ALASKA LNG

DOCKET NO. CP17-___-00
RESOURCE REPORT NO. 6
GEOLOGICAL RESOURCES
PUBLIC

DOCUMENT NUMBER: USAI-PE-SRREG-00-000006-000

RESOURCE REPORT No. 6
SUMMARY OF FILING INFORMATION [1]

Filing Requirement	Found in Section
1. Identify the location (by milepost) of mineral resources and any planned or active surface mines crossed by the proposed facilities – Title 18 Code of Federal Regulations (CFR) part (§) 380.12 (h)(1 & 2) • Describe hazards to the facilities from mining activities, including subsidence, blasting, slumping or land sliding or other ground failure.	6.3; Appendix A, Table 3
2. Identify any geologic hazards to the proposed facilities. 18 CFR (§ 380.12(h)(2))	6.4
3. Discuss the need for and locations where blasting may be necessary in order to construct the proposed facilities. 18 CFR (§ 380.12(h)(3))	6.5
4. For liquefied natural gas (LNG) projects in seismic areas, the materials required by "Data Requirements for the Seismic Review of LNG Facilities," National Bureau of Standards Information Report 84-2833 – 18 CFR § 380.12 (h)(5)	6.4.1
5. For underground storage facilities, how drilling activity by others within or adjacent to the facilities would be monitored, and how old wells would be located and monitored within the facility boundaries. 18 CFR (§ 380.12(h)(6))	NA

[1] Guidance Manual for Environmental Report Preparation, Volume I (FERC, 2017). Available online at: https://www.ferc.gov/industries/gas/enviro/guidelines/guidance-manual-volume-1.pdf.

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BLM	9/26/2016	4.2.1 Mainline and Appendix B – Potential Sources for the Mainline. The proposed management plan for the BLM's Central Yukon Field Office Management Plan (CYFO RMP) provides specific actions to effectively implement the Plan's management decisions. With regards to developing potential mineral sites, the applicant should be aware that CYFO RMP is examining required operating procedures which include: 1) maintaining a 300 foot zone of undisturbed vegetation on either side of the Jim River and Prospect Creek downstream from the eastern edge of the inner corridor. ; 2) confining Off Road Vehicle (ORV) operations to soils with low erosion potential or to times of the year when the surface (30 cm) is frozen and has sufficient snow cover to protect the integrity of the vegetation ground cover existent on site.	Comment noted. The Applicant will address these stipulations during construction and operations as a part of their ROW Grant and Mineral Use permitting.
BLM	9/26/2016	Fine gravel storage: It will be required that substrate suitable for bank swallow colonization (fine materials) are stored at less than vertical slopes to prevent bank swallow colonization.	Comment has been noted. Gravel and other industrial material resources will be stored according to Best Management Practices described in Section 7.2.1.
EPA	9/30/2016	Geological Hazards - The Reports address a number of geological hazards, including seismic, volcanic, fault rupture, soil liquefaction, tsunamis and seiches, avalanches, etc. We recommend that the Reports include an Emergency Response Plan for the proposed project facilities, such as the LNG plant, marine terminals, GTP, West Dock, mainline pipeline, etc to address the potential risk for a catastrophic incident associated with the geological hazards.	The Applicant will address this comment after the DEIS but prior to the issuance of the FEIS.
EPA	9/30/2016	Liquefaction Facility - Existing erosion protection measures adjacent to the proposed facility location including sheet pile walls, gabions, and large rip-rap appear to have proved effective at greatly reducing erosion due to wave action. We recommend that the Reports identify the proposed erosion control and structural measures planned for the LNG Plant and Marine Terminal to minimize impacts from potential landslides, wave and bluff erosion along the shoreline of Cook Inlet.	The Applicant will address this comment after the DEIS but prior to the issuance of the FEIS.
EPA	9/30/2016	Acid Rock Drainage and Metal Leaching (ARD/ML) - Segments along the mainline pipeline would encounter potential areas of high/moderate ARD/ML hazards. In areas where construction activities are expected to excavate, disturb, or expose bedrock there could be potential for ARD/ML. We recommend that the Reports evaluate design best practices and measures that could be implemented to avoid and minimize the potential for ARD/ML, such as rerouting the pipeline to avoid areas of high/moderate ARD/ML potential, elevating the pipeline on VSMs, ARD/ML buffering, etc. In addition, we recommend that the Reports evaluate the factors and variables that affect ARD/ML which could be used to identify mitigation measures to minimize impacts. We recommend considering additional tests to model ARD/ML rates for certain types of material in the project area. We recommend that a ARD/ML Disposal/Management Plan be developed to ensure that adverse effects are minimized.	The Applicant will address this comment prior to the issuance of the DEIS.
EPA	9/30/2016	Hydrologic Processes (Vertical Scour). Table 6.4.6-1 indicates that the Mainline pipeline segment along the Beaufort Coastal	Aboveground versus belowground design is evaluated in Resource

