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ORIGINAL

Rockies Express Pipeline LLC

March 23, 2007

Philis Posey
Acting Secretary
Federal Energy Regulatory Commission
888 First Street, NE
Washington, DC 20426

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OFFICE OF THE
SECRETARY

2007 MAR 23 A 11: 30

FEDERAL ENERGY
REGULATORY COMMISSION

Re: Rockies Express Pipeline Project, REX-East
Docket No. PF06-30

Dear Ms. Posey:

Attached for filing in the above-referenced proceeding are revisions by Rockies Express Pipeline LLC (Rockies Express) to draft Resource Report Nos. 6 and 7. The revised draft resource reports respond to the data requests propounded by Staff to Rockies Express in this proceeding.

To assist with identification of issues, Rockies Express provides a spreadsheet indicating where in the resource reports each Staff data request has been addressed. A redline of the draft resource reports also is provided to Staff.

If you have any questions with regards to these materials please contact Ryan Childs at (307) 760-5635.

Sincerely,

Shippen Howe
Van Ness Feldman
1050 Thomas Jefferson Street, NW
Washington, DC 20426

Attorney for
Rockies Express Pipeline LLC

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cc: Laura Turner
Don Hammer

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Rockies Express Pipeline-East Project Response to Data Requests Pertaining to Resource Report 6	
FERC Data Request	Resource Report and Section Revised
January 24, 2007	
27. In Table 6.2-1, fill in the data which is listed as "NA" because it was not available in a data base.	See table 6.2-1 of Resource Report 6, Rev. 1.
28. Provide a discussion on paleontological resources, including potential impacts and mitigation.	See sections 6.5 and 6.6 of Resource Report 6, Rev. 1.
29. Rockies Express should expand its discussion of impacts on mineral resources. Rockies Express indicates construction of the pipeline would not preclude affect the production of mineral resources because the majority of the existing operations are limited by roads and/or property lines. This statement may not be accurate, roads would not necessary limit underground operations and property may be sold.	See section 6.6 of Resource Report 6, Rev. 1.
30. Identify the location of abandoned coal mines by mile post, depth, and type of mining (long wall, pillar and post, etc.).	See table 6.3-2 of Resource Report 6, Rev. 1.
31. Identify the location of oil and gas wells in the vicinity of the proposed pipeline. Also, identify any gathering lines crossed by the proposed pipeline and any area where blasting may occur. Discuss what mitigation measures would be implemented to ensure no oil or gas wells would be damaged.	See sections 6.3 and 6.6 and Appendix 6C of Resource Report 6, Rev. 1.
32. Provide information on flooding and scouring and identify any areas along the proposed pipeline with the potential for severe scour.	See section 6.4.6 and table 6.4.6-1 of Resource Report 6, Rev. 1.
33. Provide a project specific blasting plan.	See Appendix 6E of Resource Report 6, Rev. 1
34. Discuss the impact on the proposed pipeline from ground subsidence (karst or mine collapse). Discuss any mitigation measure that would be used to safe guard the pipeline from these hazards.	See sections 6.3, 6.4.4, and 6.6 of Resource Report 6, Rev.1.
35. Provide approximate mile post of areas with 'moderate' and 'high' susceptibility for landslides.	See table 6.4.5-1 of Resource Report 6, Rev. 1.

Rockies Express Pipeline-East Project Response to Data Requests Pertaining to Resource Report 7	
FERC Data Request	**Resource Report and Section Revised**
January 24, 2007	
36. After construction how often would Rockies Express patrol the pipeline?	See section 7.3.1.3 of Resource Report 7, Rev. 1.
37. How would Rockies Express monitor the depth of cover over the pipeline after construction?	See section 7.3.1.3 of Resource Report 7, Rev. 1.
38. Expand Table 7.2.6-1 to include all meter stations. Soil characteristics should include hydric soils.	See table 7.2.6-2 of Resource Report 7, Rev. 1.
39. Provide the locations where Bonnell series soils are crossed. Describe the potential impacts to soils in these areas and any mitigation Rockies Express proposes in these areas.	See section 7.3.1-1 and Appendix 7D of Resource Report 7, Rev. 1.

Rockies Express Pipeline

ROCKIES EXPRESS PIPELINE-EAST PROJECT

Resource Report 6
Geologic Resources

Draft – Rev. 1

Prepared by

March 2007

ROCKIES EXPRESS PIPELINE-EAST PROJECT
Rockies Express Pipeline LLC
Resource Report 6

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Appendix 6B	Bedrock Geology Along the Rockies Express Pipeline-East Project Pipeline Route
Appendix 6C	Oil and Gas Wells within 500 feet of the Rockies Express Pipeline-East Project Pipeline Route
Appendix 6D	Agency Correspondence
Appendix 6E	Rockies Express Pipeline-East Project Blasting Plan
Appendix 6F	Engineering Assessment of Coal Mining Subsidence Effects on Rockies Express Pipeline

6.0 RESOURCE REPORT 6 – GEOLOGIC RESOURCES

Table 6-1 lists the filing requirements found in Title 18 of the Code of Federal Regulations (CFR) § 380.12 applicable to Resource Report 6 and the locations in this report where each requirement is addressed.

TABLE 6-1

Rockies Express Pipeline-East Project
Resource Report 6 Filing Requirements Checklist

Filing Requirement	Requirement Addressed	Location within this Document
18 CFR § 380.12 (h) Geological Resources	✓	Sections 6.0, 6.1, and 6.2
18 CFR § 380.12 (h)(1) Mineral Resources	✓	Section 6.3
18 CFR § 380.12 (h)(2) Existing and Potential Geologic Hazards	✓	Section 6.4
18 CFR § 380.12 (h)(3) Minimization of Adverse Effects and Blasting	✓	Section 6.6
18 CFR § 380.12 (h)(4) Mine Reclamation	NA	Not Applicable
18 CFR § 380.12 (h)(5) LNG Facilities	NA	Not Applicable
18 CFR § 380.12 (h)(6) Underground Storage	NA	Not Applicable

6.1 GEOLOGIC SETTING

6.1.1 Pipeline Facilities

The Rockies Express Pipeline-East (REX-East) Project west of the Mississippi River is located within the Dissected Till Plains Section of the Central Lowlands physiographic province. This section contains older Kansan-age (410,000 to 380,000 years ago) glacial deposits that are consequently more dissected than the younger Wisconsinan-age (12,000 to 10,000 years ago) and Illinoian-age (310,000 to 130,000 years ago) glacial deposits of the Till Plains Section to the east. This section is mantled with loess that is commonly more than 30 feet thick. Valleys in this section are more closely spaced and the uplands more rounded than they are east of the Mississippi River.

The portion of the project located east of the Mississippi River to eastern Ohio is located in the Till Plains Section of the Central Lowlands physiographic province. The Till Plains Section is characterized by knob and kettle topography but consists of broad level uplands between valleys that have steep sides and broad floodplains. This section has integrated drainage and contains few lakes or ponds. The majority of this section lies south of the extent of the most recent glaciation.

The eastern Ohio portion of the proposed project is located in the Glaciated and Unglaciated Allegheny Plateau Sections of the Appalachian Plateaus physiographic province. These sections consist of a large, highly dissected, plateau where the relief ranges from less than 100 feet to greater than 400 feet largely dependent on the presence or absence of glacial deposits (Fenneman, 1938; Hunt, 1967).

The landscape in the area of the proposed project has been shaped by multiple glacial events, which have produced a variety of erosional and depositional landforms. The predominant surficial geology of the area consists of late Wisconsinan-age and Illinoian-age glacial deposits. However, the Missouri portion of the proposed route is located in an area of pre-Illinoian-age deposits. Surficial deposits in this portion of the project typically range in thickness between 50 and 100 feet and consist of glacial till with isolated areas of alluvium, residuum, and colluvium. The Illinois and Indiana portions of the proposed project is underlain by mostly end and ground moraine deposits consisting of loamy till, as well as areas of alluvium and outwash deposits. Surficial deposits in this area range in thickness from 0 to 300 feet but the majority of the route will cross areas with greater than 25 feet of unconsolidated material at the surface. Surficial deposits in the western Ohio portion of the proposed project are relatively similar to those described above. However, the unglaciated eastern portion of Ohio consists mostly of colluvium with isolated areas of lacustrine and alluvium deposits. Table 6A-1 in Appendix 6A summarizes by milepost the surficial geology crossed by the pipeline route (Fullerton et al., 2004).

Elevations along the pipeline route range from 424 to 1,332 feet above sea level (see table 6.1.1-1). Topography in the project area ranges from flat to very steep, with slopes ranging from 0 to greater than 30 percent along the pipeline route. Approximately 69 percent of the pipeline route will cross soils with slopes of 5 percent or less (U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), 1994).

TABLE 6.1.1-1

Rockies Express Pipeline-East Project
Range of Elevations Along the Proposed Pipeline Route

State/County	Begin Milepost	End Milepost	Elevation Above Mean Sea Level (feet) Minimum	Average	Maximum
MISSOURI					
Audrain	0.0	15.8	737	764	783
Ralls	15.8	19.8	731	757	775
Pike	19.8	43.0	447	685	888
ILLINOIS					
Pike	43.1	71.2	425	574	751
Scott	71.2	86.3	424	570	679
Morgan	86.3	106.4	591	667	712
Sangamon	106.4	132.0	535	607	655
	134.7	135.2	585	589	591
Christian	132.0	134.7	543	575	593
	135.3	151.0	565	598	626
Macon	151.0	172.0	589	679	734
Moultrie	172.1	187.5	660	682	726
Douglas	187.5	214.6	621	654	692
Edgar	214.6	238.1	586	652	693
INDIANA					
Vermillion	238.1	247.2	460	620	662
Parke	247.2	267.8	460	667	797
Putnam	267.9	286.8	664	855	985
Hendricks	286.8	304.1	699	866	960
Morgan	304.1	318.4	616	696	795
Johnson	318.4	338.5	664	757	837

TABLE 6.1.1-1

Rockies Express Pipeline-East Project
Range of Elevations Along the Proposed Pipeline Route

State/County	Begin Milepost	End Milepost	Elevation Above Mean Sea Level (feet) Minimum	Average	Maximum
Shelby	338.5	357.9	675	766	879
Decatur	357.9	376.1	814	957	1,068
Franklin	376.1	404.0	596	876	1,010
OHIO					
Butler	404.0	435.9	609	722	930
Warren	435.9	457.8	655	864	990
Clinton	457.9	472.1	840	1,009	1,083
Greene	472.1	474.9	1,060	1,069	1,086
Fayette	474.9	498.3	810	982	1,060
Pickaway	498.3	522.4	659	768	876
Fairfield	522.4	546.8	832	972	1,111
Perry	546.8	564.7	749	983	1,110
Muskingum	564.7	590.2	675	909	1,131
Guernsey	590.3	609.8	796	981	1,238
	611.6	611.8	1,175	1,192	1,212
Noble	609.8	611.6	1,008	1,174	1,260
	611.8	616.6	938	1,099	1,271
Belmont	616.6	632.3	986	1,183	1,333
Monroe	632.3	637.6	1,035	1,187	1,316
Project Total			424	790	1,332

The majority of the project is underlain by middle to upper Paleozoic sedimentary rock with areas of lower Paleozoic sedimentary rock in western Ohio and eastern Indiana (Reed and Bush, 2005). The area crossed by the pipeline route in Missouri and Illinois is predominantly underlain by Pennsylvanian age limestone, shale, and sandstone. The western Indiana and eastern Ohio portion of the pipeline route are underlain by similar bedrock, which consists of mostly Pennsylvanian and Mississippian age shale, siltstone, and sandstone. The remainder of the project area is underlain by mostly Ordovician and Silurian limestone and dolomite. Table 6B-1 in Appendix 6B summarizes by milepost the geologic units crossed by the REX-East Project pipeline route (Gray et al., 1987; Slucher, 2006; Illinois State Geological Survey (ISGS), 1996a; Missouri Department of Natural Resources, Division of Geology and Land Survey (MDNR, DGLS), 2006a).

The proposed laterals to the meter stations will be located in the same geological setting, and affect the same geological resources, as the corresponding milepost (i.e., the meter station milepost) along the proposed pipeline route.

6.1.2 Aboveground Facilities

The REX-East Project includes the construction and operation of five new compressor stations located along the REX-East Project pipeline route, one new compressor station located on the existing REX-West pipeline, and construction of a compressor station at its previously certificated pig launcher and receiver facility on the REX-Entrega pipeline. Additional aboveground facilities will include 20 meter stations, 42 pipeline valves and associated interconnects, 4 launchers, and 4 receivers (see section 1.1.2.2 of Resource Report 1). With the exception of the two compressor stations in Wyoming and Nebraska (Arlington and Bertrand), all of the aboveground facilities associated with the REX-East Project will be located in close proximity to the pipeline and will be underlain by geologic resources described above for the pipeline facilities. The proposed compressor stations along the REX-West and REX-Entrega pipeline routes are underlain by Tertiary-age sandstone, shale, and siltstone with surficial deposits consisting of mostly alluvium and eolian deposits.

6.2 BLASTING

Based on analysis of the state-level State Soil Geographic (STATSGO) database, approximately 12 percent (79.3 miles) of the pipeline route will cross areas with bedrock at depths of less than 60 inches (USDA, NRCS, 1994). The majority of these soils are located along the eastern Ohio portion of the proposed route. Analysis of the county-level Soil Survey Geographic Database (SSURGO) database showed similar results with approximately 84.8 miles of the proposed route being underlain by shallow bedrock (USDA, NRCS, 2003). Approximately one half of this bedrock is considered paralithic (soft) and will not likely require blasting during construction. The remaining areas will cross soils with a lithic contact (hard bedrock) within 60 inches of the surface that may require blasting or other special construction techniques during installation of the proposed pipeline. A milepost-specific list of the soil map units along the proposed route that contain bedrock within 60 inches of the surface is included in Appendix 7E. Table 6.2-1 provides a summary by county of the shallow bedrock along the proposed route based on analysis of the SSURGO database. Spatial SSURGO data was unavailable for Macon County, Illinois and Fayette County, Ohio. However, based on the STATSGO database, no soils with shallow bedrock will be crossed in those counties.

TABLE 6.2-1

Rockies Express Pipeline-East Project
Shallow Bedrock Along the Proposed Pipeline Route [a]

State/County	Crossing Length (miles)	Bedrock Type [b]	
		Lithic (miles)	Paralithic (miles)
MISSOURI			
Audrain	15.8	–	–
Ralls	4.0	–	–
Pike	23.2	0.1	0.1
Missouri Subtotal	43.0	0.1	0.1
ILLINOIS			
Pike	26.2	0.1	–
Scott	15.1	–	–
Morgan	20.1	–	–
Sangamon	26.2	–	–
Christian	18.4	–	–
Macon [c]	21.1	–	–
Moultrie	15.4	–	–
Douglas	27.2	–	–
Edgar	23.5	–	–
Illinois Subtotal	195.2	0.1	0.0
INDIANA			
Vermillion	9.1	–	0.1
Parke	20.6	–	–

TABLE 6.2-1

Rockies Express Pipeline-East Project
Shallow Bedrock Along the Proposed Pipeline Route [a]

State/County	Crossing Length (miles)	Bedrock Type [b] Lithic (miles)	Paralithic (miles)
Putnam	19.0	--	--
Hendricks	17.3	--	--
Morgan	14.3	--	0.0
Johnson	20.1	--	--
Shelby	19.5	--	--
Decatur	18.2	0.4	--
Franklin	27.9	--	3.6
Indiana Subtotal	165.9	0.4	3.7
OHIO			
Butler	31.9	--	9.9
Warren	21.9	0.1	2.6
Clinton	14.3	0.1	--
Greene	2.8	--	--
Fayette [c]	23.4	--	--
Pickaway	24.1	--	--
Fairfield	24.4	1.0	0.1
Perry	17.9	5.5	2.8
Muskingum	25.5	7.9	12.1
Guernsey	19.7	3.7	10.3
Noble	8.6	1.1	2.7
Belmont	15.7	14.1	1.2
Monroe	5.3	3.8	1.5
Ohio Subtotal	233.6	37.3	43.2
Project Total	637.6	37.8	47.0

[a] Based on analysis of the Soil Survey Geographic (SSURGO) database.
[b] Paralithic refers to "soft" bedrock that will not likely require blasting during construction. Lithic refers to "hard" bedrock that may require blasting or other special construction techniques during installation of the proposed pipeline.
[c] Spatial SSURGO data was not available. Based on analysis of the State Soil Geographic (STATSGO) database.

Note: The numbers in this table have been rounded for presentation purposes. As a result, the totals may not reflect the exact sum of the addends in all cases. Some totals may be off by 0.1 place.

6.3 MINERAL RESOURCES

A wide variety of exploitable and potentially exploitable mineral resources occur in the states affected by the REX-East Project. The most predominant exploitable resource found in the states crossed by the pipeline route is crushed stone. Crushed stone accounted for between 31 and 44 percent of the total nonfuel raw mineral production value of each respective state in 2004. Another predominant exploitable resource found in the states affected by the project is cement. Portland and masonry type cement, combined accounted for between 9 and 29 percent of the total nonfuel mineral production value of each respective state in 2004. Additional mineral resources in the states crossed by the pipeline route include sand and gravel, lead, lime, and salt. Nonfuel mineral resources in Nebraska consist of cement, sand and gravel, and crushed stone. In Wyoming, nonfuel mineral resources include soda ash, bentonite, Grade-A helium, and portland cement (U.S. Geologic Survey (USGS), 2004).

Rockies Express received scoping comments regarding potential impacts on mining operations in the vicinity of the project area. USGS topographic maps and 2005 aerial photography were used to identify surface features possibly associated with mining or mineral resources. Table 6.3-1 identifies mining and mineral resource areas within 1,500 feet of the pipeline route. All of the localities listed are associated with non-metallic resources and include two quarries, two gravel pits, and six sand/gravel pit. No mineral resources have been identified within 1,500 feet of the Arlington and Bertrand Compressor Stations in Wyoming and Nebraska, respectively.

TABLE 6.3-1

Rockies Express Pipeline-East Project
Mineral Resources within 1,500 feet of the Proposed Pipeline Route [a]

State/County	Milepost	Operation	Distance and Direction from the Right-of-Way
ILLINOIS			
Pike	59.9	Quarry	1,300 feet Southeast
	70.6	Gravel Pit	1,250 feet South
Douglas	199.8	Quarry	500 feet North
INDIANA			
Morgan	309.9	Sand / Gravel Pit [b]	575 feet West
	314.8	Sand / Gravel Pit [b]	1,000 feet Northeast
	315.0	Sand / Gravel Pit [b]	500 feet West
OHIO			
Butler	424.2	Gravel Pit	450 feet Southwest
	429.9	Sand / Gravel Pit [b]	1,000 feet North
	434.3	Sand / Gravel Pit [b]	215 feet North
	471.5	Sand / Gravel Pit [b]	1500 feet North

[a] Based on a review of U.S. Geological Survey (USGS) topographic maps and 2005 aerial photography.
[b] Based on interpretation of 2005 aerial photography. Not identified on USGS topographic maps.

Oil and gas production is another exploitable resource found in the states crossed by the project. Although the majority of the oil and gas fields in Missouri, Illinois, Indiana, and western Ohio are located outside the region that will be crossed by the pipeline route, the eastern Ohio portion of the pipeline will cross numerous oils and gas fields, particularly in Perry, Muskingum, and Guernsey Counties (Ohio Department of Natural Resources, Division of Geological Survey (ODNR, DGS), 2004). No oil and gas wells were identified in Missouri (MDNR, 2002). However, oils and gas wells were identified in Christian County, Illinois; Shelby and Decatur Counties, Indiana; and throughout eastern Ohio (ISGS, 2007; Indiana Geological Survey (INGS), 2002; ODNR, DGS, 2004). Table 6C-1 in Appendix 6C identifies by milepost the oil and gas wells within 500 feet of the proposed pipeline route. Oil and gas production is also common in Wyoming and Nebraska; however, no wells have been identified in the vicinity of the proposed compressor stations along the REX-West and REX-Entrega pipeline routes.

The proposed pipeline route will cross two coal producing regions of the United States, the Interior region in Missouri, Illinois, and Indiana, and the Appalachian region in Ohio. In 2005, these states accounted for approximately 8 percent of all United States coal production.

Wyoming is located in the Western coal producing region and accounted for 36 percent of United States coal production in 2005. No coal was produced in Nebraska in 2005 (Energy *Information Administration, 2006*).

Underground mining for coal has occurred in the states crossed by the project since the 1800s. In the United States, the traditional method used is room-and-pillar mining. This consists of excavating an area ("room") while leaving pillars of coal in place to support the mine roof. The other basic method of underground coal mining is longwall mining. Longwall mining involves the essentially complete removal of coal contained in a large rectangular block or "panel." Following removal of the coal, the mined-out area is allowed to collapse. Longwall mining coal production has grown rapidly over the past 50 years and is now one of the principal underground mining methods in the United States (Energy Information Administration, 1995).

