in the vicinity of the Project." Include an estimated schedule when final Project design would be completed and this information would be provided to the FERC.	Section 6.3.
11.	Include the following measures that would be instituted with regards to mining: a. communication plans or procedures that would be used with mine operators including what activities would require mine operators to notify MVP; b. specific limitations that may affect mining along the Project such as restrictions to excavation, heavy equipment movement, blasting, and planned subsidence for room and pillar mining operations; and c. specific measures that would be used in regards to landsliding and slumping, blasting, excavation, heavy equipment movement, and planned mine subsidence within proximity to the proposed Project.	Sections 6.6.1.2 and 6.6.2. Appendix C.2.
12.	Include a detailed discussion of abandoned, active and reclaimed mine lands as discussed in West Virginia Department of Environmental Protection's May 22, 2015 letter to the FERC. Include proposed avoidance, minimization, and mitigation measures.	Sections 6.3, 6.6.1.2, 6.6.2, and Appendix 6-C.2.
13.	Include a figure that depicts the USGS Seismic Hazard Maps for ground accelerations with a 10 percent probability of being exceeded within 50 years.	Section 6.4.1.2. Appendix 6-D.1.
14.	Section 6.4.1 states "MVP will evaluate soil texture class, presence of high water tables, surface hydrology, and floodplain information through the Project area to determine where concrete coating, concrete weights or gravel-filled blankets may be required." Include a table of the locations where Mountain Valley intends to use concrete coating, concrete weights, or gravel filled blankets.	Section 6.4.1, Table 6.4-2.

<table>
<tr><th colspan="2">FERC Environmental Information Request for Resource Report 6
Dated August 11, 2015</th></tr>
<tr><th>Request</th><th>Location in Resource Report</th></tr>
<tr><td>15. Revise section 6.4.2 to include a map and table which identifies areas with a high probability of containing karst features. Also revise section 6.4.2 to:
a. identify measures that would be implemented in areas of known or potential karst. The measures should address:
I. BMPs to prevent contamination of groundwater and karst systems from run-off from the right-of-way;
II. pre- and post-construction monitoring of water quality and yield of wells and springs used for domestic supplies within 150 feet of the right-of-way;
III. identify the construction set-back from wells, springs, and karst surface expressions;
IV. blasting in karst terrain, and potential impact on wells and springs;
V. equipment storage, fueling, and maintenance procedures;
VI. procedures in the event of an unanticipated discovery of karst features during construction; and
VII. description of measures that would be implemented to repair or mitigate the development of a sinkhole in proximity to the pipeline, and the monitoring of these features during Project operation.
b. include the results of geotechnical or geophysical evaluations and studies; and
c. documentation of consultations with federal, state, and local agencies with regards to karst features.</td><td>Section 6.4.2 and Karst Hazards Assessment, Appendix 6-D.2, Figure 6.4-2, Section 6.6.1.5 and Karst Mitigation Plan. – Appendix 6-D.2.</td></tr>
<tr><td>16. Include a detailed discussion regarding the structural integrity of modern pipelines and their performance in karst areas, including an assessment of the possible unsupported span width of the proposed pipeline.</td><td>Sections 6.4.2.1 and 6.1.1.5. Appendix 6-D.2, Sinkhole Hazards Assessment.</td></tr>
<tr><td>17. Clarify if Mountain Valley consulted with any appropriate West Virginia resource agencies about caves along the pipeline route.</td><td>Section 6.4.2 and Appendix 6-D.2</td></tr>
<tr><td>18. Include the information depicted in figure 6.4-2 in a table format by MP.</td><td>Table 6.4-5 (Figure 6.4-2 is now Figure 6.4-3).</td></tr>
<tr><td>19 Revise table 6.4.3 to include the depth of the caves and potential for bat habitat.</td><td>Section 6.4.2.2 and Table 6.4.4.</td></tr>
<tr><td>20. Revise section 6.4.2 to include the results of the site evaluations for areas identified to contain potential landslide hazards (such as MP 144.6 and MP 232.5). Discuss if the evaluation will include on-site geologic reconnaissance, aerial photograph and LiDAR evaluation. Specifically, address how the results of this study would be used to reduce the potential for landslides to occur during construction and operation of the Project. Include a table that identifies areas of high potential for landslides by MP, ranks the potential hazards, how this ranking may trigger additional investigations or re-routing, and the construction mitigation measures and operational monitoring. This study should be conducted by a state certified geologist or geotechnical engineer.</td><td>Section 6.4.3, Table 6.4-6 and Section 6.6.1.2.</td></tr>
<tr><td>21. Clarify the asterisk found in table 6.4-4 at MP 144.6.</td><td>Table 6.4-6.</td></tr>
<tr><td>22. Section 6.6.1.4 states “where MVP will dispose of excess rock outside of the approved right-of-way, an approved landfill or alternative upland area will be utilized.” Clarify what is meant by “alternative upland area.”</td><td>Section 6.6.1.4.</td></tr>
</table>

FERC Environmental Information Request for Resource Report 6 Dated August 11, 2015		
	Request	**Location in Resource Report**
23.	Revise section 6.6.1.5 to discuss proposed avoidance, minimization, and mitigation measures for sinkholes identified in table 6.4-2 as “in alignment,” within 200 feet of the centerline, “crosses,” and at MP 194 (open throat sinkhole). This section should also include avoidance, minimization, and mitigation measures for caves identified in table 6.4-3 as “adjacent” and “crosses.”	Section 6.6.1.5, Karst Mitigation Plan – Appendix 6-D.2, Karst Hazards Assessment – Appendix 6-D.2, Table 6.4-4.
24.	Section 6.6.1.1 states “the pre-construction condition of structures and utilizes will be documented.” However, this section later states “pre- and post-blasting structural surveys will be conducted structures and water supply wells within 150-feet of the blasting as necessary.” Clarify the use of the term “as necessary.”	Section 6.6.1.1 and Appendix 6-B.
25.	Section 6.6.1.3 states “pipeline design and construction should incorporate earthquake-induced seismic loading criteria listed in table 6.6-1.” Clarify what is meant by this statement and if Mountain Valley would adhere to the criteria in table 6.6-1.	Sections 6.4.1 and 6.6.1.3. Appendix 6-D.1.
26.	Appendix 6C states that wells within 0.25 miles of the proposed Project are identified, while table 6-C-1 states wells within the vicinity of the proposed Project are identified. Clarify this apparent discrepancy.	Appendix 6-C and Table 6-C-1.

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GEOLOGIC RESOURCES
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LIST OF ACRONYMS AND ABBREVIATIONS

ATWS	additional temporary work space
asml	above mean sea level
CFR	Code of Federal Regulations
FERC	Federal Energy Regulatory Commission
GCSZ	Giles County Seismic Zone
MMI	Modified Mercalli Intensity
MP	milepost
MVP	Mountain Valley Pipeline, LLC
PFZ	Pembroke Fault Zone
PGD	permanent ground deformation
Plan	FERC May 2013 version of the Upland Erosion Control, Revegetation, and Maintenance Plan
Procedures	FERC May 2013 version of the Wetland and Waterbody Construction and Mitigation Procedures
Project	Mountain Valley Pipeline Project
RM	Richter Magnitude
Transco	Transcontinental Gas Pipe Line Company, LLC
USDOT	United States Department of Transportation
USFS	United States Forest Service
USGS	United States Geological Society
Virginia DMME	Virginia Department of Mines, Minerals, and Energy
WVDEP	West Virginia Department of Environmental Protection
WVGES	West Virginia Geologic and Economic Survey

RESOURCE REPORT 6
GEOLOGIC RESOURCES

Introduction

Mountain Valley Pipeline, LLC (MVP), a joint venture between EQT Midstream Partners, LP and affiliates of NextEra Energy, Inc., WGL Holdings, Inc., Vega Energy Partners, Ltd., and RGC Midstream, LLC, is seeking a Certificate of Public Convenience and Necessity from the Federal Energy Regulatory Commission (FERC) pursuant to Section 7(c) of the Natural Gas Act authorizing it to construct and operate the proposed Mountain Valley Pipeline Project (Project) located in 17 counties in West Virginia and Virginia. MVP plans to construct an approximately 301-mile, 42-inch-diameter natural gas pipeline to provide timely, cost-effective access to the growing demand for natural gas for use by local distribution companies, industrial users and power generation facilities in the Mid-Atlantic and southeastern markets, as well as potential markets in the Appalachian region.

The proposed pipeline will extend from the existing Equitrans, L.P. transmission system and other natural gas facilities in Wetzel County, West Virginia to Transcontinental Gas Pipe Line Company, LLC's (Transco) Zone 5 compressor station 165 in Pittsylvania County, Virginia. In addition to the pipeline, the Project will include approximately 171,600 horsepower of compression at three compressor stations along the route, as well as measurement, regulation, and other ancillary facilities required for the safe and reliable operation of the pipeline. The pipeline is designed to transport up to 2.0 million dekatherms per day (MMDth/d) of natural gas. Resource Report 1 provides a complete summary of the Project facilities and a general location map of the Project facilities (Figure 1.2-1).

Environmental Resource Report Organization

Resource Report 6 is prepared and organized according to the FERC *Guidance Manual for Environmental Report Preparation* (August 2002). This report is organized by Project components and describes the existing geologic setting and resources, potential impacts, and mitigation in relation to the Project components. Section 6.1 describes the geologic setting; Section 6.2 describes locations along the pipeline with blasting potential; Section 6.3 describes mineral resources; Section 6.4 discusses geologic hazards; Section 6.5 discusses paleontological resources; Section 6.6 discusses impacts and mitigation; Section 6.7 discusses the impacts of the Project on the Jefferson National Forest; and Section 6.8 presents the list of references that formed the basis for Resource Report 6.

6.1 GEOLOGIC SETTING

The pipeline route begins in Wetzel County, West Virginia; traverses Harrison, Doddridge, Lewis, Braxton, Webster, Nicholas, Greenbrier, Fayette, Summers, and Monroe Counties in West Virginia; and Giles, Craig, Montgomery, Roanoke, Franklin, and Pittsylvania Counties in Virginia. Along the route, topography ranges from 586 feet to 3,741 feet above mean sea level (amsl). Resource Report 1 Appendix 1-B includes a topographic map book of the Project.

6.1.1 Regional Physiographic Setting

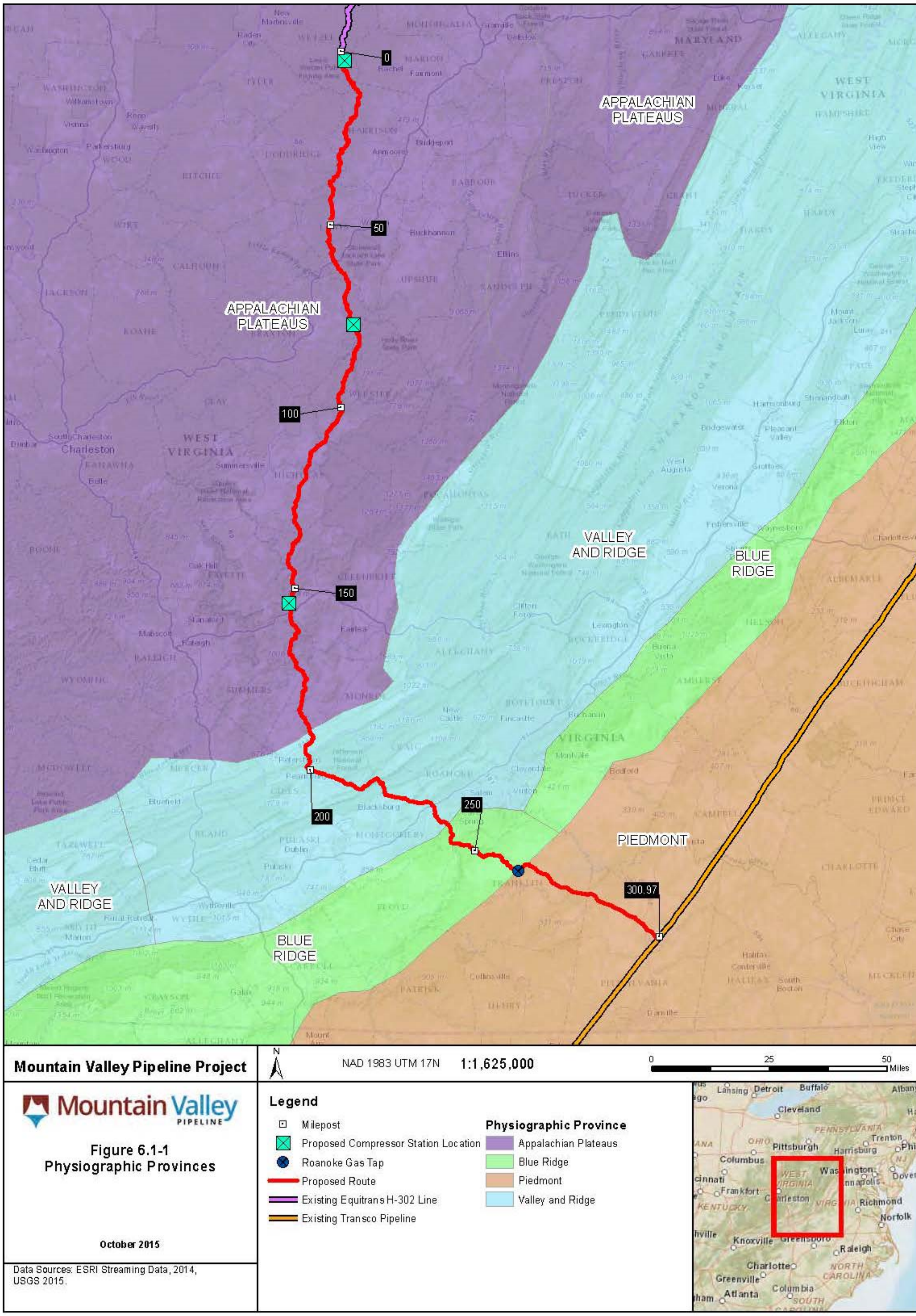
The pipeline route crosses four physiographic provinces including the Appalachian Plateau, Valley and Ridge, Blue Ridge, and Piedmont provinces (Figure 6.1-1). Geologic hazards in these provinces include steep slopes, the potential for landslides, areas of karst terrain (in the Valley and Ridge and Blue Ridge provinces), and a seismic zone centered within the Valley and Ridge province. Except for less than 10 miles of Monroe County, the Project in West Virginia is entirely located within the Appalachian Plateau province. Although some parts of the Plateau exhibit a low relief plateau-like morphology, much of the Appalachian Plateau is strongly dissected by stream erosion and the topography is rugged. Regional scale folds in the Plateau formed in response to shortening on thrust faults that do not reach the present surface and are rooted to the east/southeast in the Valley and Ridge province.

The portion of the Project located in the Appalachian Plateau province is on a dissected plateau that is underlain mainly by horizontally bedded sedimentary rocks. The narrow, level valleys and narrow, sloping ridgetops are separated by long, steep and very steep side slopes. In general, this plateau is underlain mostly by horizontal layers of Pennsylvanian-age sandstone, siltstone, shale, coal, and some limestone (WVGES 2015a; USGS 1997). The rocks exposed in the northern part of the Plateau are younger than those exposed in the southern part. The boundary between the Appalachian Plateau province and the Valley and Ridge province is characterized by a complex and rather abrupt change in the topography, stratigraphy, and structure, called the Allegheny Front. The Allegheny Front is a structural geologic transition from the low-amplitude folds and flat-lying rocks in the Plateau to the tight folds of the Valley and Ridge province.

The Valley and Ridge province is traversed by the Project in southern Monroe County, West Virginia and Giles, Craig, Montgomery, and Roanoke Counties, Virginia. The Valley and Ridge province is a long belt of parallel mountain ridges and valleys trending in a northeast direction. Geologic forces squeezed the originally flat-lying sedimentary layers and folded them into a series of arches (anticlines) and troughs (synclines). Erosion of these folds over geologic time has produced a distinctive repeating landscape of ridges and valleys. Resistant sandstone or conglomerate forms the top of strike ridges and the mid-to-upper area of the dip slopes. In contrast, the lower flanks of the ridges are underlain by shale, and in some areas, by carbonate bedrock (limestone and dolomite). The valleys are underlain by shale and carbonate bedrock. Some limestone areas contain caves, sinkholes, and other karst features (William and Mary 2015a; USGS 1997; WVGES 2015a). Karst areas along the Project are further discussed in Section 6.4.2.

The Blue Ridge province is crossed by the Project route from Roanoke County to within Franklin County, Virginia. The province is characterized by the northeast-trending Blue Ridge Mountains that tower above the eastern border of the Valley and Ridge province (WVGES 2015a). The Blue Ridge province is composed of Mesoproterozoic crystalline rock in its core and Late Neoproterozoic to Early Paleozoic cover rock on its flanks; and has been thrust to the northwest over Paleozoic rocks of the Valley and Ridge province. Rock types in the province include: granitic gneiss, granite, biotite gneiss, and schist.

The Piedmont province is crossed within Franklin and Pittsylvania Counties, Virginia. The Piedmont province consists of low, rounded hills with gentle slopes and a few isolated ridges. The province is characterized by gently rolling topography, deeply weathered bedrock, and a relative paucity of solid outcrop. Rocks are strongly weathered in the Piedmont's humid climate and bedrock is generally buried under a thick (6 to 65 feet) blanket of weathered rock that has formed clay-rich soils. Outcrops are commonly restricted to stream valleys where the soil layer has been removed by erosion. A variety of igneous and metamorphic rocks make up the bedrock of the Piedmont province including schists, gneiss, and granite. Most of these rocks range in age from Proterozoic to Paleozoic and form the internal core of the ancient Appalachian mountain belt. The province is bounded on the east by the Fall Zone, which separates the province from the Coastal Plain.


APPALACHIAN PLATEAUS
APPALACHIAN PLATEAUS
VALLEY AND RIDGE
VALLEY AND RIDGE
BLUE RIDGE
BLUE RIDGE
PIEDMONT
0
50
100
150
200
250
300.97
Charleston
WEST VIRGINIA
VIRGINIA
MARYLAND
Mountain Valley Pipeline Project
NAD 1983 UTM 17N
1:1,625,000
0
25
50 Miles
Mountain Valley PIPELINE
Figure 6.1-1
Physiographic Provinces
October 2015
Data Sources: ESRI Streaming Data, 2014, USGS 2015.
Legend
Milepost
Proposed Compressor Station Location
Roanoke Gas Tap
Proposed Route
Existing Equitrans H-302 Line
Existing Transco Pipeline
Physiographic Province
Appalachian Plateaus
Blue Ridge
Piedmont
Valley and Ridge
Detroit
Buffalo
Cleveland
Pittsburgh
Harrisburg
Columbus
Washington
Richmond
Norfolk
Knoxville
Raleigh
Charlotte
Greenville
Columbia
Atlanta

6.1.2 Topography

Topography along the pipeline route varies from flat to slopes exceeding 45 percent. Elevation ranges are shown by county in Table 6.1-1. Elevation ranges from 586 feet amsl in Pittsylvania County, Virginia to 3,741 feet amsl in Roanoke County, Virginia. For topographic details along the MVP route, see the U.S. Geological Society (USGS) 7.5-minute series topographic quadrangle excerpts located in Resource Report 1.