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		Plain (1.28 miles) is in an area susceptible to hydrological processes, such as vertical scour, channel migration, avulsions, and rapid lake drainage, which can lead to infrastructure failure through destabilization of structures. We recommend that the Mainline pipeline segment evaluate an aboveground pipeline on VSMs along the Beaufort Coastal Plain to avoid and minimize potential impacts from hydrologic processes.	Report No. 10, Section 10.4.5.1.
EPA	9/30/2016	In addition to monitoring measures at ARD/ML sites, we recommend water quality sampling and testing of adjacent surface waters in areas with high/moderate ARD/ML before, during and after project construction activities.	It is contemplated at this time that water quality sampling will not be completed at ARD sites.
EPA	9/30/2016	We recommend that the Blasting Plan should also include “continuous and non-continuous permafrost soils” as resources that are of concern during blasting activities and should be addressed in the final Plan.	Appendix B of Resource Report No. 3 has been updated.
EPA	9/30/2016	Paleontological Resources Management Plan – We recommend that the Reports include a public summary version of the Plan that is not considered privileged and confidential.	FERC will provide a public summary in the course of drafting and releasing the EIS for public comment.
EPA	9/30/2016	Paleontological Field Survey Reports – We recommend that the Reports include a public summary version of the Field Survey Reports that are not considered privileged and confidential.	FERC will provide a public summary in the course of drafting and releasing the EIS for public comment.
NPS	9/26/2016	Regarding soils and geologic resources, the information provided in RR-6 is not sufficient to properly analyze impacts or process a Right-of-Way application, should the project cross Denali National Park. Substantially more park-specific information at a greater level of detail is needed.	The Denali Park route alternative is not the preferred route and is not analyzed in detail at this time.
NPS	9/26/2016	A lot more information on paleontology is needed to analyze impacts and inform mitigation. AK-LNG will need to coordinate with the NPS to identify specific data and information needs should a Denali route be analyzed in the EIS.	If the route crosses National Park Service lands (NPS), efforts will be made to coordinate with the NPS for appropriate surveys.
NPS	9/26/2016	The geohazards section in RR-6 largely provides background information and summary tables. There is no way to discern if the known specific geohazards are being properly addressed or not.	The Applicant will address this comment prior to the initiation of the EIS process.
NPS	9/26/2016	There is no mention of the vast fossil assemblage in the (Lower) Cantwell Formation. Many published papers are available, describing everything from crayfish burrows to dinosaurs. Dinosaur bones have now been discovered. The project will need to account for this resource.	The vast fossil assemblage in the lower Cantwell Formation is discussed in Section 6.6.2.1.6.
ADNR/DOG	9/25/2016	In the middle of the 3rd paragraph, this sentence doesn’t read properly: “The site lies in a synclinal flat between cored by seismogenic blind-thrust faults. “	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DOG	9/25/2016	In the 2nd sentence, the term “tracts” should be changed to “areas”. In DNR lease sales, the term “tract” has a specific meaning: one of the hundreds or thousands of nominally square, numbered blocks of acreage that are offered for lease sale bidding. That meaning is incompatible with the way it is used in this sentence. As written, the sentence goes on to	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.

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		imply that the Prudhoe Bay field itself is a lease sale tract – this is erroneous and misleading.	
ADNR/DMLW/SCRO	9/25/2016	The Application for Permits to Mine in Alaska (APMA) will not initiate agency permitting for sand and gravel (borrow) operations. The APMA is for locatable minerals only. A Material Sale Contract Application package through ADNR DMLW SCRO is required to process requests for borrow pits. The Material Sale Contract application package does not initiate applications that may be required of other agencies for the requested activity.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DMLW/SCRO	9/25/2016	The Material Sites table needs to include a legal description in Meridian, Township, Range and Section in order to review the sites outside of the AKLNG GIS Mapper. If the Material Site is existing, a State of Alaska file number (ADL #) should be included for reference. Table 4	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Energy	9/25/2016	The second paragraph starts with “Valley bottoms are filled with deep colluvium…..”. Change deep to thick.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Energy	9/25/2016	The first sentence in the third paragraph does not make sense as written. As written it states that sedimentary are interspersed with sedimentary rocks.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Energy	9/25/2016	Not sure why the Nikolai Greenstone is mentioned as it is not present anywhere near the mainline. It’s one of the defining units in Wrangellia and is prominent in the eastern Alaska Range. The Nikolai is not present in the western Alaska Range, but other Triassic volcanic units are.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Energy	9/25/2016	Second paragraph states that terranes were accreted from south to north, which is inconsistent with the oldest accreted terranes in the north. The oldest accreted terranes were accreted first, so accretion took place from north to south. Change “from the south to the north” to “from the north to the south”.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Energy	9/25/2016	Nonconformity is misspelled in the first sentence and it is the wrong term to use in this context throughout most of the basin. Tertiary sedimentary rocks in Cook Inlet basin unconformably overlie Mesozoic sedimentary rocks throughout most of the basin. In relatively small areas within the basin and, locally along the basin margins, Tertiary strata nonconformably overlie igneous and metamorphosed igneous rocks.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Energy	9/25/2016	The Sterling Formation is Pliocene. The uppermost beds could be as young as Pleistocene but all available age control indicate a Pliocene age. Change the second sentence to – The Pliocene Sterling Formation and overlying Quaternary sediments constitute up to……..The Sterling Formation alone is up to 11,000 feet thick in the East Foreland area (Calderwood and Fackler, 1972), so the combined thickness of Sterling plus overlying Quaternary sediments is greater than 10,000 feet.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DG	9/25/2016	Add siltstones and coal seams to the list of lithologies in the third sentence, first paragraph (Cook Inlet Ecoregion). Both	The Applicant will address State of Alaska agency comments during the