According to the 2004 Keystone Coal Industry Manual, active coal mining operations occur in eight of the counties crossed by the pipeline route: Sangamon County, Illinois; Parke County, Indiana; and Perry, Muskingum, Guernsey, Noble, Belmont, and Monroe Counties, Ohio (Mining Media, 2004). Based on a review of aerial photography and USGS topographic mapping, no active coal mines were identified within 0.5 mile of the pipeline route or associated facilities. Additionally, no abandoned mines were identified along the pipeline route in Missouri or Indiana (MDNR, 2006b; INGS, 2002). However, portions of the pipeline route in Illinois and Ohio will cross areas underlain by abandoned underground mines (Stiff, 1997; Crowell, et al., 2006). Table 6.3-2 identifies areas along the proposed pipeline route underlain by abandoned underground mines. To determine the depths of these mines, Rockies Express consulted with the ODNR, DGS. The ODNR, DGS staff stated that it was difficult to determine the depth of a mine at a particular location due to the fact that reported depths, if present, represent an average elevation or the elevation at a specific location. The ODNR, DGS staff also stated that the depth of the mines can vary substantially between mining operations as well as within an *individual mine, depending on its size (Gordon, 2007).*

TABLE 6.3-2

Rockies Express Pipeline-East Project
Abandoned Underground Mines Along the Proposed Pipeline Route [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Type of Mining	Identification Code
ILLINOIS					
Sangamon	117.4	118.9	1.4	Room and Pillar	193
	118.9	118.9	<0.1	Room and Pillar	193
Douglas	208.1	208.2	0.1	Room and Pillar	668
	208.5	211.8	3.2	Room and Pillar	668
OHIO					
Perry	559.6	559.6	<0.1	Room and Pillar	341278020802
	559.8	559.9	0.1	Room and Pillar	341278003302
	560.0	560.0	0.1	Room and Pillar	341278003302
	560.0	560.1	0.1	Room and Pillar	341278003302
	561.0	561.1	0.1	Room and Pillar	341278035602
	562.2	562.2	0.1	Room and Pillar	341278026002
	562.3	562.4	0.1	Room and Pillar	341278026002
	562.5	562.8	0.2	Room and Pillar	341278026002
	562.8	563.1	0.3	Room and Pillar	341278026002
	563.2	563.5	0.4	Room and Pillar	341278026002

TABLE 6.3-2

Rockies Express Pipeline-East Project
Abandoned Underground Mines Along the Proposed Pipeline Route [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Type of Mining	Identification Code
Muskingum	565.4	565.5	0.1	Room and Pillar	341198019102
	565.5	565.6	<0.1	Room and Pillar	341198019102
	565.7	565.8	0.1	Room and Pillar	341198019102
	565.9	565.9	0.1	Room and Pillar	341198019102
	566.1	566.6	0.5	Room and Pillar	341198019102
	569.2	569.6	0.3	Room and Pillar	341198019402
	570.0	570.0	<0.1	Room and Pillar	341198022002
	570.0	570.2	0.1	Room and Pillar	341198022002
Guernsey	593.9	594.5	0.7	Room and Pillar	340598004802
	594.5	594.7	0.2	Room and Pillar	340598005202
	594.7	594.9	0.2	Room and Pillar	340598004802
	594.9	595.0	0.2	Room and Pillar	340598005202
	595.0	595.1	<0.1	Room and Pillar	340598004802
	596.1	596.3	0.2	Room and Pillar	340598002802
	596.4	596.5	0.1	Room and Pillar	340598002802
	597.3	597.7	0.4	Room and Pillar	340598000302
	598.8	599.4	0.6	Room and Pillar	340598000602
	599.4	600.3	1.0	Room and Pillar	340598005402
	600.4	600.8	0.5	Room and Pillar	340598004902
	600.9	601.1	0.3	Room and Pillar	340598004902
	601.1	602.1	0.9	Room and Pillar	340598005002
	602.3	602.3	<0.1	Room and Pillar	340598003502
	602.3	602.9	0.5	Room and Pillar	340598003502
	604.4	604.6	0.2	Room and Pillar	340598006502
	604.6	604.7	<0.1	Room and Pillar	340598006502
	604.7	604.7	<0.1	Room and Pillar	340598006502
Belmont	628.2	628.3	0.2	Room and Pillar and Longwall	340138030202
	628.4	629.6	1.3	Room and Pillar and Longwall	340138030202
Monroe	632.3	632.4	0.1	Room and Pillar	340138027002
	632.8	637.6	4.8	Room and Pillar	340138027002

[a] Stiff, 1997; Crowell, et al., 2006

One impact of underground mining, particularly longwall mining, is subsidence at the surface when the mine collapses. Subsidence from underground mining takes two forms, pit and sag. Pits are usually 6 to 8 feet deep and range from 2 to 40 feet in diameter, although most are less than 16 feet across. Newly formed pits have steep sides with straight or bell-shaped walls. Sag subsidence forms a gentle depression over a broad area. Some sags may be as large as a whole mine panel several hundred feet long and a few hundred feet wide. Several acres of land may be affected. During sag subsidence the ground drops vertically and moves horizontally toward the center of the sag. At the surface, the sag may be much broader than the collapsed part of the mine. For example, a roof failure in a mine 160 feet deep could cause minor surface subsidence more than 75 feet beyond the edge of the undermined area. The potential damage of subsidence on structures (e.g., building, roads, or utility lines) at or near the surface depends on the structures orientation and position within the subsided area (Energy Information Administration, 1995).

6.4 GEOLOGIC HAZARDS

6.4.1 Seismic Hazards

Earthquake intensity is a measure of the extent to which man-made structures are damaged by a seismic event and generally depends on distance from the epicenter of that event. The Modified Mercalli Intensity (MMI) scale 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 are thrown into the air (Cargo and Mallory, 1977). Table 6.4.1-1 describes a range of earthquake intensities and their potential effects, some of which might be experienced in the REX-East Project area.

TABLE 6.4.1-1

Rockies Express Pipeline-East Project
Range of Earthquake Intensities [a]

Modified Mercalli Intensity Value	Description of Intensity (Severity) Factors
I	Not felt except by a very few people under especially favorable circumstances.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like a passing truck.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate damage in well-built ordinary structures; considerable damage in poorly-built or badly designed structures. Some chimneys broken. Noticed by persons driving automobiles.
XII	Damage Total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

[a] Modified from Cargo and Mallory, 1977.

Seismic activity in the region surrounding the pipeline route is generally linked to the New Madrid seismic zone. The center of the zone, or area in which the probability of a seismic event is highest, is located south of the project area, along the adjoining boundaries of Missouri, Arkansas, and Tennessee. Between December 1811 and February 1812, three of the most powerful earthquakes in United States history originated in this area. Of the three major shocks that occurred within the series, historic evidence indicates that at least one of the shocks originated in Missouri. It is reported that these three main shocks reached intensity XII, the maximum on the MMI scale (USGS, 2006a). Since that time numerous intensity V or greater earthquakes have been reported in Missouri, Illinois, Indiana, and Ohio. Numerous seismic events have also been recorded in Wyoming and Nebraska. The majority of these events, however, did not occur in the vicinity of the project area.

Based on the Seismic Source Zones Map provided in Algermissen et al. (1982), the majority of the project area (including Nebraska) could experience about three to six intensity V earthquakes every 100 years (maximum Richter magnitude of 6.1). However, portions of the project in Indiana and western Ohio could experience between 11 and 15 intensity V earthquakes every 100 years (maximum Richter magnitude of 6.1). The proposed compressor station along the REX-Entrega pipeline in Wyoming is located in Seismic Source Zone that could experience as many as 45 intensity V earthquakes every 100 years (maximum Richter magnitude of 6.1). However, no intensity V earthquakes have been recorded in the vicinity of the compressor station site.

6.4.2 Active Faults

The proposed REX-East Project pipeline route and associated facilities (including Nebraska and Wyoming) will not cross any identified Quaternary-aged faults (National Atlas of the United States, 2007; USGS, 2006b). However, in southeastern Illinois and southwestern Indiana the proposed project will cross an area containing features interpreted to be the result of earthquake induced liquefaction. Liquefaction features in this area provide evidence of Quaternary faulting; however, no individual faults have been identified. These features consist of clastic dikes filled with sand and gravel that are planar and have a near vertical orientation. The project area is located on the far northern portion of the area defined as containing these features and is well north of the Wabash Valley fault system (Obermeir and Crone, 1994; René and Stanonis, 1995).

6.4.3 Soil Liquefaction

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. The Federal Energy Regulatory Commission (FERC) defines areas with potential for seismic soil liquefaction in the "Order Establishing Guidelines for the Submission of Required Data for Pipeline Projects" issued July 27, 1988. Based on this document, areas with the potential for soil liquefaction are:

- underlain by Holocene deposits which are likely to be non-cohesive, such as alluvial, lacustrine, and shoreline deposits;
- where the water table occurs at 10 feet or less below the surface; and
- where the USGS Open File Report 82-1033 (Algermissen et al., 1982) indicates a 10 percent probability that horizontal ground accelerations of 10 percent of gravity or greater will be exceeded in 50 years (referred to as "seismic threshold").

In the vicinity of the proposed REX-East Project, the floodplains of the Illinois River, the Mississippi River, and most of the other rivers that will be crossed by the pipeline route have the potential of being underlain by Holocene deposits. In addition, the water table below portions of the project area occurs at 10 feet or less below the land surface. However, the FERC-defined seismic threshold is not met anywhere in the project area (including Nebraska and Wyoming); peak horizontal ground accelerations with 10 percent probability of exceedance in 50 years are only 6 percent of gravity or less (USGS, 2002). Therefore, based on the FERC-defined criteria, soil liquefaction is not a significant hazard in the vicinity of the proposed project. The proposed project will cross an area in the Wabash Valley region identified as containing liquefaction features. However, no historical earthquakes in this area have been strong enough to cause liquefaction. These features were likely the result of prehistoric events in the Holocene and late Pleistocene epochs (Obermeir and Crone, 1994).

6.4.4 Karst Potential / Ground Subsidence

Karst features such as sinkholes, caves, and caverns can form as a result of the long-term action of groundwater on soluble carbonate rocks (e.g., limestone and dolostone). Underground mining also poses risks to engineered structures due to the potential of the overlying strata to collapse into the void formed by the extraction of minerals (see section 6.3).

Approximately 24 percent of the pipeline route is located in areas that are considered to have the potential for karst features. These areas are generally considered to have the potential for karst features from 10 to 200 feet below the ground surface in gently dipping to flat-lying beds of carbonate rock. Potential features consist of fissures, tubes, and caves that are generally less than 1,000 feet long and 50 feet in vertical extent (Davies, et al., 1984; National Atlas of the United States, 2007). The majority of theses areas are located in Missouri, western Illinois, and eastern Indiana. Table 6.4.4-1 identifies areas along the proposed pipeline route with the potential for karst features.

TABLE 6.4.4-1

Rockies Express Pipeline-East Project
Areas Along the Proposed Pipeline Route with the Potential for Karst Features [a]

State/County	Begin Milepost	End Milepost	Length (miles)
MISSOURI			
Pike	25.4	42.7	17.2
Missouri Subtotal			17.2
ILLINOIS			
Pike	54.5	71.2	16.7
Scott	71.2	83.5	12.3
Illinois Subtotal			29.0
INDIANA			
Putnam	268.0	281.5	13.5
Shelby	342.5	357.9	15.4
Decatur	357.9	376.1	18.2
Franklin	376.1	397.2	21.1
Indiana Subtotal			68.2
OHIO			
Clinton	462.7	472.1	9.4
Greene	472.1	474.9	2.8
Fayette	474.9	498.3	23.4
Pickaway	498.3	499.2	0.9
Ohio Subtotal			36.5
Project Total			150.9

[a] Davies, et al., 1984; National Atlas of the United States, 2007

The proposed compressor stations along the REX-West and REX-Entrega pipeline routes are not located in areas considered to have the potential for karst features. Rockies

Express is not aware of any known karst features in the vicinity of the REX-East Project area and does not anticipate any impacts on the proposed project facilities from karst development.

Based on the digital soil mapping (i.e., SSURGO) for the areas along the pipeline route with the potential for karst features, only about 2 percent of the soils crossed in those areas contain shallow bedrock.

6.4.5 Landslides

Landslides involve the down slope movement of earth materials under a force of gravity due to natural or man-made causes. The majority (94 percent) of the REX-East Project is in a low landslide incidence area (Godt, 1997). However, portions of the pipeline route located in eastern Ohio are in moderate and high incidence areas (Godt, 1997). In addition, portions of the low incidence areas crossed in this area and isolated areas along the pipeline route are considered to be moderately or highly susceptible to landslides. Table 6.4.5-1 identifies areas along the proposed pipeline route with moderate or high susceptibility to landslides (Godt, 1997). Based on an analysis of the STATSGO database (digital soil survey data), the majority (69 percent) of the soils crossed by the pipeline route have slopes less than or equal to 5 percent and, therefore, are less susceptible to landslides. However, the percent slope is greater than 30 percent in portions of the higher incidence/susceptibility areas referred to above (USDA, NRCS, 1994). Small, localized debris flows or slides may also occur in the vicinity of river and stream banks with steep slopes, particularly after intense precipitation events (USGS, 2000).

TABLE 6.4.5-1

Rockies Express Pipeline-East Project
Areas Along the Proposed Pipeline Route with Moderate or High Susceptibility to Landslides [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Susceptibility	Incidence
MISSOURI					
Audrain	7.8	15.8	8.0	Moderate	Low
Ralls	15.8	19.8	4.0	Moderate	Low
Pike	19.8	36.4	16.6	Moderate	Low
	36.4	43.0	6.7	High	Low
Missouri Subtotal			35.3		
ILLINOIS					
Pike	43.0	69.7	26.7	High	Low
Illinois Subtotal			26.7		
INDIANA					
Hendricks	290.8	300.9	10.0	Moderate	Low
	300.9	304.1	3.3	Moderate	Low
Morgan	304.1	306.4	2.2	Moderate	Low
Franklin	378.8	396.1	17.3	High	Low
Indiana Subtotal			32.9		
OHIO					
Perry	556.3	564.7	8.4	High	Low
Muskingum	564.7	575.9	11.1	High	Low
	575.9	590.3	14.4	High	Low
Guernsey	590.3	590.3	<0.1	High	Low
	590.3	593.3	3.0	High	Moderate
	593.3	601.2	8.0	High	Low
	601.2	609.8	8.5	High	Moderate

TABLE 6.4.5-1

Rockies Express Pipeline-East Project
Areas Along the Proposed Pipeline Route with Moderate or High Susceptibility to Landslides [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Susceptibility	Incidence
Noble	609.8	611.6	1.9	High	Moderate
Guernsey	611.6	611.8	0.2	High	Moderate
Noble	611.8	616.6	4.7	High	Moderate
Belmont	616.6	616.6	0.1	High	Moderate
	616.6	632.3	15.6	High	High
Monroe	632.3	637.6	5.3	High	High
Ohio Subtotal			81.2		
Project Total			176.0		

[a] Source: Godt, 1997

6.4.6 Stream Bottom Scour

Sediments composing the substrate below active stream channels are susceptible to scour during flood conditions. Normal stream bottom scour can remove surface cover from the pipeline and could expose the pipe if scour depths exceed pipe burial depths. Stream scour from flood currents could also expose the pipeline to excessive lateral forces and create unsupported spans of pipe. Scour potential depends largely on flood flow characteristics and grain size of the bottom sediments. Significant stream scour is normally limited to areas where the crossing location is near a bend in the waterbody. Based on a review of the current pipeline crossing locations and aerial photography, table 6.4.6-1 identifies areas along the pipeline route with the potential for severe stream scour.

TABLE 6.4.6-1

Rockies Express Pipeline-East Project
Waterbodies Crossed by the Proposed Pipeline Route with the Potential for Severe Stream Scour [a]

State/County	Milepost	Waterbody
ILLINOIS		
Pike	47.3	Sny River
Douglas	193.3	Kaskaskia River
INDIANA		
Parke	250.7	Leatherwood Creek
Putnam	269.8	Raccoon Creek
Johnson	337.1	Sugar Creek
OHIO		
Pickaway	514.2	Walnut Creek

[a] Based on interpretation of 2005 aerial photography.

The proposed crossing method for these waterbodies is identified in Appendix 2A of Resource Report 2. Rockies Express intends to cross waterbodies at perpendicular angles away from bends and will install the pipeline at a sufficient depth (greater than 5 feet) to prevent exposure due to stream scour. The pipe will therefore be located well below potential scour depths.

During the pre-filing scoping process, a landowner expressed concern about pipe exposure due to flooding and erosion at the Walnut Fork and Pipe Creek crossings in Franklin County, Illinois. *Based on topography, this area may have the potential for flooding; however,* these locations have a well established riparian zones and active cultivation on the adjacent bank. Rockies Express is committed to preventing pipe exposure at waterbody crossing and will utilize mitigations measures (e.g., rip rap, seeding) as needed to prevent severe stream scour.

6.5 PALEONTOLOGICAL RESOURCES

Rockies Express consulted with various state agencies to identify potential areas of sensitive paleontological resources along the pipeline route. To obtain project-specific information, Rockies Express provided these offices with maps of the proposed route. The MDNR, DGLS; ISGS; and INGS did not identify any specific significant paleontological resources in the vicinity of the proposed pipeline route that need protection. In addition, any bedrock that may be trenched through is sufficiently duplicated in areas adjacent to the right-of-way so that no significant impacts on paleontological resources will result from the loss of bedrock in the trench (Kaden, 2007; Keith, 2007; Mikulic, 2007). The ODNR, DGS staff identified three areas (MPs 441.0 to 445.7, MPs 447.6 to 449.8, and MPs 457.8 to 460.9) with the potential to contain Ohio's official fossil (trilobite genus *Isotelus*). However, the ODNR, DGS staff also stated that, although these specimens are rare, there is no need for precaution with regard to construction (Shrake, 2007). Rockies Express also consulted with the Illinois State Museum (ISM) at the request of ISGS staff. The ISM identified various Wisconsinan-age and Illinioan-age surficial deposits in the vicinity of the project with the potential for fossil assemblages. These include the Kelllerville, Vandalia, Radnor, and Hagerstown members of the Glasford Formation, and the Wedron and Equality Formations (Saunders, 2007). *Table 6.5-1 identifies areas along the Illinois portion of the proposed pipeline route underlain by these* formations (ISGS, 1984; ISGS, 1996b). The various members of the Glasford formation are not especially fossiliferous, but isolated material has been found in these deposits. The Wedron and Equality formations, however, can be significantly fossiliferous for large mammals (Saunders, 2007). Correspondence related to paleontological resources in the project area are included in Appendix 6D.

TABLE 6.5-1

Rockies Express Pipeline-East Project
Geologic Formations Along the Proposed Pipeline Route In Illinois with the Potential for Paleontological Resources [a]

County	Begin Milepost	End Milepost	Length (miles)	Symbol	Formation - Member
Pike	65.3	70.4	5.1	gk	Glasford - Kellerville
Scott	75.0	86.3	11.3	gv	Glasford - Vandalia
Morgan	86.3	94.7	8.4	gv	Glasford - Vandalia
	95.1	105.1	10.0	gv	Glasford - Vandalia
	105.1	106.0	0.9	gha	Glasford - Hagarstown
	106.0	106.4	0.4	gv	Glasford - Vandalia
Sangamon	106.4	120.4	14.0	gv	Glasford - Vandalia
	121.3	125.5	4.2	gv	Glasford - Vandalia
	126.2	131.6	5.4	gv	Glasford - Vandalia
Christian	132.1	132.5	0.4	gv	Glasford - Vandalia
	133.1	134.7	1.6	gv	Glasford - Vandalia
Sangamon	*134.7*	*135.2*	0.5	gv	Glasford - Vandalia
Christian	135.2	141.8	6.6	gv	Glasford - Vandalia

TABLE 6.5-1

Rockies Express Pipeline-East Project
Geologic Formations Along the Proposed Pipeline Route in Illinois with the Potential for Paleontological Resources [a]

County	Begin Milepost	End Milepost	Length (miles)	Symbol	Formation - Member
	141.8	151.0	9.2	gr	Glasford - Radnor
Macon	151.0	153.9	2.9	gr	Glasford - Radnor
	154.5	160.2	5.7	wp	Wedron - Piatt
	160.2	164.5	4.3	wp	Wedron - Piatt
	164.5	164.9	0.4	wf	Wedron - Fairgrange
	164.9	169.3	4.4	wp	Wedron - Piatt
	169.3	172.0	2.7	wp	Wedron - Piatt
Moultrie	172.0	172.8	0.8	wp	Wedron - Piatt
	172.8	187.5	14.7	wp	Wedron - Piatt
Douglas	187.5	187.9	0.4	wp	Wedron - Piatt
	188.3	192.5	4.2	wp	Wedron - Piatt
	193.1	195.1	2.0	wb	Wedron - Batestown
	195.1	201.0	5.9	wb	Wedron - Batestown
	201.0	202.4	1.3	ed	Equality - Dolton
	202.4	202.5	0.1	wb	Wedron - Batestown
	203.1	204.6	1.5	ed	Equality - Dolton
	204.6	205.2	0.6	wb	Wedron - Batestown
	205.2	212.3	7.0	ec	Equality - Carmi
	212.3	213.4	1.0	ec	Equality - Carmi
	213.4	214.6	1.2	wb	Wedron - Batestown
Edgar	214.6	227.9	13.3	wb	Wedron - Batestown
	229.1	232.6	3.5	wb	Wedron - Batestown
	233.7	234.8	1.1	wb	Wedron - Batestown
	235.3	236.3	1.0	wb	Wedron - Batestown
	237.0	238.1	1.1	wb	Wedron - Batestown

[a] Source: Saunders, 2007; Illinois State Geological Survey, 1984 and 1996b

6.6 CONSTRUCTION IMPACTS AND MITIGATION

Pipelines are designed and installed in accordance with the U.S. Department of Transportation's standards found in Title 49 CFR Part 192, Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards. Each pipeline is designed and constructed to provide adequate protection from washouts, floods, unstable soils, landslides, or other hazards that may cause the pipe to move or to sustain abnormal loads.

The overall effects of construction and operation of the proposed REX-East 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 right-of-way resulting from grading and trenching operations. Rockies Express will minimize impacts by returning contours to pre-construction 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 may be required to create a safe and stable land surface to support the facility.

Rockies Express has received scoping comments regarding potential impacts due to erosion during construction in areas with steep terrain. The construction procedures described in section 1.4 of Resource Report 1 and section 7.3.1 of Resource Report 7 will minimize the potential for slope failure and erosion. These techniques include erosion control devices and other best management practices as outlined in the REX-East Project Upland Construction Plan (REX-East Plan) (see Appendix 1C of Resource Report 1) and REX-East Project Wetland and Waterbody Construction and Mitigation Procedures (REX-East Procedures) (see Appendix 1D of Resource Report 1), and the Agricultural Impact Mitigation Plan (see Appendix 1E of Resource Report 1).

If consolidated rock is encountered during construction, Rockies Express' preferred procedure will be to fracture and excavate the bedrock using standard construction equipment. Blasting of bedrock will only be required in areas where hard, crystalline bedrock is encountered that are not easily removed by conventional excavation methods. If blasting is necessary, Rockies Express' construction contractor will use blasting technique as outlined in the Rockies Express project-specific Blasting Plan to assist in the removal of rock from the pipeline trench (see Appendix 6E). All blasting techniques will be in compliance with federal, state, and local regulations governing the use of explosives. To avoid damage, the contractor will conduct pre-blasting evaluations of the rock, as needed, and develop site-specific blasting operations and monitoring plans to be approved by Rockies Express. Control of blasting will limit stresses on existing pipelines, nearby domestic structures, water supply and oil and gas wells, or electrical transmission tower footings that are located near the project area. Blasting will not begin until occupants of nearby buildings, stores, residences, places of business, and farms have been notified. Where necessary, excess rock will be hauled off the right-of-way or, subject to landowner approval and applicable permit conditions, disposed of on the right-of-way. Rockies Express is currently developing procedures and engineering standards that will address blasting around its pipeline.