Surficial geology is generally described in Section 6.1.1 by physiographic province and in Section 6.1.3 in terms of geologic formations. The underlying bedrock and structural geologic features are the primary features, along with water erosion that have influenced topography in the Project area. Although areas of alluvial and other deposits that form soils and river valleys and terraces exist in the Project area, these areas have not been mapped and are discontinuous across small distances.

Table 6.1-1

Minimum and Maximum Elevations by County

State / County	Minimum Elevation (feet amsl)	Maximum Elevation (feet amsl)
West Virginia		
Wetzel	865	1,660
Harrison	997	1,652
Doddridge	943	1,500
Lewis	809	1,632
Braxton	830	1,868
Webster	996	2,769
Nicholas	1,748	3,202
Greenbrier	2,388	3,475
Fayette	2,665	2,802
Summers	1,502	3,733
Monroe	1,567	3,458
Virginia		
Giles	1,645	3,453
Craig	2,150	3,002
Montgomery	1,177	3,002
Roanoke	1,386	3,741
Franklin	792	3,167
Pittsylvania	586	949

6.1.3 Regional Geology

The Project traverses geology of numerous timeframes and rock types as summarized in Table 6.1-2. A complete table, by milepost (MP), of the geology along the MVP alignment, as well as geologic mapping, is available from West Virginia (West Virginia GIS Technical Center 2015a) and Virginia (Virginia DMME 2015a) and is provided in Appendix 6-A. The map set showing the permanent Project facilities and the construction work spaces are provided in Resource Report 1. The locations of the above-ground facilities are also noted in Table 6.1-2. A generalized geologic cross section through the physiographic provinces in West Virginia and Virginia is also provided in Appendix 6-A.

The Project area is underlain by rocks from the Pennsylvanian and Permian periods from approximate MP 0.0 to MP 67. The rocks include the Dunkard and Monongahela groups as mapped in West Virginia and predominantly consist of sandstone. During the Permian Period, the Appalachian mountain building episode occurred with folding and thrust-faulting of previously deposited strata. Several synclines and anticlines formed as a result of the deformation and erosion that took place thereafter filling the subsiding terrestrial basin to the west in the Project area (WVGES 2015a). The Pennsylvanian Conemaugh group sandstone and shale formations and Pottsville group sandstone formations are crossed by the Project from approximate MP 67 to MP 149. During the Pennsylvanian period, conditions were swampy, and thousands of feet of non-marine sandstone, shale, and coal were deposited.

The Mississippian Mauch Chunk, Greenbrier, and Pocono groups and Pennsylvanian Pottsville group are crossed by the Project from approximate MP 149 to MP 193. The Mauch Chunk group formations are dominated by shale and sandstone rock, the Greenbrier group by limestone, and the Pocono group by limestone. A sea covered this area during in the Middle Mississippian Period (about 330 million years ago). During this time, the Greenbrier Group, composed mainly of limestone, was deposited. The sea retreated near the end of the Mississippian Period and the area became swampy (USGS 1997). Limestone from approximate MP 172.0 to MP 173.4, in Summers County, West Virginia, is characterized by karst terrain features as further discussed in Section 6.4.2.

Devonian, Ordovician, and Silurian age formations are crossed by the Project from MP 193 to MP 216. Formations include the Ordovician limestones, shale, and sandstone; Lower Devonian and Silurian undivided sandstone and limestone; Ordovician shale and mudstone; and the Cambrian-Ordovician Knox group dolostone and limestone. Mountain-building episodes formed mountains to the east that were a source of sediments during the Ordovician, Silurian, and early Devonian periods. Highlands to the northeast formed during a subsequent mountain building episode and were the source of clastic sediments in the Middle and Late Devonian Period. Ordovician limestone formations, crossed by the Project from approximate MP 193.9 to MP 217.2, are characterized by karst terrain as further discussed in Section 6.4.2. The Knox group and undivided limestone, crossed by the Project from approximate MP 193.9 to MP 194.8, in Monroe County, West Virginia, in segments from MP 197.6 to MP 215.6, in Giles County, Virginia, and from MP 215.6 to MP 217.2 in Craig County, Virginia, is characterized by karst terrain as further discussed in Section 6.4.2.

Later, a marine sea deposited sediment to form marine limestones, shales, siltstones, and sandstones in the Project area during the Cambrian and Ordovician periods (WVGES 2015a). Devonian shale formations; Cambrian dolostone and limestone formations; Lower Ordovician and Upper Cambrian undivided limestone formations; and Ordovician shale and mudstone formations are crossed by the Project from MP 214 to MP 233. The Cambrian Elbrook dolostone; Pumpkin Valley shale; Rome Formation shale and siltstone; and the Chilhowee group quartzite and conglomerate are traversed from MP 233 to MP 239. Proterozoic and Cambrian granite, gneisses, and schists are traversed from MP 239 to MP 300.1. The Project endpoint from MP 300.1 to MP 300.97 is mapped as Upper Triassic sandstone. The Elbrook dolostone and limestone and Knox group crossed in Montgomery County from approximate MP 220.6 to MP 234.0 is characterized by karst terrain as further discussed in Section 6.4.2.

By late Cambrian time, a shallow sea covered most of the Project area. Marine deposition took place throughout most of this and the succeeding Ordovician Period (USGS 1997).

Table 6.1-2

Geology by Project Milepost

County / Above-ground Facilities	Start MP	End MP	Length (miles)	Geologic Age	Geologic Unit ("Group" in West Virginia)	Geologic Unit ("Formation" in West Virginia)	Rock Type
West Virginia							
Wetzel (Equitrans Mobley Interconnect Meter Station, Bradshaw Compressor Station), Harrison (Sherwood Interconnect Meter Station), Doddridge, Lewis	0.0	42.7	42.7	Pennsylvanian and Permian	Dunkard	Greene, Washington, Waynesburg	sandstone, potential coal seams
Lewis, Braxton	42.7	71.5	28.8		Monongahela	Uniontown, Pittsburgh	
				Pennsylvanian	Conemaugh a/	Casselman, Glenshaw	shale, potential coal seams
Braxton	71.5	80.3	8.8	Pennsylvanian	Conemaugh b/	Allegeny, Casselman, Glenshaw	sandstone, shale, potential coal seams
					Monongahela a/	Uniontown, Pittsburgh	sandstone, potential coal seams
					Pottsville (MP 75) c/	Kanawha	
Webster	80.3	109.5	29.2		Conemaugh	Allegheny, Casselman, Glenshaw	sandstone, shale, potential coal seams
					Pottsville	Kanawha, New River	sandstone, potential coal seams
Nicholas	109.5	109.8	0.3				
Webster	109.8	110.6	0.8				
Nicholas	110.6	135.0	24.4				
Greenbrier	135.0	153.8	18.8			Kanawha, New River, Pocohontas	
				Mississippian	Mauch Chunk (MP 143.7)	Bluestone, Princeton	shale/sandstone, potential coal seams
Fayette	153.8	154.3	0.5				
Greenbrier	154.3	156.7	2.4				
Summers	156.7	173.4	16.7	Pennsylvanian	Pottsville	Pocahontas	sandstone, potential coal seams
				Mississippian	Mauch Chunk	Bluestone, Princeton, Hinton	shale/ sandstone, shale
Monroe	173.4	191.4	18.0			Hinton, Bluefield	shale
					Greenbrier		limestone
					Pocono	Maccrady	shale
	191.4	193.9	2.5	Devonian	Chemung		
						Brallier	
	193.9	195.5	1.6	Ordovician	Beekmantown		limestone
					St. Paul		
					Trenton, Black River		
					Martinsburg		shale
					Juniata, Oswego		sandstone

Table 6.1-2

Geology by Project Milepost

County / Above-ground Facilities	Start MP	End MP	Length (miles)	Geologic Age	Geologic Unit ("Group" in West Virginia)	Geologic Unit ("Formation" in West Virginia)	Rock Type
Virginia							
Giles	195.5	197.4	1.9	Lower Devonian and Silurian	Lower Devonian and Silurian Formations - undivided		sandstone, limestone
	197.4	201.4	4.0	Cambrian - Ordovician	Knox Group		shale, mudstone
	201.4	215.6	14.2	Ordovician	Mocassin Formation, Bays Formation, Unit C, Unit B, Unit A		dolostone (dolomite), limestone
				Ordovician	Juniata Formation, Reedsville Shale, Trenton Limestone, Eggleston Formation		shale, mudstone
				Cambrian - Ordovician	Knox Group		dolostone (dolomite), limestone
Craig	215.6	217.2	1.6	Ordovician	Juniata Formation, Reedsville Shale, Trenton Limestone, Eggleston Formation		shale, mudstone
Montgomery	217.2	217.7	0.5	Lower Devonian and Silurian	Lower Devonian and Silurian Formations - undivided		sandstone, limestone
	217.7	219.4	1.7	Devonian	Millboro Shale and Needmore Formation		black shale, shale
					Brallier Formation		shale, siltstone
					Chemung Formation		shale, sandstone
	219.4	220.4	1.0	Mississippian	Price Formation		sandstone, shale
	220.4	224.9	4.5	Cambrian, Upper Cambrian - Lower Ordovician	Elbrook Formation		dolostone (dolomite), limestone
					Lower Ordovician and Upper Cambrian Formations - undivided		limestone, dolostone (dolomite)
	224.9	226.5	1.6	Ordovician	Mocassin Formation, Bays Formation, Unit C, Unit B, Unit A		shale, mudstone
					Juniata Formation, Reedsville Shale, Trenton Limestone, Eggleston Formation		
	226.5	227.3	0.8	Lower Devonian and Silurian	Lower Devonian and Silurian Formations - undivided		sandstone, limestone
	227.3	232.5	5.2	Devonian	Millboro Shale and Needmore Formation		black shale, shale
					Brallier Formation		shale, siltstone
					Chemung Formation		shale, sandstone
	232.5	236.1	3.6	Cambrian	Elbrook Formation		dolostone (dolomite), limestone
					Pumpkin Valley Shale and Rome Formation; Chilhowee Group		shale, siltstone; quartzite, conglomerate
Roanoke	236.1	239.2	3.1		Chilhowee Group		quartzite, conglomerate
	239.2	244.4	5.2	Proterozoic Y	layered pyroxene granulite		granulite
					charnockite		granitic gneiss
					porphyritic leucocharnockite		granite

Table 6.1-2

Geology by Project Milepost

County / Above-ground Facilities	Start MP	End MP	Length (miles)	Geologic Age	Geologic Unit ("Group" in West Virginia)	Geologic Unit ("Formation" in West Virginia)	Rock Type
Franklin	244.4	251.5	7.1				
					layered biotite granulite and gneiss		gneiss, granulite
					porphyroblastic biotite-plagioclase augen gneiss		augen gneiss
					layered quartzofeldspathic augen gneiss and flaser gneiss		felsic gneiss, flaser gneiss
	251.5	253.5	2.0	Proterozoic Z	Ashe Formation - biotite gneiss		biotite gneiss
	253.5	256.6	3.1	Proterozoic Y	layered quartzofeldspathic augen gneiss and flaser gneiss		felsic gneiss, flaser gneiss
	256.6	279.2	22.6	Proterozoic Z, Proterozoic Z – Cambrian	Ashe Formation - biotite gneiss		biotite gneiss
					Alligator Back Formation - feldspathic metagraywacke		meta-argillite, schist
					Alligator Back Formation - actinolite schist		schist
	279.2	281.1	1.9	Proterozoic Z – Cambrian, Cambrian, Cambrian, Proterozoic Z	Alligator Back Formation - actinolite schist		schist
Pittsylvania / Transco Interconnect Meter Station	281.1	300.0	18.9				
					Alligator Back Formation - feldspathic metagraywacke		meta-argillite, schist
					Candler Formation - phyllite and schist		phyllite, schist
					Bassett Formation - amphibolite		amphibolite, gneiss
					Bassett Formation - biotite gneiss		biotite gneiss, gneiss
					Fork Mountain Formation		mica schist, gneiss
	300.0	300.1	0.1	Cambrian, Proterozoic Z - Cambrian	Leatherwood Granite		granite
					Fork Mountain Formation		mica schist, gneiss
	300.1	301.0	0.9	Upper Triassic	Newark Supergroup - sandstone, siltstone and shale, interbedded		sandstone, siltstone

a/ Occasional occurrences only
b/ Dominant occurrence in County
c/ Beginning occurrence at specified milepost

The mountain building period near the end of Ordovician time formed a high mountainous area east of the Project area. These highlands formed the main source of sediments for the succeeding Silurian Period and part of the Devonian Period. Both clastics and carbonates were deposited in a mixed marine and nonmarine environment.

At the close of Mississippian time, about 310 million years ago, the Project area was essentially a land area, subject to erosion. Early in the succeeding Pennsylvanian Period, the area was eroded and subsided to near sea level, and for more than 50 million years continued to subside at about the same rate that deposition was taking place. Swamp conditions prevailed, resulting in the deposition of thousands of feet of nonmarine sandstone and shale and the many important coal seams that we know today.

Sometime during the Permian Period, roughly 270 to 225 million years ago, the Appalachian Orogeny began. Compressive tectonic forces folded, uplifted and thrust faulted bedrock to the west-northwest, underlying what is now identified as the Project area of south-southeast West Virginia and west-southwest Virginia. Sediment deposition and basin filling ceased in what is now identified as the Project area, and erosion began taking place to change the landform to what is observed today. This orogeny played a major part in the formation of the Appalachian Mountains as we know them today.

6.2 SHALLOW BEDROCK

Areas where shallow bedrock may be encountered along the pipeline route, based on attribute data provided in the state-level soil geographic databases (USDA 2015) for West Virginia and Virginia, are provided in a table and the map set included in Appendix 6-B. The table listing evaluates shallow bedrock at every milepost tenth to depths of 7 feet or less, and the map set shows shallow bedrock areas of 5 feet or less. This information, along with geology information provided in Appendix 6-A, provides preliminary information to assist in the identification of potential areas crossed by the pipeline where bedrock could be encountered during excavation of the pipeline trench and where blasting or other methods of mechanical rock removal might be required. Based on this information, approximately 112 miles, or approximately 37 percent, of the pipeline route are located in areas of bedrock with depths of less than 7 feet, and approximately 28 miles, or approximately 9 percent, of the pipeline route, are located within areas of bedrock with depths of less than 5 feet. Mitigation proposed for blasting is discussed in Section 6.6.1.1, and a Draft Blasting Plan is provided at the end of Appendix 6-B.

6.3 MINERAL RESOURCES

Exploitable and potentially exploitable mineral resources occur in the area affected by the Project, including economically significant coal, shale, and oil and gas resources. Mineral resources within 0.25 mile of the Project were identified from a review of topographic maps, USGS and state database searches (USGS 2015a, 2015b; Virginia DMME 2015b; West Virginia GIS Technical Center 2015b), and field studies (Draper Aden Associates 2015a – Appendix 6-D.2). Table 6.3-1 lists the mineral resources identified. Inactive iron pits were identified at MP 211 in Giles County, Virginia and at MP 274.4 in Franklin County, Virginia, an inactive nickel mine was identified at MP 251.9 in Franklin County, Virginia, and an active clay mine was identified at MP 234.2 in Montgomery County, Virginia. Otherwise, mineral resources identified in the Project area include oil and gas, coal, sand, gravel, and crushed rock. As depicted in the table, there are no aboveground facilities located in the vicinity of mining areas excepting a few block valve locations.

Table 6.3-1

Mineral Resources Within 0.25 mile of the MVP Project Work Spaces

State / County	Milepost / Aboveground Facility	Mineral Resource / Name of Mine	Location	Status	Data Source
West Virginia					
Harrison	16.0	Sand and gravel / Quarry	0.25 mile west	unknown	f/
	19.1 – 25.4	Coal / American Mountaineer Mine	Permit area crossed	unknown	d/ (underground mining limits)
	28.1 – 28.7	Coal / Pittsburgh	Permit area crossed	unknown	d/ (underground mining limits)
Lewis	46	Coal / Strip mine area	0.25 mile east	unknown	f/
	47.4 – 47.8	Coal / Strip mine area	0.25 mile east	unknown	f/
	48.1 – 48.2	Coal / Strip mine area	Within 0.1 mile	unknown	f/
	48.8	Coal / Strip mine area	0.25 mile east	unknown	f/
	50.8	Coal / Mid-Southern Energy Corp.	1,069 feet west	revoked	d/
Webster	92.8	Coal / Juliana Mining Company Inc. (Lower Laurel Surface Mine)	381 feet east	renewed	d/
	93.9 – 95.1	Coal / Strip mine area	0.35 mile east	unknown	f/
	101.8 – 103.3 / block valve	Coal / 82 East Surface Mine	Permit area crossed	not started, permit expires 2017	d/
	103.0	Coal surface mine / ICG Eastern, LLC (82 East Surface Mine)	1,000 – 1,170 feet east	Inactive and not started	d/
	103.2 – 103.3	Coal surface mine / ICG Eastern, LLC	Permit area crossed	Inactive and not started	d/
	103.3	Coal / Abandoned mine	960 feet west	abandoned	d/
	107.2	Coal / Tammie Lynn Coal Co Inc.	1,050 feet west	Completely released	d/
Nicholas	109.7 – 109.9	Surface coal mine / K & B Coal Co	Permit area crossed	Closed/revoked	d/
	110.9	Surface coal mine / K & B Coal Co	870 feet west	revoked	d/
	111.0 – 111.1 / block valve	Surface coal mine / K & B Coal Co	Permit area crossed	revoked	d/
	117.8 – 117.9	Coal / Donegan 10 Plant, Falcon Land Co Inc.	Permit area crossed	Closed, Phase 2 release, revegetated	d/
	117.9 – 118.0	Coal / Strip mine area	Area is crossed	unknown	f/
	118.2	Coal / Mining area	0.2 mile east	unknown	f/