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GS/Energy		lithologies are abundant in the Tertiary stratigraphy of the basin.	State permitting processes and timeframes.
ADNR/DG GS/Energy	9/25/2016	There as several problems with the first paragraph. The discussion of the formations is uneven and haphazard, and the Fortress Mountain Formation was not included. Suggested revision: "Bedrock in the Brooks Range Foothills Ecoregion predominantly consists of Lower and Upper Cretaceous sedimentary rocks including, from oldest to youngest, the Okpikruak, Kongakut, Fortress Mountain, Torok, Nanushuk, Seabee, Tuluvak, Canning, Schrader Bluff, Prince Creek, and Sagavanirktok Formations. The Okpikruak, Kongakut, lower part of the Fortress Mountain, Torok, lower part of the Seabee, and Canning Formations include sandstones and shales deposited in deep marine environments. The upper part of the Fortress Mountain, Nanushuk, upper part of the Seabee, Tuluvak, Schrader Bluff, Prince Creek, and Sagavanirktok Formations were deposited in fluvial, deltaic, and shallow marine environments and include conglomerates, sandstones, siltstone, shales, and coals." See Mull and others (2003, USGS Professional Paper 1673) for details regarding current stratigraphic nomenclature.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DG GS/Energy	9/25/2016	Strata overlying the Usibelli Group in the vicinity of the mainline include the Nenana Gravel.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DG GS/Energy	9/25/2016	The Kahiltna Flysch sequence in this area of the Alaska Range is not part of the Gravina-Nutzotin Belt. It is correlative with rocks of this belt, but the "Gravina-Nutzotin belt" is in the eastern Alaska Range and is nowhere near the proposed mainline.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DG GS/Energy	9/25/2016	Delete Nikolai Greenstone. See comment for section 6.2.1.2.8	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DG GS/Energy	9/25/2016	Exploration licenses have been issued to specific companies for work in the Nenana and Susitna basins. Doyon is currently exploring for oil and gas in the Nenana basin, a short distance west of the city of Nenana.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DG GS/Energy	9/25/2016	Coal resources in the Nenana basin are not limited to the Nenana Valley. There are significant coal resources in the Susitna basin, but not within a 0.5 mile of the proposed mainline. This basin is incorrectly lumped as part of the Cook Inlet basin on Figure 6.2.1-1	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DG GS/Energy	9/25/2016	Coseismic subsidence associated with the M9.2 earthquake affected large areas of south-central Alaska. Coseismic subsidence could be a hazard over the lifetime of the liquefaction facility.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DG GS/Energy	9/25/2016	See comment for section 6.4.7.1.4.7	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.

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ADNR/DGGS/Engineering Geology	9/25/2016	"However, though glaciers have modified much of Alaska, much of the low-lying terrain along the proposed corridor between the Brooks Range and the Alaska Range has not been altered." This is misleading - the low-lying terrain has been altered by geologic processes, just not directly by glaciers.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	"Permafrost is continuous throughout the Brooks Range, creating surficial formations similar to those occurring farther north." Suggest further explanation of this statement. Surficial geology is much different here than in the coastal plain to the north. Are there specific permafrost features?	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	"Bedrock is overlain in the lower areas by Pleistocene sediments, including alluvium, colluvium, glacial deposits, and loess." Suggest pointing out the loess and colluvium is commonly ice-rich.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	"The Kobuk Ridges and Valleys Ecoregion has largely been shaped by glacial activity throughout the recent ice age." Clarify what is meant by "recent ice age" – "shaped by glacial activity during the most recent major ice age (Pleistocene)."	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	"South of Livengood, the Mainline transects the Ray Mountains Ecoregion for over 170 miles." Incorrect? Statement suggests the Ray Mountains Ecoregion extends south of Fairbanks.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	"The mountains are now unglaciated and covered with colluvial and eolian deposits." Unglaciated implies there was never ice here, suggest use "deglaciated".	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	There is no mention of loess in this region, which is a major surficial deposit that can be very thick in some places, as well as hosting much of the ice-rich permafrost mentioned in the text.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	"The land is covered in numerous lakes, ponds, and wetlands, and permafrost is virtually absent." To avoid confusion suggest using the terminology of Jorgenson, 2008—the permafrost would be sporadic or isolated.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	"Pingos, small ice-cored hills that result from permafrost expansion, make up occasional modest topographic highs, rising just tens of feet from the flat plains." Suggest rewording to avoid implying that permafrost is expanding. Replace "permafrost expansion" with "ice growth."	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	This table seems overly generalized and is not consistent with text. For example, descriptions for anticipated surficial geology in the Brooks Range Foothills Ecoregion of the table are inconsistent with what is discussed in the text. (Section 6.2.3.2.2). It is not clear why some surficial geology units are included and others omitted. Glacial deposits are an important component of the Brooks Range Foothills but they are completely absent from the table. (Table/Figure # 6.2.3-1)	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Engineering	9/25/2016	"Lag gravel: Sediments deposited by glaciers with subsequent removal of fine and medium-grained particles;" Lag gravel can originate from other sources, not just from glacially deposited	The Applicant will address State of Alaska agency comments during the State permitting processes and