Rockies Express received scoping comments regarding the removal of excavated rock fragments and other debris following construction. Rockies Express will not permanently windrow rock along the right-of-way unless permission is secured from the landowner or land managing agency. Disposal of rock debris will be in areas approved by the individual landowners or land management agency in accordance with the REX-East Plan and regulatory requirements. Should Rockies Express have to dispose of excess rock outside of the right-of-way, an approved landfill or alternative upland area will be utilized. Permits and clearances will be obtained for off-right-of-way disposal areas.

Rockies Express received scoping comments regarding potential impacts on the project facilities due to earthquakes. Based on the low probability of localized earth movements or geological hazards in the vicinity of the project, Rockies Express does not anticipate any problems attributable to such movements or hazards along the majority of the pipeline or other project facilities. The intensity, frequency, and duration of impacts resulting from the potential hazard of minor earthquakes cannot be 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 Palmer, 1996). Only large, abrupt ground displacements have caused serious impacts on pipeline facilities. Due to the very limited potential for large, seismically-induced ground movements in the REX-East Project area, there is very little risk of earthquake-related impacts on the pipeline and other project facilities.

Where potential landslide hazards cannot be avoided, Rockies Express will implement mitigation measures to stabilize these areas. Measures could involve burial of the pipeline below the potential landslide depth if feasible and/or drainage control. Drainage control can include, but is not limited to, frequent slope and ditch breakers, subsurface gravel or cobble drains, and culverts and drainage ditches to divert water away from the right-of-way. In accordance with the REX-East Plan, Rockies Express 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 to the land surface. Groundwater discharging at the land surface is then redirected off the right-of-way by the slope breakers. Used in combination, these structures prevent subsurface piping of soils that can lead to slope instability and failure.

The proposed pipeline will not preclude the expansion of the majority of the mining operations identified in table 6.3-1 because expansion of most of the existing facilities is currently precluded by roads, waterbodies, current property boundaries, and/or collocated utility lines.

Rockies Express received scoping comments regarding the impact on mines and quarries with specific concerns raised about quarries near MP 315 in Morgan County, Indiana. The pipeline in this location is in close proximity to the White River, which already precludes the expansion of the mining operations much beyond the location of the proposed pipeline route. The pipeline route may also preclude expansion of the mining operations near MPs 424.2 and 434.4. However, Rockies Express is working with landowners in the area to minimize the impacts on existing commercial establishments. Should the mining companies expand to adjacent properties that are crossed by the proposed pipeline route, Rockies Express will work with the mining companies to minimize impacts on mining operations while protecting the integrity of the pipeline. Rockies Express is familiar with mining holdings and will use precautionary measures as needed. Historical data has shown that pipeline projects and mining operations have been able to coexist.

As discussed in section 6.3, the project will cross coal mining areas in Illinois, Indiana, and Ohio, and oil and gas fields in eastern Ohio. No abandoned mines were identified in the vicinity of the project area in Missouri and Indiana. However, abandoned underground mines were identified in Illinois and Ohio. Rockies Express identified 19.7 miles of abandoned underground mines that will be crossed by the proposed pipeline route, the majority of which are located in eastern Ohio. Rockies Express commissioned a study of the potential for damage to the pipeline by coal mining subsidence along the route. A draft version of this study is included as Appendix 6F. The objective of the investigation was to determine the capacity of the pipeline to deform to accommodate ground subsidence before reaching a limit where damage will occur. The study also provided design mitigation measures or protective measures that could be undertaken at the time of the subsidence event. Mitigation measures include limiting the depth of cover and the use of granular cohesionless backfill and/or low-friction coating or geotextile wrap to reduce the axial soil restraint. In addition, the study recommended the use of appropriate weld material and procedures to assure the mobilization of plastic behavior in the pipe without brittle failure of the weld joints. Rockies Express is coordinating with various mining companies to identify potential areas of future mining expansion, particularly in eastern Ohio, to determine if the mitigation measures described above will be necessary.

Ground subsidence may also occur in areas identified as having the potential for karst features. The fact that pipelines are structurally strong and narrow in width greatly reduces the probability that a critical size sinkhole will develop in close enough proximity to impact the integrity of the pipeline. Steel pipe has considerable strength as a structural member. Allowable span lengths that will prevent over-stressing the steel depend upon pipe diameter, wall thickness, and soil conditions. If necessary, Rockies Express will make minor route adjustments to avoid sinkholes and/or develop specific design and monitoring criteria, which may include sinkhole stabilization and/or use of heavier wall pipe.

Because oil and gas is generally produced from depths of more than 1,000 feet, construction of the pipeline is not expected to affect the ability of the wells to produce oil and/or natural gas. Rather, any construction-related damage that could occur will be limited to surface or near-surface components of the wells and gathering systems, which could temporarily disrupt production until repairs are made. Prior to construction, Rockies Express will identify all oil and gas wells and associated facilities within the construction right-of-way. Rockies Express will either avoid these facilities or take appropriate precautions to protect the integrity of such facilities. Mitigation measures will be implemented as necessary to ensure that no oil and gas wells are damaged during the construction and operation of the proposed project. Potential impacts of blasting on nearby wells will be mitigated by implementing Rockies Express' project-specific Blasting Plan. However, if unexpected damage to oil and gas well facilities occurs during construction or operation of the proposed project, all facilities will be repaired to preconstruction condition or better.

Regarding paleontological resources, Rockies Express' Environmental Inspectors will be instructed to take note of any significant paleontological materials encountered during trenching operation, and will notify the appropriate personnel if significant fossil materials are encountered. However, based on the consultations discussed above, construction of the proposed project will not likely have significant impacts on paleontological resources.

6.7 REFERENCES

Algermissen, S. T., D. M. Perkins, P. C. Thenhaus, S. L. Hanson, and B. L. Bender. 1982. Probabilistic Estimates of Maximum Acceleration and Velocity on Rock in the Contiguous United States. Open-File Report 82-1033. United States Department of the Interior, United States Geological Survey. Washington, DC. 98 pp plus map.

Cargo, D. N. and B. F. Mallory. 1977. Man and His Geologic Environment. 2nd Edition. 581 pp.

Crowell, D. L., C. E. Banks, and J McDonald. 2006. Abandoned Underground Mines of Ohio. Obtained from the Ohio Department of Natural Resources, Division of Geological Survey on November 2006.

Davies, W. E., J. H. Simpson, G. C. Ohlmacher, W. S. Kirk, and E. G. Newton. 1984. Engineering Aspects of Karst. United States Geological Survey. Reston, Virginia.

Energy Information Administration. 1995. Longwall Mining. Available online at http://tonto.eia.doe.gov/FTPROOT/coal/tr0588.pdf

Energy Information Administration. 2006. Annual Coal Report. Available online at http://www.eia.doe.gov/cneaf/coal/page/acr/acr_sum.html

Fenneman, N. M. 1938. Physiography of Eastern United States. McGraw-Hill Book Company, Inc. 714 pp.

Fullerton, D. S., C. A. Bush, and J. N. Pennell. 2004. Map of Surficial Deposits and Materials in the Eastern and Central United States. United States Geological Survey Geological Investigation Series I-2789.

Godt, J. W. 1997. Landslide Overview Map of the Conterminous United States. United States Geological Survey Open-File Report 97-289. Available on the internet at: http://landslides.usgs.gov/learningeducation/nationalmap/index.php

Gordon, C. 2007. Telephone communication on March 15 between S. Holden (Natural Resource Group, Inc.) and C. Gordon (Ohio Department of Natural Resources, Division of Geological Survey).

Gray, H. H., C. H. Ault, and S. J. Keller. 1987. Bedrock Geologic Map of Indiana. Indiana Geological Survey Miscellaneous Map 48.

Hunt, C. B. 1967. Physiography of the United States. W. H. Freeman and Company. 480 pp.

Kaden, S. 2007. Telephone Communication on January 10 between S. Holden (Natural Resource Group, Inc.) and S. Kaden (Missouri Department of Natural Resources, Division of Geology and Land Survey).

Keith, B. D. 2007. Telephone Communication on February 22 between S. Holden (Natural Resource Group, Inc.) and B. D. Keith (Indiana Geological Survey).

Illinois State Geological Survey. 1984. Quaternary Geology of Illinois. Available on the internet at: http://www.isgs.uiuc.edu/nsdihome/webdocs/browse.html

Illinois State Geological Survey. 1996a. Bedrock Geology of Illinois. Available on the internet at: http://www.isgs.uiuc.edu/nsdihome/webdocs/browse.html

Illinois State Geological Survey. 1996b. Quaternary Geology of Illinois. Available on the internet at: http://www.isgs.uiuc.edu/nsdihome/webdocs/browse.html

Illinois State Geological Survey. 2006. Illinois Oil and Gas Resources (ILOIL) Internet Map Service. Available online at: http://www.isgs.uiuc.edu/oilgas/iloil/launchims.htm

Indiana Geological Survey. 2002. Abandoned Mine Lands in Indiana. Available online at: http://igs.indiana.edu/arcims/statewide/download.html

Indiana Geological Survey. 2002. Petroleum Well Locations in Indiana. Available online at: http://igs.indiana.edu/arcims/statewide/download.html

Mikulic, D. G. 2007. Telephone Communication on January 10 between S. Holden (Natural Resource Group, Inc.) and D. G. Mikulic (Illinois State Geological Survey).

Mining Media. 2004. 2004 Keystone Coal Industry Manual. Prairieville, LA.

Missouri Department of Natural Resources. 2002. Oil and Gas in Missouri. Geological Survey and Resource Assessment Division fact sheet number 19.

Missouri Department of Natural Resources, Division of Geology and Land Survey, Geological Survey Program. 2006a. State Bedrock Geology (Tertiary) – State of Missouri. Available online at: http://msdisweb.missouri.edu/datasearch/ThemeList.jsp.

Missouri Department of Natural Resources, Division of Geology and Land Survey, Geological Survey Program. 2006b. Inventory of Mines, Occurrences, and Prospects in Missouri. Available online at: http://msdisweb.missouri.edu/datasearch/ThemeList.jsp.

National Atlas of the United States. 2007. Available online at: http://nationalatlas.gov/natlas/Natlasstart.asp

Obermeier, S.F., and A. J. Crone, compilers, 1994, Fault number 1024, Wabash Valley *liquefaction features, in Quaternary fault and fold database of the United States*: United States Geological Survey. Available online at: http://earthquakes.usgs.gov/regional/qfaults

Ohio Department of Natural Resources, Division of Geological Survey. 2004. Oil and Gas Fields Map of Ohio. Available online at: http://www.dnr.state.oh.us/geosurvey/pdf/pg01.pdf

Ohio Department of Natural Resources, Division of Geological Survey. 2004. Oil and Gas Interactive Web Map. Available online at: http://www.dnr.state.oh.us/website/geosurvey/oilgas/disclaimer.htm

O'Rourke, T. D. and M.C. Palmer. 1996. Earthquake performance of gas transmission pipelines. Earthquake Spectra. Vol. 12, No. 3, p.493-527.

Reed, J. C. Jr., and C. A. Bush. 2005. Generalized Geologic Map of the United States, Puerto Rico, and the U.S. Virgin Islands. Available online at: http://pubs.usgs.gov/atlas/geologic/

René, R. M., and F. L. Stanonis. 1995. Reflection Seismic Profiling of the Wabash Valley Fault System in the Illinois Basin. United States Geological Survey Professional Paper 1538-0.

Saunders, J. 2007. Email Communication on February 13 between S. Holden (Natural Resource Group, Inc.) and J. Saunders (Illinois State Museum).

Shrake, D. L. 2007. Email Communication on March 6 between S. Holden (Natural Resource Group, Inc.) and D. L. Shrake (Ohio Department of Natural Resources, Division of Geological Survey).

Slucher, E. R., E. M. Swinford, G. E. Larsen, G. A. Schumacher, D. L. Shrake, C. L. Rice, M. R. Caudill, R. G. Rea, and D. M. Powers. 2006. Bedrock Geology of Ohio. Ohio Department of Natural Resources, Division of Geological Survey Map BG-1 Version 6

Stiff, B. J. 1997. Areas Mined for Coal in Illinois. Illinois State Geological Survey. Available online at: http://www.isgs.uiuc.edu/nsdihome/browse/statewide/coalmines_py.e00

United States Department of Agriculture, Natural Resources Conservation Service. 1994. State Soil Geographic (STATSGO) database for Illinois, Indiana, Ohio, and Missouri. Available online at: http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/

U.S. Department of Agriculture, Natural Resources Conservation Service. 2003. Soil Survey Geographic (SSURGO) Database. Available online at: http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/

United States Geological Survey. 2000. Landslide Hazards. United States Geological Survey Fact Sheet FS2000-071. Available on the internet at: http://pubs.usgs.gov/fs/fs-0071-00/

United States Geological Survey. 2002. National Seismic Hazard Mapping Project, National Seismic Hazard Maps. Available online at: http://eqint.cr.usgs.gov/eq-men/html/custom2002-06.html

United States Geological Survey. 2004. Mineral Yearbook. Available on the internet at: http://minerals.usgs.gov/minerals/pubs/state/

United States Geological Survey. 2006a. Earthquake Information Center. Available online at: http://neic.usgs.gov/neis/states.php

United States Geological Survey. 2006b. Earthquake Hazard Program Quaternary Fault and Fold Database. Available online at: http://earthquake.usgs.gov/regional/qfaults/

ROCKIES EXPRESS PIPELINE-EAST PROJECT

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APPENDIX 6A
Surficial Geology Along the
Rockies Express Pipeline-East Project Pipeline Route

TABLE 6A-1

Surficial Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	Age	Description
MISSOURI						
Audrain	0.0	0.4	0.4	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
	0.4	15.8	15.4	tb	Pre-Illinoian age	Loamy till
Ralls	15.8	19.8	4.0	tb	Pre-Illinoian age	Loamy till
Pike	19.8	33.0	13.2	tb	Pre-Illinoian age	Loamy till
	33.0	38.1	5.1	(zh)	Quaternary and Tertiary age	Cherty decomposition residuum, solution residuum, and colluvium on limestone, shale, and sandstone
	38.1	42.7	4.6	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
	42.7	43.0	0.3	water		Open water
ILLINOIS						
Pike	43.0	43.3	0.3	water		Open water
	43.3	50.4	7.0	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
	50.4	51.3	1.0	ra	Quaternary and Tertiary age	Cherty, clayey to sandy solution residuum
	51.3	53.6	2.2	el	Holocene and late Wisconsin age	Loess
	53.6	58.4	4.8	tb	Pre-Illinoian age	Loamy till
	58.4	62.7	4.3	ra	Quaternary and Tertiary age	Cherty, clayey to sandy solution residuum
	62.7	63.7	1.0	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
	63.7	64.5	0.8	ra	Quaternary and Tertiary age	Cherty, clayey to sandy solution residuum
	64.5	68.1	3.8	tk	Illinoian age	Loamy till--Ground-moraine deposits
	68.1	69.8	1.6	ra	Quaternary and Tertiary age	Cherty, clayey to sandy solution residuum
	69.8	71.2	1.4	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
Scott	71.2	73.7	2.5	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
	73.7	74.2	0.5	ra	Quaternary and Tertiary age	Cherty, clayey to sandy solution residuum
	74.2	75.7	1.5	tk	Illinoian age	Loamy till--Ground-moraine deposits
	75.7	76.0	0.3	ra	Quaternary and Tertiary age	Cherty, clayey to sandy solution residuum
	76.0	79.1	3.1	tk	Illinoian age	Loamy till--Ground-moraine deposits
	79.1	86.3	7.2	tk	Illinoian age	Loamy till--Ground-moraine deposits
Morgan	86.3	105.5	19.1	tk	Illinoian age	Loamy till--Ground-moraine deposits
	105.5	106.4	1.0	ka	Illinoian age	Ice-contact sand and gravel
Sangamon	106.4	106.7	0.3	ka	Illinoian age	Ice-contact sand and gravel
	106.7	131.3	24.6	tk	Illinoian age	Loamy till--Ground-moraine deposits

TABLE 6A-1

Surficial Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	Age	Description
	131.3	132.0	0.7	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
Christian	132.0	134.0	2.0	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
	134.0	134.7	0.6	tk	Illinoian age	Loamy till--Ground-moraine deposits
Sangamon	134.7	135.2	0.6	tk	Illinoian age	Loamy till--Ground-moraine deposits
Christian	135.2	151.0	15.7	tk	Illinoian age	Loamy till--Ground-moraine deposits
Macon	151.0	153.5	2.5	tk	Illinoian age	Loamy till--Ground-moraine deposits
	153.5	155.7	2.2	gg	Wisconsin and Holocene age	Outwash sand and gravel
	155.7	158.9	3.2	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	158.9	160.4	1.5	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	160.4	169.5	9.1	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	169.5	172.0	2.6	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
Moultrie	172.0	173.0	1.0	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	173.0	187.5	14.5	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Douglas	187.5	193.6	6.1	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	193.6	195.0	1.4	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	195.0	200.6	5.5	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	200.6	203.9	3.3	lc	Holocene and late Wisconsin age	Clay and silt
	203.9	207.3	3.4	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	207.3	213.5	6.2	lc	Holocene and late Wisconsin age	Clay and silt
	213.5	214.6	1.2	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Edgar	214.6	230.4	15.7	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	230.4	235.9	5.5	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	235.9	237.3	1.4	gg	Wisconsin and Holocene age	Outwash sand and gravel
	237.3	238.1	0.9	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
INDIANA						
Vermillion	238.1	244.9	6.8	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	244.9	245.8	0.9	tk	Illinoian age	Loamy till--Ground-moraine deposits
	245.8	245.9	0.1	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	245.9	245.9	<0.1	tk	Illinoian age	Loamy till--Ground-moraine deposits
	245.9	246.9	0.9	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	246.9	247.2	0.4	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits

TABLE 6A-1

Surficial Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	Age	Description
Parke	247.2	248.5	1.3	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	248.5	249.8	1.3	gg	Wisconsin and Holocene age	Outwash sand and gravel
	249.8	251.0	1.2	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	251.0	251.7	0.7	gg	Wisconsin and Holocene age	Outwash sand and gravel
	251.7	267.8	16.2	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Putnam	267.8	268.2	0.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	268.2	269.3	1.1	tk	Illinoian age	Loamy till--Ground-moraine deposits
	269.3	269.4	0.1	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	269.4	270.4	1.0	tk	Illinoian age	Loamy till--Ground-moraine deposits
	270.4	286.8	16.4	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Hendricks	286.8	293.5	6.7	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	293.5	294.4	0.9	gg	Wisconsin and Holocene age	Outwash sand and gravel
	294.4	295.4	1.0	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	295.4	296.8	1.4	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	296.8	300.9	4.1	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	300.9	304.1	3.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Morgan	304.1	306.4	2.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	306.4	310.8	4.4	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	310.8	314.2	3.4	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	314.2	316.8	2.7	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	316.8	318.4	1.5	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Johnson	318.4	334.5	16.1	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	334.5	338.5	3.9	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
Shelby	338.5	339.4	0.9	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	339.4	340.6	1.2	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	340.6	341.1	0.5	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	341.1	344.0	2.9	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	344.0	349.5	5.6	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	349.5	357.9	8.4	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Decatur	357.9	366.2	8.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	366.2	371.9	5.6	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits

TABLE 6A-1

Surficial Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	Age	Description
	371.9	374.4	2.6	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	374.4	376.1	1.7	tk	Illinoian age	Loamy till--Ground-moraine deposits
Franklin	376.1	380.7	4.6	tk	Illinoian age	Loamy till--Ground-moraine deposits
	380.7	381.5	0.8	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
	381.5	385.2	3.8	tk	Illinoian age	Loamy till--Ground-moraine deposits
	385.2	385.8	0.6	al	Holocene and late Wisconsin age	Channel and flood-plain alluvium
	385.8	391.4	5.5	tk	Illinoian age	Loamy till--Ground-moraine deposits
	391.4	392.0	0.6	cc	Holocene and late and middle Pleistocene age	Carbonate-boulder or carbonate-clast colluvium
	392.0	394.8	2.9	gg	Wisconsin and Holocene age	Outwash sand and gravel
	394.8	404.0	9.2	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
OHIO						
Butler	404.0	405.5	1.5	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	405.5	408.8	3.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	408.8	410.0	1.1	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	410.0	421.6	11.6	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	421.6	430.4	8.9	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	430.4	433.7	3.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	433.7	435.9	2.2	lc	Holocene and late Wisconsin age	Clay and silt
Warren	435.9	436.6	0.7	lc	Holocene and late Wisconsin age	Clay and silt
	436.6	437.2	0.6	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	437.2	451.6	14.4	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	451.6	452.9	1.3	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	452.9	455.7	2.8	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	455.7	457.8	2.1	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
Clinton	457.8	459.4	1.5	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	459.4	471.9	12.5	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	471.9	472.1	0.3	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
Greene	472.1	474.1	1.9	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	474.1	474.9	0.9	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Fayette	474.9	479.6	4.7	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	479.6	480.1	0.6	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits

TABLE 6A-1

Surficial Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	Age	Description
	480.1	483.5	3.4	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	483.5	485.0	1.5	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	485.0	489.7	4.7	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	489.7	491.5	1.8	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	491.5	498.3	6.8	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
Pickaway	498.3	507.5	9.2	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	507.5	508.4	0.8	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	508.4	512.5	4.2	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	512.5	512.6	0.1	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	512.6	514.1	1.4	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	514.1	522.4	8.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	522.4	522.4	<0.1	kg	Late Wisconsin and Holocene age	Ice-contact sand and gravel
Fairfield	522.4	523.1	0.7	kg	Late Wisconsin and Holocene age	Ice-contact sand and gravel
	523.1	523.4	0.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	523.4	524.1	0.7	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	524.1	525.6	1.5	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	525.6	526.9	1.3	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	526.9	527.6	0.7	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	527.6	529.2	1.6	lc	Holocene and late Wisconsin age	Clay and silt
	529.2	531.5	2.2	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	531.5	532.7	1.2	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	532.7	535.0	2.3	tl	Late Wisconsin and Holocene age	Loamy till--Ground-moraine deposits
	535.0	535.8	0.8	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	535.8	538.4	2.6	lo	Holocene and late Wisconsin age	Clay and silt
	538.4	539.5	1.1	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	539.5	540.6	1.1	lc	Holocene and late Wisconsin age	Clay and silt
	540.6	546.8	6.2	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
Perry	546.8	547.2	0.4	tm	Late Wisconsin and Holocene age	Loamy till--End-moraine deposits
	547.2	564.5	17.4	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
	564.5	564.7	0.2	cs	Holocene and late and middle Pleistocene age	Calcareous shale-chip and siltstone-clast colluvium
Muskingum	564.7	571.2	6.5	cs	Holocene and late and middle Pleistocene age	Calcareous shale-chip and siltstone-clast colluvium