Table 6.3-1

Mineral Resources Within 0.25 mile of the MVP Project Work Spaces

State / County	Milepost / Aboveground Facility	Mineral Resource / Name of Mine	Location	Status	Data Source
	118.4 – 118.6	Coal / Mining area	Area is crossed at Gauley River crossing	unknown	f/
	119.9 – 120.1	Coal / Strip mine area	0.1 mile east	unknown	f/
	119.9 / block valve	Coal / Green Valley Coal Company	560 feet east	renewed	d/
	120.0	Coal / Green Valley Coal Company	393 feet east	Completely released	d/
	121.9 – 126.0	Coal / Quinwood No. 7 Mine	Permit area crossed	unknown	d/ (underground mining limits)
	126.2 – 126.3	Coal / Green Valley Coal Company, Potato Hole Knob Deep Mine	Permit area crossed	new	d/
	126.7 – 131.2	Coal / unknown	Permit area crossed	unknown	d/ (underground mining limits)
	132.0	Coal / Strip mine area	0.2 mile east	unknown	f/
	132.1	Coal / Strip mine area	crossed	unknown	f/
	133.1	Coal / Strip mine area	0.25 mile east	unknown	f/
	133.6	Coal / unknown	802 feet west	unknown	d/ (underground mining limits)
	133.9 – 134.3	Coal / Strip mine area	0.1 mile west	unknown	f/
	134.4 – 135.7	Coal / Strip mine area	0.2 mile east	unknown	f/
Greenbrier	134.4 – 136.5	Underground coal mine / Green Valley Coal Company, Alex Energy Inc.	Permit area crossed	Active, reclaimed, numerous outfalls	d/
	138.3 – 138.4	Underground coal mine / Green Valley Coal Company, Alex Energy Inc.	Permit area crossed	renewed	d/
	138.3 – 138.4 / block valve	Sewell Valley #1 Mine/ Surface Coal Mine, Green Valley Coal Company, Warrior Energy Resources LLC	Permit area crossed	Active, reclamation only, numerous outfalls	d/
	138.4 – 139.4 / block valve	Coal / Strip mine area	0.25 mile on both sides	unknown	f/
	139.5	Coal / Strip mine area	Crossed	unknown	f/
	142.1	Coal / Strip mine area	0.25 mile east	unknown	f/

Table 6.3-1

Mineral Resources Within 0.25 mile of the MVP Project Work Spaces

State / County	Milepost / Aboveground Facility	Mineral Resource / Name of Mine	Location	Status	Data Source
	144.2	Underground Coal mine / Lynn Dale Coal Co	433 feet west	revoked	d/
	145.7 – 146	underground coal mine (room and pillar) / Little Sewell No. 1 Deep Mine, Midland Trail Resources LLC	Permit area crossed, also 364 feet east	Inactive, one historic outfall	d/
	145.8 – 146.3	Coal / Strip mine area	0.2 mile west	unknown	f/
	146	Surface coal / Double N Mining Co, Inc.	79 feet west, 364 feet east	revoked	d/
	146.0 – 146.7	Surface coal / Double N Mining Co., Inc.	Permit area crossed, and 1,200 feet east	Closed, no coal removed	d/
	147 – 147.1	Coal / Strip mine area	crossed	unknown	f/
	147.1 – 148.5	Coal / Strip mine area	0.1 mile east	unknown	f/
	148.5 – 148.6	Coal / Strip mine area	crossed	unknown	f/
Virginia					
Giles	199.6	Unknown / Quarry	0.35 mile east	unknown	f/
	209.9	Limestone / Quarry	600 feet northeast	inactive	c/, e/
	211 / block valve	Iron / Price Prospect	<0.1 mile west (270 feet)	inactive	a/
Montgomery	234.2	Clay / Number 2 Pit Old Virginia Brick Company	<0.1 mile west (600 feet)	active	a/, f/
	234.4 / block valve	Unknown / Quarry	<0.1 mile west	unknown	f/
Franklin	251.9	Nickel / Lick Fork Mine (Mackusick Mine/Flat Run Mine; John Light's Mine)	<0.1 mile west (4 feet)	inactive	a/
	274.4	Iron pit / unknown	<0.1	inactive	c/
Pittsylvania	278.9	Unknown / Underground mine	<0.1	inactive	c/
	292.3	Sand and gravel pit (granite) / unknown	<0.1	inactive	c/

Sources: a/ USGS 2015a; b/ USGS 2015b; c/ Virginia DMME 2015b; d/ West Virginia GIS Technical Center 2015b; e/ Draper Aden Associates 2015a; f/ topographic map review

6.3.1 Sand, Gravel, Clay, and Crushed Rock

A quarry that is likely associated with sand and gravel or crushed stone production was identified in West Virginia near MP 16 in Harrison County. In Virginia, a quarry was identified at MP 199.6, and a limestone quarry was identified near MP 209.9 in Giles County. All of these quarries are indicated to be historic and inactive. Another inactive granite rock sand and gravel pit was identified near MP 292.3 in Pittsylvania County.

6.3.2 Oil and Gas

Oil and gas well information was obtained from the West Virginia Geologic and Economic Survey (WVGES 2015b), the West Virginia Department of Environmental Protection (WVDEP 2015), and the Virginia Department of Mines, Minerals, and Energy (Virginia DMME) oil and gas well location database (Virginia DMME 2015c). A full listing of oil and gas wells and map set showing these well locations within 0.25 of the pipeline alignment are included in Appendix 6-C.1. Table 6.3-2 provides a summary of this information. There are 347 oil and gas wells in West Virginia within 0.25 miles of the Project route according to the WVGES data source. During on-site review of the pipeline route where MVP obtained survey access, the route was adjusted as needed to avoid known oil and gas wells. See Resource Report 10 Table 10.6-20. No oil and gas wells were identified in the state of Virginia within this same search area.

Table 6.3-2

Oil and Gas Wells Within 0.25 mile of the MVP Pipeline Construction Workspace

State / County	# of Wells (WVGES)	Well Types (WVGES)	# of Wells (WVDEP)
West Virginia			
Wetzel	33	Gas, oil and gas, other (primarily oil wells)	36
Harrison	101	Gas, oil, oil and gas (primarily gas)	106
Doddridge	32	Primarily gas with some oil and gas	31
Lewis	145	Primarily gas with some oil, oil and gas, and a few injection wells	171
Braxton	24	All gas with a few dry	26
Webster	1	All dry	3
Nicholas	0	None	6
Greenbrier	1	All dry	1
Virginia			
No oil and gas wells identified within 0.25 mile of route in Virginia.			
Sources: WVGES 2015b; WVDEP 2015; Virginia DMME 2015			

The northern portion of the Project is within the Marcellus Shale formation gas production area, and additional exploration and production wells are likely to be installed or planned in this portion of the Project area. The potential impacts of the Project on the volume of gas available for exploration and production are minimal. The excavation area for the pipeline is limited to the upper strata, above the gas production zones. With modern drilling technology, including horizontal production wells, well pads can be situated outside the pipeline right-of-way and still successfully exploit any gas present at depths beneath the pipeline. As the reservoir is competent bedrock, removal of gas from the reservoir is not expected to affect the integrity of the pipeline. Construction and operation of the pipeline will not have any impact on mineral rights aside from the inability to mine materials within the pipeline right-of-way.

MVP will work with landowners and operators of active oil and gas wells to identify and verify the location of facilities and to minimize adverse impacts. Wells currently in place were considered in the pipeline routing design and avoided. Land personnel will conduct title research and communicate with landowners, which should avoid conflicts between planned wells and pipeline construction. MVP will coordinate with landowners and negotiate compensation where applicable. MVP will work with landowners and operators to ensure that access is maintained as needed to existing operations (e.g., to oil/gas wells). The Project would not interfere with future development of oil and gas resources because the linear Project footprint can be avoided using existing oil and gas extraction techniques (horizontal drilling) that can access these resources under the Pipeline alignment. In addition, it is common practice and a possible option to relocate a pipeline following negotiation and mutual agreement with the landowner and mineral owner to aid in mineral resource recovery and development.

6.3.3 Coal

Significant underground mining has taken place in 69 of 73 of West Virginia's mineable coal beds. The Washington, Sewickley, Redstone, Uniontown and Pittsburgh seams of coal are present in geologic formations crossed by the Project from Wetzel to Lewis Counties in West Virginia. The geologic formations that include the Elk Lick, Bakerstown, Freeport, and Pottsville group coal seams are crossed in Braxton, Webster, Nicholas, and Greenbrier Counties, West Virginia. The Pocahontas Nos. 1-7 coal seams are crossed in a few areas of Summers County, West Virginia. Based on the review of coal mine information included in Table 6.3-1, permitted coal mining was identified in Harrison, Lewis, Webster, Nicholas, and Greenbrier Counties in West Virginia. The production potential, based on economic considerations and the thickness of the coal deposit, of these seams is apparently not significant through remaining portions of the Project area. Permitted areas that have not yet been mined are crossed at MP 103.0, and from MP 103.2 to MP 103.3 in Webster County, West Virginia. The permit expires in 2017. Permitted mines that have been closed or their permits revoked are crossed from MP 109.7 to MP 109.9 and from MP 111.0 to MP 111.1 in Nicholas County. Permitted mines that have been reclaimed or that are in the reclamation process are crossed from MP 117.8 to MP 117.9 in Nicholas County, from MP 134.4 to MP 136.5 and from MP 138.3 to MP 138.4 in Greenbrier County. Abandoned mine features compiled by the Office of Abandoned Mine Lands and Reclamation (AMLR) of the WVDEP (West Virginia GIS Technical Center 2015b) were used to identify an abandoned mine west of MP 103.3 in Webster County. Historic strip mining was identified from topographic maps in numerous areas of the Project in Lewis Webster, Nicholas, and Greenbrier Counties in West Virginia. No coal mines were identified in the state of Virginia (VDMME 2015) within this same search area.

MVP has made an effort to avoid as many active mines as possible. However, the pipeline alignment crosses four underground mining boundaries in West Virginia:

- American Mountaineer Mine: Located in Harrison, West Virginia between MP 19.1 through MP 25.4;
- Pittsburgh Mine: Located in Harrison County, West Virginia between MP 28.1 through MP 28.7;
- Quinwood No. 7 Mine: located in Nicholas County, West Virginia between MP 121.9 through MP 126.0; and

- Mine (unknown name): located in Nicholas County, West Virginia between MP 126.7 through MP 131.2.

Mine operators will be contacted to coordinate the design of any necessary mitigation measures to be used during construction and operation of the Pipeline. In areas of historic strip mining, MVP will ensure handling of soils and excavated materials to protect water resources (see Resource Report 2) and adjacent soils. Final Project design cannot be achieved until MVP is able to survey the entire pipeline route. Once surveys are complete, MVP will finalize the pipeline route and provide any changes to the FERC.

6.3.4 Uranium

In West Virginia, uranium can be found in coal seams, however in these areas, uranium concentrations are typically low (<2 parts per million) and similar to mean background concentration world-wide (Draper Aden Associates 2015b – Appendix 6-B). Therefore, uranium is not anticipated to be encountered at above normal background concentrations in West Virginia.

In Virginia, uranium-enriched bedrock can be found in the Blue Ridge and Piedmont provinces. These formations typically include silica-rich meta-igneous rocks such as granite, alkali-rich plutonic rocks, and pegmatites. In the Valley and Ridge province, carbonaceous black shales often contain relatively elevated uranium content. Surface weathering of these rocks may provide sources for uranium to impact nearby soil and water resources. The only uranium deposits identified in the vicinity of the Project are located at Coles Hill, in Pittsylvania County, Virginia (Draper Aden Associates 2015b). These deposits are notable for relative enrichment above background (Virginia DMME 2015d). Two separate uranium mineral deposits have been delineated at the Coles Hill site: the South Coles Hill Deposit and North Coles Hill Deposit. The Coles Hill Uranium property was identified as a potential concern during scoping and contains two large uranium deposits. The north deposit is about 4 miles northeast and the south deposit is about 3.8 miles northeast, respectively, of the southern endpoint (MP 300.9) of the pipeline alignment. Based on the significant distance from the Project, the uranium deposits are not anticipated to cause concerns. In addition, the pipeline does not cross any known areas of uranium-enriched bedrock; therefore, it is not expected that uranium will be encountered or exposed during Project construction.

6.3.5 Impacts to Geologic Resources and Mitigation

Because of the narrow construction footprint of the pipeline, impacts to the recovery of aggregates and coal would be minimal. Because all Project facilities are surficial, the impacts on oil and gas resource recovery also will be minimal. Pipeline construction activities will be coordinated with oil and gas producers to avoid any adverse impacts on production and transportation of oil and gas.

6.4 GEOLOGIC HAZARDS

6.4.1 Seismic Hazards

6.4.1.1 Earthquakes

Seismic hazards are characterized in terms of the severity of ground shaking, typically expressed as peak ground acceleration, and permanent ground displacement resulting from surface faulting or triggered by ground shaking. Earthquake magnitude is measured using the Richter Magnitude (RM) scale. RM is a logarithmic measure of ground shaking based on data collected by seismometers. The RM scale is based on ground motion and does not take into account distance from source and structural stability of the subsurface. RM is, therefore, not a representative measure of the intensity of the seismic event at a given location. The intensity of a seismic event is measured using the Modified Mercalli Intensity (MMI) scale. MMI provides a measure of the intensity of ground movement felt in a given area based on damage assessments and eyewitness reports. MMI ranges from an earthquake intensity value of I, in which the earthquake is not felt, to an intensity value of XII, in which damage is nearly total, large rock masses are displaced, and objects thrown about.

Earthquakes have occurred in the area of the Project alignment, largely due to trailing edge tectonics and residual stress release from past orogenic (i.e., mountain building) events. There have been five seismic events with magnitudes of 4 or greater having epicenters within a 100-mile radius of the Project route that have been recorded since 1976 (USGS 2015c), as shown in Table 6.4-1. The largest earthquake recorded for Virginia is a magnitude 5.8 earthquake that occurred on August 23, 2011 near Mineral, Virginia (CVSZ). This epicenter is greater than 100 miles from the Project area.

Table 6.4-1

Earthquakes Epicenters (magnitude 4 and greater) within 100 miles of the MVP Pipeline Since 1976

State / Lat/Long (UTC)	Date and Time	Magnitude (RM)	Depth
West Virginia			
37.362°N 81.624°W	1976-06-19 05:54:13	4.7	5.0 km
Virginia			
37.238°N 81.987°W	1988-04-14 23:37:31	4.1	0.0 km
37.200°N 81.920°W	2006-11-02 17:53:02	4.3	1.0 km
37.157°N 81.975°W	2006-11-23 10:42:57	4.3	0.0 km
37.136°N 82.068°W	1989-04-10 18:12:16	4.3	0.0 km

Source: USGS 2015c
UTC = lat/long as based on universal time zone coordinated
km = kilometer

Previous to 1976, historical information was identified from USGS earthquake history information for West Virginia and Virginia (USGS 2015d). The largest earthquake recorded for West Virginia is an apparent (i.e., preceded modern seismic networks) magnitude 5.9 earthquake that occurred in 1897 in Giles County, Virginia. A strong earthquake (MM-V to MM-VI) in the Charles Town/Martinsburg, West Virginia area occurred on April 2, 1909. The total felt area included places in West Virginia, Virginia, Maryland, and Pennsylvania. The epicenter was near the convergence area of the four States' boundaries. An April 23, 1959, earthquake (MM-I to MM-IV) located along the Virginia - West Virginia border region caused minor damage in Giles County, Virginia. Probably the strongest, most widely felt earthquake in West Virginia's history occurred on November 19, 1969. However, only minor damage in areas of West Virginia and Virginia was sustained from the magnitude 4.3 shock. The earthquake was felt in areas of West Virginia, Virginia, Georgia, Kentucky, Maryland, North Carolina, Ohio, South Carolina, and Tennessee. Giles County, Virginia was the center of a strong earthquake (MM-VIII) recorded on May 31, 1897 and a moderate disturbance on May 30, 1974 (MM-V).

The USGS monitors seismic activities outside of the town of Blacksburg, Virginia. Empirical data has been recorded during the entrance of the Virginia Tech Hokies during some home football games on the Virginia Tech campus that have measured seismic events upwards of 4.0 on the Richter scale. No discoverable utility pipeline damage has been identified in the literature search during these common event periods. Local utility pipe design standards are far less stringent than PHMSA design criteria for natural gas transmission pipelines.

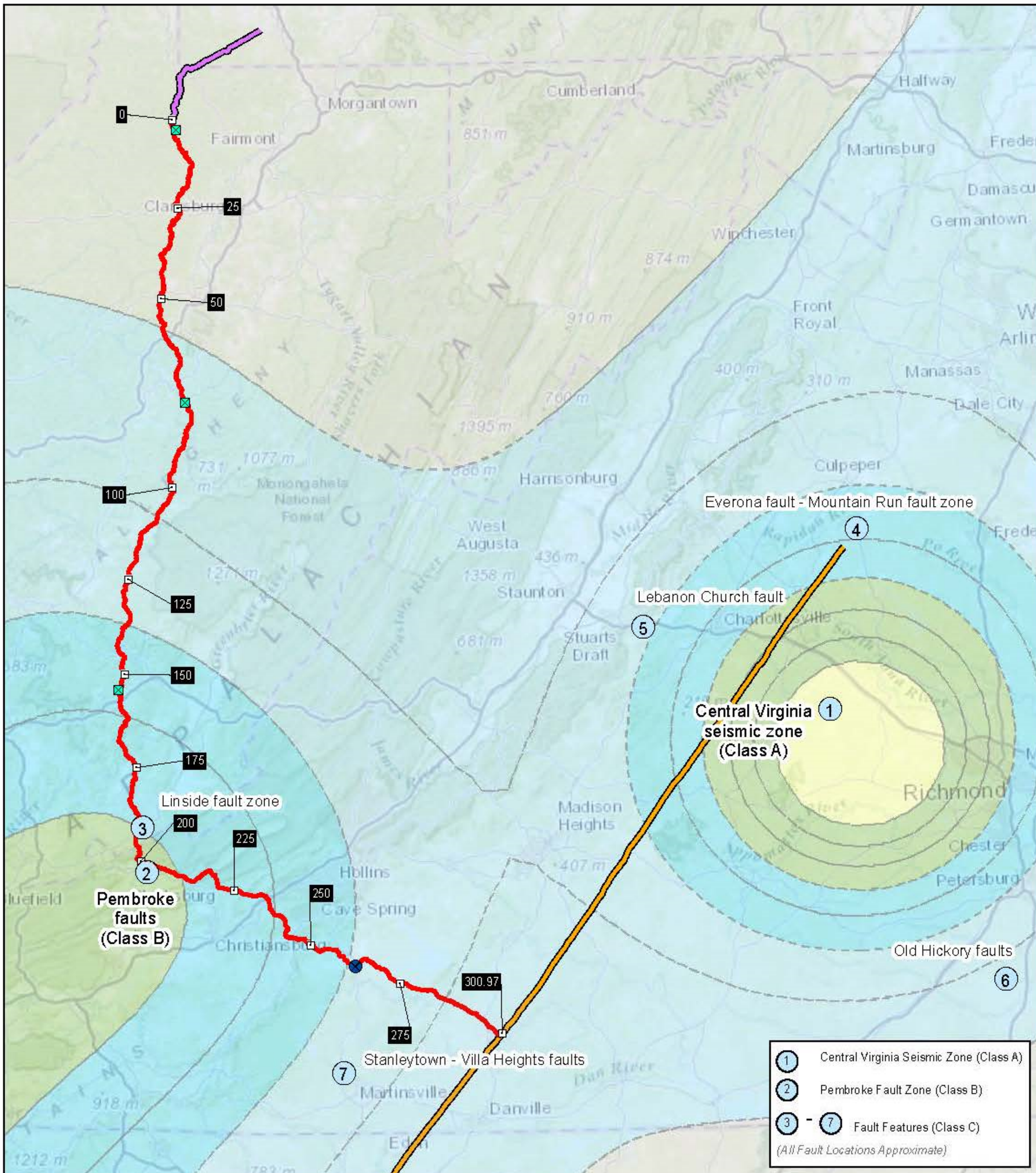
6.4.1.2 Seismicity

The level of ground shaking that results from an earthquake is primarily a function of earthquake magnitude and distance from the center of earthquake energy release. A probabilistic estimate of ground shaking hazards considers the statistical variability in earthquake magnitude and distance from the site of interest. Potential seismic hazards related to ground shaking along the MVP route are based upon a 2 percent annual probability of exceedance over a 50-year period. The annual probability is the same approximate frequency of exceedance specified in U.S. building codes for the design of new buildings. The annual probability of exceedance is a very conservative hazard definition for the Project considering the much greater direct safety and damage consequences associated with building collapse compared to a gas transmission pipeline failure. For this reason, it is judged reasonable and appropriate to screen from further consideration those seismic hazards with an annual likelihood of occurrence less than 2 percent over a 50 year period (D.G. Honegger 2015a – Appendix 6-D.1). Figure 6.4-1 depicts the peak ground acceleration with a 2 percent probability of exceedance over a 50-year period. Peak ground acceleration estimates for the MVP alignment range from approximately 0.05 g to 0.16 g (i.e., expressed as a fraction of gravitational acceleration, g), with a 2 percent probability of occurring in 50 years (i.e., mean return period of approximately 2,500 years) (Draper Aden Associates 2015c – Appendix 6-D.1).