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Geology		sediment	timeframes.
ADNR/DGGS/Engineering Geology	9/25/2016	"Flooding hazards exist during the spring thaw, when melting snow and ice combines with increased precipitation, leading to high stream discharges and increased stream loads." 1) Flooding hazards exist during times other than spring thaw. Prolonged large rain events can also lead to flooding. 2) Regarding statement of increased precipitation in the spring – is this important because it is liquid precipitation? Are there data to support the claim of increased precipitation (of any type) during the spring thaw?	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Mineral State s	9/25/2016	Many pages (see listing to left in this spreadsheet) refer to "DGGS, 2011." There is no DGGS, 2011 publication in the references list. The correct reference needs to be added to either the references or the text pages.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Minerals	9/25/2016	Edit final paragraph on p. 6-28. …..potentially exploitable mineral resource…metallic (gold, silver, lead, zinc, etc.),….Suggest this change because many other metallic minerals may be present.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Minerals	9/25/2016	Add, rare-earth elements to the list; Between mileposts 334 and 347, in the tributaries to, and the Ray River itself, alluvial gravels and terrace gravels may contain elevated levels of tin and rare-earth elements. This is documented in the following 3 publications: Bachmann, E.N., Blessington, M.J., Freeman, L.K., Newberry, R.J., Tuzzolino, A.L., Wright, T.C., and Wylie, William, 2013, Geochemical major-oxide, minor-oxide, trace-element, and rare-earth-element data from rocks and stream sediments collected in 2012 in the Ray Mountains area, Beaver, Bettles, Livengood, and Tanana quadrangles, Alaska: Alaska Division of Geological & Geophysical Surveys Raw Data File 2013-5, 4 p. doi:10.14509/25386; Blessington, M.J., Reioux, D.A., and Werdon, M.B., 2013, Analyses of historic. U.S. Bureau of Mines rock and heavy mineral concentrate samples for geochemical trace-element and rare-earth element data--Ray Mountains and Kanuti-Hodzana uplands area, Alaska: Alaska Division of Geological & Geophysical Surveys Raw Data File 2013-7, 2 p. doi:10.14509/25581; and, Tuzzolino, A.L., Freeman, L.K., and Newberry, R.J., 2014, Geochemical major-oxide, minor-oxide, trace-element, and rare-earth-element data from rock samples collected in 2013 in the Ray Mountains area, Bettles A-1 and A-6 quadrangles, Alaska: Alaska Division of Geological & Geophysical Surveys Raw Data File 2014- 17, 3 p. doi:10.14509/27325	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADNR/DGGS/Minerals	9/25/2016	It is incorrect to say "Within these regions, there are no significant exploration projects currently underway." Between mileposts 396 and 411, the proposed Mainline route crosses through an area of very high gold and base-metal potential. Within 5 miles of the proposed mainline route, a significant copper-gold discovery was made at Shorty Creek by Freegold Ventures, and International Tower Hill Mines discovered almost 20 million ounces of gold at Money Knob. There is potential for additional mineral discovery during pipeline construction in this area. 1) Section 6.3.1 needs to be updated to acknowledge there is potential for mineral discoveries in this area during construction; 2) In 2016, DGGS will be putting out	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.

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		a new detailed geologic map covering this area, which may be useful for construction planning (Twelker and others, 2016, in prep.).. Use of geophysical data to identify permafrost locations: DGGS airborne-geophysical datasets, including resistivity (electromagnetic) data, cover a small portion of the proposed pipeline route; they are available here: http://dggs.alaska.gov/geophysics/general-info.php Inversions (special processing) of resistivity data provide information useful for directly locating permafrost features. Permafrost is a geologic hazard that is present north of the Alaska Range in many areas of the proposed pipeline route, and presents a significant construction difficulty. DGGS could fly a resistivity survey over the proposed pipeline route, invert the data to identify areas of permafrost, and make this data publically available, which would then help focus geotechnical investigations.	
ADNR/DGGS/Minerals	9/25/2016	Prior to any construction activities, all mining claim locations and mineral sites in Appendix A, Table 3 will need to be updated. These are not static datasets, as each year new claims are actively staked and dropped, and new mineral localities are being compiled by USGS on an on-going basis.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
SOA / ADNR / OHA /SHPO	9/25/2016	RR 4 needs to cross-reference other, related resource reports, including but not limited to as RR 5, RR 8 (for visual), and RR 6.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADOT&PF/ Statewide D&ES	9/25/2016	Potential Construction impacts should include the competition for material between the Project and other uses – specifically highway construction and maintenance purposes. Where does any of the reports address and propose mitigation for the need to maintain borrow sources for highway needs in the future. If sources are depleted along the state highway system it will increase the cost of both future construction and maintenance. Potential mitigation should include stockpiling additional material for future road purposes. It does not appear that Appendix F addresses this.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADOT&PF/ Statewide D&ES	9/25/2016	It states in the last sentence of this section. “results of this study indicate that there are no known NOA hazards within the Project area.” I believe a pit at approx. MP 105 on the Dalton Highway had NOA. Does this fall within the “Project area”?	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADOT&PF/ Statewide D&ES	9/25/2016	Please clarify, if a FDL is within 200 ft of the Dalton Hwy and it is advancing 150 ft. per year, then the road would already be overtaken. ADOT has provided the Applicant with the most recent plans to realign the Dalton Hwy in the vicinity of the FDL at Dalton Hwy MP 219.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADOT&PF/ Statewide D&ES	9/25/2016	New borrow locations whose access is to/from a state highway will require a driveway permit issued by ADOT	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADOT&PF/ Statewide D&ES	9/25/2016	Table 4 - In general, the sites listed in the table don’t always match up with the sites shown on Web Mapper. For example, in the table Site no. 86 is listed at Approx. Rev B MP 502 and Site Name / Location 37-2-099- 2FP. On Web Mapper there	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.