TABLE 6A-1

Surficial Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	Age	Description
	571.2	575.9	4.7	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
	575.9	576.0	0.1	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
	576.0	577.4	1.4	(ag)	Holocene and late Wisconsin age	Alluvial, outwash, ice-contact, and glacial-lake deposits
	577.4	590.3	12.9	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
Guernsey	590.3	598.0	7.8	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
	598.0	599.6	1.6	(In)	Illinoian age	Slack-water lake deposits and alluvium
	599.6	605.2	5.6	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
	605.2	607.2	2.0	(In)	Illinoian age	Slack-water lake deposits and alluvium
	607.2	607.2	<0.1	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
	607.2	607.3	0.1	(In)	Illinoian age	Slack-water lake deposits and alluvium
	607.3	609.5	2.2	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
	609.5	609.8	0.3	(In)	Illinoian age	Slack-water lake deposits and alluvium
Noble	609.8	611.6	1.9	(In)	Illinoian age	Slack-water lake deposits and alluvium
Guernsey	611.6	611.8	0.2	(In)	Illinoian age	Slack-water lake deposits and alluvium
Noble	611.8	612.5	0.6	(In)	Illinoian age	Slack-water lake deposits and alluvium
	612.5	612.6	0.2	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
	612.6	612.8	0.2	(In)	Illinoian age	Slack-water lake deposits and alluvium
	612.8	616.6	3.7	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
Belmont	616.6	632.3	15.7	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium
Monroe	632.3	637.6	5.3	cl	Holocene and late and middle Pleistocene age	Clastic-clast colluvium

[a] Fullerton et al., 2004

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APPENDIX 6B
Bedrock Geology Along the
Rockies Express Pipeline-East Project Pipeline Route

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
MISSOURI						
Audrain	0.0	1.2	1.2	Pc	Pennsylvanian	Cabaniss Subgroup
	1.2	9.7	8.5	Pm	Pennsylvanian	Marmaton Group
	9.7	10.0	0.3	Pc	Pennsylvanian	Cabaniss Subgroup
	10.0	10.7	0.6	Pm	Pennsylvanian	Marmaton Group
	10.7	11.3	0.7	Pc	Pennsylvanian	Cabaniss Subgroup
	11.3	15.8	4.5	Pm	Pennsylvanian	Marmaton Group
Ralls	15.8	16.0	0.2	Pm	Pennsylvanian	Marmaton Group
	16.0	18.9	3.0	Pc	Pennsylvanian	Cabaniss Subgroup
	18.9	19.8	0.9	Pm	Pennsylvanian	Marmaton Group
Pike	19.8	20.9	1.1	Pm	Pennsylvanian	Marmaton Group
	20.9	28.7	7.8	Pc	Pennsylvanian	Cabaniss Subgroup
	28.7	28.9	0.2	Mo	Mississippian	Osagean Series
	28.9	29.8	0.9	Mk	Mississippian	Kinderhookian Series
	29.8	30.1	0.3	Omk	Ordovician	Maquoketa and Kimmswick formations
	30.1	30.8	0.7	Mk	Mississippian	Kinderhookian Series
	30.8	31.0	0.2	S	Silurian System	Silurian System
	31.0	31.9	0.9	Omk	Ordovician	Maquoketa and Kimmswick formations
	31.9	32.3	0.4	S	Silurian System	Silurian System
	32.3	33.3	1.0	Omk	Ordovician	Maquoketa and Kimmswick formations
	33.3	33.5	0.2	S	Silurian System	Silurian System
	33.5	33.9	0.5	Mk	Mississippian	Kinderhookian Series
	33.9	34.9	1.0	Mo	Mississippian	Osagean Series
	34.9	36.1	1.2	Mk	Mississippian	Kinderhookian Series
	36.1	38.1	0.1	Mo	Mississippian	Osagean Series
	36.1	39.0	2.9	Mk	Mississippian	Kinderhookian Series
	39.0	41.7	2.7	Omk	Ordovician	Maquoketa and Kimmswick formations
	41.7	43.1	1.4	Qal	Quaternary alluvium	Quaternary alluvium
ILLINOIS						
Pike	43.1	47.5	4.5	7550	Ordovician	Galena-Platteville
	47.5	50.5	2.9	7390	Ordovician	Maquoketa
	50.5	50.7	0.2	6700	Silurian	Undifferentiated
	50.7	51.1	0.4	5810	Devonian - Upper	

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
	51.1	52.2	1.0	5420	Mississippian	Kinderhookian
	52.2	52.8	0.6	5810	Devonian - Upper	
	52.8	54.0	1.2	5420	Mississippian	Kinderhookian
	54.0	55.4	1.4	5255	Mississippian	Lower Valmeyeran
	55.4	55.5	0.1	3030	Pennsylvanian	Spoon
	55.5	56.3	0.8	5255	Mississippian	Lower Valmeyeran
	56.3	56.9	0.6	5420	Mississippian	Kinderhookian
	56.9	58.2	1.3	5255	Mississippian	Lower Valmeyeran
	58.2	61.2	2.9	5420	Mississippian	Kinderhookian
	61.2	70.0	8.8	5255	Mississippian	Lower Valmeyeran
	70.0	70.4	0.4	5420	Mississippian	Kinderhookian
	70.4	71.2	0.8	5810	Devonian - Upper	
Scott	71.2	73.2	2.0	5810	Devonian - Upper	
	73.2	73.7	0.5	5420	Mississippian	Kinderhookian
	73.7	77.8	4.1	5255	Mississippian	Lower Valmeyeran
	77.8	80.4	2.8	5175	Mississippian	Middle Valmeyeran
	80.4	81.6	1.2	3030	Pennsylvanian	Spoon
	81.6	86.3	4.7	2480	Pennsylvanian	Carbondale
Morgan	86.3	88.9	2.5	2480	Pennsylvanian	Carbondale
	88.9	94.8	6.0	2120	Pennsylvanian	Modesto
	94.8	95.4	0.6	2480	Pennsylvanian	Carbondale
	95.4	106.4	11.0	2120	Pennsylvanian	Modesto
Sangamon	106.4	118.9	12.5	2120	Pennsylvanian	Modesto
	118.9	119.9	1.0	1880	Pennsylvanian	Bond
	119.9	121.5	1.7	2120	Pennsylvanian	Modesto
	121.5	131.6	10.0	1880	Pennsylvanian	Bond
	131.6	132.0	0.5	2120	Pennsylvanian	Modesto
Christian	132.0	133.4	1.4	2120	Pennsylvanian	Modesto
	133.4	134.7	1.2	1880	Pennsylvanian	Bond
Sangamon	134.7	135.2	0.6	1880	Pennsylvanian	Bond
Christian	135.2	143.5	8.3	1880	Pennsylvanian	Bond
	143.5	147.2	3.7	2120	Pennsylvanian	Modesto
	147.2	151.0	3.8	1880	Pennsylvanian	Bond

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
Macon	151.0	156.8	5.9	1880	Pennsylvanian	Bond
	156.8	167.3	10.5	1550	Pennsylvanian	Mattoon
	167.3	169.0	1.7	1880	Pennsylvanian	Bond
	169.0	172.0	3.0	1550	Pennsylvanian	Mattoon
Moultrie	172.0	187.5	15.4	1550	Pennsylvanian	Mattoon
Douglas	187.5	195.6	8.2	1550	Pennsylvanian	Mattoon
	195.6	196.1	0.5	1880	Pennsylvanian	Bond
	196.1	196.5	0.4	2120	Pennsylvanian	Modesto
	196.5	196.9	0.4	2480	Pennsylvanian	Carbondale
	196.9	197.4	0.5	3030	Pennsylvanian	Spoon
	197.4	197.8	0.4	5175	Mississippian	Middle Valmeyeran
	197.8	198.3	0.4	5810	Devonian - Upper	
	198.3	201.1	2.8	5880	Devonian - Middle	
	201.1	201.8	0.7	5810	Devonian - Upper	
	201.8	202.5	0.7	5175	Mississippian	Middle Valmeyeran
	202.5	203.1	0.6	3030	Pennsylvanian	Spoon
	203.1	204.9	1.8	2480	Pennsylvanian	Carbondale
	204.9	205.8	0.9	2120	Pennsylvanian	Modesto
	205.8	207.4	1.5	2480	Pennsylvanian	Carbondale
	207.4	210.7	3.3	2120	Pennsylvanian	Modesto
	210.7	214.6	3.9	2480	Pennsylvanian	Carbondale
Edgar	214.6	220.3	5.7	2480	Pennsylvanian	Carbondale
	220.3	221.7	1.3	2120	Pennsylvanian	Modesto
	221.7	229.6	7.9	1880	Pennsylvanian	Bond
	229.6	231.3	1.7	2120	Pennsylvanian	Modesto
	231.3	232.5	1.2	1880	Pennsylvanian	Bond
	232.5	234.3	1.8	2120	Pennsylvanian	Modesto
	234.3	238.1	3.8	2480	Pennsylvanian	Carbondale
INDIANA						
Vermillion	238.1	242.6	4.5	P2	Pennsylvanian	Carbondale Group
	242.6	244.6	1.9	P1	Pennsylvanian	Raccoon Creek Group
	244.6	245.1	0.6	P2	Pennsylvanian	Carbondale Group
	245.1	245.4	0.3	P1	Pennsylvanian	Raccoon Creek Group

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
	245.4	246.9	1.5	P2	Pennsylvanian	Carbondale Group
	246.9	247.2	0.3	P1	Pennsylvanian	Raccoon Creek Group
Parke	247.2	267.8	20.6	P1	Pennsylvanian	Raccoon Creek Group
Putnam	267.8	271.3	3.5	P1	Pennsylvanian	Raccoon Creek Group
	271.3	271.8	0.5	M3	Mississippian	Blue River Group
	271.8	272.9	1.1	P1	Pennsylvanian	Raccoon Creek Group
	272.9	273.5	0.6	M3	Mississippian	Blue River Group
	273.5	275.5	2.1	P1	Pennsylvanian	Raccoon Creek Group
	275.5	278.2	2.6	M3	Mississippian	Blue River Group
	278.2	280.7	2.5	M2	Mississippian	Sanders Group
	280.7	286.8	6.1	M1	Mississippian	Borden Group
Hendricks	286.8	304.1	17.3	M1	Mississippian	Borden Group
Morgan	304.1	318.4	14.3	M1	Mississippian	Borden Group
Johnson	318.4	332.8	14.4	M1	Mississippian	Borden Group
	332.8	338.5	5.6	Dm	Devonian-Mississippian	New Albany Shale
Shelby	338.5	339.0	0.5	Dm	Devonian-Mississippian	New Albany Shale
	339.0	357.9	18.9	D	Devonian	Muscatatuck Group
Decatur	357.9	361.4	3.5	D	Devonian	Muscatatuck Group
	361.4	362.3	0.9	S	Silurian	Louisville Limestone through Brassfield Limestone, or Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
	362.3	362.8	0.5	D	Devonian	Muscatatuck Group
	362.8	363.1	0.4	S	Silurian	Louisville Limestone through Brassfield Limestone, or Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
	363.1	363.4	0.2	D	Devonian	Muscatatuck Group
	363.4	363.9	0.5	S	Silurian	Louisville Limestone through Brassfield Limestone, or Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
	363.9	366.5	2.6	D	Devonian	Muscatatuck Group
	366.5	366.9	0.4	S	Silurian	Louisville Limestone through Brassfield Limestone, or Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
	366.9	368.2	1.4	D	Devonian	Muscatatuck Group

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
	368.2	376.1	7.9	S	Silurian	Louisville Limestone through Brassfield Limestone, or Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
Franklin	376.1	376.3	0.2	S	Silurian	Louisville Limestone through Brassfield Limestone, or Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
	376.3	376.6	0.4	O4	Ordovician	Whitewater Formation
	376.6	377.8	1.1	S	Silurian	Louisville Limestone through Brassfield Limestone, or Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
	377.8	378.5	0.7	O4	Ordovician	Whitewater Formation
	378.5	379.2	0.7	S	Silurian	Louisville Limestone through Brassfield Limestone, or Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
	379.2	380.5	1.3	O4	Ordovician	Whitewater Formation
	380.5	381.8	1.3	O3	Ordovician	Dillsboro Formation
	381.8	384.6	2.8	O4	Ordovician	Whitewater Formation
	384.6	386.2	1.6	O3	Ordovician	Dillsboro Formation
	386.2	386.5	0.3	O4	Ordovician	Whitewater Formation
	386.5	387.7	1.2	O3	Ordovician	Dillsboro Formation
	387.7	389.1	1.4	O4	Ordovician	Whitewater Formation
	389.1	391.9	2.8	O3	Ordovician	Dillsboro Formation
	391.9	393.4	1.6	O2	Ordovician	Kope Formation
	393.4	398.1	4.6	O3	Ordovician	Dillsboro Formation
	398.1	398.9	0.8	O4	Ordovician	Whitewater Formation
	398.9	399.8	0.9	O3	Ordovician	Dillsboro Formation
	399.8	402.1	2.3	O4	Ordovician	Whitewater Formation
	402.1	404.0	1.9	O3	Ordovician	Dillsboro Formation
OHIO						
Butler	404.0	405.7	1.7	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	405.7	406.5	0.8	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	406.5	406.9	0.4	Ok	Upper Ordovician	Kope Formation
	406.9	407.7	0.8	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
	407.7	412.0	4.2	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	412.0	412.8	0.8	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	412.8	413.6	0.8	Ok	Upper Ordovician	Kope Formation
	413.6	415.1	1.5	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	415.1	416.4	1.3	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	416.4	416.8	0.4	Odl	Upper Ordovician	Drakes, Whitewater, Saluda, and Liberty formations undivided
	416.8	417.6	0.8	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	417.6	418.7	1.1	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	418.7	421.8	3.0	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	421.8	422.2	0.4	Ok	Upper Ordovician	Kope Formation
	422.2	423.0	0.8	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	423.0	428.5	5.6	Ok	Upper Ordovician	Kope Formation
	428.5	431.1	2.5	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	431.1	431.4	0.3	Ok	Upper Ordovician	Kope Formation
	431.4	434.3	2.9	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	434.3	435.9	1.6	Ok	Upper Ordovician	Kope Formation
Warren	435.9	436.0	0.1	Ok	Upper Ordovician	Kope Formation
	436.0	437.7	1.7	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	437.7	440.1	2.3	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	440.1	440.4	0.3	Odl	Upper Ordovician	Drakes, Whitewater, Saluda, and Liberty formations undivided
	440.4	441.2	0.8	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	441.2	449.9	8.7	Odl	Upper Ordovician	Drakes, Whitewater, Saluda, and Liberty formations undivided
	449.9	450.3	0.4	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
	450.3	450.7	0.4	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	450.7	451.5	0.8	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	451.5	452.4	0.8	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	452.4	455.9	3.6	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	455.9	457.2	1.3	Ogm	Upper Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation undivided
	457.2	457.8	0.6	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
Clinton	457.8	458.4	0.6	Owa	Upper Ordovician	Waynesville formation, Arnheim Shale and limestone undivided
	458.4	460.2	1.8	Odl	Upper Ordovician	Drakes, Whitewater, Saluda, and Liberty formations undivided
	460.2	462.7	2.5	Sdb	Lower Silurian	Dayton Limestone and Brassfield Formation undivided
	462.7	463.1	0.4	Oc	Upper Ordovician	Cincinnati group
	463.1	463.3	0.2	Sdb	Lower Silurian	Dayton Limestone and Brassfield Formation undivided
	463.3	464.5	1.2	Se	Lower Silurian	Estill Shale and Drowning Creek Formation undivided
	464.5	464.7	0.2	Sdb	Lower Silurian	Dayton Limestone and Brassfield Formation undivided
	464.7	465.7	1.0	Oc	Upper Ordovician	Cincinnati group
	465.7	465.8	0.1	Sdb	Lower Silurian	Dayton Limestone and Brassfield Formation undivided
	465.8	466.7	0.9	Se	Lower Silurian	Estill Shale and Drowning Creek Formation undivided
	466.7	467.6	0.9	Sdb	Lower Silurian	Dayton Limestone and Brassfield Formation undivided
	467.6	467.7	0.1	Se	Lower Silurian	Estill Shale and Drowning Creek Formation undivided
	467.7	471.0	3.4	Scl	Upper and Lower Silurian	Cedarville, Springfield, and Euphemia Dolomites, Massi Shale and Laurel Dolomite undivided
	471.0	471.6	0.6	Scl	Upper and Lower Silurian	Cedarville, Springfield, and Euphemia Dolomites, Massi Shale and Laurel Dolomite undivided
	471.6	472.1	0.5	Scl	Upper and Lower Silurian	Cedarville, Springfield, and Euphemia Dolomites, Massi Shale and Laurel Dolomite undivided
Greene	472.1	474.9	2.8	Scl	Upper and Lower Silurian	Cedarville, Springfield, and Euphemia Dolomites, Massi Shale and Laurel Dolomite undivided
Fayette	474.9	478.6	3.7	Scl	Upper and Lower Silurian	Cedarville, Springfield, and Euphemia Dolomites, Massi Shale and Laurel Dolomite undivided
	478.6	484.9	6.3	Stg	Upper and Lower Silurian	Tymochtee and Greenfield Dolomites undivided

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
	484.9	485.7	0.8	Scl	Upper and Lower Silurian	Cedarville, Springfield, and Euphemia Dolomites, Massi Shale and Laurel Dolomite undivided
	485.7	493.3	7.6	Stg	Upper and Lower Silurian	Tymochtee and Greenfield Dolomites undivided
	493.3	495.4	2.1	Ss	Upper and Lower Silurian	Salina Group
	495.4	495.6	0.2	Stg	Upper and Lower Silurian	Tymochtee and Greenfield Dolomites undivided
	495.6	498.3	2.7	Ss	Upper and Lower Silurian	Salina Group
Pickaway	498.3	499.0	0.7	Ss	Upper and Lower Silurian	Salina Group
	499.0	499.8	0.8	Stg	Upper and Lower Silurian	Tymochtee and Greenfield Dolomites undivided
	499.8	503.2	3.4	Ss	Upper and Lower Silurian	Salina Group
	503.2	507.3	4.1	Dc	Middle and Lower Devonian	Columbus Limestone
	507.3	508.6	1.3	Ss	Upper and Lower Silurian	Salina Group
	508.6	509.3	0.7	Dc	Middle and Lower Devonian	Columbus Limestone
	509.3	522.4	13.1	Doh	Upper Devonian	Ohio Shale
Fairfield	522.4	523.6	1.2	Doh	Upper Devonian	Ohio Shale
	523.6	525.3	1.7	MDsb	Lower Mississippian and Upper Devonian	Sunbury Shale, Berea Sandstone, and Bedford Shale undivided
	525.3	525.7	0.4	Mlc	Upper and Lower Mississippian	Logan and Coyahago Formations undivided
	525.7	530.7	5.0	Mcb	Lower Mississippian	Black Hand Member of Cuyahoga Formation
	530.7	531.4	0.7	Mlc	Upper and Lower Mississippian	Logan and Coyahago Formations undivided
	531.4	532.7	1.3	Mcb	Lower Mississippian	Black Hand Member of Cuyahoga Formation
	532.7	532.8	0.1	Mlc	Upper and Lower Mississippian	Logan and Coyahago Formations undivided
	532.8	537.0	4.2	Mcb	Lower Mississippian	Black Hand Member of Cuyahoga Formation
	537.0	546.8	9.8	Mlc	Upper and Lower Mississippian	Logan and Coyahago Formations undivided
Perry	546.8	547.4	0.6	Mlc	Upper and Lower Mississippian	Logan and Coyahago Formations undivided
	547.4	560.2	12.8	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
	560.2	560.3	0.1	Pc	Upper Pennsylvanian	Conemaugh Group
	560.3	564.7	4.4	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
Muskingum	564.7	565.5	0.8	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
	565.5	565.9	0.4	Pc	Upper Pennsylvanian	Conemaugh Group
	565.9	566.2	0.3	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
	566.2	567.9	1.7	Pc	Upper Pennsylvanian	Conemaugh Group
	567.9	569.6	1.7	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
	569.6	573.0	3.4	Pc	Upper Pennsylvanian	Conemaugh Group
	573.0	573.4	0.4	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
	573.4	574.2	0.8	Pc	Upper Pennsylvanian	Conemaugh Group
	574.2	574.9	0.7	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
	574.9	577.6	2.8	Pc	Upper Pennsylvanian	Conemaugh Group
	577.6	578.0	0.4	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
	578.0	580.5	2.5	Pc	Upper Pennsylvanian	Conemaugh Group
	580.5	582.2	1.7	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
	582.2	585.6	3.4	Pc	Upper Pennsylvanian	Conemaugh Group
	585.6	586.4	0.8	Pm	Upper Pennsylvanian	Monongahela Group
	586.4	586.5	0.1	Pc	Upper Pennsylvanian	Conemaugh Group
	586.5	586.9	0.4	Pm	Upper Pennsylvanian	Monongahela Group
	586.9	587.1	0.2	Pc	Upper Pennsylvanian	Conemaugh Group
	587.1	587.9	0.8	Pm	Upper Pennsylvanian	Monongahela Group
	587.9	588.3	0.4	Pc	Upper Pennsylvanian	Conemaugh Group
	588.3	588.6	0.3	Pm	Upper Pennsylvanian	Monongahela Group
	588.6	588.7	0.1	Pc	Upper Pennsylvanian	Conemaugh Group
	588.7	588.9	0.2	Pm	Upper Pennsylvanian	Monongahela Group
	588.9	590.2	1.4	Pc	Upper Pennsylvanian	Conemaugh Group
Guernsey	590.2	596.3	6.1	Pc	Upper Pennsylvanian	Conemaugh Group
	596.3	598.0	1.7	Pap	Middle and Lower Pennsylvanian	Allegheny and Pottsville groups undifferentiated
	598.0	606.4	8.4	Pc	Upper Pennsylvanian	Conemaugh Group
	606.4	606.8	0.4	Pm	Upper Pennsylvanian	Monongahela Group
	606.8	607.7	0.9	Pc	Upper Pennsylvanian	Conemaugh Group
	607.7	607.8	0.1	Pm	Upper Pennsylvanian	Monongahela Group
	607.8	609.5	1.7	Pc	Upper Pennsylvanian	Conemaugh Group
	609.5	609.7	0.2	Pm	Upper Pennsylvanian	Monongahela Group
Noble	609.7	610.4	0.6	Pm	Upper Pennsylvanian	Monongahela Group
	610.4	611.2	0.8	Pc	Upper Pennsylvanian	Conemaugh Group
	611.2	611.6	0.4	Pm	Upper Pennsylvanian	Monongahela Group
Guernsey	611.6	611.8	0.2	Pm	Upper Pennsylvanian	Monongahela Group
Noble	611.8	616.3	4.5	Pm	Upper Pennsylvanian	Monongahela Group
	616.3	616.6	0.3	PPd	Lower Permian and Upper Pennsylvanian	Dunkard Group
Belmont	616.6	617.6	1.0	PPd	Lower Permian and Upper Pennsylvanian	Dunkard Group