The MVP alignment crosses terrain in southern West Virginia and southwestern Virginia where estimates of probabilistic ground motion exceed 10 percent of gravity (>0.1 g). This area generally corresponds to the Giles County Seismic Zone (GCSZ), described in more detail below. Modern earthquake hazard analysis no longer refers to GCSZ, and instead identifies the Pembroke Fault Zone (PFZ) as the focal point of this seismic area. The PFZ is a geographically defined area in Giles County, Virginia associated with a relatively high density of earthquake epicenters. The PFZ is primarily known for being the epicenter of a strong May 31, 1897 earthquake that was subsequently characterized under modern standards of MM-VIII, magnitude 5.8.

Another recognized seismic zone in the region of the MVP alignment is the Central Virginia Seismic Zone (see Figure 6.4-1), located more than 100 miles east of the MVP alignment, and due to this distance it is not considered a factor in relation to the Project.

Federal regulations for natural gas pipelines do not contain explicit requirements for seismic design. However, 49 Code of Federal Regulations (CFR) Subpart C Section 192.103 requires natural gas transmission pipelines to withstand anticipated external pressures and loads after installation. Accepted and proven practices for the seismic design of buried pipeline systems are embodied in industry guidance documents that have been developed based upon project-specific design requirements developed for major pipeline projects. These guidelines specifically related to pipelines were updated by the Pipeline Research Council International (PRCI) in 2004 (D.G. Honegger 2015a).



Mountain Valley Pipeline Project

NAD 1983 UTM 17N   1:1,778,000   0 5 10 20 30 40 Miles

Mountain Valley PIPELINE

Figure 6.4-1
Seismic Hazards

October 2015

Data Sources: ESRI Streaming Data, 2014, USGS, Draper Aden Associates 2015.

Legend
- Milepost
- Proposed Compressor Station Location
- Roanoke Gas Tap
- Proposed Route
- Existing Equitrans H-302 Line
- Existing Transco Pipeline

Seismic Hazards; Peak Acceleration*
- 0.04
- 0.06
- 0.10
- 0.14
- 0.20

*Expressed as a fraction of standard gravity (g) with 2% probability of exceedance in 50 years. V_{S30} = 760 m/s

6.4.1.3 Active Faults

Surface fault rupture is an important consideration for buried pipelines because pipelines crossing fault zones must deform longitudinally and in flexure to accommodate ground displacement. If a pipeline crosses an active fault, it is necessary to delineate its location, orientation, width of fault rupture zone, and the amount and direction of potential fault displacement. In current practice, special pipeline design considerations are warranted when crossing faults that are classified as active (D.G. Honegger 2015a).

The MVP alignment was evaluated for the presence of potential active faults (Quaternary age faulting) and the potential for ground movement and failure (Draper Aden Associates 2015c). Activation of faults (i.e., fractures in rock where there has been displacement) can cause seismic events. Faults that demonstrate evidence of movement within the Quaternary age (1.8 million years ago to present), and particularly faults showing movement in the Holocene Epoch (11,500 years to present), are generally considered to present a potential risk for seismic hazards to structures including natural gas pipelines.

The USGS (2006) compiled geological information on Quaternary faults throughout the United States. The faults have been categorized into four classes (Class A, B, C, and D) based on what is known about the feature's Quaternary activity. The MVP alignment does not traverse any Class A feature (where there is convincing evidence of Quaternary activity). The MVP alignment is located within 5 miles of one Class B feature (requires further study in order to confidently define their potential as possible sources of earthquake-induced ground motion). The remaining features considered by USGS either lack convincing geologic evidence of Quaternary tectonic faulting or have been studied carefully enough to determine that they do not pose a significant seismic hazard (Classes C and D).

The Linside fault zone is located along northwest edge of the PFZ and is crossed by the Project alignment in southern Monroe County, West Virginia. However, no recent/Quaternary movement of the fault zone has been demonstrated and the fault zone was dismissed as a potential concern in regard to the Project. The PFZ was identified by the USGS (2006) and is considered a Class B fault zone because the origin is not clearly identified as crustal faulting or subsurface karst collapse. Thrust faults associated with the Allegheny structural front, PFZ, and Valley and Ridge province include the St. Clair fault, the Narrows fault, the Pulaski fault, and the Blue Ridge fault. These faults generally fall within the area of the PFZ which has recently been studied by the USGS (2014a). The MVP alignment traverses the Valley and Ridge province (encompassing the ancient inactive thrust faults) from approximately MP 195 to MP 238 in Monroe County, West Virginia, and Giles and Montgomery Counties, Virginia. The St. Clair fault at approximately MP 195 corresponds to the Alleghenian Orogeny structural front that transitions from the Appalachian Plateau geologic province (located northwest of the fault) to the Valley and Ridge province located to the southeast. The St. Clair fault strikes in a northeasterly fashion through Giles County in Virginia, and Monroe County in West Virginia in the Project area. The observed thrust faults in the Valley and Ridge province are low-angle reverse faults that are no longer active because the tectonic regime that formed the thrust faults is no longer active, nor of particular concern to the Project. The Project alignment does not traverse known faults with recent (Quaternary) movement, such that risk to the pipeline by permanent ground deformation (PGD) from fault rupture is negligible. Therefore, avoidance of the PFZ and Project-specific mitigation is not considered necessary. As discussed in Section 6.6.1.3, the Project would be designed to meet ground motion guidelines for the PFZ.

6.4.1.4 Soil Liquefaction and Lateral Spreading

Soil liquefaction is a phenomenon often associated with seismic activity in which saturated, non-cohesive soils temporarily lose their strength and liquefy (i.e., behave like viscous liquid) when subjected to forces such as intense and prolonged ground shaking. Areas susceptible to liquefaction may include soils that are generally sandy or silty and are generally located along rivers, streams, lakes, and shorelines or in areas with shallow groundwater. There have been no documented occurrences of soil liquefaction from seismicity in the MVP alignment and alternatives.

The minimum earthquake moment magnitude to trigger liquefaction is generally taken to be 5.0 (D.G. Honegger 2015a – Appendix 6-D.1). This is based upon the lack of observed manifestations of liquefaction following such small earthquakes and the limited number of significant stress cycles that can be generated by such a small earthquake. The impact of liquefaction on buried pipelines is limited to relatively modest amounts of flotation, sinking, and general ground settlement from dissipation of excess pore water pressure. Pipeline flotation or sinking requires the pipe to be located below the ground water table within a zone of liquefiable soil. Whether a pipe will tend to float or sink depends upon the buoyancy of the pipeline and the residual strength of the liquefied soil.

Therefore, sites where liquefaction might be possible along the MVP route are likely to be low-lying areas near creek and stream crossings where there are softer sediments and a high groundwater table. The likelihood of an earthquake greater than magnitude 5.0 in a 50 year time period is less than 2 percent except for portions of the MVP alignment from roughly MP 165 to MP 240 (D. G. Honegger 2015a). Therefore, portions of the pipeline north and south of this alignment segment are not considered to be at risk for liquefaction hazards due to low-probability of major earthquake occurrence and related ground motion. Stream crossings are discussed in Resource Report 2. Potential areas of concern for liquefaction would include crossings between MP 165 and MP 240 that will be constructed in soft sediments. Table 6.4-2 provides a list of floodplain crossing areas that are likely to encounter soft sediments. There are 19 crossings between MP 165 and 240. The inherent design of modern pipeline systems affords protection for all but the most severe earthquake hazards, particularly liquefaction. Newer pipelines exhibit elastic behavior and are significantly less vulnerable to earthquake effects, including liquefaction, differential settlement, violent shaking, and ground strain, than older types of pipe installed over 50 years ago. Today's pipe has greater ability to conform to ground movements both from vibration and slippage.

The pipeline will be constructed of carbon steel pipe, manufactured in accordance with American Petroleum Institute (API) specifications for welded steel line pipe for use in conveying gas in the natural gas industries (API 5L). The pipe will be protected from corrosion by an external fusion-bonded epoxy coating in combination with an impressed current cathodic protection system.

Modern pipelines are made of ductile steel with full penetration welds, resulting in a system with substantial inherent ductility. Because of this ductile behavior, buried pipelines can withstand considerable soil distortion or differential displacement in cohesive or granular soils without rupture. Toughness (strength and ductility) and flexibility of both pipes and joints are the two governing factors related to the seismic performance of buried pipelines. Modern steels have good post-yield characteristics in axial tension. A pipeline that is properly oriented in its trench can accommodate ground movement by means of combined axial tension and bending. Modern steel pipelines have performed well under liquefaction-induced lateral spreading.

Table 6.4-2

Flood Zones That Require Pipeline Weights (Aggregate Filled Sacks)

Milepost	County	Floodplain Waterbody	Length Crossed (feet)
0.7	Wetzel	North Fork Fishing Creek	466
5.0	Wetzel	Price Run	642
15.5	Harrison	Little Tenmile Creek	310
18.8	Harrison	Rockcamp Run	217
23.1	Harrison	Indian Run	173
26.0	Harrison	Salem Fork	434
34.9	Doddridge	Laurel Run	200
42.7	Lewis	Right Fork Freemans Creek	135
46.0	Lewis	Left Fork Freemans Creek	332
55.2	Lewis	Sand Fork	242
58.6	Lewis	Indian Fork	182
62.3	Lewis	Oil Creek	167
72.6	Braxton	Falls Run	273
75.0	Braxton	Little Kanawha River	805
81.7	Webster	Left Fork Holly River	243
82.4	Webster	Oldlick Creek	569
84.1	Webster	Right Fork Holly River	210
87.4	Webster	Elk River	441
93.1	Webster	Camp Creek	783
97.7	Webster	Amos Run	438
98.7	Webster	Lost Run	127
98.9	Webster	Laurel Creek	227
109.9	Webster	Strouds Creek	258
114.0	Nicholas	Big Beaver Creek	236
115.8	Nicholas	Big Beaver Creek	117
118.6	Nicholas	Gauley River	402
126.5	Nicholas	Hominy Creek	256
140.1	Greenbrier	Meadow Creek	97
143.7	Greenbrier	Meadow River	333
146.7	Greenbrier	Little Sewell Creek	252
154.5	Greenbrier	Buffalo Creek	320
155.4	Greenbrier	Morris Fork	277
169.8	Summers	Hungard Creek	163
170.4	Summers	Greenbrier River	1,841
171.8	Summers	Kelly Creek	172
181.9	Monroe	Indian Creek	112
186.7	Monroe	Hans Creek	258

Table 6.4-2

Flood Zones That Require Pipeline Weights (Aggregate Filled Sacks)

Milepost	County	Floodplain Waterbody	Length Crossed (feet)
191.1	Monroe	Dry Creek	330
199.4	Giles	Stony Creek	729
203.3	Giles	Little Stony Creek	313
209.9	Giles	Sinking Creek	166
211.6	Giles	Greenbrier Branch	87
218.1	Montgomery	Craig Creek	981
218.6	Montgomery	Craig Creek	220
223.9	Montgomery	Mill Creek	411
225.2	Montgomery	North Fork Roanoke River	567
225.5	Montgomery	North Fork Roanoke River	60
225.6	Montgomery	North Fork Roanoke River	116
225.7	Montgomery	North Fork Roanoke River	428
229.2	Montgomery	Bradshaw Creek	377
233.6	Montgomery	Roanoke River	1,446
260.8	Franklin	Little Creek	842
262.2	Franklin	Blackwater River	200
262.4	Franklin	Blackwater River	400
262.5	Franklin	Blackwater River	142
262.8	Franklin	Blackwater River	698
263.3	Franklin	Blackwater River	269
266.6	Franklin	Maggodee Creek	166
266.9	Franklin	Blackwater River	204
281.6	Pittsylvania	Jonnikin Creek	83
281.9	Pittsylvania	Jonnikin Creek	28
284.3	Pittsylvania	Rocky Creek	130
286.3	Pittsylvania	Pigg River	402
287.1	Pittsylvania	Harpen Creek	290
287.7	Pittsylvania	Harpen Creek	167
289.2	Pittsylvania	Harpen Creek	178
291.4	Pittsylvania	Cherrystone Creek	182
292.4	Pittsylvania	Cherrystone Creek	224
293.7	Pittsylvania	Pole Bridge Branch	292
298.6	Pittsylvania	Little Cherrystone Creek	177
299.1	Pittsylvania	Little Cherrystone Creek	1,466
300.2	Pittsylvania	Little Cherrystone Creek	131
300.3	Pittsylvania	Little Cherrystone Creek	359
Grand Total			**25,971**

The best construction practices used to mitigate the effects of possible seismic liquefaction are the same as those used to minimize the potential buoyancy effect of the pipeline during construction. MVP has evaluated soil texture class, presence of high water tables, surface hydrology, and floodplain information throughout the Project area to determine where aggregate filled sacks may be required. These areas are listed in Table 6.4-2. The floodplains/waterbodies between MP 185 and MP 240 are in areas that might be susceptible to soil liquefaction based on their location in the seismic zone. However, aggregate filled sacks in these areas would mitigate potential effects.

Lateral spreads involve the horizontal movement of competent surficial soils due to liquefaction of an underlying deposit. Lateral spread movement is the most common and one of the most severe earthquake-generated ground displacement hazards for buried pipelines. As documented in D.G. Honegger 2015a, the potential for lateral spreading is limited to the occurrence of an earthquake with a magnitude of 6.0 or above. For the 50-year time period, the probability of an earthquake exceeding a magnitude 6.0 is less than 1 percent. Based upon this, the probability of an earthquake capable of producing lateral spread displacement can be discounted as a credible seismic hazard (D. G. Honegger 2015a).

6.4.1.5 Seismicity in Relation to Landslides and Rock Falls

Strong ground shaking during earthquakes may trigger landslides and/or rock falls in a variety of geologic and topographic settings. An approximate estimate of the magnitude of triggered landslides can be made using the approach sometimes adopted for regional identification of the extent of landslide hazards. Such an assessment would use information on slope angle and the strength of the soils overlying the slope.

The potential for slope displacement triggered by seismic ground shaking cannot be ruled out. Based on a maximum PGA of 0.14 g, the potential for credible triggered slide hazards exist only for those slopes steeper than 54 percent. Calculations presented in D.G. Honegger 2015a indicate that the pipeline can be designed to withstand substantial slide displacement for the landslide hazards in the Project area. Areas of landslide hazard are further discussed in Section 6.4.3. The only portion of the Project that has slopes steeper than 54 percent is at MP 126 in Nicholas County, West Virginia.

6.4.2 Karst Potential / Ground Subsidence

The pipeline route crosses karst terrain characterized by dissolution of the soluble rock formations, such as limestone and dolostone, to form sinkholes, caves, and underground waterways. Karst terrain often has unique hydrology and highly productive aquifers, which can be highly susceptible to contamination. Sinkholes, which are a major feature of karst terrain, fall into two broad categories: vault collapse sinkholes and cover-collapse sinkholes. Vault-collapse sinkholes are characterized by the sudden catastrophic failure of a subterranean cavern vault or a cavern roof, causing the rapid displacement of surface materials into the resulting void. The more common sinkhole type, a cover-collapse sinkhole, forms from the transport of soil materials from the surface into the bedrock through pre-existing voids or conduits. The resulting voids from this process are filled with the surrounding soil materials (a process called piping), and over time, form a noticeable depression on the land surface. This natural process can be exacerbated by impacts such as:

- an increase or redirection of overland or subsurface hydrology, which could accelerate the transportation of soil materials;
- removal of vegetative cover and topsoil, which can reduce the cohesive strength of soils; and

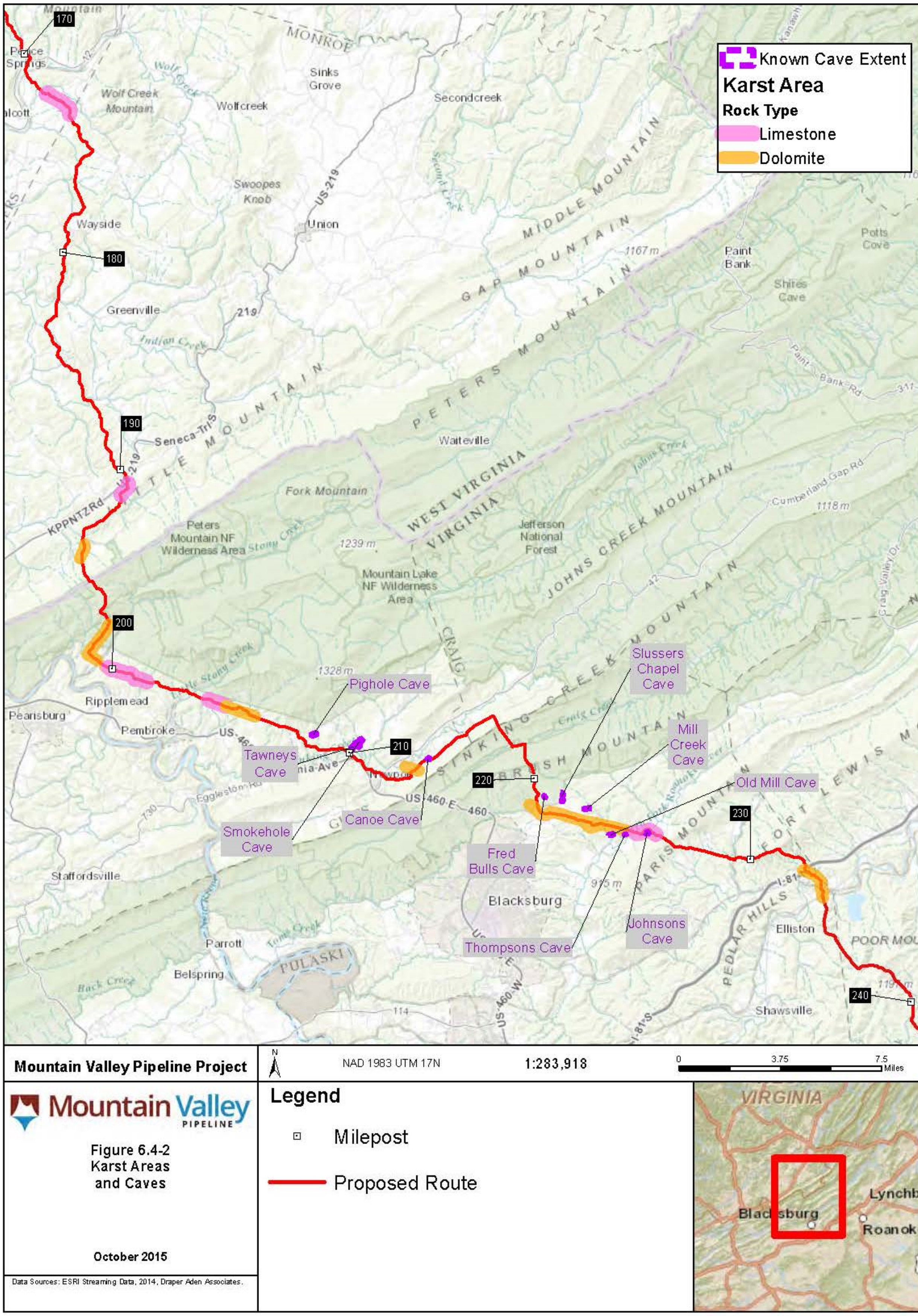
- sudden changes in the elevation of the water table (e.g., due to drought, over excessive water removal through pumping of wells, quarry or mine dewatering), which removes the natural buoyancy of the water supporting a soil plug in a bedrock channel.