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		are two Alternative sites shown at Rev B MP 501, both in Township 08S, Range 09W Section 26. Our records show this site to be in Section 27. I have attached a spreadsheet that combines AKLNG and ADOT material site information for sites with a common Material Site Number.	
ADF&G	9/25/2016	This section on instream blasting should note all blasting in anadromous or resident fish streams shall comply with the Alaska Department of Fish and Game's 2013 Alaska Blasting Standard for the Proper Protection of Fish. A Title 16 fish habitat permit will be required for any blasting in or near a fish-bearing waterbody that may adversely affect fish. See: Timothy, J. 2013. Alaska blasting standard for the proper protection of fish. Alaska Department of Fish and Game, Habitat Publication No. 13-03, Douglas, Alaska.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
ADF&G	9/25/2016	A schedule identifying when blasting will occur should apply to all fish streams, not just those greater than 10 feet wide.	The Applicant will address State of Alaska agency comments during the State permitting processes and timeframes.
USFWS	9/26/2016	Hydrocarbon Spills- The RRs do not contain an in-dpeth spill analysis for LNG and other petroleum products. A thorough discussion of impacts associated with accidental releases of liquefied natural gas and/or fuel spills into watercourses and the coastal and marine environments of Cook Inlet and the Beaufort Sea is warranted. Section 4.12 of the NPR-A IAP/EIS (2012) (http:www.blm.gov/ak) could be used as a template for this discussion. The Service would appreciate reviewing the spill analysis before the RRs are finalized.	See Section 11.5.3 of Resource Report 11 discusses hazard analysis and siting requirements.
USFWS	9/26/2016	Would up to 5 years' worth of impacts really be short term? From a wetlands perspective alone, the Service considers temporary (short term impacts) to be 3 growing seasons or less. We have concerns about the Applicant considering any impact beyond 3 years to be short term.	Yes, impacts with some lasting effects that could extend up to 5 years would be considered short-term. The only mention of short-term impacts in Section 6.4 is in regard to impacts following fault rupture displacement. In regard to re-establishing vegetation, some areas may take slightly longer than 3 years to stabilize.
USFWS	9/26/2016	Has the Applicant considered any modeling for climate change in regard to siting project infrastructure and flood events, etc. Modeling should include forecasted analyses and include the most recent climate change data available. Relying on 50 year-old flood return data is no longer sufficient.	The Applicant has considered the *FERC Guidance Manual for Environmental Report Preparation* and relevant guidance in the development of Resource Reports. Resource Report No. 1, Sections 1.3 and 1.3.2.1.1) include consideration of future climate scenarios, including geothermal/permafrost issues, marine issues, and wildfire issues. In regard to permafrost thaw, the chilling of the pipeline would help to mitigate future climate change and permafrost thaw; some thaw settlement is likely to occur, but the pipeline would be monitored, inspected, and maintained through