TABLE 6B-1

Bedrock Geology by Milepost Segment Along the Rockies Express Pipeline-East Project Pipeline Route [a]

State / County	Begin Milepost	End Milepost	Length (miles)	Unit Symbol	System	Geologic Unit
	617.6	618.0	0.4	Pm	Upper Pennsylvanian	Monongahela Group
	618.0	623.0	5.0	PPd	Lower Permian and Upper Pennsylvanian	Dunkard Group
	623.0	624.3	1.3	Pm	Upper Pennsylvanian	Monongahela Group
	624.3	632.3	8.0	PPd	Lower Permian and Upper Pennsylvanian	Dunkard Group
Monroe	632.3	637.6	5.3	PPd	Lower Permian and Upper Pennsylvanian	Dunkard Group

[a] Gray et al., 1987; Slucher, 2006; Illinois State Geological Survey (ISGS), 1996a; Missouri Department of Natural Resources, Division of Geology and Land Survey (MoDNR, DGLS), 2006a

ROCKIES EXPRESS PIPELINE-EAST PROJECT

Resource Report 6

APPENDIX 6C
Oil and Gas Wells within 500 feet of the Rockies Express Pipeline-East Project Pipeline Route

TABLE 6C-1

Rockies Express Pipeline-East Project
Oil and Gas Wells within 500 feet of the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Milepost	Operation	Distance and Direction from the Right-of-Way
ILLINOIS			
Christian	132.6	Oil well	400 feet North
	123.9	Oil well	400 feet North
	133.0	Oil well	300 feet North
	144.5 [b]	Oil well	113 feet North
INDIANA			
Shelby	353.8	Gas well	362 feet North
	355.8	Gas well	63 feet South
	356.1	Gas well	9 feet South
Decatur	359.5	Gas well	134 feet North
	362.1	Gas well	265 feet North
	367.0	Gas well	110 feet North
	367.5	Gas well	216 feet South
	368.4	Gas well	254 feet North
OHIO			
Fairfield	538.8	Gas well	120 feet North
	541.4	Gas well	121 feet North
	544.6	Gas well	291 feet South
Perry	547.7	Oil and gas well	328 feet South
	551.1	Oil and gas well	185 feet North
	553.5	Gas well	6 feet South
	553.7	Gas well	181 feet North
	554.1	Oil well with gas show	141 feet North
	554.7	Gas well	316 feet North
	556.1	Oil and gas well	134 feet North
	556.3	Oil and gas well	491 feet South
	558.5	Oil and gas well	165 feet North
	558.8	Oil and gas well	163 feet South
	560.0	Gas well	402 feet South
	560.4	Oil and gas well	287 feet South
	560.6	Oil and gas well	280 feet South
	561.6	Oil and gas well	172 feet North
	563.3	Oil well	313 feet North
	563.5	Oil and gas well	478 feet North
	563.7	Oil and gas well	98 feet North
	564.3	Oil and gas well	435 feet North
	564.4	Oil well	344 feet South
	564.7	Oil and gas well	215 feet North
Muskingum	565.4	Oil and gas well	454 feet South
	567.2	Gas well	243 feet South
	567.7	Gas well	304 feet South
	569.9	Oil well	412 feet South
	570.2	Oil well	268 feet North
	570.3	Oil well	480 feet North
	572.2	Oil and gas well	10 feet North
	572.7	Oil and gas well	135 feet North
	573.0	Gas well with oil show	405 feet North

TABLE 6C-1

Rockies Express Pipeline-East Project
Oil and Gas Wells within 500 feet of the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Milepost	Operation	Distance and Direction from the Right-of-Way
	573.7 [b]	Oil well	179 feet South
	574.7	Gas well	251 feet South
	575.5	Oil and gas well	197 feet North
	576.0	Gas well	199 feet South
	576.3 [b]	Oil well	101 feet South
	576.6	Oil and gas well	184 feet South
	577.1	Oil well with gas show	254 feet North
	578.2	Oil well	257 feet South
	578.8	Gas show	72 feet South
	578.9	Gas show	112 feet North
	579.5 [b]	Oil well	208 feet North
	579.9	Oil and gas well	113 feet North
	580.6	Oil well	241 feet South
	581.4 [b]	Oil well	140 feet South
	581.6 [b]	Oil well	114 feet South
	583.2	Oil and gas well	477 feet North
	583.2 [b]	Oil well	188 feet South
	583.3	Oil and gas well	385 feet North
	583.4 [b]	Oil well	112 feet North
	583.6	Oil and gas well	118 feet South
	583.6 [b]	Oil well	176 feet North
	583.7	Oil and gas well	192 feet South
	583.9	Gas well	278 feet North
	584.0	Oil and gas well	12 feet South
	584.1	Gas well with oil show	308 feet North
	584.2	Oil and gas well	163 feet North
	584.4	Gas well with oil show	377 feet North
	586.5	Gas well	377 feet South
	587.6	Oil and gas well	177 feet North
	588.1	Oil and gas well	448 feet South
	588.5	Oil and gas well	482 feet North
	590.2	Gas well with oil show	454 feet North
Guernsey	590.6	Oil and gas well	257 feet South
	591.0	Oil and gas well	351 feet South
	591.6	Oil and gas well	363 feet North
	594.1	Oil and gas well	147 feet North
	596.5	Oil well with gas show	46 feet South
	597.1	Oil and gas well	327 feet South
	597.6	Oil well	19 feet North
	602.0	Gas well	216 feet South
	602.9	Gas well	136 feet South
	603.1	Gas well	303 feet North
	603.9	Gas well with oil show	238 feet North
	605.1	Gas well with oil show	38 feet North
Noble	614.5	Gas well	131 feet North
	614.9	Gas well	270 feet North
Belmont	616.7	Gas well	11 feet North

TABLE 6C-1

Rockies Express Pipeline-East Project
Oil and Gas Wells within 500 feet of the Rockies Express Pipeline-East Project Pipeline Route [a]

State/County	Milepost	Operation	Distance and Direction from the Right-of-Way
	625.6	Oil well	33 feet North
Belmont	627.1	Oil well with gas show	350 feet North
Monroe	633.8	Gas well	30 feet North
	633.9	Gas well	5 feet North

[a] Missouri Department of Natural Resources, 2002; Illinois State Geological Survey, 2007; Indiana Geological Survey, 2002; Ohio Department of Natural resources, Division of Geological Survey, 2004

[b] Well location identified by the field survey crews.

ROCKIES EXPRESS PIPELINE-EAST PROJECT

Resource Report 6

APPENDIX 6D
Agency Correspondence

NATURAL RESOURCE GROUP, INC.

LOG

LOG OF TELEPHONE CONVERSATION

CALL TO/FROM WHOM: Chris Gordon	PHONE NO.: (614) 265-6594
COMPANY: Ohio Department of Natural Resources, Division of Geological Survey	
NRG CONTACT: Steven Holden	PHONE NO.: (401) 278 - 4308
DATE: March 15, 2007	NRG OFFICE LOCATION: Providence
RE: Consultation regarding abandoned underground mines in Ohio	

LOG OF CONVERSATION:

Holden spoke to Chris Gordon, Geologist at the ODNR, DGS, regarding abandoned underground mines along the Ohio portion of the Rockies Express East Pipeline Project. Holden provided Gordon with a digital shape file of the proposed route in order to identify the project area. Gordon then provided information about the abandoned mines crossed by the project. Holden also inquired about the depth of the mines crossed. Gordon stated that the depth reported, if any, represented a particular location or average elevation in the mine. He also stated that the actual elevation of the mine can vary a significant number of feet depending on the size of the mine making the determination of the depth at a specific location difficult, if possible at all. Holden thanked Gordon for his time and ended the call.

LOG

LOG OF TELEPHONE CONVERSATION

CALL TO/FROM WHOM: Scott Kaden (Geologist III)	PHONE NO.: (573) 368-2183
COMPANY: Missouri Department of Natural Resources, Division of Geology and Land Survey	
NRG CONTACT: Steven Holden	PHONE NO.: (401) 278 - 4308
DATE: January 10, 2007	NRG OFFICE LOCATION: Providence
RE: Consultation regarding paleontological resources in Missouri	

LOG OF CONVERSATION:

Holden spoke to Scott Kaden, Geologist at the MoDNR, Division of Geology and Land Survey, regarding paleontological resources along the Missouri portion of the Rockies Express East Pipeline Project. Holden provided Kaden with and overview map showing the project area. Kaden stated that paleontological resources in the part of the state crossed by the project would not be an issue. He stated that there may be some fossils found if areas of limestone are crossed but they will not be unique. Holden thanked Kaden for his time and ended the call.

NATURAL RESOURCE GROUP, INC.

LOG

LOG OF TELEPHONE CONVERSATION

CALL TO/FROM WHOM:	PHONE NO.:
Donald G. Mikulic, Ph.D.	(217) 244-2415

COMPANY:
Illinois State Geological Survey

NRG CONTACT:	PHONE NO.:
Steven Holden	(401) 278 - 4308

DATE:	NRG OFFICE LOCATION:
January 10, 2007	Providence

RE:
Consultation regarding paleontological resources in Illinois

LOG OF CONVERSATION:

Holden spoke to Don Mikulic, Geologist at the ISGS, regarding paleontological resources along the Illinois portion of the Rockies Express East Pipeline Project. Holden provided Mikulic with and overview map showing the project area. Mikulic stated that paleontological resources in the part of the state crossed by the project would not be an issue due to the fact that the area crossed consisted of unconsolidated quaternary deposits. Mikulic Recommended that Holden contact Jeff Saunders at the Illinois State Museum to obtain further information regarding fossils in that area. Holden thanked Mikulic for his time and ended the call.

From: Jeff Saunders

To: Steve Holden;

CC:

Subject: Re: Consultation on proposed pipeline route

Date: Tuesday, February 13, 2007 3:52:42 PM

Attachments:

Dear Steve Holden:

Although bedrock in our state along your route would not be a concern, the superficial deposits overlying bedrock may potentially be.

At the Illinois State Museum we hold on reposit or record remains of Quaternary (Ice Age) fossils collected in superficial glacial deposits overlying bedrock in Sangamon, Moultrie, Edgar, Douglas, and Christian counties. There are of course also a variety of important archaeological resource sites known from throughout central Illinois, including the counties your transect indicates. But you indicate your interest in only those that are paleontological.

To address paleontological concerns I suggest you obtain a copy of the map "Quaternary Deposits of Illinois," available from the Illinois State Geological Survey:

<http://library.isgs.uiuc.edu/dbtw-wpd/exec/dbtwpub.dll?AC=GET_RECORD&XC=/d
btw-wpd/exec/dbtwpub.dll&BU=http%3A%2F%2Flibrary.isgs.uiuc.edu%2Fdbtw-wpd%2F
textbase%2Flopsearch.htm&TN=lop&SN=AUTO13243&SE=1361&RN=7&MR=20&TR=0&TX=1000
&ES=0&CS=1&XP=&RF=results&EF=&DF=details&RL=0&EL=0&DL=0&NP=3&ID=&MF=&MQ=&TI=
0&DT=&ST=0&IR=2077&NR=0&NB=0&SV=0&BG=0&FG=0&QS=>

On the basis of Quaternary geology shown on this map, your route through
southern Pike, Scott, Morgan, and Sangamon counties traverses the Kellerville and Vandalia till members of the Glasford Formation (of Illinois Episode age). These deposits are not especially fossiliferous, but isolated material has been
found. Across northern Christian County your route traverses the Radnor and Hagerstown members of the Glasford Fm. The Hagerstown member is a ridged-drift complex that embraces kettle deposits. One of these kettles, at Hopwood Farm in
Montgomery County, contained a fossil assemblage including Hesperotestudo crassiscutata, an extinct giant tortoise. This was a very significant and unexpected discovery, since reported in the literature. As your route moves into southern Macon and thence eastward through northern Moultrie, central Douglas, and northern Edgar counties, it crosses various members of the Wedron and Equality formations (of Wisconsin Episode age), both of which have great potential as being significantly fossiliferous for large mammals. Surficial deposits of the Wedron and Equality formations in the region include a

diversity of both isolated (e.g., the skull of a bison on the west bank of the Kaskaskia River, ca. 3 miles se of Sullivan, in Moultrie County) and associated/articulated (e.g., "a nearly perfect skeleton of a mastodon ... in one of the sloughs of ... [Edgar] county") material.

Examples of additional fossils along your route include (taxon X county): Castoroides ohioensis (Giant beaver)--Sangamon County; Procyon lotor (Raccoon)--Sangamon County; Mammut americanum (American mastodont)--Sangamon, Macon, and Edgar counties; Mammuthus sp. (mammoth)--Sangamon, Christian, and Macon counties; Mammuthus primigenius (woolly mammoth)--Sangamon and Macon counties; Cervus elaphas (Wapiti)--Sangamon County; Odocoileus (deer)--Sangamon County; Cervalces scotti (Stag-moose)--Sangamon County; Bison bison (Bison)--Sangamon and Moultrie counties; Bootherium bombifrons (Harlan's muskox)--Sangamon County.

Regarding Illinois Archaeological Sites, the Illinois State Museum houses the archaeological site files for the state. The "curator" of this record is Nick Klobucher. Nick's email is klob@museum.state.il.us

I hope this information is helpful and useful.

Sincerely,

Jeff S.

At 12:36 PM 1/11/07 -0600, you wrote:
>
> Mr. Saunders,
> My name is Steve Holden with Natural Resource Group. My company is preparing
> and Environment Report for a proposed pipeline from Missouri to Ohio. We
> would like to identify any potential paleontological resources along the
> proposed route (see attached map - larger scale maps are available if
> needed). I spoke to Don Mikulic at the ISGS who stated that it would not
> likely be an issue but that I should contact you as a follow up to our
> conversation.
>
> I would not anticipate encountering large areas of bedrock due to the shallow
> depth of the trench (7 feet). However, we would like to identify any
> potential areas of concern.
>
> Thank you for your assistance,
> Steve
>
>
> ----------
> <http://www.nrginc.com/>f9787b.jpg

NATURAL RESOURCE GROUP, INC.

LOG

LOG OF TELEPHONE CONVERSATION

CALL TO/FROM WHOM:	PHONE NO.:
Brian D. Keith (Senior Scientist)	(217) 244-2415
COMPANY: Indiana State Geological Survey	
NRG CONTACT: Steven Holden	PHONE NO.: (401) 278 - 4308
DATE: February 22, 2007	NRG OFFICE LOCATION: Providence
RE: Consultation regarding paleontological resources in Indiana	

LOG OF CONVERSATION:

Holden spoke to Brian Keith, Senior Scientist at the INGS, regarding paleontological resources along the Indiana portion of the Rockies Express East Pipeline Project. Holden explained the location of the project and offered to provide Keith with and overview map showing the project area. Keith stated that would not be necessary. Keith stated that due to the shallow depth of the trench and the cover of glacial material, construction would not create an issue and nothing unique would likely be encountered. Keith also stated that some invertebrates may be encountered but they will not be unique and there is no way of predicting their location. Holden thanked Keith for his time and ended the call.

From:	Shrake, Doug
To:	Steve Holden;
CC:	
Subject:	Paleontological Resources along route in Ohio
Date:	Tuesday, March 06, 2007 8:27:28 AM
Attachments:	Paleontological Resources of Ohio Portion.doc Isotelus-Ohios Fossil.pdf

---

Dear Steve:

I have attached two files to this message. One is a letter discussing my findings relative to any paleontological resources along the Rocky Express pipeline route through Ohio. The second file is a PDF of Isotelus: Ohio's State Fossil.

Please telephone or email me if you need any further assistance.

<<Paleontological Resources of Ohio Portion.doc>>

<<Isotelus-Ohios Fossil.pdf>>

Doug

Douglas L. Shrake, PG
Senior Geologist
Geologic Mapping & Industrial Minerals Group
ODNR-Division of Geological Survey
2045 Morse Road, C-2
Columbus, Ohio 43229-6693
614-265-6579
Fax: 614-447-1918
Mailto:doug.shrake@dnr.state.oh.us
http://www.ohiodnr.com/geosurvey

Steve Holden
Natural Resource Group, Inc.

Dear Steve:

I have completed my review of the proposed Rocky Express Pipeline route through Ohio with regard to encountering possible paleontologic resources. My initial evaluation of the pipeline route possibly encountering any significant paleontologic resources not being of concern was correct. The route does not appear to cross any "known unique paleontologic intervals".

The only potential for excavating a significant paleontologic specimen will occur in the route interval from 430 to 460. The Upper Ordovician-age Waynesville and Liberty Formations encountered in this interval have the potential to produce large specimens of Ohio's official fossil the Isotelus trilobite (see GeoFact 6: *Isotelus*: Ohio's State Fossil - http://www.ohiodnr.com/geosurvey/geo_fact/geo_f06.htm). Large specimens of this trilobite are known from excavations within the shale layers of the aforementioned southwestern Ohio bedrock formations. Although such specimens are rare, there is no need for precaution with regard to excavating a specimen.

- In the 430-440 interval the portion of the route from its intersection with Clear Creek east to where the route crosses Ohio State Route 741 just west of Red Lion, Ohio.
- In the 440-450 interval the section of concern is east from the route's intersection with Township Line Road to the route's intersection with the Little Miami River east of Waynesville, Ohio.
- In the 450-460 interval the section of concern is east from the route's intersection with the Warren-Clinton County line to its Intersection with Gurneyville Rd.

If you need additional, information let me know.

Sincerely,

Douglas L. Shrake, Senior Geologist, PG
Geologic Mapping and Industrial Minerals Group
2045 Morse Road, C-2
Columbus, Ohio 43229-6693
OFFICE: 614-265-6579
FAX: 614-447-1918
doug.shrake@dnr.state.oh.us
http://www.ohiodnr/geosurvey

OHIO GEOLOGY

GEOFACTS No. 6

OHIO DEPARTMENT OF NATURAL RESOURCES • DIVISION OF GEOLOGICAL SURVEY

ISOTELUS: OHIO'S STATE FOSSIL

On June 20, 1985, Ohio House Bill 145 designated the trilobite genus *Isotelus* as the official state invertebrate fossil of Ohio. With the signing of this bill, *Isotelus* joined Ohio's other official state symbols, which include the ladybug (insect), red carnation (flower), flint (gemstone), cardinal (bird), white-tail deer (animal), tomato juice (beverage), and of course, the state tree, the buckeye.

HOW *ISOTELUS* WAS CHOSEN AS THE STATE FOSSIL OF OHIO

Ohio has long been known worldwide for the abundant and well-preserved fossils collected throughout the state. Individuals involved in geologically related activities in Ohio, either as professionals or hobbyists, had long thought that Ohio should have an official state fossil. This idea finally became a reality largely through the efforts of two Dayton, Ohio, area elementary school classes, Doris Swabb's third graders at Beavertown School in Kettering and Virginia Evers' fourth graders at St. Anthony School in Dayton.

After visiting the Dayton Museum of Natural History (now known as the Boonschoft Museum of Discovery) and viewing a cast of the famous Huffman Dam specimen of *Isotelus*, the students and teachers came up with the idea of trying to have the Huffman Dam trilobite designated as the official state fossil of Ohio. The students wrote letters to Representatives Robert L. Corbin and Robert E. Hickey of Dayton, who agreed to sponsor legislation in the Ohio House of Representatives to make the Huffman Dam *Isotelus* the official state fossil. Senator Charles Horn of Dayton agreed to do the same in the Ohio Senate.

The proposal for a state fossil received widespread publicity in newspapers and on television. Support for the idea came from various geologic interest groups throughout the state. Rather than naming only one specimen as the state fossil, the bill, which was drafted with technical assistance from the Division of Geological Survey, actually designated the trilobite genus *Isotelus* as the official state invertebrate fossil. Ultimately, the bill passed both the Ohio House of Representatives and the Ohio Senate with little opposition.

Isotelus is a most suitable selection for the state fossil. Not only are specimens of this trilobite, or at least fragments, moderately abundant in the rocks exposed in southwestern Ohio, but they are represented by the Huffman Dam specimen, which is one of the largest complete trilobites ever collected.

WHAT IS A TRILOBITE?