MVP has been studying the route extensively through publically available study data along with physically traversing the areas, with landowner access, by geologic karst experts. MVP deployed a team to evaluate the karst terrain of southern West Virginia and southwestern Virginia in proximity to the Project alignment. The team holds qualifications of, or performed this work under the direction of, a professional geologist having direct work experience with karst hydrology and geomorphic processes. The team experience included over 70 years of combined direct field experience evaluating karst features in the vicinity of the Project alignment. Based on a review of mapping from the USGS, WVDEP, and VDMME, and field reconnaissance, the Project in West Virginia and Virginia will cross approximately 22.2 miles of discontinuous areas known to contain karst features approximately between MP 172 and MP 234 (see Figure 6.4-2). The remaining areas crossed by the Project were determined not to have the geologic conditions necessary for significant karst formation. Where warranted, minor route adjustments have been or will be made to avoid these features. Route adjustments made to-date to avoid karst features are identified in Resource Report 10.

Karst terrain areas are crossed by the current alignment in Summers and Monroe Counties in West Virginia, and Giles, Craig and Montgomery Counties in Virginia. Identification of karst features within 0.25 mile of the MVP alignment as documented in the Karst Hazards Assessment report (Appendix 6-D.2). The features identified in the report include drainages crossed by the Project alignment that lead to karst features. This section provides a summary and discussion of the information and findings included in that assessment report related to the Project. Where warranted, minor route adjustments have been or will be made to avoid these features. Route adjustments, both major (most significantly Alternative 200) and minor, made to-date to avoid karst features are identified in Resource Report 10.

6.4.2.1 Sinkholes

As result of the analysis performed as identified in Section 6.4.2 above, MVP has identified sinkholes located within approximately 0.25 mile of the pipeline (Draper Aden Associates 2015a). Identified sinkholes are listed in Table 6.4.3. Provided that a buried pipeline can span a sinkhole while loaded with soil overburden, the sinkhole will not pose a threat to the integrity of the pipeline. Non-linear pipe-soil interaction finite element analyses were used modeling to assess the pipeline response to sinkhole settlement were performed (H.G. Honegger 2015b, Appendix 6-D.2) to evaluate enhanced design criteria in areas of karst terrain. A screening chart (Figure 2 in Appendix 6-D.2) was developed as part of the study to relate the allowable sinkhole span to the depth of cover for a pipe wall thickness of 0.74 inches, which will be the minimum pipe wall thickness in karst area. Based upon the results of the analyses, the smallest sinkhole span that can be tolerated by the pipeline is 57 feet, corresponding to 10 feet of cover, and the largest sinkhole span that can be accommodated is 145 feet for 3 feet of cover. The analyses provided documentation that MVP will have adequate response time to mitigate sinkhole formations in the event they should occur.



Mountain Valley PIPELINE

Figure 6.4-2
Karst Areas
and Caves

October 2015

Data Sources: ESRI Streaming Data, 2014, Draper Aden Associates.

Table 6.4-3

Identified Sinkholes Within 0.25 mile of the MVP Pipeline

State / County	Milepost	Direction / Distance (feet)	Notes
West Virginia			
Summers	172.0	South / 1,320	none
Summers	172.4	South / 240	none
Summers	172.5	North / 650	none
Summers	172.7	South / 400	none
Summers	172.7	South / 800	none
Summers	172.9	South / 500	none
Summers	173.1	East / within 150 feet	none
Monroe	191.2	Northwest / 1,320	none
Monroe	194.1	East / 1,000	none
Monroe	194.2	West / 250 feet	none
Monroe	194.2	Southwest / within 150 feet	none
Monroe	194.2	West / 700 feet	none
Monroe	194.4	West / 700 feet	none
Monroe	194.5	West / 550 feet	none
Monroe	194.6	East / within 150 feet	none
Monroe	194.6	East / 300 feet	none
Monroe	194.6	West / 200	2 sinkholes
Virginia			
Giles	198.5	East/southeast / 1,320	none
Giles	199.2	Northeast / 1,000	none
Giles	199.3	Northeast / 900	none
Giles	199.7	Northeast / 1,000	none
Giles	200.0	northeast/ 200	none
Giles	200.1 – 200.2	north / 300 - 800	4 small sinkholes
Giles	200.2	South / 600	Small sinkhole
Giles	200.3 – 200.6	south / –600 – 1,000	2 large sinkholes (sinkhole complex)
Giles	200.6 – 200.8	North / closest point within 150 feet	large sinkhole complex
Giles	200.7 – 200.8	In right-of-way	Small sinkhole
Giles	200.8	south / 300 - 400	3 sinkholes
Giles	201.1	In right-of-way	Small hole
Giles	201.1	South / 800	Large sinkhole
Giles	204.4	North / 200	small sinkhole
Giles	204.4	North / 440	sink cave (Conklin Sink Cave)
Giles	205.7	Southwest / 900	2 small sinkholes
Giles	207.7 to 207.9	Southwest / 1,000	4 small sinkholes
Giles	208.0	in right-of-way	Large sinkhole

Table 6.4-3

Identified Sinkholes Within 0.25 mile of the MVP Pipeline

State / County	Milepost	Direction / Distance (feet)	Notes
Giles	208.5	North / 1,300	Medium sinkhole (associated with Pighole Cave System)
Giles	208.6	in right-of-way	Medium sinkhole
Giles	208.7 – 208.9	South / 150 - 300	Numerous small to medium size sinkholes
Giles	208.7 – 208.9	North / 250	1 small and 1 medium sinkhole
Giles	208.9	In right-of-way	none
Giles	209.0	north / 150	small sinkhole
Giles	209.3 – 209.5	North / 150 – 1,000	5 small sinkholes
Giles	210.1	South / 1,000	Large sinkhole
Giles	210.1 – 210.2	North / 150 - 250	2 small sinkholes
Giles	210.2	North / 1,300	Small sinkhole
Giles	210.2	South / 800	none
Giles	211.1 – 211.2	crosses	Saltville Fault (structural disconformity, possible preferential hydrology, voids)
Giles	211.8	North / 180	small sinkhole
Giles	212.6 – 212.8	South / 170 - 600	3 small sinkholes
Giles	212.7 – 212.8	North / 150	2 small sinkholes
Giles	212.8	North / within 150 feet	Small sinkhole
Giles	213.2	South / 600 - 900	3 small sinkholes
Giles	213.5	South / 600 - 900	2 small sinkholes
Giles	213.7	North / 160 - 350	Small sinkhole and large sinkhole containing trash
Giles	213.8	South / Within 150 feet	Small sinkhole
Giles	213.9 – 214.1	North / 400 - 950	4 small sinkholes
Giles	213.9 – 214.1	South / 300 - 400	2 small sinkholes
Giles	214.2 – 214.3	South / 450	2 small sinkholes
Giles	214.6	North / 280	Small sinkhole
Giles	215.2	North / 500	Large sinkhole filled with trash
Giles	215.3	North / 500	sinkhole
Giles	215.6	South / Within 150 feet	2 small sinkholes
Giles	215.7	Within right-of-way	Large sinkhole
Giles	215.8	Within right-of-way	sinkhole
Giles	215.8 – 215.9	North / 160 - 350	3 sinkholes
Craig	216.8	North / 230	Shallow sinkhole
Craig	216.8	East / within 150 feet	sinkhole
Montgomery	220.6 – 220.8	–within right-of-way and crossing, skirts sinkhole plain along the western edge	Mount Tabor Sinkhole Plain, numerous sinkholes

Table 6.4-3 Identified Sinkholes Within 0.25 mile of the MVP Pipeline			
State / County	**Milepost**	**Direction / Distance (feet)**	**Notes**
Montgomery	220.8 – 222.4	Crosses sinkhole plain	Mount Tabor Sinkhole Plain, numerous sinkholes
Montgomery	222.7 – 222.9	South / 600 – 1,000	3 sinkholes
Montgomery	223.4 – 223.6	North / 80 – 300, within 150 feet	3 sinkholes
Montgomery	223.6	South / 1,200	sinkhole
Montgomery	224.5 – 224.7	South / 150 - 300	4 small sinkholes
Montgomery	224.7	North / 200 - 600	5 small sinkholes
Montgomery	224.8 – 224.9	South / 400 - 800	2 small sinkholes
Montgomery	224.9	–South / within 150 feet	sinkhole
Montgomery	225.0	north / 170	2 sinkholes
Montgomery	225 – 225.2	North / 200 – 1,200	3 sinkholes
Montgomery	225.5 – 225.9	South / 400 - 500	3 sinkholes
Montgomery	233.1	–north / within 150 feet	sinkholes
Montgomery	233.4	North/northeast / 400	2 sinkholes
Source: Draper Aden Associates 2015a, Appendix 6-D.2			

6.4.2.2 Caves

MVP has identified caves located within approximately 0.25-mile of the pipeline. Identified caves are listed below, and also summarized in Table 6.4-4.

Bobcat Cave. The location of the cave entrance is unknown but is thought to be near MP 194.4. The cave is described as a small room located in a large sink hole.

Rich Creek Cave. At the closest point, at about MP 194.5, the pipeline would be about 1,500 feet west. The cave has not been surveyed or mapped. Rich Creek Spring daylights from the cave and the underground stream can be followed along a walking-sized passage for several hundred yards to the northeast.

Lhoist Cave. At the closest point, at about MP 199.9, the pipeline would be about 370 feet south. Lhoist Cave is 72 feet long and 8 feet deep.

Crooks Crevice. At the closest point, at about MP 201.2, the pipeline would be about 600 feet south. Crooks Crevice is approximately 50 feet long and 50 feet deep.

Williams Contact Shaft. The cave entrance is approximately 140 feet from the right-of-way near MP 203.9 and is 75 feet deep. It is formed at the contact between the Moccasin formation and undivided limestone.

Mahaffey Trash Cave. At the closest point, at about MP 203.9, the pipeline would be about 800 feet south. The cave entrance is filled with trash.

High Voltage Cave. At the closest point, at about MP 204.1, the pipeline would be within 150 feet of the right-of-way; the cave is within the electric line right-of-way.

Conklin Sink Cave. Specific information on the size of the cave is not available. The cave is formed in a sinkhole and is located about 440 feet northeast of MP 204.4.

Echols Cave. Echols cave is 535 feet long and 30 feet deep. The cave is located 700 feet southwest of MP 208.3.

Pig Hole Cave Area. Pig Hole Cave is 6,230 feet long and 428 feet deep and is characterized by extensive vertical development intersecting horizontal passages formed along strike at multiple levels. At the closest point, at about MP 208.3 the pipeline would be about 400 feet south of the main entrance to Pig Hole Cave. There are also several smaller caves and a number of sinkholes in the area surrounding the main cave. Additionally three swallets (locations where surface water sinks into the ground) were observed in the area. The geologic setting is within undivided Middle Ordovician limestone. The cave is considered significant by the Virginia Cave Board and the Virginia Speleological Survey in the categories of geology, hydrology, length, depth, paleontology, recreation, and esthetics (Draper Aden Associates 2015a).

Tawneys Cave. Tawneys Cave has two entrances located south and within 150 feet of MP 209.1. The pipeline route would cross the cave extent from MP 209.0 to MP 209.2. This cave is characterized as a large horizontal set of passages that likely represent a paleo flow route for waters which now resurge just upstream at Smokehole. A sinkhole entrance likely caused a separation from Smokehole cave. Tawneys Cave is considered significant by the Virginia Cave Board and the Virginia Speleological Survey in the categories of geology, hydrology, biology, history, recreation, and esthetics.

Smokehole Cave. The Smokehole Cave system is located greater than 1,320 feet north of MP 210.2. The geologic setting is Middle Ordovician limestones at the lower end of Clover Holler and immediately uphill of an extremely significant karst water resurgence known as Smokehole Spring. Nearly all surface water quickly sinks into a well-documented karst flow system. Smokehole cave lies just behind Smokehole Spring and is reported at 9,354 feet long with a vertical extent of 112 feet. Smokehole Cave is considered significant by the Virginia Cave Board and the Virginia Speleological Survey in the categories of geology, hydrology, biology, length, and esthetics (Draper Aden Associates 2015a). The Virginia Outdoors Foundation, an agency of the Commonwealth of Virginia, holds an open space easement (perpetual conservation restrictions) over most of Smokehole Cave, including its hillside entrance.

Mount Tabor Sinkhole Plain and Caves area. This karst area is located between MP 220.6 and MP 222.4. Just north of the town of Blacksburg between Brush Mountain and Paris Mountain lies a rolling karst valley that forms the headwaters of the North Fork and the Roanoke River. The valley is made up of Lower Ordovician and Upper Cambrian limestones and dolostones. The area around Mt. Tabor Road is highly karstified with an abundance of sinkholes forming a small sinkhole plain. Numerous small caves are present, a few in the 1000-foot range and one approaching a mile long. Waters of the Mt. Tabor sinkhole plain flow easterly collecting in the mile long Slussers Chapel Cave. The cave is located over 4,000 feet north of the pipeline alignment. Slussers Chapel Cave is owned by the Cave Conservancy of the Virginias to protect rare species and is considered significant by the Virginia Cave Board and the Virginia Speleological Survey in the categories of geology, hydrology, biology, length, and esthetics (Draper Aden Associates 2015a). The stream from Slussers Chapel reappears in Mill Creek Cave from which emerges a large spring. Mill Creek Cave is a 1,323 foot long stream and spring cave located about 2,400 feet north of

MP 223. Mill Creek Cave is owned by the Nature Conservancy and Virginia DCR and is part of a Natural Area Preserve for unique habitat protection. It is considered significant by the Virginia Cave Board and the Virginia Speleological Survey in the categories of geology, hydrology, and esthetics (Draper Aden Associates 2015a). Old Mill Cave is a 1,100 foot long base level stream cave emerging as a spring at the foot of the hill and is located over 1,950 feet south of MP 219.4. Old Mill Cave is considered significant by the Virginia Cave Board and the Virginia Speleological Survey in the categories of geology, hydrology, biology, and esthetics (Draper Aden Associates 2015a). Johnsons Cave is near the north fork of the Roanoke River and carries a small stream. Johnsons Cave is located about 300 feet south of MP 225.5 and carries a small stream.

Underwoods Cave No. 1 is located approximately 850 feet southwest of MP 221.3 and is about 30 feet long and 25 feet deep. Fred Bulls Cave is located over 1,200 feet east of MP 220.7 and is noted as having subsurface flow under the alignment. Longs Cave No. 2 is located approximately 2,000 feet north of MP 222 and is about 80 feet long and 20 feet deep. Red Hawk Cave and Bob Henderson Cave are mapped approximately 1,700 and 1,200 feet, respectively north of MP 223.5 and MP 224, respectively. Thompsons Cave is located approximately 1,100 feet south of MP 224.8.

Canoe Cave extends below the alignment of the Project. The cave is approximately 1,000 feet in length. The alignment overlies the surface-projection of a portion of Canoe Cave. Small sinkholes were observed at the ground surface during field confirmation of the cave location, suggesting that portion of the cave below the alignment is relatively near the ground surface. Historic (1943) mapping of the cave indicated underground stream flow derived most likely from the northeast along the flank of the upland mountain ridge.