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			in-line inspection and through a comprehensive field monitoring program over the life of the Project to ensure safe operation.
USFWS	9/26/2016	Table 6.5.1-1. Table indicates 28.1 trench miles to be blasted from MP 0-61.8. However, it is our understanding construction along this stretch will be in the winter, which would require blasting through the frozen tundra. Can you clarify? We pose this question because it ties in with salvaging organics/tundra for reclamation. If about half of this stretch will not be blasted, are there plans for salvaging the tundra mat? It also may be possible to salvage the relatively "softer" organic layer (compared to the tighter subsoil), even when frozen. This valuable reclamation resource should be salvaged when possible.	The Applicant will address this comment prior to the initiation of the EIS process.
USFWS	9/26/2016	For material sites that may have exposed rock faces or existing stockpiles, consideration should be given to the potential presence of peregrine falcons and cliff swallow nests on these substrates. Although these are artificial sites, active nests are protected under the Migratory Bird Treaty Act. We recommend the Applicant and its operators be aware of this possibility and consult with the USFWS for guidance.	Comment acknowledged.
USFWS	9/26/2016	We recommend using filter fabric under gravel roads to prevent road material from being "punched into" the ground (especially common in permafrost when the active layer has thawed and in wet areas) and to assist with reclaiming temporary roads. Another consideration is to use foam boards under roads to help prevent thaw.	The Applicant will address this comment prior to the initiation of the EIS process.
USFWS	9/26/2016	The Service recommends standardizing buffers across the entire project to include a minimum 50- foot vegetated buffer between all project activities and wetlands, non-fish-bearing streams and resident streams. A 100-foot minimum vegetated buffer between all project activities and anadromous waters and streams leading to anadromous waters should be established. Vegetated buffers greater than 100 feet are recommended between material sites and larger rivers to maintain the integrity of the material site during flood events.	Comment acknowledged, all ATWS (such as staging areas and additional spoil storage areas) would be located at least 50 feet away from all waterbodies. See Appendix N of Resource Report No. 2, Section V. B.2.a.
USFWS	9/26/2016	Berms between streams/rivers and materials sites should be designed to avoid the potential to trap fish; the design should consider the potential for high water events that increase the risk of moving fish into the excavation site and then trapping them in the site when flood waters recede.	Comment acknowledged.
USFWS	9/26/2016	Consider using correct soils terminology. In the Interior of Alaska, for example, to use the term "topsoil" would be inaccurate as there typically is little to no topsoil/mineral soil layer (A Horizon). A typical soil profile for the Interior is an organic layer (O Horizon) over a subsoil layer (B Horizon) (Paul, J. 29 August 2016. Pers. Comm.) It is confusing when Project refers to "topsoil" when discussing North Slope or Interior soils. For reference Ping, Chien-Lu, et al. (2006) offers soil profile descriptions for Interior as follows: Upland, North-facing slopes, stunted black spruce, cold soils: O horizon thickness = 25-45 cm A horizon = rare, 0-10 cm if present Upland, South facing slopes, mixed deciduous spruce, warm	Topsoil and soil horizons are discussed in further detail in Resource Report 7 in Sections 7.3 and 7.4.5.

Resource Report No. 6
Agency Comments and Requests for Information Concerning Geological Resources

Agency	Date	Comment	Response/Resource Report Location
		soils: O horizon thickness = 0-15 cm A horizon = rare, 0-10 cm if present Lowlands, stunted black spruce and/or tussock tundra, cold and wet soils: O horizon thickness = 20-40 cm, range to >1m A horizon = very rare Ping, Chien-Lu, et al. 2006. "State factor control of soil formation in interior Alaska." Alaska's changing boreal forest. Edited by FS Chapin III, M. Oswood, K. Van Cleve, LA Viereck, and DL Verbyla. Oxford University Press, Oxford, UK (2006): 21-38).	
USFWS	9/26/2016	We recommend the following BMPs for mine site closure on the Arctic Coastal Plain: Side slopes no steeper than 3:1 and preferably shallower; Berms placed on entire perimeter of mine site. This should be done at onset of excavation for safety and to prevent thermokarst and draining of adjacent wetlands; Bi-annual inspections (at break-up and prior to freeze-up) to check stability of berms and for possible erosion; Removal of berms once site has completely filled with water. We do not recommend mine site restoration on the Arctic Coastal Plain beyond following the BMPs for stability and safety listed above. The littoral zone in ACP ponds and lakes is extremely shallow and generally does not exceed 2-3 ft. The re-creation of these shallow littoral habitats in mine sites on the ACP is not practicable because once the mine site is filled with water the back-filled material usually subsides to depths beyond the littoral zone limit. In addition, suitable fill material is limited and therefore abating the subsidence with additional material usually is not possible. Lastly, unless the mine site is day-lighted into a stream, the excavation can take 10 or more years to fill with water. The combination of these factors renders mine site restoration with productive littoral zone habitat to be impracticable on the ACP. However, mine sites can be a source of organic material and/or tundra sod blocks for use in other wetland restoration projects on the ACP. The organic layer (top 12 to 18 inches) can be harvested over the entire footprint of a proposed mine site prior to excavation and stored separately from the overburden. The organic material can be used for wetland restoration projects (i.e.; gravel pad removal) elsewhere. Tundra sod blocks also can be harvested from the footprint of a proposed mine site. The blocks can be harvested, stacked, wrapped in plastic, and stored (at least 1-2 years) for later use in ACP wetland restoration projects.	The Applicant will address this comment prior to the initiation of the EIS process.
USFWS	9/26/2016	The Service appreciates the BMP for creating wildlife habitat using ponds in areas other than on the Arctic Coastal Plain (see comment above). The following is our standard general recommendation for creating these shallow littoral areas/zones at excavation sites that fill with water: "We recommend the creation of a shallow littoral shelf along the majority of the perimeter of the site to help attract a variety of wildlife and for wetland mitigation credit. The shallow littoral area should include: 1) a 20 to 30 foot wide underwater shallow littoral shelf along the bank with slopes no steeper than 10H:1V and a depth of 3 to 6 feet, which is the depth range for most rooted aquatic vegetation, 2) irregular shorelines and, if practicable, islands and peninsulas to maximize the shore- to-water interface, 3) spreading two-to-four inches of organic materials along the shallow littoral shelf and shoreline to maximize natural revegetation and productivity, and 4) at least a 25-foot wide buffer of native vegetation around most, if not all, of the	The Applicant will address this comment prior to the initiation of the EIS process.

Resource Report No. 6 Agency Comments and Requests for Information Concerning Geological Resources			
Agency	**Date**	**Comment**	**Response/Resource Report Location**
		excavation site to help filter sediment and pollutants before they can enter this newly created waterbody. " Please note the above recommendations do not apply for pond creation/restoration on the Arctic Coastal Plain.	