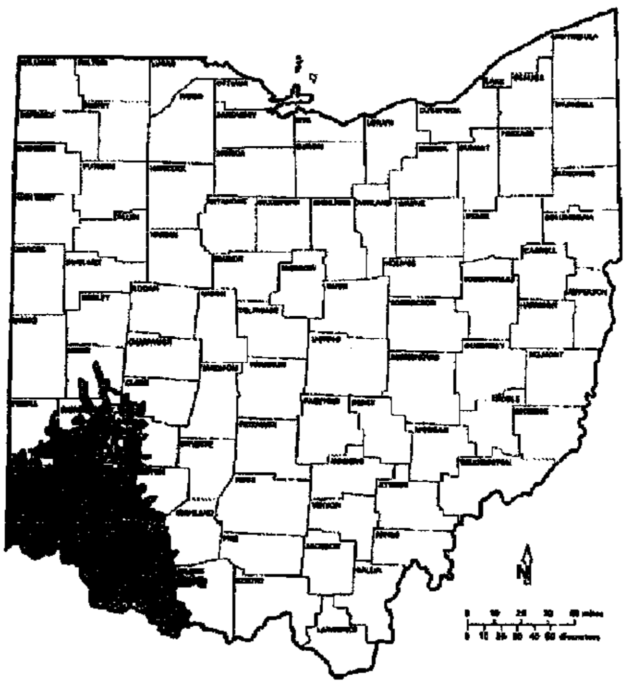
Trilobites are an extinct class of the Phylum Arthropoda, which includes among its living members the horseshoe crab, crabs, lobsters, shrimp, scorpions, spiders, and insects. Trilobites first appeared in the fossil record about 542 million years ago and became extinct about 251 million years ago. Trilobites lived in marine environments, where they burrowed in sediment, crawled along the sea floor, or were free swimming. Most trilobites ate mud from the sea floor, whereas others filtered food directly from the water, scavenged, or were predators. They grew by periodically molting their exoskeleton, a hard, outer shell similar in composition to fingernails. Thus, one trilobite could leave behind numerous fossil fragments representing shed exoskeletons. For defense against predators, some trilobites had sharp spines on their exoskeletons, and all had the ability to enroll, much like the pill bug or armadillo of today, thereby enclosing their legs and softer underside within their hard outer exoskeleton.

ISOTELUS AND ITS HISTORY IN OHIO

Isotelus has had a long and illustrious history in Ohio, in terms of both geologic time and scientific study. *Isotelus* is known from rocks of Ordovician age, about 488 to 443 million years ago. In southwestern Ohio, only rocks of Late Ordovician age (455 to 443 million years ago) are exposed. These rocks consist of about 820 feet of comparatively thin, alternating layers of limestones and shales. These beds were deposited as limy mud and clay on the floor of a warm, shallow, tropical sea that covered Ohio during the Ordovician.

Specimen of Isotelus *collected from Huffman Dam, near Dayton, in 1919.*

The first serious study of Ohio's Ordovician rocks was undertaken by the first Geological Survey of Ohio in 1837-1838. At this time John Locke mapped portions of the southwestern corner of the state. Among Locke's many discoveries were partial remains of a large specimen of *Isotelus*. Because of its size, Locke named the trilobite *Isotelus maximus*. He later changed the name to *Isotelus megistos*, but today *I. maximus* is the accepted species name. Locke collected only the pygidium (tail) of the trilobite but, by proportional comparison, he estimated that the complete trilobite would have been about 21 inches in length.



Outcrop area of Ordovician rocks in Ohio.

Perhaps the most famous *Isotelus* specimen was discovered in 1919 by workmen digging an outlet tunnel during the construction of the Huffman Dam on the Mad River northeast of Dayton. This giant specimen of *Isotelus* measures 14½ inches long by 10¼ inches wide. Through the efforts of Arthur E. Morgan, chief engineer of the Miami Conservancy District, the trilobite came into the hands of August F. Foerste, a Dayton area high school teacher and one of Ohio's most renowned and prolific paleontologists. Foerste's research association with the National Museum of Natural History (the Smithsonian Institution) in Washington, D.C., resulted in the specimen being transferred to that institution for permanent display. The Huffman Dam trilobite still occupies a prominent position in the paleontological exhibits at the Smithsonian and is still one of the largest, complete trilobites of any kind ever collected.

FURTHER READING

Eckert, A. W., 1961, The mammoth trilobite of Dayton: Science Digest, July, p. 67-70.

Feldmann, R. M., and Hackathorn, Merrianne, eds., 1996, Fossils of Ohio: Ohio Division of Geological Survey Bulletin 70, 577 p.

Foerste, A. F., 1919, Notes on *Isotelus*, *Acrolichas*, *Calymene*, and *Encrinus*: Denison University Scientific Laboratories Journal, v. 19, p. 65-82.

Hansen, M. C., 1985, *Isotelus*—Ohio's State Fossil: Division of Geological Survey, Ohio Geology, Summer, p. 1-4.

_________ 1989, Large *Isotelus* found: Division of Geological Survey, Ohio Geology, Spring, p. 6.

Locke, John, 1838, Geological report (on southwestern Ohio): Ohio Division of Geological Survey Second Annual Report, p. 201-286.

_________ 1842, On a new species of trilobite of very large size (*Isotelus megistos*): American Journal of Science, v. 42, no. 2, p. 366-368.

Shrake, D. L., 1994, Ohio trilobites: Ohio Division of Geological Survey GeoFacts No. 5.

• This GeoFacts compiled by Douglas L. Shrake • Revised May 2005 •

Bob Taft, Governor Sam Speck, Director Thomas M. Berg, Chief

The Division of Geological Survey GeoFacts Series is available on the World Wide Web: http://www.ohiodnr.com/geosurvey/

recycled paper

ROCKIES EXPRESS PIPELINE-EAST PROJECT

Resource Report 6

APPENDIX 6E
Rockies Express Pipeline-East Project Blasting Plan

ROCKIES EXPRESS PIPELINE COMPANY LLC

ROCKIES EXPRESS PIPELINE-EAST PROJECT
BLASTING PLAN

March 2007

PRELIMINARY

Prepared by:

NATURAL RESOURCE GROUP, INC.

Natural Resource Group, Inc.

BLASTING PLAN

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1.0 INTRODUCTION

This Blasting Plan outlines the procedures and safety measures that the Contractor will adhere to while implementing blasting activities along the pipeline right-of-way during construction of Rockies Express Pipeline Company LLC's (Rockies Express') Rockies Express Pipeline – East (REX-East) Project. The Contractor will be required to submit a Blasting Specification Plan to Rockies Express that is consistent with the provisions in this Blasting Plan. The Contractor's plan, when approved by Rockies Express, will be incorporated into the Contractor's scope of work.

2.0 OBJECTIVE

This Blasting Plan is intended to identify blasting procedures, including safety, use, storage, and transportation of explosives that are consistent with minimum safety requirements as defined by federal (e.g., Title 27 CFR 181 - Commerce in Explosives; Title 49 CFR 177 - Carriage by Public Highway; Title 29 CFR 1926.900 et seq. Sub-part U - Safety and Health Regulations for Construction - Blasting and Use of Explosives; Title 29 CFR 1910.109 – Explosives and Blasting Agents (OSHA); 29 CFR 1926.900-General Provisions and sections 901, 902 and 904-911), state, and local regulations. Additionally this plan is intended to address environmental aspects of blasting activities, and to identify areas of concern along the proposed pipeline route.

3.0 GENERAL REQUIREMENTS

Blasting operations shall be conducted by or under the direct and constant supervision of personnel legally licensed and certified to perform such activity in the jurisdiction where blasting occurs. Prior to any blasting activities, the contractor shall provide Rockies Express with appropriate information documenting the experience, licenses, and permits associated with blasting personnel.

Blasting-related operations including: obtaining, transporting, storing, handling, loading, detonating, and disposing of blasting material; drilling; and ground-motion monitoring shall comply with applicable federal, state, and local regulations, permit conditions and the construction contract.

Blasting for grade or trench excavation shall be used where deemed necessary by a construction expert after examination of the site and in other locations only after other reasonable means of excavation have been used and are unsuccessful in achieving the required results. Rockies Express may specify locations (e.g., foreign line crossings, near structures) where consolidated rock shall be removed by approved mechanical equipment such as rock-trenching machines, rock saws, hydraulic rams, or jack hammers in lieu of blasting.

Before blasting, a site-specific Blasting Specification Plan must be submitted by the Contractor to Rockies Express for approval. The site-specific blasting plan must be reviewed by an engineer representing Rockies Express. The engineer will analyze the data to determine the combined stress level of each affected pipeline and will make recommendations and/or forward approval to Rockies Express before blasting may commence.

Drilling and blasting shall be done with a Rockies Express Construction Inspector present. Approval is required to proceed prior to each blast. Approval does not relieve the Contractor from responsibility or liability.

4.0 PRE-BLASTING REQUIREMENTS

Prior to the initiation of blasting operations, the Contractor shall comply with the following:

- The Contractor will obtain all required federal, state, and local permits relating to the transportation, storage, handling, loading, and detonation of explosives.
- The Contractor shall place all necessary "one calls" 48 hours prior to construction where one-call systems are in place.
- The Contractor shall be responsible for the protection of existing underground facilities.
- Before performing any work on, or accessing the right-of-way, the Contractor shall verify to Rockies Express that all property owners have been notified of the impending construction.
- The Contractor shall submit to the Rockies Express representative its site-specific Blasting Plan for approval prior to execution of blasting activity.

5.0 SITE-SPECIFIC BLASTING PLANS

Based on analysis of the state-level State Soil Geographic database, approximately 13 percent (79.4 miles) of the pipeline route will cross areas with bedrock at depths of less than 60 inches (Natural Resources Conservation Service, 1994). (Note: the minimum excavation, even in areas of consolidated rock, will exceed 60 inches to allow for a minimum of 6-inches of bedding or padding material.) The majority of these soils are located along the eastern Ohio portion of the proposed route. Analysis of the county-level Soil Survey Geographic Database showed similar results with approximately 84.4 miles of the proposed route being underlain by shallow bedrock. Approximately one-half of this bedrock is considered paralithic (soft) and may not require blasting during construction. The remaining areas will cross soils with a lithic contact (hard bedrock) within 60 inches of the surface that may require blasting or other special construction techniques during installation of the proposed pipeline. For each area determined to require blasting, a site-specific blasting plan will be created. The Contractor's site-specific blasting plan shall include at a minimum the following information:

- Blaster's name, company, copy of license, and statement of qualifications; seismograph company, names, equipment and sensor location;
- Site location (milepost and stationing), applicable alignment sheet numbers, and associated rock type and geological structure (solid, layered, or fractured);
- Copies of all required federal, state, and local permits;
- Methods and materials including explosive type, product name and size, weight per unit, and density; stemming material; tamping method; blasting sequence; use of non-electrical initiation systems *for* all blasting operations; magazine type and locations for storage of explosives and detonating caps;

- Site dimensions including explosive depth, distribution, and maximum charge and weight per delay; hole depth, diameter, pattern, and number of holes per delay;

- Dates and hours of conducting blasting, distance and orientation to nearest aboveground and underground structures; schedule identifying when blasting would occur within each waterbody greater than 10 feet wide, or within any designated coldwater fishery; and

- Blasting procedures for:

    - Storing, handling, transporting, loading, and firing explosives;

    - Prevention of misfires, flyrock, fire prevention, noise, and stray current accidental-detonation;

    - Signs, flagmen, and warning signals prior to each blast;

    - Those locations where the pipeline route:

        - Parallels or crosses an electrical transmission corridor, cable or pipeline;
        - Parallels or crosses a highway or road;
        - Is within or adjacent to treed areas;
        - Approaches within 200 feet of a water well or spring; or
        - Approaches within 1,000 feet of any residence, building or occupied structure;

    - Local notification;

    - Inspections after each blast; and

    - Disposal of waste blasting material.

6.0 MONITORING

During blasting operations the contractor will be required to monitor operations in the following manner:

- The Contractor shall provide seismographic equipment to measure the peak particle velocity (PPV) of all blasts in the vertical, horizontal, and longitudinal directions. Seismic monitoring can only be discontinued if a) the blasting schedule and blasting performance consistently produce PPVs at the pipeline that are lower than the maximum allowable limit and b) a Rockies Express representative provides written authorization.

- The contractor shall measure the PPV at the adjacent pipeline; at any water wells, potable springs, and at any above ground structure within 200 feet of the blasting.

- The contractor shall complete a Blasting Log Record immediately after each blast and submit a copy to a Rockies Express representative.

7.0 SAFETY

7.1 Protection of Aboveground and Underground Structures

Where blasting is determined to be required, Rockies Express will identify any municipal water mains proposed for crossing, and will consult the local water authority. Reports of identified crossings will include location by milepost, owner, and status and results of contacts with the water authority.

The Contractor will exercise control to prevent damage to aboveground and underground structures including buildings, pipelines, utilities, springs, and water wells. The Contractor will implement the following procedures:

- If blasting occurs within 200 feet of identified water well or potable springs, water flow performance, and water quality testing will be conducted before blasting. If the water well or spring is damaged, the well or spring will be repaired or other wise restored or the well owner will be compensated for damages. Rockies Express will provide an alternative potable water supply to the landowner until repairs occur. Locations of water wells or systems within 200 feet of blasting activities are indicated on Rockies Express' construction alignment sheets.

- If blasting occurs within 200 feet of any aboveground structures, the Contractor and Rockies Express representative will inspect structures before and after blasting. In the unlikely event that damage occurs to the aboveground structure, the owner will be compensated.

- The contractor shall be responsible for the ultimate resolution of all damage claims resulting from blasting. Such liability is not restricted by the 200-foot inspection requirement cited above.

- Blasting will not be allowed within 15 feet of an existing pipeline, unless specifically authorized by Rockies Express.

- Holes that have contained explosive material shall not be re-drilled. Holes shall not be drilled where danger exists of intersecting another hole containing explosive material.

- Blasting mats or padding shall be used on all shots where necessary to prevent scattering of loose rock onto adjacent property and to prevent damage to nearby structures and overhead utilities.

- Blasting shall not begin until occupants of nearby buildings, stores, residences, places of business, places of public gathering, and farmers have been notified by the contractor sufficiently in advance to protect personnel, property, and livestock. The contractor shall notify all such parties at least 48 hours prior to blasting.

- Blasting in or near environmentally sensitive areas such as streams and wildlife areas may include additional restrictions.
- All blasting shall be subject to the following limitations.
  - Maximum peak particle velocity of 12.0 inches per second in any of three mutually perpendicular axes, measured at the lesser distance of the nearest facility or the edge of the permanent easement.
  - Maximum drill size shall be 2.5 inches unless approved by Rockies Express.
  - Maximum quantity of explosive per delay shall be governed by the recorded measurements as influenced by work site conditions.
  - Explosive agents and ignition methods shall be approved by Rockies Express. ANFO and other free flowing explosives and blasting agents are not acceptable and shall not be used.
  - Drill holes shall not be left loaded overnight.
  - Good stemming material is to be used in all holes.
- The drilling pattern shall be set in a manner to achieve smaller rock fragmentation (maximum 1 foot in diameter) in order to use as much as possible of the blasted rock as backfill material after the pipe has been padded in accordance with the specifications. The Contractor shall submit the proposed drilling pattern to Rockies Express for approval.
- Under pipeline crossings and all other areas where drilling and blasting is required within 15 feet of existing facilities:
  - Drill holes shall be reduced to a maximum of 2 inches or less in diameter.
  - The number of holes shot at one time shall be limited to three unless otherwise approvedby Rockies Express.
  - Appropriate delay between charges to attain desired fragmentation.

7.2 Protection of Personnel

The Contractor shall include in its procedures all federal, state, county, and local safety requirements for blasting. The Contractor's procedures shall address, as a minimum, the following requirements:

- Only authorized, qualified, and experienced personnel shall handle explosives.
- No explosive materials shall be located where they may be exposed to flame, excessive heat, sparks, or impact. Smoking, firearms, matches, open flames, and heat- and spark-producing devices shall be prohibited in or near explosive magazines or while explosives are being handled, transported, or used.

- A code of blasting signals shall be established, posted in conspicuous places and utilized during blasting operations. Employee training shall be conducted on the use and implementation of the code.

- The contractor shall use every reasonable precaution including, but not limited to, visual and audible warning signals, warning signs, flag person, and barricades to ensure personnel safety.

- Warning signs, with lettering a minimum of 4 inches in height on a contrasting background, will be erected and maintained at all approaches to the blast area.

- Flaggers will be stationed on all roadways passing within 1,000 feet of the blast area to stop all traffic during blasting operations.

- All personnel not involved in the actual detonation shall stand back at least 1,000 feet and workers involved in the actual detonation shall stand back at least 650 feet from the time the blast signal is given until the "ALL CLEAR" has been sounded.

- No loaded holes shall be left unattended or unprotected. No explosives or blasting agent shall be abandoned.

- In the case of a misfire, the blaster shall provide proper safeguards for personnel until the misfire has been re-blasted or safely removed.

- The exposed areas of the blast will be matted wherever practicable. In cases where such a procedure is not deemed to be feasible, the Contractor will submit an alternative procedure for review by Rockies Express and the site in question must be visited and examined by the consultant before any approval is granted.

- Rockies Express may employ two-way radios for communication between vehicles and office facilities. The contractor shall advise Rockies Express and other pipeline contractors of any need to cease use of such equipment during blasting activities.

- All loading and blasting activity shall cease and personnel in and around the blast area will retreat to a position of safety during the approach and progress of an electrical storm irrespective of the type of explosives or initiation system used. **THIS IS A MAJOR SAFETY PRECAUTION AND WILL ALWAYS BE OBSERVED.** All explosive materials, all electrical initiation systems, and all non-electric initiation systems are susceptible to premature initiation by lightning.

- Previous blast areas must be inspected to verify the absence of misfires. No drilling may commence until such inspection occurs. If a misfire occurs adjacent to a hole to be drilled, the misfire will be cleared by the blaster using whatever techniques are called for by the situation prior to commencement of drilling. If a misfire occurs at some distance from the drilling area, drilling may be stopped while clearing preparations are underway. When the misfire is to be cleared by re-shooting, drilling will be shutdown and personnel evacuated to a place of safety prior to detonation.

- All transportation of explosives will be in accordance with applicable federal, state, and local laws and regulations. Vehicles used to transport explosives shall be in proper working condition and equipped with tight wooden or non- sparking metal floor and sides. If explosives are carried in an open-bodied truck, they will be covered with a waterproof and flame-resistant tarpaulin. Wiring will be fully insulated to prevent short-circuiting and at least two fire extinguishes will be carried. The truck will be plainly marked to identify its cargo so that the public may be adequately warned. Metal, flammable, or corrosive substances will not be transported in the same vehicle with explosives. There will be no smoking and unauthorized or unnecessary personnel will not be allowed in the vehicle. Competent, qualified personnel will load and unload explosives into or from the vehicle.

- No sparking metal tools will be used to open kegs or wooden cases of explosives. Metallic slitters will be used to open fiberboard cases, provided the metallic slitter does not come in contact with the metallic fasteners of the case. There will be no smoking, no matches, no open lights, or other fire or flame nearby while handling or using explosives. Explosives will not be placed where they are subject to flame, excessive heat, sparks, or impact. Partial cases or packages of explosives will be re-closed after use. No explosives will be carried in the pockets or clothing of personnel. The wires of an electric blasting cap shall not be tampered with in any way. Wires will not be uncoiled. The use of electric blasting caps will not be permitted during dust storms or near any other source of large charges of static electricity. Uncoiling of the wires or use of electric caps will not be permitted near radio-frequency transmitters. The firing circuit will be completely insulated from the ground or other conductors.

- No blast will be fired without a positive signal from the person in charge. This person will have made certain that all surplus explosives are in a safe place; all persons, vehicles, and/or boats are at a safe distance; and adequate warning has been given. Adequate warning of a blast will consist of but not be limited to the following:

    - Notification to nearby homeowners and local agencies if necessary;

    - Stop vehicular and/or pedestrian traffic near the blast site; and

    - Signal given by an air horn, whistle or similar device using standard warning signals.

- Only authorized and necessary personnel will be present where explosives are being handled or used.

- Condition of the hole will be checked with a wooden tamping pole prior to loading. Surplus explosives will not be stacked near working areas during loading. Detonating fans will be cut from spool before loading the balance of charge into the hole. No explosives will be forced into a bore hole past an obstruction. Loading will be done by a blaster holding a valid license or by personnel under his direct supervision.

- Fly-rock leaving the right-of-way shall be collected immediately and disposed of at disposal sites approved by Rockies Express. This work shall not be left to the cleanup crew.

7.3 Protection of Threatened and Endangered Species

Rockies Express will consult with state and federal agencies regarding areas proposed for blasting where sensitive habitats or species are known to occur. Areas identified as containing sensitive habitats or species, as directed by the appropriate agencies, will be staked and flagged. A qualified project biologist will survey the proposed blasting zone identified by the pipeline contractor immediately in advance of any drilling or blasting. Areas will be checked before and after blasting for the presence of sensitive species, and disturbance to species and habitats will be resolved in accordance with guidance provided by the appropriate agencies.

7.4 Lightning Hazard

A risk of accidental detonation caused by lightning strikes exists at any time the workplace is experiencing an electrical storm and there are loaded holes on site. If this hazard is judged to exist by the Rockies Express representative, work shall discontinue at all operations and workers will be moved to secure positions away from the loaded holes. Furthermore, workers shall not return to the work site until the storm has passed and the Rockies Express representative has indicated it is clear to return.

Rockies Express' Contractor shall have on site approved lightning detectors (model SD-2508 manufactured by Electronics Div. of S.D.I. International, Model 350 manufactured by Thomas Instruments Inc., Skyscan Lighting Detector manufactured by Skyscan Technologies or equivalent) capable of measuring the degree of electrical activity as a storm approaches, and the distance to the storm front from the instrument on the right-of-way.

8.0 IN-WATER BLASTING

Rockies Express will consult the appropriate agencies regarding waterbody crossings where blasting may be required, to determine the presence and quality of local fisheries. The type of explosive, size of charges, sequence of firing, etc. will be selected to minimize shock wave stresses on aquatic life adjacent to the blasting area.

Where specified, the contractor shall furnish the necessary labor and equipment to employ air bubble curtains at water crossings for the protection of existing pipelines, wildlife or other facilities. In the case of river, creek or lake crossings, any necessary blasting operations shall be carried out in such a manner that they conform in all respects with the limitations, requirements and procedures required by the authority having jurisdiction. Explosives used for river, lake or creek crossings shall be non-sympathetically propagating explosives and shall be approved by Rockies Express.

Notifications will be made to all appropriate resource agencies.

9.0 STORAGE REQUIREMENTS

All explosives, blasting agents, and initiation devices shall be stored in locked magazines that have been located, constructed, approved, and licensed in accordance with local, state, and federal regulations. Magazines shall be dry, well-ventilated, reasonably cool (painting of the exterior with a reflective color), bullet and fire resistant, and kept clean.