Table 6.4-4

Identified Caves within 0.25 mile of the MVP Pipeline

State / County	Milepost	Direction / Distance (feet)	Cave Name	Extent / Depth (feet)
West Virginia				
Monroe	194.4	Unknown cave extent, location uncertain (about 1,200 west)	Bobcat Cave	unknown
Monroe	194.5	Unknown cave extent, entry located 1,500 feet west	Rich Creek Cave	900 / 20
Virginia				
Giles	199.9	South / 370	Lhoist Cave	72 / 8
Giles	201.1	within right-of-way	Possible cave (no name)	unknown
Giles	201.2	South / 600	Crooks Crevice	50 / 50
Giles	203.9	within 150 feet	Williams Contact Shaft	75 / 75
Giles	203.9	South / 800	Mahaffey Trash Cave	unknown
Giles	204.1	within 150 feet	High Voltage Cave	unknown
Giles	204.4	North / 440	Conklin Sink Cave	unknown
Giles	208.3	Southwest / 700	Echols Cave	535 / 30
Giles	208.3 – 208.5	North / 400	Pighole Cave System	6,230 / 428

Table 6.4-4

Identified Caves within 0.25 mile of the MVP Pipeline

State / County	Milepost	Direction / Distance (feet)	Cave Name	Extent / Depth (feet)
Giles	209.9 – 210	North / 700	Tawneys Cave System (2 entrances within 1,320 feet)	3,980 / 50
Giles	210.2	North / not located within 1,320 feet	Smokehole Cave System	9,354 / 112
Giles	210.4	South / 160	Hog Hole #2	10 / 9
Giles	210.5	South / 200	Overlooked Cave	unknown
Giles	213.7 – 213.8	crosses	Canoe Cave	1,000 / unknown
Giles	213.9	crosses	unknown	Contact - Limestone, End dolomite, Begin limestone. Little to no historic cave review performed in this area. High karst feature potential.
Giles	214.9	South / 200	unknown	unknown
Craig	216.8	East / 140	unknown	unknown
Montgomery	220.7	East / 1,200	Fred Bulls Cave	215 / 15, Stream cave trending southeast
Montgomery	221.3	Southwest / 850	Underwoods Cave No. 1	30 / 25
Montgomery	222.0	North / 2,000	Longs Cave No. 2	80 / 20
Montgomery	223.0	North / 2,400+	Mill Creek Cave	1,323 / unknown
Montgomery	223.5	North / 1,700	Red Hawk Cave	8 / 5
Montgomery	224.0	North / 1,200	Bob Henderson Cave	46 / 22
Montgomery	224.3	South / 1,950	Old Mill Cave	1100 / 20
Montgomery	224.6 – 224.7	South / 170	Hancocks Blowhole Caves No.1, No.2	50 / unknown, unknown
Montgomery	224.8	South / 1,100	Thompsons Cave	475 / 25
Montgomery	224.9	North / 180	Possible cave entrance (no name)	unknown
Montgomery	225.5	Southeast / 300	Johnsons cave	600 / 10
Source: Draper Aden Associates 2015a				

6.4.2.3 Karst Hazards Assessment

In general, sinkholes are considered a minor hazard that can either be avoided or mitigated as described in Section 6.6.1.5. Hazards identified by Draper Aden are provided in Appendix 6-D.2, Table 2.1. Most of the hazards are small karst features (sinkholes and caves) that can either be avoided by small adjustments to the Project right-of-way or can be mitigated as described in Section 6.6.1.5 and the Karst Mitigation Plan (Appendix 6-D.2). General methods that would be employed to avoid impacts to both area geology and hydrology include prevention of discharges in karst areas and the implementation of the ESC to protect stormwater runoff from causing adverse impacts during construction.

For springs located in karst areas, a testing program will be implemented to protect these resources (see Resource Report 2).

There is only one significant concern identified in the Karst Hazards Assessment (Appendix 6-D.2). It is noted that the significant concerns previously identified in the April 2015 filing with FERC have been addressed, primarily via pipeline reroutes to avoid the features of concern. However, construction across or in the near vicinity of Canoe Cave and a nearby spring at MP 213.7 may lead to impacts to that natural resource, long-term differential settlement, and pipeline instability. Construction run-off and fluid discharge may impact the cave, which may in turn lead to subsurface discharge to groundwater. MVP will adjust construction activities as needed based on field observation, to avoid direct encounter with area overlying cave following consultation with FERC and all other applicable resource agencies. The underground stream flow is likely coming from the northeast along the flank of the mountain. The lakes noted on the cave map are most likely connected to this flow path.

6.4.3 Landslides

The pipeline route is in an area of susceptibility for landsliding as shown in Figure 6.4-3, with corresponding documentation provided in Table 6.4-5. Slope information along the Project is provided in Resource Report 1, Appendix 1-I. Landslides in the Project area occur primarily in weathered bedrock or colluvial (loose) soil and within old landslide debris located on steep slopes. Numerous landslides on the Appalachian Plateau have developed in soils derived from Pennsylvanian and Permian sedimentary rocks (Watt 1982). Shale, especially red beds and shale-limestone sequences, disintegrate rapidly into clayey soil upon exposure. Most landslides involving soil and weathered bedrock consist of smooth, integrated, thin earth-flow slabs that may be many square meters in area but generally are less than about 8 feet thick. Commonly, the slabs move no faster than about 3 feet or 6 feet per year and are normally underlain by material containing water with a hydrostatic head of as much as 7 feet. In both the folded Appalachians and the Blue Ridge Mountains, numerous slow-moving debris slides form in colluvial soil and scree that are particularly abundant on slopes underlain by sandstone and metamorphic rocks. Urban and rural land development is increasing the number of landslides in the Project area. Large excavations and fills located in mountainous areas create the potential for many landslides.

The greatest damage and loss of life are caused by debris flows and avalanches when persistent rainfall is followed by a sudden heavy downpour. A single such storm, though often confined to a single small drainage basin, can cause from 100 to more than 1,500 landslides. In 1969, Hurricane Camille caused 1,584 debris flows and avalanches in an area of 98 kilometers in the Spring Creek watershed in eastern West Virginia (Watt 1982). On the basis of landslide areas observed since 1949 and of storm frequency, geologists of the USGS (Watt 1982) estimate that more than 10,000 debris flows and avalanches have occurred in the Appalachians during the 20th century. Heavy rainfall events have continued to cause localized landslide hazards in West Virginia. While the presence of the pipeline is unlikely to have any impact on these rare occurrences, mitigation measures will be taken as discussed in Section 6.6.1.2 to avoid exacerbating existing conditions.

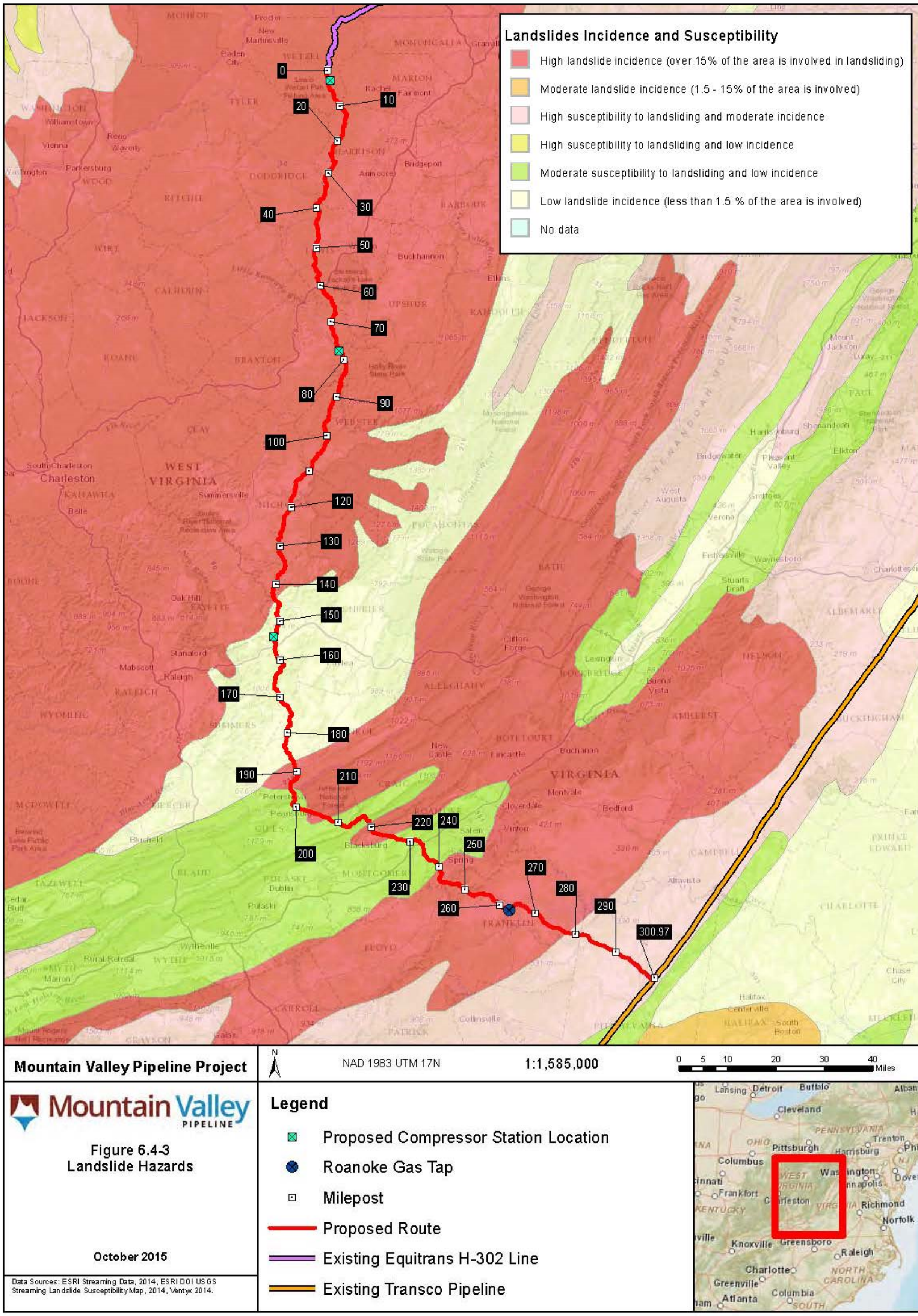


Figure 6.4-3
Landslide Hazards

Table 6.4-5

Landslide Incidence and Susceptibility Crossed by the Mountain Valley Pipeline Project Route

County	Total Crossing Length (miles)	Landslide Incidence/Susceptibility					
		High/ High	Moderate/ High	Moderate/ Moderate	Low/ High	Low/ Moderate	Low/ Low
West Virginia							
Wetzel	9.60	9.60	0.00	0.00	0.00	0.00	0.00
Harrison	23.71	23.71	0.00	0.00	0.00	0.00	0.00
Doddridge	4.84	4.84	0.00	0.00	0.00	0.00	0.00
Lewis	27.43	27.43	0.00	0.00	0.00	0.00	0.00
Braxton	14.74	14.74	0.00	0.00	0.00	0.00	0.00
Webster	30.00	30.00	0.00	0.00	0.00	0.00	0.00
Nicholas	24.70	24.70	0.00	0.00	0.00	0.00	0.00
Greenbrier	21.24	9.23	0.00	0.00	0.00	0.00	12.01
Fayette	0.49	0.00	0.00	0.00	0.00	0.00	0.49
Summers	16.66	0.00	0.00	0.00	0.00	0.00	16.66
Monroe	22.04	7.40	0.00	0.00	0.00	0.65	13.99
West Virginia Subtotal	**195.45**	**151.65**	**0.00**	**0.00**	**0.00**	**0.65**	**43.15**
Virginia							
Giles	20.10	5.05	0.00	0.00	0.00	15.05	0.00
Craig	1.63	0.00	0.00	0.00	0.00	1.63	0.00
Montgomery	18.95	6.74	0.00	0.00	0.00	10.32	0.00
Roanoke	8.28	4.26	0.00	0.00	0.00	4.02	0.00
Franklin	36.66	33.96	2.70	0.00	0.00	0.00	0.00
Pittsylvania	19.90	0.00	19.90	0.00	0.00	0.00	0.00
Virginia Subtotal	**105.52**	**50.01**	**22.60**	**0.00**	**0.00**	**31.02**	**0.00**
Total	**300.97**	**201.66**	**22.60**	**0.00**	**0.00**	**31.67**	**43.15**

Rockfalls are also a potential hazard below bedrock outcroppings at or near the top of steep slopes associated with the cliff-forming formations such as sandstones, granite, and gneiss. These outcrops may be weathered by wind or rainfall and become loosened, leading to a violent cascade downhill, often triggering a larger landslide.

MVP has performed a preliminary inventory of potential areas of landslide or rockfall concern along the pipeline alignment. This was completed through review of available historic aerial photographs, soils, topographic data to identify indications of potential landslide hazards. Areas where the alignment crosses steep hill slopes are identified in Table 6.4-6, and Appendix 6-D.3 includes a map set depicting these areas. As shown in the table, the pipeline route traverses approximately 3.8 miles of steep hill slopes that of potential stability or landslide concern.

Table 6.4-6

Areas of Potential Landslide Concern Crossed by the MVP Pipeline

Beginning MP	Ending MP	Length Crossed (feet)	Slope (%) a/	Signs of Recent Movement b/	Notes c/
3.3	3.8	2,147	33	No	Dormant slide and/or soil prone to movement. Intersects at least three natural drains.
28.1	28.4	967	29	No	Near well appurtenances. Side cut would run across at least three natural drains.
32.5	32.7	749	32	No	Dormant slide and/or soil prone to movement. Located at toe of slope. Hillside previously cleared.
33.6	33.8	570	42	No	Dormant slide and/or soil prone to movement. Located at toe of slope. Hillside previously cleared.
34.4	34.5	377	28	No	Moderate side slope, includes slight pipe bend. Cuts across at least one natural drain.
34.6	34.8	907	28	No	Downslope of ridge. Cuts across at least three, possibly four or five natural drains and one or two four-wheeler paths.
35.3	35.5	869	40	No	Construction equipment may need to be staged on sidehill here. Southeastern side less steep, may be better to stage.
43.5	43.6	494	30	No	Steep side slope, but ridge within right-of-way.
46.7	46.9	448	36	Yes	Existing dormant slide possibly upslope, and active within past twenty years. Cuts across at least one natural drain, possibly two.
53.1	53.4	872	22	No	Adjacent slopes composed of dormant slides. Moderate side slope directly below cemetery. Cuts across some kind of existing right-of-way or road, and at least two natural drains.
55.2	55.3	224	35	No	No additional information.
69.3	69.6	1,128	29	No	No additional information at this time.
81.9	82.2	1,462	35	No	Route crosses dormant slide area. Moderate side slope. No natural drains, but is directly above house or farm structure. Landowner issues may force it to be on the east side below the road, intersecting at least three natural drains.
82.6	82.7	602	45	No	Route cuts through a colluvial slope which is very prone to sliding. Very steep side slope, right above ravine, possibly crossing one natural drain.
111.7	111.8	231	12 – 39	No	No additional information at this time.
122.2	122.7	2,547	7 – 43	No	No additional information at this time.

Table 6.4-6

Areas of Potential Landslide Concern Crossed by the MVP Pipeline

Beginning MP	Ending MP	Length Crossed (feet)	Slope (%) a/	Signs of Recent Movement b/	Notes c/
122.8	122.9	362	22	No	Route crosses soil prone to movement. Mild side slope directly below power line right-of-way. Cuts across one natural drain.
126.9	127.1	631	12 – 39	No	No additional information.
127.6	127.7	423	10 – 60	No	No additional information.
131.7	131.8	646	25	No	Portion of route is adjacent to soil prone to movement to the west and a dormant slide to the east. Moderate side slope. Cuts across at least one natural drain.
203.5	203.8	1,120	39	No	Lateral slope side cut, paralleling transmission power line.
210.3	210.6	1,184	32 – 53	No	Very steep slope, centerline may or may not be on ridge. Directly above U.S. 460.
220.6	220.7	310	59	No	Very steep slope where route makes a 90 degree turn off the ridge. Very short section, but because of the severity of slope, could be prone to slippage. Cuts across one stream.
221.8	221.9	380	46	No	Steep slope runs alongside of knoll, directly above substation.
259.0	259.0	179	40	No	Steep side slope, but just for small section. Running just below ridge line through a gulley. Crosses one natural drain.
263.9	264.0	368	34	No	Steep side slope. Running just below ridge line through a gulley. Crosses one natural drain.

a/ Design slope is based on desktop and field review, or range from map analysis of alignment.
b/ Based on historical imagery.
c/ Based on available landslide mapping.

MVP is in the process of conducting field observations at these steep hill slope sites of potential stability issues. Field evaluation is currently underway for all sites for where access has been granted. These field observations of these sites include recording slope characteristics, locations of scarps, geotropically affected trees, drainage features, gullying, and GPS mapping of observed slope slides and slumps, and rockfall. These investigations are being conducted by a geotechnical engineer experienced with landslide evaluation. The findings of these observations will be filed with FERC when completed. Mitigation that may be appropriate for landslide hazard areas is discussed in Section 6.6.1.2.

MVP is in the process of reviewing areas of potential slope stability issues. This information will be assessed and field evaluations completed. The impacts to the pipeline and vice versa, will be evaluated for each area identified and mitigation measures recommended. The recommendations will be included in the final pipeline design.

6.5 PALEONTOLOGICAL RESOURCES

Areas where fossils might be encountered along the alignment include shallow areas of sedimentary rock (see Table 6.1-2 in Section 6.1 and discussion of shallow bedrock in Section 6.2). Sedimentary rock is generally present from MP 0.0 to the northern boundary of Franklin County, Virginia, near about MP 231. Metamorphic rocks including granite, gneiss, and schist are present in Franklin and Pittsylvania Counties. However, these rocks are not expected to contain fossils.

The pipeline route will cross sedimentary rocks and less-commonly Quaternary deposits containing various marine and terrestrial fossils. A gap in the local rock record spans from the Permian to the end of the Cenozoic. There are no Triassic, Jurassic, or Cretaceous rocks present in the Project area. As such, no dinosaur fossils have ever been discovered in the Project area (William and Mary 2015b). Fossils are present in the Cambrian, Ordovician, Silurian, and Devonian sedimentary rocks that crop out in the Valley and Ridge and Appalachian Plateau provinces. These rocks preserve abundant marine fossils that are an indication of the presence of extensive, shallow seas. Cambrian and Ordovician seas were home to creatures including corals, eurypterids, graptolites, nautiloids, trilobites, stromatolites, and worms. Silurian evaporites left by extremely salty seawater during a dry climate preserved eurypterids. Other Silurian life forms included nautiloids with straight shells and an abundance of ostracods. Corals were present during the transition from the Silurian to Early Devonian. By the Carboniferous (i.e., 350 million years ago) (includes Mississippian and Pennsylvanian rocks), the Project area was covered in lush, dense forests of "scale trees" (lycophytes), horsetails, and ferns. The accumulation of organic material in these large coastal swamps eventually produced coal seams (Cardwell 1977). In the Piedmont province, fossils of dinosaur footprints, freshwater fish, and insects are found in rift basin deposits of the Triassic (William and Mary 2015b). However, Triassic deposits are not present in the vicinity of the Project.

The Project area was never the site of glacial activity during the Ice Age, but was home to creatures like mammoths, mastodons, and giant ground sloths. The remains of these creatures are sometimes discovered in local caves. In 1993, two pieces of an extinct giant ground sloth shoulder blade were found in Haynes Cave of Monroe County, West Virginia (Grady 1997).

Although significant paleontological resources are not anticipated in the Project area, Environmental Inspectors will be trained regarding response if suspected paleontological resources are identified during site preparation or trench excavation.

6.6 IMPACTS AND MITIGATION

6.6.1 Construction Impacts and Mitigation

The pipeline will be designed and installed in accordance with the U.S. Department of Transportation (USDOT) standards found in 49 CFR Part 192. The pipeline will be designed and constructed to provide adequate protection from washouts, floods, unstable soils, landslides, or other geological hazards that may cause the pipe to move or to sustain abnormal loads. The overall effects of construction and operation of the Project facilities on topography and geology will be minor. Primary impacts will be limited to construction activities and will include temporary disturbance to slopes within the rights-of-way resulting from grading and trenching operations. MVP will minimize impacts by returning contours to preconstruction conditions to the maximum extent practicable. This may not be the case at the compressor stations and other associated aboveground facilities, where grading and filling could be required to create a safe and stable land surface to support the facility.