Resource Report No. 6 Public Comments			
Date	**Individual/ Organization**	**Comment**	**Response/Resource Report Location**
9/29/2016	Keith, Scott	Appendix C – Summary of Geophysical and Geotechnical Surveys Page 19 of 32 contains a reference in the first paragraph that should be corrected. "The extent of the geophysical data acquired during 2014 and 2015 is shown in Figure 5-1." In fact the data is shown in Figure 4-1. I look forward to the updates of Figures 4-1 and 4-2 (including the 2016 field data) in the final version. These show clearly the possible proposed Rev C route.	Appendix C has been updated with new field data.
9/29/2016	Keith, Scott	Appendix C – Summary of Geophysical and Geotechnical Surveys Section 4.3 Information to be Included in the FERC Application Page 22 of 32. In this section the Project reserves the right to proprietary information about the G&G information with the statement: "These studies and data represent considerable commercial value, and are to be provided to FERC on a privileged and confidential basis." The information is complex and extensive. This is a fine line. I am very interested in these details especially in the G&G data in Cook Inlet and would appreciate the projects efforts to produce summary documents for lay-persons trying to see the big picture of the G&G data.	Comment acknowledged.

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ACRONYMS AND ABBREVIATIONS

ABBREVIATION	DEFINITION
Abbreviations for Units of Measurement	
M_w	Magnitude
Other Abbreviations	
§	section or paragraph
ACP	Arctic Coastal Plain
ADF&G	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
ADOT&PF	Alaska Department of Transportation and Public Facilities
AEIC	Alaska Earthquake Information Center
AGDC	Alaska Gasline Development Corporation
AKPLIC	Alaska Public Lands Information Centers
AOGCC	Alaska Oil and Gas Conservation Commission
Applicant	Alaska Gasline Development Corporation
Applicant's Plan	Applicant's Upland Erosion Control, Revegetation, and Maintenance Plan
ARD	acid rock drainage (see also ML – metal leaching)
ARDF	Alaska Resource Data File
ASAP	Alaska Stand Alone Pipeline
BLM	United States Department of the Interior, Bureau of Land Management
CFR	Code of Federal Regulations
DGGS	Alaska Department of Natural Resources; Division of Geological and Geophysical Surveys
DMLW	Alaska Department of Natural Resources, Division of Mining, Land, & Water
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
FERC	United States Department of Energy, Federal Energy Regulatory Commission
FDL	frozen debris lobe
GIS	geographic information system
GTP	gas treatment plant
IBC	International Building Code
KPB	Kenai Peninsula Borough
KSH	Kenai Spur Highway relocation project
LiDAR	light detection and ranging
Liquefaction Facility	natural gas liquefaction facility
LNG	liquefied natural gas
LNGC	liquefied natural gas carrier
Mainline	an approximately 806-mile-long, large-diameter gas pipeline
MGS	Major Gas Sales
ML	metal leaching
MP	Mainline milepost

ABBREVIATION	DEFINITION
NOA	Naturally Occurring Asbestos
North Slope	Alaska North Slope
NPS	United States Department of the Interior, National Park Service
NRCS	Natural Resources Conservation Service
NSB	North Slope Borough
OBE	Operating Basis Earthquake
PBTL	Prudhoe Bay Gas Transmission Line
PBU	Prudhoe Bay Unit
PHMSA	United States Department of Transportation, Pipeline and Hazardous Materials Safety Administration
Project	Alaska LNG Project
PTTL	Point Thomson Gas Transmission Line
PTU	Point Thomson Unit
MGS	Major Gas Sales
RDC	Resource Development Council for Alaska
ROW	right-of-way
SSE	Safe Shutdown Earthquake
TAPS	Trans-Alaska Pipeline System
TBD	To be determined
U.S.	United States
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFWS	United States Department of the Interior, Fish and Wildlife Service
USGS	United States Department of the Interior, United States Geological Survey

6.0 RESOURCE REPORT NO. 6 – GEOLOGICAL RESOURCES

Potential geological resource impacts have been assessed in this Resource Report for both construction and operation of the proposed Project. Unless specified, impacts have been assessed specific to the Project's footprint. The impact area assessed consists of the crossing locations of the proposed facilities across surficial geology, non-energy mineral resources, oil and natural gas resources, coal resources, industrial material resources, and paleontological resources.

Impacts related to geologic hazards have been assessed on a regional basis, with the zone of influence specific to the type of hazard. For example, volcanic hazards pose a risk on a large geographic scale, while areas of potential mass wasting (i.e., the large-scale movement of geological materials, including rocks, sediments, soils, water, ice, and snow) would be specific to a general location, or Project component.

6.1 PROJECT DESCRIPTION

The Alaska Gasline Development Corporation (Applicant) plans to construct one integrated liquefied natural gas (LNG) Project (Project) with interdependent facilities for the purpose of liquefying supplies of natural gas from Alaska, in particular from the Point Thomson Unit (PTU) and Prudhoe Bay Unit (PBU) production fields on the Alaska North Slope (North Slope), for export in foreign commerce and for in-state deliveries of natural gas.