Initiation devices shall not be stored in the same box, container, or magazine with other explosives. Explosives, blasting agents or initiation devices shall not be stored in wet or damp areas; near oil, gasoline, cleaning solvents; near sources of heat radiators, steam pipes, stoves, etc. No metal or metal tools shall be stored in the magazine. There shall be no smoking, matches, open lights, or other fire or flame inside or within 50 feet of storage magazines or explosive materials. The loading and unloading of explosive materials into or out of the magazine shall be done in a business-like manner with no loitering, horseplay, or prank playing.

Magazines shall be kept locked at all times unless explosives are being delivered or removed by authorized personnel. Admittance shall be restricted to the magazine keeper, blasting supervisor, or licensed blaster. Magazine construction shall meet the requirements of Bureau of Alcohol, Tobacco and Fire Arms (ATF) P5400.7 "Explosives Law and Regulations" and be in accordance with local, state, or federal regulations and the Blaster's Handbook.

Accurate and current records shall be kept of the explosive material inventory to ensure that oldest stocks are utilized first, satisfy regulatory requirements and for immediate notification of any loss or theft. Magazine records shall reflect the quantity of explosions removed, the amount returned, and the net quantity used at the blasting site.

When explosive materials are taken from the storage magazine, they shall be kept in the original containers until used. Small quantities of explosive materials may be placed in day boxes, powder chests or detonator boxes. Any explosive material not used at the blast site shall be returned to the storage magazine and replaced in the original container as soon as possible.

Magazine locations shall be in accordance with local, state, or federal regulations. Where no regulations apply, magazines shall be located in accordance with the latest edition of the 175th Anniversary Edition of the Blaster's Handbook and ATF P5400-7 Explosives Law and Regulations.

Magazines shall be marked in minimum 3-inch high letters with the words "DANGER - EXPLOSIVES" prominently displayed on all sides and roof.

ROCKIES EXPRESS PIPELINE-EAST PROJECT

Resource Report 6

APPENDIX 6F
Engineering Assessment of Coal Mining Subsidence Effects on Rockies Express Pipeline

DRAFT

ENGINEERING ASSESSMENT OF COAL MINING SUBSIDENCE EFFECTS ON ROCKIES EXPRESS PIPELINE

by

D. J. Nyman & Associates

Houston, Texas

prepared for

Rockies Express Pipeline

Houston, Texas

February 19, 2007

Rev. A

Important Notice: This Rev. A draft dated 2-19-07 is an in-progress work by D. J. Nyman & Associates and has been released to REX Pipeline ONLY for the express purpose of review and comment.

D.J. Nyman & Associates

REVISION RECORD

Revision No.	Date	Pages	Description
A	*19-Feb-07*	*All*	*Draft for review and comment.*

February 19, 2007

Rockies Express Pipeline
500 Dallas, Suite 1000
Houston, TX 77002

Attn: Mr. Gayle Pritchard

SUBJECT: Engineering Assessment of Coal Mining Subsidence Effects on Rockies Express Pipeline

Dear Mr. Pritchard:

We are pleased to submit our draft report on the engineering assessment of the coal mining subsidence effects on the 42-inch Rockies Express (REX) Pipeline. The objective of our assessment was to determine the capacity of the pipeline to deform to accommodate ground subsidence movement before reaching a limiting strain condition for which damage to the pipeline could reasonably be expected and to recommend design mitigation measures or protective measures that could be undertaken at the time of the subsidence event. The assessment has included the geotechnical characterization of subsidence displacement and a general review of regulations pertinent to longwall mining subsidence rights.

Based upon the results of our analyses of seven example scenarios of longwall mining subsidence, we conclude that the 42-inch gas pipeline has adequate capacity to withstand the expected displacement patterns without reaching a limiting stress condition applicable to displacement-controlled loading. Notwithstanding the favorable result of our assessment, REX Pipeline should locate the pipeline strategically to minimize exposure to areas of past or possible future mining and should be vigilant in monitoring mining activity along the right-of-way during operations.

Important Notice: This Rev. A draft is an in-progress work by D. J. Nyman & Associates and issued at this time to REX Pipeline ONLY for the express purpose of soliciting review comments. The content of this report is subject to revision pursuant to our own peer review and reconciliation of a few open items.

We appreciate the opportunity to be of service to REX Pipeline. Please contact us if you have questions or comments concerning our draft report.

Very truly yours,

D.J. Nyman

Douglas J. Nyman, Ph.D., P.E.

Principal Engineer

Enclosure

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SUMMARY

[To be added in next draft.]

1. INTRODUCTION

Rockies Express Pipeline (REX Pipeline) plans to construct a 42-inch natural gas pipeline from Audrain, Missouri, in eastern Missouri to Oakford, Pennsylvania, near Philadelphia, as shown for reference in Figure 1, a distance of approximately ___ miles. The pipeline route crosses active coal mining areas in Illinois, Indiana, Ohio, West Virginia and Pennsylvania. The ground surface above areas of underground mining is subject to subsidence, which may take the form of pit, sag or trough subsidence.

Pit subsidence is a circular hole in the ground with essentially vertical sidewalls and a diameter ranging from a few feet to about 40 feet. Sag subsidence is rectangular depression developed over room-and-pillar mines. Pit and sag subsidence are similar in that they occur more or less randomly and unexpectedly when pillars of coal collapse under overburden loading, typically well after an underground mine has been abandoned. Trough subsidence forms over high extraction retreat or longwall panels as the mining operation progresses and can be readily predicted as a function of the size and thickness of the mined panel, the depth of the coal seam, and the geologic structure of the overburden strata.

Subsidence associated with coal mining is an important concern for pipelines simply because a buried pipeline must deform axially and in bending to accommodate the vertical and horizontal displacement of the ground surface that occurs during or following an underground mining operation. Depending on the amount and distribution of ground displacement, subsidence could produce strains in buried pipelines in excess of that experienced for normal operating conditions and accommodated by conventional design. When feasible, pipelines should be routed to avoid areas that may subject to future mining activity, especially longwall mining where ground subsidence is a virtual certainty. However, avoidance of such areas is often not possible; hence, steps must be taken to protect the pipeline against subsidence through design measures, , implementation of field mitigation measures once mining is scheduled to happen, or both.

D. J. Nyman & Associates (DJNA) was commissioned by Gulf Interstate Engineering Company, on behalf of Rockies Express Pipeline, to conduct an engineering assessment of the potential for damage to the 42-inch gas pipeline by coal mining subsidence along the route. In particular, the objective of the investigation is to determine the capacity of the pipeline to deform to accommodate ground subsidence movement before reaching a limiting strain condition for which damage to the pipeline could reasonably be expected and to recommend design mitigation measures or protective measures that could be undertaken at the time of the subsidence event.

1.1 Work Scope

The work scope addresses coal mining subsidence effects generically, because the location of future longwall mining activity and possible pit or sag subsidence over abandoned or active mines cannot be accurately predicted relative to the pipeline route. Thus, the objective is to provide a broad characterization of coal mining along the right-of-way, an assessment of the effects of probably subsidence scenarios, and recommendations for mitigation as needed during the operating life of the project. It is incumbent upon REX Pipeline to locate the pipeline strategically to minimize exposure to areas of past or possible future mining and to be vigilant in monitoring such activity along the right-of-way during operations.

The work scope consisted of the following general tasks:

1. Characterize Subsidence-Induced Ground Displacement. Ground subsidence patterns (vertical and horizontal ground displacement) were characterized for longwall mining and for random surface depressions (pits or sags) that might occur over room-and-pillar mines. This information was compiled from available case history studies of subsidence and augmented by use of the Virgina Tech Surface Displacement Prediction System (SDPS) computer program. Seven example scenarios of longwall mining subsidence were developed for locations in central Illinois, eastern Ohio, and either West Virginia or Pennsylvania for typical thicknesses of coal, depths of coal, and overlying geologic strata. Worst-case scenarios for localized collapse depressions over room-and-pillar mines will also be developed from documented case histories.

2. Analysis of Representative Subsidence Cases). Finite element analysis (FEA) were performed to assess pipeline performance in for representative subsidence scenarios as follows:

   a. Long wall mining subsidence effects on conventional buried pipeline for the most severe of the seven hypothetical cases developed in Task ___ above. Five cases were investigated for various parallel, perpendicular and oblique angle crossings. Three cases investigated the response of a bend within the subsidence zone. Model variations included changes in pipe wall thickness and soil restraint (strength).

   b. The results of the analysis cases were used to assess the effectiveness of minimizing the effect of long wall mining subsidence by temporarily providing additional flexibility by removing soil cover over the pipeline.

   c. Analysis of pipeline freespan stress due to subsidence in previously mined areas (pits or sags). Considering the simplicity of this analysis, spreadsheet calculations were used in lieu of FEA.

3. Mining Rights Overview. A brief overview of regulations pertinent to longwall mine subsidence rights was prepared. This overview was broad-based and limited in scope, since there are many variations of agreements that have been negotiated between owners (previous and current) of mineral rights and surface property owners, and which may or may not include provision for protecting utilities and infrastructure such as an operating pipeline. The overview includes information on the implementation of the Surface Mining and Reclamation Control Act (SMCRA) by the states crossed by the REX Pipeline, and contact information for the various state agencies. The diversity of issues involved is illustrated by two example cases.

4. Obtain and Assess Coal Resource and Mining Maps. State maps of abandoned and operating coal mines and unmined coal resources were obtained for the states crossed by the REX Pipeline (Illinois, Indiana, Ohio, West Virginia and Pennsylvania) from state, federal and other readily available public sources. This task did not include contact with individual coal companies to obtain detailed information on mining activity. Maps and GIS computer files have been delivered separate from this report to REX Pipeline for incorporation into the project GIS as appropriate and feasible.

5. Strategies for Mitigation of Subsidence Effects. An overview discussion of mining subsidence mitigation strategies is provided that covers issues related to right-of-way acquisition, construction, operations, periodic surveillance, and alternatives for field intervention (protection) when needed.

1.2 Project Team

The engineering assessment was managed and directed by Dr. D. J. Nyman. Dr. K. O'Conner developed a characterization of general subsidence scenarios (distribution of vertical and horizontal displacement) that could generally be expected along the pipeline route. Mr. D. G. Honegger conducted the pipeline stress analysis for various selected subsidence scenarios. Professor C. H. Dowding of Northwestern University conducted a geotechnical peer review of the report.

2. LONGWALL MINING AND SUBSIDENCE

The assessment of coal mining subsidence effects on the REX Pipeline is limited primarily to consideration of longwall mining, because longwall mining generally poses a more serious threat to a buried pipeline due to the propagation of the subsidence pattern across the ground surface in concert with the mining that takes place underground. The ground subsidence pattern takes the form of a reasonably predictable trough depression that will subject a buried pipeline to bending deformation and axial strain.

Pit and sag subsidence over room and pillar mines is much less of a threat to a buried pipeline, particularly considering its sporadic and generally unpredictable nature. Pit subsidence is localized, with depression areas generally less than 40 feet in diameter, which could be easily spanned by a 42-inch pipeline at standard burial depth. Sag subsidence takes in a larger area, but much less than would occur in conjunction with longwall mining, and generally with less vertical displacement and horizontal strain. Considering the foregoing reasons, it is appropriate to limit this assessment mainly to the effects of longwall mining.

2.1 Background

The longwall mining technique involves use of moveable roof supports, which make it possible to excavate blocks of coal on the order of 1000 feet wide and 5,000 to 10,000 feet long. A shearer moves across the full width of a panel making a cut about 3 ft deep and loads the coal onto a conveyor that transports it to another loading point. Hydraulic roof supports are advanced behind the shearer so the mine roof and overlying rock fracture and collapse into the void behind the supports. Caving and fracturing propagate up through the overlying rock mass and bulking occurs until the collapsed rock provides support for the overlying strata.

With this loss of support due to the extraction of the coal seam, subsidence of the overlying rock mass is a certainty and the ground surface ultimately deforms into a trough with maximum subsidence of 50 to 80 percent of the mined thickness as shown by the transverse profile in Figure 2. Around the margins of this trough, differential vertical movement of the surface leads to tilting of the ground surface which causes horizontal surface displacement. The assessment of pipeline response to subsidence must account for this horizontal component of displacement in addition to the more obvious vertical component.

2.2 Surface Tilt, Curvature, Horizontal Displacement and Horizontal Strain

As subsidence occurs, the ground surface deforms into the shape of a trough that elongates as the mine face advances. Around the margins of the trough the surface slopes down over the edges of the longwall panel. If one were to watch a utility pole located over the panel in time lapse animation, it would be observed that the pole not only experiences vertical settlement, but that it also tilts. If the pole is located over the centerline of a longwall panel in which the face is advancing from west to east, the top of the pole will tilt toward the west as it is undermined. The tilt will increase in magnitude and then decrease as the mine face advances past that location. The tilt magnitude is a function of panel advance (i.e., the mine face location at any point in time), and the pole may actually become vertical again once mine face has advanced a well past the pole location.

Locations close to the edge of the panel will experience a residual amount of tilt (i.e., sloping of the ground surface) as shown in Figure 2. The amount of residual tilt depends on the location with respect to the edge of the panel with the maximum residual tilt occurring at locations above the edge of the panel and the minimum residual tilt occurring at locations above the centerline of the panel (Figure 2).

Horizontal ground displacement is caused by differences in the tilt experienced at different locations above the panel. For example, assume that a row of utility poles is located along the centerline of a longwall panel. Two adjacent poles over the concave portion of the subsidence profile would be tilted so their tops are farther apart than their bottoms, and a wire suspended between these poles would be stretched (i.e., experience tensile strain). Horizontal displacement is proportional to slope (tilt) by a constant, c, that varies in value from 0.35 to 0.4 times the depth / tangent of angle of influence [$c = (-0.35 \pm 0.05)\ (h / \tan \beta)$].

Two adjacent poles in the convex portion of the subsidence profile would be tilted so that their tops are closer than their bottoms and a pipe suspended between these poles would be compressed (i.e., experience compressive strain). The difference in tilt between points along a profile is the curvature. The curvature profile is plotted in Figures 3 and 4, and is the cause of strain on the ground surface. Horizontal strain is proportional to curvature by the same constant, *c*.

2.3 Case History Data

Case history information was assembled for longwall coal mine panels in the Illinois Basin and Appalachian Basin. The panels are located in Illinois, Ohio, West Virginia, and Pennsylvania. Subsidence over each panel was monitored by periodic surveys of benchmarks installed along transverse and longitudinal lines on the ground surface. A summary of the mine location, coal seams, longwall panel geometry, and measured subsidence is shown in Table 1. The photos in Figures 5 through 8 illustrate surface subsidence associated with some of these cases. These measured parameters were used to calibrate the model input parameters for the SDPS program as discussed in Section 2.4 below.

2.4 Prediction of Surface Subsidence

Subsidence is the vertical component of displacement on the ground surface. As shown in the cross-section in Figure 3, subsidence ranges from zero (no displacement) outside the margins of the longwall panel and increases to a point of maximum displacement at a point over the central part of the panel. The idealized shape of the subsidence profile is an S-curve that is asymptotic to the points of zero and maximum displacement. Within the transition zone, the ground surface is exposed to zones of tensile curvature and compressive curvature, which correspond to horizontal ground movement. The compressive and tensile curvature zones are separated by a point of inflection (maximum slope).

Prediction of surface subsidence involves the use of mathematical models to compute the subsidence profile. The Surface Displacement Prediction System (SDPS), a computer software package developed at Virginia Tech, utilizes the influence function numerical method. This method assumes that extracting a tiny element of an underground coal seam will cause the ground surface to subside into a shape described by a normal probability distribution (Figure 9). The surface point directly above the extracted element receives the most amount of influence. Coal seam elements offset from this location have less influence on that surface point. The final subsidence at this point on the surface is the summation of the influence of each mined out element of the longwall panel.

This calculation is repeated for each point on the surface at which it is desired to predict subsidence given the following parameters (Figures 2 and 3):

1. Width, w – width of the longwall panel
2. Mine depth, h – total thickness of strata overlying the longwall panel
3. Mined thickness, m – height of opening created by mining
4. % hard rock – Factor which accounts for the relative strength of strata within the overburden
5. S_{max} – maximum subsidence (greatest over critical or supercritical longwall panels for which the width to depth ratio, w/h, is greater than 1.2)
6. Subsidence factor – ratio of maximum subsidence to mined thickness = S_{max}/m
7. Inflection Point – Point where $s = S_{max}/2$ and is also the point of zero curvature (transition from positive to negative curvature)
8. Angle of influence, β – angle from horizontal of a line extending from the coal seam below the inflection point to the point of "zero" subsidence on the surface (set equal to 0.06 S_{max})
9. Horizontal strain factor – ratio of horizontal strain to curvature [also the ratio of horizontal displacement to tilt (i.e., slope)] at any point on the surface = - (0.35±0.05) x (h / tan β)
10. Edge Adjustment – Factor which shifts the location of the inflection point with respect to the edge of the longwall panel and accounts for cantilevering of strata over the edge of the panel

The SDPS model was calibrated for each longwall panel using the subsidence measurements. The back-calculated model parameters (angle of influence, % hard rock, subsidence factor, and edge adjustment) were used as input, and each calibrated model was used to compute subsidence, slope, displacement, curvature, and strain. Analyses were performed to represent an array of points on the surface that extended 200 feet beyond the longwall panel when the face was at least 2000 feet from the beginning of the panel (to model a geometry in which the maximum subsidence has occurred). With this information from the calibrated models, estimates of vertical and horizontal ground displacement patterns for any pipeline alignment through the zone of ground subsidence could be obtained. A summary of the calibrated model parameters and location of the pipeline intersection point is shown in Table 2.

Since the edge adjustment is a numerical parameter used to fit the calculated and measured subsidence profiles over the edge of the panel, the value of this parameter is generally consistent with the distance from the corner of the longwall panel to the pipeline intersection point.

Surface tilt and horizontal displacement are vectors with an x-component (Figure 11) and a y-component (Figure 12). A vector can be resolved into orthogonal components along any direction. For a pipeline alignment that crosses diagonally over a longwall panel there will be a component along the axis of the pipeline and a component perpendicular to the pipeline.

3. ASSESSMENT OF PIPELINE RESPONSE TO SUBSIDENCE

The assessment of subsidence effects on the REX 42-inch natural gas pipeline involved the following general tasks:

1. Define the vertical and horizontal ground displacement patterns representative of the range of displacements that might occur as a result of mine subsidence
2. Define a pipeline alignment through the subsidence zone that would result in the most demanding condition in terms of pipeline stresses
3. Assess the effectiveness of measures that could be implemented during pipeline construction or just prior to mining to reduce pipeline stresses

3.1 Subsidence Displacements

Since the specific pipeline alignment geometry above coal reserves or specific plans for conducting future mining operations are not known, defining the ground displacements associated with mining subsidence relied upon seven case histories of subsidence from coal mines in Illinois, Ohio, Pennsylvania, and West Virginia, as previously described in Section 2. Based upon these case histories, a limited set of ground displacement patterns were selected for analysis. The selection of ground displacement patterns was based on the following considerations:

1. Pipeline bending stresses from vertical or horizontal ground displacement will increase as the distance over which the maximum ground displacement develops decreases.
2. Pipeline axial stresses from vertical ground displacement will decrease as the length of pipeline within the bottom of the subsidence bowl increases. The longer pipeline length allows the pipeline to stretch to accommodate the longer subsided surface distance with a lower level of strain compared to a shorter pipeline length. This means that the most demanding subsidence condition will exist once the panel has advanced to the point that the subsidence pattern is critical, as opposed to super-critical.
3. Pipeline axial stresses from horizontal ground displacement parallel to the pipeline alignment will increase as the length of pipeline exposed to horizontal ground displacement increases. The amount of horizontal ground displacement is generally of less importance considering that the horizontal ground displacements are typically about two orders of magnitude greater than the relative displacement between the pipeline and the soil necessary to develop the full axial soil restraint.

Defining the ground displacement patterns representative of the most abrupt vertical and horizontal ground displacement for pipeline alignments parallel (longitudinal) or perpendicular (transverse) to the direction of panel advance was based upon comparing normalized plots of displacement patterns up to the point where the vertical ground displacement is maximum. A comparison of all such displacement patterns is provided in Figure 13. The overall comparison is only plotted to the point of maximum vertical subsidence since the case histories considered various mined panel dimensions that resulted in both critical and supercritical subsidence patterns. For analysis, points of constant subsidence were omitted or symmetry was assumed to obtain a representative critical displacement pattern. The displacement patterns that bound all transverse cases are the patterns from the Galatia Mine and the Powell Case No. 2. The subsidence displacement patterns from these two cases are provided in Figure 14.

In addition to longitudinal and transverse ground displacement patterns, the patterns for a pipeline alignment that diagonally crosses a corner of the projected panel zone on the surface were examined. The diagonally ground displacement pattern is characterized by vertical settlement at the center of the pipeline crossing and combined axial, horizontal and vertical ground displacements on either side. This case was examined because it was not clear that the more complex ground displacement pattern for a diagonal pipeline crossing would be more or less severe than the purely longitudinal or transverse crossing directions. The ground displacement patterns for a diagonal pipeline alignment were determined as illustrated in Figure 15 and described below:

1. Ground subsidence contours were developed for a length of panel advance that leads to super-critical ground displacement.
2. From the subsidence contour plot, the point closest to the projection on the ground surface of a corner of the mined panel that also experiences the maximum vertical ground displacement was determined.
3. The pipeline alignment for determining vertical and horizontal ground displacements was defined as passing through the point identified in step 2 and perpendicular to a line bisecting the projection on the ground surface of a corner of the mined panel.

For wide panels, the primary difference between the longitudinal or transverse displacement patterns and the diagonal displacement patterns is that the horizontal ground displacements are oriented at a 45° angle to the pipeline, as opposed to parallel to the pipeline (see Figure 16 as an example for the Galatia Mine). For narrower panels, there is an additional difference related to the fact that the diagonal pipeline alignment can pass through a zone where the displacements are affected by an adjacent corner. This effect is most pronounced for the Peng Case as illustrated in Figure 17. For this reason, the diagonal for the Peng Case was selected as a bounding case.