6.6.1.1 Blasting

MVP will try to minimize the amount of blasting required to the extent practicable. However, blasting may be required in certain areas of shallow bedrock. Although areas of shallow bedrock (and potential blasting) have been identified, the specific extent of blasting for the Project would be identified during site-specific construction activities. Where consolidated rock is encountered during construction, MVP's preferred procedure will be to fracture and excavate the bedrock using standard construction equipment. Blasting of bedrock may be required in areas where hard, massive bedrock is not easily removed by conventional excavation methods.

An evaluation of shallow bedrock for rippability may be conducted at selected locations where blasting is anticipated. Areas where blasting may be required will be surveyed for features such as structures and utilities. The pre-construction condition of structures and utilities will be documented. If blasting is conducted within 150 feet of an active water well or spring, MVP will implement measures to protect the water supply (see Resource Report 2). To ensure responsiveness to the concerns of affected landowners, MVP will evaluate landowner complaints or damage associated with blasting to wells, homes, or outbuildings. If damage is substantiated, MVP will negotiate a settlement with the landowner that may include repair or replacement.

Where unrippable subsurface rock is encountered, approved alternative methods of excavation will be explored including: rock trenching machines, rock saws, hydraulic rams, jack hammers, or blasting. The alternative method to be used will be dependent on the proximity to: structures, pipelines, wells, utilities, water resources, etc., and the capabilities of the alternative excavation method. Should blasting for ditch excavation be necessary, care will be taken to prevent damage to underground structures (e.g., cables, conduits, and pipelines) or to springs, water wells, or other water sources. Blasting mats or padding will be used as necessary to prevent the scattering of fly rock. All blasting will be conducted during daylight hours and will not begin until occupants of nearby buildings, stores, residences, places of business, and farms have been notified. Where competent bedrock occurs in the stream bed, blasting may be used to reduce bedrock so that the trench can be excavated. All blasting will be in accordance with the MVP Blasting Plan. Pre- and post- blasting structural surveys will be conducted for structures and water supply wells within 150-feet of the blasting areas. Per Section III of the FERC Plan, MVP will develop the Final Blasting Plan in consultation with appropriate agencies.

The contractor shall prepare a detailed Blasting Plan for each distinct blasting area and submit it to MVP for approval prior to commencing any blasting activities. The contractor will also be required to apply for and comply with any state or local permitting regulations. No blasting shall be done without prior approval of MVP and proper permitting. In no event shall explosives be used where, in the opinion of MVP, such use will endanger existing facilities.

If blasting is conducted within 150 feet of an active water well, MVP will conduct a pre-construction evaluation of the well. Upon request by a landowner who had a pre-construction test, a post-construction test will be performed. Landowners will be contacted by an MVP representative and a qualified independent contractor will conduct the testing.

MVP will evaluate, on a timely basis, landowner complaints regarding damage resulting from blasting to wells or structures. If the damage is substantiated, MVP will negotiate a settlement with the landowner that may include repair or replacement.

6.6.1.2 Slope Failure, Landsliding, and Subsidence

Steep topography offers some challenges to the construction of the pipeline. It also can also affect the reliability of the pipeline should failures occur that would result in displacement of the pipeline. Safety, both for construction workers and facilities and individuals located above and below the alignment must also be considered. The alignment of the pipeline will be evaluated and slide risk areas identified in advance of construction and mitigation measures prepared for both construction and long term stability. The potential for instability both in rock and earth slopes will be evaluated as part of the pipeline design. Earth slopes will be evaluated for shallow sloughing, surface erosion, and deep seated sliding, while rock slopes will be assessed based on rock structure and potential for block sliding. As discussed in Section 6.4.3 the field evaluation of the identified areas is currently underway.

Where stability issues are identified, mitigation measures will be considered that include, realignment of the pipeline to avoid areas of instability, deepening the pipeline below surface instability, buttressing, surface and subsurface drainage, rock bolting/soil anchors, surface stabilization matting, and regrading slopes to stable configurations. The construction has the potential to alter the stability of the slopes positively or negatively depending upon the circumstances. Where the construction flattens the top of slopes, it will likely enhance stability, and where it requires excavation near the base of slopes, it would tend to destabilize them. The pipeline route has been sited to avoid the need for excavation at the base of potentially unstable slopes to the extent practicable. Minor route modifications may be made in the future if needed to maximize slope stability. In addition, maintaining proper drainage during construction and operation will help to maintain slope stability. The construction erosion and sediment control measures will be designed to avoid concentration of runoff onto or into steep areas prone to slope instability. Concentration of surface water will be discouraged through restoring the original grade as closely as practical and through use of water bars where necessary to divert surface flow off of the right-of-way.

The overall effects of construction and operation of the Project facilities on topography and geology will be minor. Primary impacts will be limited to construction activities and will include temporary disturbance to slopes within the construction right-of-way resulting from grading and trenching operations.

MVP will minimize impacts by returning contours to pre-construction conditions to the maximum extent practicable, in accordance with the FERC May 2013 version of the Upland Erosion Control, Revegetation, and Maintenance Plan (Plan) and FERC May 2013 version of the Wetland and Waterbody Construction and Mitigation Procedures (Procedures). This may not be the case at the compressor stations and other associated aboveground facilities, where grading and filling may be required to create a safe and stable land surface to support the permanent aboveground facility.

The pipeline route has been sited to avoid steep sidehill slopes to the extent possible. Minor route adjustments may also be made during final design if needed to further minimize sidehill construction and thereby minimize the likelihood of landslides. Where sidehill construction cannot be avoided, alternate construction methods may be utilized. Measures could involve the use of drainage controls. Drainage controls can include, but are not limited to, frequent slope and trench breakers, subsurface gravel or cobble drains, and culverts and drainage ditches to divert water away from the right-of-way. MVP will install permanent trench breakers and permanent slope breakers in areas of steep slopes. Trench breakers are designed to prevent preferential water flow along the pipeline trench by diverting subsurface water flow. Used in combination with slope breakers, these structures prevent subsurface erosion of soils that can lead to slope instability and failure. These techniques and other best management practices are outlined in the typical construction drawings included in Appendix 1-D, Typical Construction Drawings, of Resource Report 1.

Underground Mining

It is possible that ground subsidence could occur as a result of underground mining. Measures are in place in West Virginia and Virginia that are designed to protect the integrity and service of pipelines in areas where mining takes place. Surface and strip mine operators are required by State and Federal regulations to ensure protection of pipelines during mining activities via notification of activities planned to affected pipeline operators. This notice shall include information such as the location of the mining operation, the mining company contact information, including all relevant engineering and operations personnel and proposed dates of operations. Each company may have a different method of notifying pipeline operators, but all are required to file long-term plans with the appropriate government entity. WVDEP- Division of Mining and Reclamation and Virginia DMME house the information provided by mine operators for the states of West Virginia and Virginia, respectively. In all cases, the best method of information gathering and activity notification occurs when a relationship exists between the mining company and the pipeline operator.

CB radios would be used as the main form of communication on active mining sites. Blasting activities by the mine operator would require them to notify MVP. Mining can occur along the project as long as the mine operator is not within the 125’ construction corridor. Blasting operations performed by the operator of a mine will need to follow MSHA and Federal Regulations for blast zones. Room and pillar mining does not have planned subsidence. Environmental controls will be in place along the right-of-way to prevent these activities from encroaching on the pipeline right-of-way.

Mitigation in Areas of Steep Slopes

Ideally, the final pipeline configuration will result in all slopes having long term stable configurations. However, where an existing failure area is in close proximity to the pipeline, or there remains some uncertainty, it may be appropriate to provide some slope monitoring. MVP will evaluate each condition and assess the appropriate monitoring. In some cases, this may be limited to periodic visual evaluation, but in others, more robust monitoring may be appropriate. Technologies used for monitoring will include radar interferometry, time domain reflectometry, extensometers, inclinometers and appropriate telemetry for remote monitoring of inaccessible areas. If continuous remote monitoring is required, time domain relectometry (TDR) is likely to be the method of choice. This method employs a single coaxial cable that is laid across the area or features that are suspected to have movement. As the earth moves, it strains the cable changing the dielectric constant of the cable. The location of movement can be assessed remotely from one end of the cable. This method is proven to be reliable and low cost and can be installed in boreholes or in trenches thousands of feet long. In any case, the specific requirements will be established for each location.

MVP is in the process of reviewing areas of potential slope stability issues. This information will be assessed when the field evaluations are completed. The impacts to the pipeline and vice versa, will be evaluated for each area identified and mitigation measures recommended. The recommendations will be included in the final pipeline design.

The potential for rockfall will be evaluated for all locations where steep rock exposures are present and where rock excavation is planned along steep slopes where there is the potential for excavated material to be lost down the slopes. In the latter case, barriers will be created during excavation to contain the trench spoils and prevent loss down slope. In the former case, the integrity of the exposure will be evaluated by an engineering geologist to assess the potential for rock to be dislodged by construction activities. Loose rock that could be dislodged will be removed by scaling or bolted in place where appropriate. Rockfall catchment structures will be constructed below all areas where loose rock could escape down the slope. These may include anchored steel netting, soil or rock berms, or precast concrete barriers placed to trap any falling rock. Alternately for public areas, such as roads, the down slope area could be closed and the work done when no one is present, perhaps at night, and the area could be reopened after. All of these elements will be incorporated in a rockfall protection plan prior to construction within these areas.

For long term landslide prevention, engineering evaluation and stability analysis will be completed for the final grading and stabilization and grading measures will be taken to assure long term stability. This may include constructing slope buttresses, flattening grades, installing subsurface drains, and special erosion protection and surface drainage measures.

MVP’s design specifications, based on slope severity and orientation, will incorporate measures such as: super silt fence, silt fence, sock filtration, temporary and permanent water bars, ditch breakers, temporary mulch, and erosion control blankets. On steep slopes, various measures will be taken in order to properly control erosion and sedimentation on the right-of-way. MVP’s design specifications, based on slope severity and orientation, will incorporate measures such as super silt fence, silt fence, sock filtration, straw bales, temporary and permanent water bars, ditch breakers, temporary mulch, and erosion control blankets. Spoil piles from trenching operations will be staged along the side of the right-of-way and will be compacted via rolling with dozers on site as additional material is added. Once a soil pile is completed, it will be temporarily mulched to control washouts. Additionally, spoil piles will be separated at intervals of 50 feet by temporary water bars which will serve to slow the flow of runoff down the right-of-way and divert it into straw bales or No. 3 aggregate. Hay bales, silt fence, and super silt fence would be used to stop rocks from rolling off the right-of-way. Other measures such as erosion control blankets, temporary mulching, and sock filtration may be used.

Within the trench sand filled sacks will be stacked across the width of the trench. This will permit water to filter through without carrying large amounts of soil with it. Similarly, permeable trench breakers constructed of sand or concrete filled sacks will be installed along the open ditch. In some cases these trench breakers may be retained after construction to provide increased long-term slope stability.

In addition to the aforementioned measures taken on slopes to control erosion and sedimentation, trench drains will be installed on side slopes and excessively steep slopes before the pipe is placed in order to channel water away from the ditch, and will remain in place after construction is complete. These drains will be constructed by digging a small ditch lined with 1 inch stone (or similar), on which a section of perforated tile or pipe will be laid. The remainder of the ditch will be filled with the same type of stone, which may be taken from the excavated spoils, to the top of the ditch, except where this drain crosses the pipeline. In these instances, stone backfill in the drain will only extend to the bottom of the pipe, after which typical trench backfill will be used. For very steep slopes (parallel to the pipeline alignment), these drains will daylight either at the bottom of a very steep slope into a wooded area or near a roadway. On lateral slopes they will daylight at the low point along the section onto a riprap pad near the edge of the right-of-way or into a wooded area off the right-of-way. This will serve to drain the pipeline trench of water, which will naturally travel to the low points along a slope.

For side hill construction tree stumps and other organic material are to be removed from backfill material, since their inclusion in the restored right-of-way can lead to soil saturation and eventual slippage. Special attention will be paid to ensuring that natural drains alongside slopes are properly restored after construction activities are complete. In order to accomplish this, additional French drains or rock lined channels may be constructed to efficiently convey water across or around the right-of-way. Where possible, compaction on side cut sections will be completed in 12-inch lifts using a sheep's foot roller.

In mountainous areas where the pipeline will encounter steep slopes exceeding 30 percent, MVP will employ special construction techniques where the slopes typically exceed 30 to 35 percent. These construction techniques will require expanded workspace areas. The dimensions of these ATWS will vary depending upon the degree and length of the slope. Land requirements for ATWS are identified in Resource Report 1. In rugged terrain, temporary sediment barriers, such as silt sock and reinforced silt fences, will be installed during clearing to prevent movement of sediment off of the right-of-way. In addition, temporary slope breakers may be installed during grading in accordance with the E&SCP to reduce water runoff or divert water to vegetated areas. Construction activities on rugged terrain will be similar to the typical construction sequence described in Resource Report 1; however, equipment will be tethered via winch lines to other equipment at the top of the slopes to ensure the safety of the construction personnel and surrounding areas.

All construction equipment and their winch lines will be inspected prior to operation to ensure the equipment is operable and sound. Spoil piles adjacent to the trench will be protected by temporary sediment barriers to keep excavated soils on the right-of-way. Pipe joints will be stockpiled at the top or bottom of each slope. A side-boom tractor will be suspended from a winch that will carry one joint at a time up or down the slope and place the joint along the trenchline. The joint will then be lowered into the ditch by a tractor. Welders will connect the joint to the previous joint within the trench to assemble the pipeline. Once welding is complete, the welds will be visually and radiographically inspected. The weld joints will be hand coated with fusion bonded epoxy in accordance with required specifications. The coating will be inspected for defects and repaired, if necessary. Sand breakers will be installed in the trench along the pipeline to prevent or slow the movement of water along the trench. The pipeline will be padded and the trench will be backfilled by equipment tethered to the winch tractors. The surface of the right-of-way will be restored to original contours, and permanent slope breakers will be installed in accordance with the E&SCP. Erosion control blankets, in lieu of mulch, will be installed on steep slopes to provide stabilization for vegetation.

The first 12 inches above the top of the pipe will be clean fill free of rocks from the excavation. The remaining fill of the trench will be the composed of the excavation material removed at the time of the excavation. If additional fill is brought in to complete the fill of the excavation and/or restoration, it will be either flowable fill or topsoil. The soil will have the same properties, once replaced and compacted, as it did in pre-existing conditions. Slope stability, in this case then, is more a function of environmental factors than inherent soil characteristics. These mainly arise as a result of inadequate site drainage. To address the impacts of excessive water infiltration into the right-of-way on steep slopes (parallel with the pipeline), water bars will be constructed and maintained during and after construction, which will channel water running downslope into catch basins at the edge of the right-of-way filled with 3-inch stone. This will slow the velocity of the runoff and divert it into more vegetated areas.

When steep side slopes are encountered, additional measures will be taken to ensure slope stability. Slope stability will be addressed during Project design and construction for both excessively steep parallel and side slopes. In areas where the Project route crosses laterally across the face of a slope, or side slope construction, cut-and-fill grading may be required to establish a safe, flat work terrace; this may require ATWS along the construction right-of-way. Construction in these areas will be accomplished in most cases by constructing a fill surface on which the equipment will be staged. This fill surface will be completely stripped of all vegetative matter and root systems, which will decay if filled over and consequently degrade the integrity of the slope. Similarly, all tree stumps, vegetative matter, root systems, and wood chips potentially generated during grading and clearing will be removed from the material that will be used for backfilling. During pipeline installation, ditch drains constructed of perforated pipe and backfilled with one inch stone, as described above, will be installed at all low points where water pools to drain it from the right-of-way. These drains will daylight at the edge of the right-of-way onto riprap or stone dispersion pads. They will be maintained as constructed after pipeline construction is completed and after the right-of-way is restored to pre-existing conditions. Trench breakers, constructed of dirt or sand filled sacks that extend to the top of the trench, may also be installed on excessively steep slopes. These trench breakers may be retained after restoration of the right-of-way to provide long-term stability. In addition, on steep parallel slopes, sand or dirt filled sacks stacked two high will be laid at intervals across the width of the right-of-way to slow runoff while the trench is open and to prevent excessive material loss.

6.6.1.3 Earthquakes and Liquefaction

Current worldwide design practice for buried steel pressure pipelines used for transmission of natural gas recognize that seismic hazards with a credible potential to cause pipeline damage are limited to those that produce permanent deformation of the ground along the pipeline alignment. These hazards primarily include surface faulting, liquefaction, liquefaction-induced lateral spread movement, landslides, and near-surface settlement. Seismic wave propagation (ground shaking) can only pose a significant threat to buried steel pipelines under very limited conditions (D.G. Honegger 2015).

There are no active faults crossed by the Project. The only significant seismic source zone is the Central Virginia seismic zone that is not associated with faults that rupture the ground surface. Therefore, potentially significant seismic threats to the Project are limited to liquefaction, lateral spread displacement, and triggered slope movement. All of these potential hazards are related to the severity of earthquake ground shaking (D.G. Honegger 2015).

Overall, compared to more seismically active regions of the United States, the relative risk to pipeline construction and operation presented by earthquake-induced ground motion in the Project area is moderate to low. There is no practical avoidance method for the Project alignment, and based on risk, mitigation measures through pipeline design are sufficient to ensure pipeline integrity. The pipeline alignment does not cross a known or inferred Class A fault or fault zone with evidence of tectonic origin and Quaternary movement. Therefore, avoidance considerations are not required. The Class B Pembroke faults are mapped within the general vicinity of the Project, but these features are questionable as to whether they are fault-related, or subsidence related, and in any case they appear to present negligible risk to Project construction and operation. Inactive ancient thrust faults in the Valley and Ridge province (e.g., St. Clair fault) do not pose a specific hazard to the pipeline alignment.

Buried natural gas pipelines typically span large areas and are subject to a relative degree of seismic risk depending upon the regional tectonic regime. It is generally considered that buried pipelines may be affected by ground movement relative to the surrounding overburden or bedrock, with the primary risk for damage being PGD and less-so transient seismic wave propagation (Yokel and Mathey 1992; O'Rourke and Liu 1999).

The Project alignment does not traverse known faults with recent (Quaternary) movement, such that risk to the pipeline by PGD from fault rupture is negligible. PGD (including fault rupture, settlement, landslides, soil liquefaction) due to intense seismic wave propagation also appears to carry negligible risk to the pipeline, as discussed below.

The largest earthquakes recorded for Virginia and West Virginia include (1) an apparent (i.e., preceded modern seismic networks) magnitude 5.9 earthquake that occurred in 1897 in Giles County, Virginia and (2) a magnitude 5.8 earthquake that occurred on August 23, 2011 near Mineral, Virginia. No characteristics of PGD were observed in association with these earthquakes. Historically, most earthquakes recorded in Virginia and West Virginia range from approximately magnitude 2 to 4 (Draper Aden Associates 2015c).