3.2 Pipeline Response to Representative Subsidence Displacements

The analysis of soil-pipeline interaction effects in areas of ground subsidence requires the utilization of analytical procedures that can account for the actual stress-strain characteristics of the pipeline material, the nonlinear behavior of the surrounding soil mass, and large displacement effects. Nonlinear finite element procedures are generally appropriate for this type of analysis. The advantage of using the finite element procedure for the fault-crossing problem is that it allows a more complete assessment of the behavior of the pipeline. Stresses, strains, and displacements can be determined for virtually any number of locations of interest, and the sensitivity of the results to parameter variation can be investigated with relative ease.

The finite element analysis of the REX pipeline response was performed using the ANSYS computer program. ANSYS is a widely-accepted general purpose finite element stress analysis program that has the capability to account for geometric, material, and boundary condition nonlinearities. Specifically, nonlinear spring elements were used to simulate soil restraints and plastic pipe elements were used to represent the pipeline. The large displacement analysis option of ANSYS was invoked to account for the geometric changes in stiffness due to large transverse displacements of the pipe. Details on the use and capabilities of ANSYS can be found in the program user's manual (ANSYS, Inc., 1999a, 1999b, and 1999c). The pipeline evaluations included consideration of the effects of internal pressure, thermal differential, and soil loads generated by ground displacement. Soil overburden loads also act on the pipeline but are negligible for the ranges of soil cover considered.

3.2.1 Characterization of Soil Restraint

Site-specific soils information is not available for the proposed pipeline alignment. Therefore, soil restraint for the analysis of pipeline response was estimated based upon a range of assumed soil properties:

1. Unit weight = 120 pcf, internal friction angle = 36°
2. Unit weight = 120 pcf, internal friction angle = 40°
3. Unit weight = 120 pcf, internal friction angle = 32°, cohesion = 420 psf

The soil cover was assumed to be 4 feet and the pipe was assumed to be coated with fusion bonded epoxy. With these assumptions, the soil restraints acting on the pipeline in the axial, horizontal, and vertical directions were computed using the relationships in Honegger and Nyman (2004), and representative values were selected for analysis (see Table 3).

3.2.2 Definition of Ground Displacement Patterns for Analysis

Normalized ground displacement shapes selected for analyses focused on those corresponding to the Galatia Mine and Powell Case No. 2. Considering that the maximum vertical subsidence from any case approached 5 feet, a 5-foot vertical displacement was selected as a target pipeline displacement capacity. The ratio of maximum horizontal subsidence displacement to vertical subsidence displacement was taken from the case history displacement shape (0.43 for Galatia Mine and 0.44 for Powell Case No.2). The maximum displacement applied in the analyses was twice that for the Galatia Mine and Powell Case No. 2 in order to assess the margin against potentially unacceptable pipeline response for displacements greater than the 5-foot target vertical displacement capacity.

3.2.3 Pipeline Model

The pipeline was modeled using non-linear pipe elements with the element length equal to one pipe diameter. The pipeline was modeled with fixed end conditions with the total length of the pipeline models selected to extend beyond the zone of imposed ground displacement such that the fixed-end constraints did not influence the behavior of the pipe in the region of ground displacement. A straight pipeline alignment was assumed for the cases where the displacement profile represented (1) a transverse or longitudinal crossing of the subsidence zone, and (2) a diagonal crossing of a corner of the subsidence zone. To assess the effects of a bend in the pipeline alignment, a pipeline geometry consisting of a single 90° bend with a bend radius of 5 pipe diameters was used.

A total of seven cases were analyzed as summarized in Table 4. From Table 4, the pipe diameter and wall thickness were the same for all cases (42-inch outside diameter, 0.540-inch wall thickness). The pipe material was taken to be API 5L Grade X70 except for one case where the impact of a weaker pipe material was investigated (API 5L Grade X42) for the purpose of comparison. The internal pressure of the pipeline was taken to be 1,480 psi (except for the case with X42 steel which used a reduced pressure of 888 psi). The pipe material was represented by a multilinear curve in the analysis as shown in Figure 18.

3.2.4 Pipeline Acceptance Criteria

Two conditions were assumed to represent unacceptable pipeline response:

1. Maximum longitudinal tension stress in the pipe from pressure and applied ground displacement greater than 90% of the specified minimum yield strength (SMYS)
2. Maximum longitudinal compression strain in the pipe with no internal pressure and applied ground displacement greater 75% of the strain estimated to coincide with the onset of pipe wall wrinkling.

The above criteria are considered acceptable for continued safe operation of the pipeline provided that there are no other sources of pipe stress (e.g., thermal stresses, stresses from non-subsidence ground displacement), significant pipe defects (e.g., corrosion or weld cracks), or unusual fabrication features (e.g., large mismatch in wall thickness, large alignment offset at girth welds). The impact of other acceptance criteria can readily be determined from plots of the strains computed for the various analysis cases.

The analysis results were presented in terms of computed pipeline strains, consistent with the longitudinal compression acceptance criterion. Based upon the stress-strain curve used in the analyses, 90% SMYS for X70 material corresponds to a computed longitudinal strain of 0.23%.

Longitudinal compression strain limits are based upon relationships developed by Dorey et al. (2001) to predict the onset of geometrical instability of the pipe wall. The Dorey et al. (2001) relationships are cited in the PRCI guidelines. The relationships for compression strains at the onset of pipe wall wrinkling are provided for two types of typical pipeline stress-strain curves: (1) those exhibiting typical rounded shapes at yield and (2) those that exhibit a distinct yield plateau. For API 5L Grade X70 steel, a rounded yield shape is appropriate.

Rounded Stress-Strain Curve with Pipe End Offset at Girth Weld:

$$\varepsilon_{cv} = 0.437\left(\frac{t}{D}\right)^{1.72}\left[1-0.892\left(\frac{p}{p_y}\right)\right]^{-1}\left(\frac{E}{\sigma_y}\right)^{0.70}\left(1.09-\left(\frac{\Delta}{t}\right)^{0.086}\right) \le 0.02 \qquad (1a)$$

Rounded Stress-Strain Curve with Plain Pipe Imperfection

$$\varepsilon_{ci} = 0.056\left(\frac{t}{D}\right)^{1.59}\left[1-0.868\left(\frac{p}{p_y}\right)\right]^{-1}\left(\frac{E}{\sigma_y}\right)^{0.85}\left(1.27-\left(\frac{imp}{t}\right)^{0.15}\right) \le 0.02 \qquad (1b)$$

where:

- t = pipe wall thickness
- D = pipe outside diameter
- p = internal pressure
- p_y = internal pressure to produce hoop stress equal to yield stress
- σ_y = yield stress
- E = modulus of elasticity of pipe material
- imp = blister-type initial imperfection expressed as a percentage of wall thickness
- Δ = offset between pipe joints at girth weld

As can be noted in the Dorey et al. (2001) relationships provided as Equation 1, the relationships require an estimate of either a pipe imperfection or girth weld offset as input. A girth weld offset is considered more likely and an offset of 2 mm is considered a reasonable value although the maximum fabrication allowance is commonly 3 mm. Strains computed using Equation 1 increase with increasing internal pipe pressure, reflecting a decreasing tendency for wrinkling with an increase in biaxial stress from increased hoop tension. Strains induced by ground subsidence are considered permanent and it is therefore appropriate to apply Equation 1 for a potential pipeline shutdown condition with no internal pressure.

With a 2 mm offset and no internal pressure, Equation 1 results in a compression strain for onset of wrinkling equal to 0.41% and an allowable compression strain of 0.31%, considering 75% of the onset of wrinkling strain. Since the compression strain considering wrinkling corresponds to a pipe stress greater than 90% of SMYS, the allowable compression strain is limited to 0.23%.

3.2.5 Straight Pipeline Analysis Cases and Analysis Results

A total of five straight pipeline cases were analyzed. The key model parameters for these cases are summarized in Table 4 and described below. The pipeline is assumed to be X70 with an internal pressure of 1,480 psi unless noted otherwise.

1. Straight pipeline subject to critical subsidence pattern from the Galatia Mine subsidence analysis.
2. Straight pipeline with reduced strength (X42, 888 psi) subject to critical subsidence pattern from the Galatia Mine subsidence analysis.
3. Straight pipeline subject to diagonal subsidence pattern from the Galatia Mine subsidence analysis.
4. Straight pipeline subject to critical subsidence pattern from the Powell Case No. 2 subsidence analysis.
5. Straight pipeline with axial soil resistance reduced by 50% subject to critical subsidence pattern from Powell Case No. 2 subsidence analysis.
6. Pipeline with a 90° bend subject to critical vertical subsidence and maximum horizontal subsidence along each leg of the bend from the Powell Case No. 2 subsidence analysis.
7. Pipeline with axial soil resistance reduced by 50% and a 90° bend subject to critical vertical subsidence and maximum horizontal subsidence along each leg of the bend from the Powell Case No. 2 subsidence analysis.

Results from the analyses are presented in terms of plots of maximum tension and compression strain versus vertical subsidence displacement. While each of the above cases are discussed briefly below, it is important to compare the results from all cases with the allowable tension and compression strain limits. This comparison is shown in Figure 19. As can be seen in Figure 19, the computed pipeline strains for the target vertical subsidence of 5 feet are approximately 60% and 75% of the allowable strain limits for tension and compression, respectively. These strain levels indicate that with the assumptions used in the pipeline analyses, there is little risk to the 42-inch gas pipeline from mining subsidence for the subsidence displacement patterns that envelop the representative subsidence ground displacement deformation patterns.

A brief commentary on each analysis case is given in the subsections below.

3.2.5.1 Case 1: Critical Galatia Mine Transverse Subsidence

The pipeline model geometry and applied displacements for Case 1 are shown in Figure 20. Plots of the absolute value of longitudinal strain at the end of the analysis and variation of maximum longitudinal strain versus vertical subsidence displacement are provided in Figure 21. The computed strains vary nearly linearly with applied displacement with nearly equal tension and compression strain magnitude. At five feet of subsidence, the maximum tension and compression strains are 0.12% and 0.10%, respectively.

3.2.5.2 Case 2: Reduced SMYS, Critical Galatia Mine Transverse Subsidence

The low strains computed in Case 1 (corresponding to pipe stresses less than 36 ksi) were somewhat surprising given past reports of pipeline damage from mining subsidence (Peng, et al., 1980). To investigate whether or not the low strains computed in Case 1 were attributable to the high strength pipe, Case 2 considered the same pipeline and soil displacements as Case 1 but the pipe material was modeled as X42 and the internal pressure was reduced to 888 psi to provide the same ratio of hoop stress to SMYS. Plots of the absolute value of longitudinal strain at the end of the analysis and variation of maximum longitudinal strain versus vertical subsidence displacement are provided in Figure 22. The results from Case 2 indicate that the computed tensile strains are reduced substantially (about half of the tension strain for Case 1) with the lower strength pipe material and the compression strains were nearly the same as Case 1. At five feet of subsidence, the maximum tension and compression strains are 0.07% and 0.10%, respectively. This difference is attributed to the difference in the stress-strain curves between X70 and X42, particularly the fact that the X42 pipe stress-strain curve is nonlinear at the level of compressive strain computed for Case 2 while the X70 stress-strain curve is linear at the computed strains.

3.2.5.3 Case 3: Diagonal Galatia Mine Subsidence

The ground displacement pattern for a pipeline alignment diagonally crossing a corner of the subsidence zone has a potential to produce higher bending deformations in the pipeline at the point where the maximum vertical displacement coincides with the double-curvature bending deformations from horizontal displacement coincide. This effect will be more pronounced for cases with more abrupt transitions in horizontal and vertical ground displacement. For this reason, only the diagonal displacement pattern for the Galatia Mine was examined as an enveloping case. The pipeline model geometry and applied displacements for Case 3 are shown in Figure 23. Plots of the absolute value of longitudinal strain at the end of the analysis and variation of maximum longitudinal strain versus vertical subsidence displacement are provided in Figure 24. At five feet of subsidence, the maximum tension and compression strains are 0.14% and 0.12%, respectively. Since these strains are close to the values of strain computed in Case 1, further analyses focused on other transverse displacement patterns.

3.2.5.4 Case 4: Critical Powell Case No. 2 Transverse Subsidence

The ground displacement patterns for the Powell Case No. 2 represent a case where the distance to develop the maximum vertical and horizontal displacements are much greater than any other subsidence case examined. Considering that the displacement necessary to mobilize the full axial load on the pipeline (0.2 inches) is much less than the horizontal ground displacement, the axial load imposed on the pipe is largely a function of the length of pipeline exposed to horizontal ground displacement. Since the ground displacement patterns have been modified to represent the critical subsidence condition, the axial loads from horizontal ground displacement act to force the pipeline to move axially toward the point of maximum vertical subsidence. The pipeline model geometry and applied displacements for Case 4 are shown in Figure 25. Plots of the absolute value of longitudinal strain at the end of the analysis and variation of maximum longitudinal strain versus vertical subsidence displacement are provided in Figure 26. Note that the pipe strain magnitudes increase from the left and right sides of the subsidence zone and are maximum at the center of the subsidence zone where the full effects of axial load are combined.

At five feet of subsidence, the maximum tension and compression strains are 0.08% and 0.23%, respectively. The maximum compression strain at five feet of subsidence is nearly twice as great as computed for Case 1. The tension strain for Case 4 is nearly constant for more than 2.5 feet of subsidence. The maximum tension strain occurs outside of the subsidence zone and is related to soil restraining the pipeline from being forced into the subsidence zone from the horizontal ground displacement.

3.2.5.5 Case 5: Reduced Axial Soil Restraint, Critical Powell Case No. 2 Transverse Subsidence

From Cases 1 through 4, it is evident that subsidence patterns with horizontal ground displacements occurring over a long distance can have the most significant impact on pipeline strains. One means of reducing the strains experienced by the pipeline would be to reduce the maximum axial soil restraint that can act on the pipeline. This could be achieved by placing a 6-inch layer of lightly compacted sand backfill around the pipeline during construction. Another means of reducing axial soil restraint would be to wrap the pipeline with two separate layers of geotextile fabric, creating a low friction sliding surface between the pipe and soil. Both of these approaches can reduce the soil restraint by roughly a factor of two compared to the assumed soil restraint. To investigate the benefit of reduced axial restraint, Case 5 was taken to be identical to Case 4 except for a 50% reduction in axial soil restraint. Plots of the absolute value of longitudinal strain at the end of the analysis and variation of maximum longitudinal strain versus vertical subsidence displacement are provided in Figure 27 along with the results from Case 4 for comparison.

At five feet of subsidence, the maximum tension and compression strains are 0.04% and 0.11%, respectively. These strains are essentially half of the corresponding strains computed for Case 4, illustrating the dominant effect of axial soil restraint on pipeline response.

3.2.6 90° Bend Analysis Cases and Analysis Results

The straight pipeline analysis cases indicate that strains resulting from the mine subsidence cases considered are expected to be within the allowable strain limits for maximum vertical subsidence less than 5 feet. Three additional analysis cases were formulated to examine the response of a pipeline with a bend within the subsidence zone. Considering possible variations in bend angle, bend radius, and bend location within the zone of ground subsidence would require tens of cases and is beyond the scope of this assessment. Instead, the bend analysis cases focused on what is considered to be the most severe bend angle and bend location within the subsidence zone. This bounding bend configuration, which is illustrated in Figure 28, was a 90° bend oriented such that each leg of the bend was subjected to horizontal subsidence ground displacements acting parallel to the leg of the bend. The bend radius was assumed to be five pipe diameters (17.5 feet). The ground subsidence pattern for the Powell Case No. 2 was used in the analyses since this pattern exhibits the largest zone of horizontal ground displacement.

3.2.6.1 Case 6: 90° Bend, Critical Powell Case No. 2 Subsidence

The pipeline model geometry and applied displacements for Case 6 are shown in Figure 29. Plots of the absolute value of longitudinal strain at the end of the analysis and variation of maximum longitudinal strain versus vertical subsidence displacement are provided in Figure 30. The horizontal ground displacements parallel to the legs of the bend are sufficient to create bending strains in the bend that exceed the allowable strains and the nominal yield strain of the pipe steel (nominal yield strain is 0.5%). The variation in strain with subsidence displacement is nearly linear, indicating the forces transmitted to the bend from the soil loads acting on the legs of the bend are much greater than the resistance of the bend. At 5 feet of displacement, the computed tension and compression strains are 0.76% and 1.22%, respectively. The allowable strain limits are exceeded for vertical subsidence greater than 1.3 feet.

3.2.6.2 Case 7: 90° Bend, Reduced Axial Soil Restraint, Critical Powell Case No. 2 Subsidence

Case 7 was identical to Case 6 except that the axial soil restraint was reduced by 50%. Plots of the absolute value of longitudinal strain at the end of the analysis and variation of maximum longitudinal strain versus vertical subsidence displacement are provided in Figure 31. The 50% reduction in axial soil restraint results in roughly a 50% reduction in computed strains. At 5 feet of displacement, the computed tension and compression strains are 0.44% and 0.74%, respectively. However, there is little change in the vertical subsidence associated with exceeding the allowable strain limits, 1.4 feet compared to 1.3 feet for Case 6. The variation in strain with subsidence displacement is nearly linear for subsidence displacements less than approximately 3 feet, the rate of increase in strain with subsidence displacement decreases for greater amounts of subsidence. The change in the strain versus displacement behavior indicates that the bend resistance is more comparable to the loads induced from horizontal ground displacement.

3.2.6.3 Case 8: 90° Bend, Reduced Axial Soil Restraint, 0.750-inch Wall Thickness, Critical Powell Case No. 2 Subsidence

Case 8 was identical to Case 7 except that the pipe wall thickness was increased to 0.750 inches, the X70 wall thickness planned for Class II areas. The increase in pipe wall thickness increases the bending resistance in the 90° bend by 39% compared to the 0.540-inch wall thickness. Plots of the absolute value of longitudinal strain at the end of the analysis and variation of maximum longitudinal strain versus vertical subsidence displacement are provided in Figure 32. The increase in pipe wall thickness reduces the computed strains at 5 feet of vertical subsidence to 0.23% tension and 0.31% compression. Furthermore, the computed strains are nearly constant for subsidence displacements greater than approximately 4 feet, indicating the horizontal soil loads are incapable of imposing additional deformations at the bend. The tension strain is equal to the allowable tension strain and the compression strain is equal to the allowable compression strain considering prevention of onset of wrinkling, indicating that this case could be considered acceptable if it were determined that a compression strain equal to 96% of SMYS could be tolerated.

4. CONCLUSIONS AND RECOMMENDATIONS

The results from the eight analysis cases lead to the following conclusions regarding the capacity of the 42-inch natural gas pipeline to withstand expected subsidence displacements associated with panel mining operations:

1. A straight pipeline alignment should be capable of accommodating vertical and horizontal ground displacements from mining subsidence without experiencing stresses greater than 90% of SMYS.
2. Ground subsidence patterns characterized by large zones of horizontal ground displacement parallel to a straight pipe alignment (i.e., alignments parallel or perpendicular to the direction of panel advance) will experience the highest pipeline stresses.
3. The most effective means to reduce pipeline stress/strain due to subsidence is to minimize the axial soil restraint along the pipeline. Several options for minimizing axial soil restraint are discussed in Section 4.1 below.
4. Increasing the pipe wall thickness or material grade will reduce pipeline stresses related to horizontal ground displacements in a direction parallel to the pipeline alignment, but offers little benefit in reducing stress due to displacements transverse to the pipeline alignment. .
5. Pipeline sidebends within the subsidence zone may be subjected to higher stress conditions if one or both tangents are oriented parallel (or near parallel) to the direction of horizontal subsidence displacement. Conditions that can be expected to increase pipe stresses at bends include:
   a. Large bend angle, e.g., 60° to 90°;
   b. Small bend radius;
   c. Ground displacement parallel to legs of the bend;
   d. High axial soil restraint.

The above conclusions are based on the following general assumptions and conditions:

1. We have assumed that the smooth ground displacement patterns resulting from matching several case histories of monitored mine subsidence represent the range of displacement patterns that are likely to be experienced. It is noted that in several cases, the monitored ground displacement patterns were not "smooth" and did not compare well to the computed ground displacement. Plots of measured versus modeled subsidence for the seven case histories used in this assessment are provided in Figure 33. The measured ground displacements Powell Case No. 1 and No. 2 represent a

potentially more severe condition than analyzed, as judged by the abruptness of vertical changes in ground displacement.

2. It is also important to note that the subsidence patterns are idealized for a flat or nearly flat ground surface. Variations in topography or underlying geologic conditions that might lead to anomalous ground subsidence patterns have not been considered. Furthermore, in steep terrain, it is possible that subsidence might trigger landslides that could be more hazardous to a buried pipeline than the effect of subsidence itself.

3. We have considered a maximum vertical ground subsidence of 5 feet and a maximum horizontal subsidence no greater than 44% of the maximum vertical subsidence as representative of the expected mining subsidence for the proposed pipeline. These conditions are believed to be representative of what could be reasonably expected along the REX Pipeline route, but the possibility of larger vertical subsidence displacements or larger ratios of maximum horizontal displacement to maximum vertical displacement cannot be eliminated from consideration.

4. The tension and compression strain limits are based on the assumption that the pipeline girth welds overmatch the actual strength of the pipe and are free of planar girth weld defects that would limit the strain capacity compared to the pipe body. See Section 4.2 below for further discussion of welding.

5. We have relied upon judgment and relative comparisons between analyses to identify a limited set of analysis cases taken to envelop the range of pipeline response.

6. We have assumed soil conditions for the determination of axial and transverse soil restraint. Soil conditions that result in much higher levels of soil restraint, particularly axial soil restraint, could result in unacceptable pipe stresses. In addition, we have assumed uniform soil cover and have not accounted for a greater depth of soil cover that might be necessary to accommodate such situations as uneven terrain, road crossings, crossings of other pipeline or utilities.

4.1 Options for Controlling Axial Soil Restraint

The pipeline analysis cases have demonstrated the importance of limiting axial soil restraint on pipeline response. Practical means of achieving relatively low axial soil restraint involve selecting appropriate backfill material, limiting the depth of soil cover, and use of low-friction coatings or geotextile wrap. The following options are expected to result in axial soil resistance on the 42-inch pipeline less than or equal to the reduced an axial soil restraint used in the analyses (3 kips/ft):

1. Option 1
    a. Soil cover less than 4 feet;
    b. Granular cohesionless backfill with an internal friction angle of less than 40° placed a minimum of 4 inches around the pipe;