The effects of the 2011 magnitude 5.8 earthquake near Mineral, Virginia are being widely studied due to the proximity of the North Anna nuclear power station. The USGS estimated that the 2011 earthquake produced a peak ground acceleration of 0.26 g at the NAPS site. No PGD was observed. As noted above, peak seismic loading for the Project alignment in Virginia and West Virginia was estimated to be 0.28 g or less (USGS 2014a). The earthquake epicenter is over 100 miles from the Project area. In addition, considering observations and empirical data from the magnitude 5.8 Mineral, Virginia earthquake, it is concluded that there is negligible risk for PGD and related damage to the Project from a seismic event.

There are no recorded incidents of damage to a natural gas transmission pipeline in Virginia or West Virginia related to fault rupture, transient seismic energy propagation, or other earthquake- related effects. Based on the assessed seismic-related risks in West Virginia and Virginia (i.e., no known active faults at surface; probable peak ground acceleration of 0.28 g) it is anticipated that PGD hazards to the Project alignment will remain low.

In general, earthquake-induced seismic hazards presented to Project construction and operation are considered to be moderate to low, based on probabilistic estimates of ground motion.

Further pipeline design criteria would be followed as specified in USDOT Title 49 CFR Part 192, "Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards," as well as other industry standards (American Society of Civil Engineers, American Society for Mechanical Engineers, American National Standards Institute, etc.) and applicable codes typically employed for the design of buried pipe.

Beyond inertial forces caused by ground acceleration, relative ground displacement (distortions and strains noted above as PGD) caused by fault rupture, soil liquefaction, settlement, and landslides presents risk to pipeline damage. The Project alignment does not cross a known or inferred fault or fault zone with evidence of Quaternary movement. Therefore, fault rupture mitigation considerations are not required. There have been no documented occurrences of soil liquefaction from seismicity in the Project alignment, and due to low-to-moderate seismic risk, soil liquefaction is not anticipated to affect pipeline construction or operation.

Based on the low probability of localized earth movements or geological hazards in the vicinity of the Project, MVP does not anticipate any problems attributable to such movements or hazards along the majority of the pipeline or associated with aboveground facilities. The intensity, frequency, and duration of impacts resulting from the potential hazard of minor earthquakes cannot be accurately quantified. However, maintained pipelines constructed using modern arc-welding techniques have performed well in seismically active areas of the United States, such as California (O'Rourke and Liu 1999). Only large, abrupt ground displacements have caused serious impacts to pipeline facilities. Due to the limited potential for large, seismically-induced ground movements in the Project area, there is limited risk of earthquake-related impacts on the pipeline and other Project facilities.

Seismic wave propagation generally does not have serious effects on welded buried pipelines in good condition. Some situations where the wave propagation results in serious damage to a pipeline system include transition between very stiff and very soft soils. There have been no specific locations identified in the Project area where seismicity is considered a hazard. Other areas where wave propagation may result in damage to a pipeline system include locations where there is penetration of pipe located at or near compressor stations, branch-connections, pipe fittings and valves, etc. Special care has been taken in designing the pipeline system in the above situations. Valve spacing would follow USDOT requirements to localize the effects of a pipeline failure/rupture and consequent hazard.

The effect of wave propagation on pipelines can be mitigated by minimizing the interaction force at soil-pipe interfaces with suitable pipe coating. The hard and smooth fusion-bonded epoxy coating used on the pipeline exterior will reduce the coefficient of friction between pipeline and soil.

Buoyancy effects are probably of greatest concern in areas such as floodplains and river bottoms where liquefaction could take place in a large earthquake. To minimize the buoyancy effect upon the pipeline due to liquefaction in those areas, the pipeline will be designed with concrete coating, concrete weights or gravel-filled blankets, as applicable.

Soil Liquefaction

There may be some potential for ground settlement from liquefaction from roughly MP 165 to MP 240. The potential for liquefaction requires consideration of specific characteristics of soil deposits along the pipeline route. Liquefaction settlement can be screened out as not posing a credible threat to cross-country portions of the MVP provided the depth of cover is less than 10 feet. If the depth of cover exceeds 10 feet at a site where the soils are judged to have a high or very high susceptibility to liquefaction, the pipeline should be assessed for the maximum liquefaction settlement at that site. Areas of the pipeline potentially subject to such liquefaction are listed in Table 6.4-2. These locations would be designed to prevent liquefaction from impacting the pipeline.

The potential for pipeline damage from liquefaction is potentially significant only at locations where the pipeline is subject to abrupt vertical displacement. An example would be at the interface between the pipeline and a surface structure that will not settle as a result of liquefaction (e.g., a pile supported equipment pad). The mitigation for such differential settlement is to assure sufficient pipeline flexibility for vertical displacement (e.g., an expansion loop). This potential hazard can be avoided by not siting any aboveground facilities within potentially liquefiable sites (D.G. Honegger 2015).

Liquefaction hazards will be avoided in the area of potential ground settlement and liquefaction by using the following siting and construction design guidelines: limiting cover depths of the Pipeline to less than 10 feet; aboveground facilities would not be sited in potential areas of soil liquefaction; and the design would assure sufficient vertical flexibility at connections to aboveground facilities to accommodate total settlement.

Triggered Soil Displacement

The following measures would be implemented to avoid triggered slope displacement: screening of potential slopes for susceptibility to triggered displacement using criteria described in D.G. Honegger (2015); and performance of a detailed assessment where parallel displacement cannot be screened from consideration or the ground displacement is not nearly parallel to the pipeline. The following design measures would be implemented to mitigate for potential monolithic insulated joint (MIJ) failure: avoid locating an MIJ within areas where the pipeline can be loaded as a result of slope displacement; and consideration of adding a strength qualification test to MIJ specification to assure integrity for pressure and bending loads. MVP is developing risk management, avoidance, minimization, and mitigation for potential geologic hazards, including ground disturbance due to settlement, steep topography, and susceptibility for landslides as described in Section 6.4.3 and in Section 6.6.1.2. Full bench construction will be considered along with other potential mitigation measures in areas that might be susceptible to potential triggered landslides.

6.6.1.4 Rock Disposal

Shallow bedrock is expected along a portion of the pipeline. In these areas, after placing the pipeline in the excavated trench and backfilling, some excess rock may be generated that may require disposal. Disposal of excess rock debris will be within the approved construction right-of-way in areas approved by the individual landowners in accordance with regulatory requirements, or in off-site areas where disposal is not possible within the right-of-way. MVP will dispose of excess rock outside of the approved right-of-way at an approved landfill or as otherwise directed by the landowner

6.6.1.5 Karst and Sinkholes

The process for evaluation and mitigation of karst features is incorporated to the extent practical in the Karst Mitigation Plan in consideration of the recommendations presented by the Virginia Cave Board (VCB) in their April 17, 2015 letter under their section entitled “General recommendations.” Karst feature assessment and mitigation efforts that are covered in this plan will take place within the limits of land disturbance (LOD) along the MVP alignment that is underlain by karst terrain. The LOD is identified in this Plan as an area within the MVP construction easement where ground cover is removed or where the grade is altered, through MVP construction activities (clearing and grubbing, trenching, blasting, boring or drilling). It is noted that MVP does not plan to utilize horizontal directional drilling (HDD) in karst terrain.

Avoidance of a karst feature constitutes the first and foremost recommendation for mitigating impact. If an identified karst feature cannot be reasonably avoided, or if a previously unidentified karst feature is encountered or forms during construction, the Karst Mitigation Plan (Appendix 6-D.2) provides recommendations for impact mitigation and feature stabilization. The Karst Mitigation Plan (Appendix 6-D.2) describes inspections of karst features that would be conducted during Project construction. The inspection protocol requires that construction work cease if specific changes are observed within 150 feet of the karst feature. In addition, if a previously unidentified karst feature is intercepted during work activities, MVP will cease work activities within 150 feet of the feature and inspect the feature before proceeding with construction. If, upon further inspection, the feature meets the criteria of a suspected karst feature, MVP will conducted additional evaluations and propose mitigation activities if necessary.

The Karst Mitigation Plan also describes protocols in the case that a suspected karst feature forms during work activities. Such conditions would include soil subsidence, rock collapse, sediment filling, notable increased surface water infiltration, flooding, clogging and/or other changes in morphology or function that might indicate potential impact to karst terrain.

The final MVP alignment for construction has accommodated for karst feature avoidance recommendations. Therefore, a karst feature located within the LOD is likely to be minor in extent and nature and is a candidate for mitigation and stabilization prior to disturbance. The Karst Specialist (KS) will consult with MVP construction crews to determine the recommended course of action prior to tree clearing in the vicinity of the feature. It is anticipated that the most common karst feature requiring mitigation for MVP construction will be cover-collapse sinkholes. Karst feature stabilization would be completed in conjunction with recommendations from the appropriate state agency (Virginia Department of Conservation and Recreation, Karst Protection; West Virginia Department of Environmental Protection).

A karst-specific Erosion and Sediment Control (ESC) plan would be prepared by MVP's construction contractor as described in Section 3.9.5 of the Karst Mitigation Plan. The ESC would include enhanced BMPs to provide additional protection in identified karst areas of concern in the Karst Hazards Assessment (Appendix 6-D.2).

Section 3.9.6 of the Karst Mitigation Plan describes protocols for the discharge of hydrostatic test water that would avoid impacts in the area of karst terrain. Measures include controlling the rate and volume of discharge and discharge to areas downgradient of karst features to the degree feasible.

MVP will deploy a KS prior to, and during construction to confirm, monitor, and mitigate if necessary, existing karst features, and to assess and mitigate previously unidentified karst features that are encountered or observed to form during MVP land disturbance and construction.

MVP will deploy a KS prior to tree clearing and during construction activities (clearing and grubbing, trenching, blasting, boring or drilling) within karst terrain. The KS will hold qualifications of, or will work under the direction of, a certified professional geologist having direct work experience with karst hydrology and geomorphic processes.

The role of the KS is to confirm karst features in the LOD that were identified in the Karst Hazards Assessment for MVP (provided under separate cover), evaluate the LOD for previously unidentified features, observe construction activities to assist in limiting potential negative impacts, and to inspect, assess and, if necessary, mitigate karst features that are encountered or form during construction in conjunction with recommendations from the appropriate state agency (Virginia Department of Conservation and Recreation, Karst Protection; West Virginia Department of Environmental Protection).

Two or more KS will be available to conduct multiple inspections in karst terrain where MVP construction crews may be working at different locations simultaneously.

Procedures that will be used during pipeline construction activities (clearing and grubbing, trenching, blasting, boring or drilling) to limit potential impacts to karst features and related water resources are provided in the Karst Mitigation Plan (Attachment 6-D.2). The procedures include protection of existing karst hydrology; protection of karst recharge areas; if blasting is required in the area of karst features, following special construction procedures; compliance with requirements of project Spill Prevention, Control, and Countermeasures Plan (SPCC) prepared by MVP's construction contractor; confinement of project-related disturbance to the LOD; protection of sensitive karst features; and minimization erosion and enhancement of revegetation in those areas, in addition, to ESC BMPs for standard pipeline construction, which include specifications by regulatory agencies, additional BMPs will be implemented as specified by the KS; discharge of hydrostatic testing water will be avoided in karst areas to the extent practicable; and if circumstances require hydrostatic testing water to be discharged in karst areas, the KS will recommend a discharge location in accordance with specific guidelines.

The Karst Mitigation Plan states that the DCR Karst Protection Coordinator be contacted in the event that a previously unidentified karst feature is encountered during construction activities (clearing and grubbing, excavation and trenching, drilling, blasting, etc.). The DCR Karst Protection Coordinator will be notified if a previously unidentified karst feature(s) is encountered during construction activities (regardless of the selected alignment route). Procedures for evaluating and coordinating improvements to the ground or subsurface related to karst feature(s) are addressed in the Karst Mitigation Plan, and the DCR Karst Protection Coordinator will be contacted prior to site work.

Sinkhole Stabilization

Sinkholes may pose a stability challenge for pipeline construction. In addition, sinkhole areas are of concern for discovery of previously unknown subsidence and sinkhole concerns that might not be discovered until construction is in progress. These highly karstified areas crossed by the pipeline present long-term stability challenges both during construction and operation of the Project. Many of the karst and cave features are poorly documented.

Sinkholes are common surficial geomorphic expressions of karst terrain. As discussed in Section 6.4.2, modeling to assess the pipeline response to sinkhole settlement was performed (D.G. Honegger 2015b, Appendix 6-D.2) to evaluate requirements in areas of karst terrain. Based on the analyses, with 10 feet of cover, the Pipeline could span a maximum 57 foot diameter sinkhole; and with 3 feet of cover, the Pipeline could span a maximum 145 foot diameter sinkhole. Although the structural integrity of the Pipeline is shown to be stable under these conditions, avoidance and mitigation of sinkholes discovered would be conducted regardless of the soil cover and span length. As described in Section 3.5 in the Karst Mitigation Plan (Appendix 6-D.2), if a sinkhole is located within the proposed LOD (based on the required karst field inspection) and cannot be reasonably avoided, the sinkhole will be stabilized prior to construction in accordance with recommendations provided by the KS, and in conjunction with recommendations from the appropriate state agency (Virginia Department of Conservation and Recreation, Karst Protection; West Virginia Department of Environmental Protection).

Caves

The Project has been routed to avoid caves – including known underground extents – excepting one cave location in Giles County, Virginia. The underground stream flow is likely coming from the northeast along the flank of the mountain. There are also lakes located to the northwest that are likely connected to this flow path. Construction across or in the near vicinity of Canoe Cave and a nearby spring at MP 213.7 may lead to impacts to that natural resource, long-term differential settlement, and pipeline instability. Construction run-off and fluid discharge may impact the cave, which may in turn lead to subsurface discharge to groundwater. MVP will adjust construction activities as needed based on field observation, to avoid direct encounter with the area overlying the cave following consultation with FERC and all other applicable resource agencies.

6.6.2 Operational Impacts and Mitigation

Operational impacts on geologic resources are expected to be minimal. Inspection of pipeline facilities will be conducted in accordance with USDOT requirements in 49 CFR Part 192, whenever earthquakes or other natural hazards occur. Mitigation of damage caused by geologic hazards will be completed in a timely fashion in accordance with USDOT requirements.

A Fusion Bonded Epoxy (FBE) coating will be used on the pipe will protect the pipe from the effects of acid producing rock that might be encountered in the Project area.

CB radios would be used as the main form of communication on active mining sites. Blasting activities by mine operator would be required to notify MVP. Mining can occur along the project as long as the mine operator is not within the 125’ construction corridor. Blasting operations by the mine operator needs to follow MSHA and Federal Regulations for blast zones. Room and pillar mining does not have planned subsidence. Environmental controls will be in place along the right-of-way to prevent these activities from encroaching the pipeline ROW.

6.7 JEFFERSON NATIONAL FOREST

MVP will cross approximately 3.4 miles of the Jefferson National Forest (JNF) where it crosses Peters Mountain between MPs 195.3 and 196.9 (1.6 miles), Sinking Creek Mountain between MPs 217.2 and 218.0 (0.8 mile), and Brush Mountain between MPs 218.4 and 219.4 (1.0 mile). The JNF is located in the Valley and Ridge province and the Project alignment crosses Lower Devonian and Silurian sandstone and shale through the JNF. Bedrock is reported to be at a depth of greater than 7 feet through most of the alignment through the JNF excepting less than 0.5 mile that is less than 3 feet in depth. It is anticipated that minimal blasting would be required through the JNF. The JNF is located in the area with highest seismic hazards as discussed in Section 6.4.1. However, these hazards - including soil liquefaction near water crossings and the potential for landslides and rock falls - are not considered severe and can be mitigated with appropriate construction design. Karst hazards are not present along the pipeline alignment within JNF lands. Construction methods, impacts, and measures to avoid or minimize impacts related to geologic resources and hazards crossed within the JNF will be identical to that described above, except as may be specified for National Forest System lands under the terms and conditions included with the Right-of-Way Grant.

An estimated 888,000 ft^3 of material will be excavated and temporarily stored along the right-of-way within the 3.4 miles of pipeline that cross the JNF. Only one access road is anticipated to be constructed on JNF land (Pocahontas Road). Excess excavation from cut slopes will be hauled to an approved location. The JNF is managed under the 2004 Revised Land and Resource Management Plan (Forest Plan), which includes specific goals, objectives, and standards related to resources, including water resources. MVP has prepared a Forest Plan Consistency analysis for the portion of the MVP Project that crosses the JNF, including for geology resources. Results of that consistency analysis are included in Resource Report 8.

6.7.1 Paleontology

The Antiquities Act of 1906 protects “objects of antiquity” on federal lands. The Paleontological Resources Preservation Act of 2009 applies to federal lands, including the Bureau of Land Management and National Forest Service lands, as well as Native American lands, but does not apply to private land. Paleontological resources on federal lands are regulated, as outlined in 36 CFR Ch. 11 261.9 (i) and in 291. Part 291 covers the collection of paleontological resources on JNF lands. Casual collection is allowed for “common invertebrate and plant paleontological resources”. However, a permit from the United States Forest Service is required for collection of paleontological resources for scientific research.

Geology in the area of MP 195.32 to MP 196.9 is mapped as Lower Devonian and Silurian sandstone and limestone. Geology in the area of MP 217.2 to MP 219.4 is mapped as Lower Devonian and Silurian sandstone and limestone; and Devonian black shale, shale, siltstone, and sandstone. Communication with Tom Collins, Forest Geologist, revealed that no permits for the collection have been issued for the Forests (Collins, 2015) and that Mr. Collins is not aware of existing paleontological sites (collection sites or “type sections”) within the Forests. Paleontologists (Bambach, 2015; Xiao 2015; Scheckler 2015; Kowalewski 2015) familiar with the geology of the JNF did not raise concerns regarding fossil collection sites or type sections in the Project area.

Although significant paleontological resources are not anticipated in the Project area, Environmental Inspectors will be trained regarding response if suspected paleontological resources are identified during site preparation or trench excavation. MVP will temporarily suspend work and coordinate with the Forest Service in the event that a suspected paleontological find is identified in the Forest boundaries.

6.8 REFERENCES

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Appendix 6-A
Geology by Milepost
(Table, Map Set, Geologic Diagrammatic Section)

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Appendix 6-B
Depth to Bedrock by Milepost
(Table and Map Set)
and
Draft Blasting Plan

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Appendix 6-C
Mineral Resources
C.1 - Oil and Gas Wells Within 0.25 Mile of the MVP Project (Tables and Map Set)
C.2 – Uranium Report

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Appendix 6-D
Geologic Hazards
D.1 – Seismic Hazards
(2 Reports), Professional Credentials
D.2 – Karst Hazards
(Reports – Karst Hazards Reports (2 reports), Karst Mitigation Plan, Sinkhole Hazards Assessment)
D.3 – Steep Hill Slopes Crossed by the MVP Project (Map Set)