The Natural Gas Act (NGA), 15 U.S.C. § 717a(11) (2006), and Federal Energy Regulatory Commission (FERC) regulations, 18 Code of Federal Regulations (C.F.R.) § 153.2(d) (2014), define "LNG terminal" to include "all natural gas facilities located onshore or in State waters that are used to receive, unload, load, store, transport, gasify, liquefy, or process natural gas that is ... exported to a foreign country from the United States." With respect to this Project, the "LNG Terminal" includes the following: a liquefaction facility (Liquefaction Facility) in Southcentral Alaska; an approximately 807-mile gas pipeline (Mainline); a gas treatment plant (GTP) within the PBU on the North Slope; an approximately 63-mile gas transmission line connecting the GTP to the PTU gas production facility (PTU Gas Transmission Line or PTTL); and an approximately 1-mile gas transmission line connecting the GTP to the PBU gas production facility (PBU Gas Transmission Line or PBTL). All of these facilities are essential to export natural gas in foreign commerce and will have a nominal design life of 30 years.

These components are shown in Resource Report No. 1, Figure 1.1-1, as well as the maps found in Appendices A and B of Resource Report No. 1. Their proposed basis for design is described as follows.

The new Liquefaction Facility would be constructed on the eastern shore of Cook Inlet just south of the existing Agrium fertilizer plant on the Kenai Peninsula, approximately 3 miles southwest of Nikiski and 8.5 miles north of Kenai. The Liquefaction Facility would include the structures, equipment, underlying access rights, and all other associated systems for final processing and liquefaction of natural gas, as well as storage and loading of LNG, including terminal facilities and auxiliary marine vessels used to support Marine Terminal operations (excluding LNG carriers [LNGCs]). The Liquefaction Facility would include three liquefaction trains combining to process up to approximately 20 million metric tons per annum (MMTPA) of LNG. Two 240,000-cubic-meter tanks would be constructed to store the LNG. The Liquefaction Facility would be capable of accommodating two LNGCs. The size of LNGCs that the Liquefaction Facility would accommodate would range between 125,000–216,000-cubic-meter vessels.

In addition to the Liquefaction Facility, the LNG Terminal would include the following interdependent facilities:

- Mainline: A new 42-inch-diameter natural gas pipeline approximately 807 miles in length would extend from the Liquefaction Facility to the GTP in the PBU, including the structures, equipment, and all other associated systems. The proposed design anticipates up to eight compressor stations; one standalone heater station, one heater station collocated with a compressor station, and six cooling stations associated with six of the compressor stations; four meter stations; 30 Mainline block valves (MLBVs); one pig launcher facility at the GTP meter station, one pig receiver facility at the Nikiski meter station, and combined pig launcher and receiver facilities at each of the compressor stations; and associated infrastructure facilities.

  Associated infrastructure facilities would include additional temporary workspace (ATWS), access roads, helipads, construction camps, pipe storage areas, material extraction sites, and material disposal sites.

  Along the Mainline route, there would be at least five gas interconnection points to allow for future in-state deliveries of natural gas. The approximate locations of three of the gas interconnection points have been tentatively identified as follows: milepost (MP) 441 to serve Fairbanks, MP 763 to serve the Matanuska-Susitna Valley and Anchorage, and MP 807 to serve the Kenai Peninsula. The size and location of the other interconnection points are unknown at this time. None of the potential third-party facilities used to condition, if required, or move natural gas away from these gas interconnection points are part of the Project. Potential third-party facilities are addressed in the Cumulative Impacts analysis found in Appendix L of Resource Report No. 1;

- GTP: A new GTP and associated facilities in the PBU would receive natural gas from the PBU Gas Transmission Line and the PTU Gas Transmission Line. The GTP would treat/process the natural gas for delivery into the Mainline. There would be custody transfer, verification, and process metering between the GTP and PBU for fuel gas, propane makeup, and byproducts. All of these would be on the GTP or PBU pads;

- PBU Gas Transmission Line: A new 60-inch natural gas transmission line would extend approximately 1 mile from the outlet flange of the PBU gas production facility to the inlet flange of the GTP. The PBU Gas Transmission Line would include one meter station on the GTP pad; and

- PTU Gas Transmission Line: A new 32-inch natural gas transmission line would extend approximately 63 miles from the outlet flange of the PTU gas production facility to the inlet flange of the GTP. The PTU Gas Transmission Line would include one meter station on the GTP pad, four MLBVs, and pig launcher and receiver facilities—one each at the PTU and GTP pads.

Existing State of Alaska transportation infrastructure would be used during the construction of these new facilities including ports, airports, roads, railroads, and airstrips (potentially including previously abandoned airstrips). A preliminary assessment of potential new infrastructure and modifications or additions to these existing in-state facilities is provided in Resource Report No. 1, Appendix L. The Liquefaction Facility, Mainline, and GTP would require the construction of modules that may or may not take place at existing or new manufacturing facilities in the United States.

Draft Resource Report No. 1, Appendix A, contains maps of the Project footprint. Appendices B and E of Resource Report No. 1 depict the footprint, plot plans of the aboveground facilities, and typical layout of aboveground facilities.

Outside the scope of the Project, but in support of or related to the Project, additional facilities or expansion/modification of existing facilities would be needed to be constructed. These other projects may include:

- Modifications/new facilities at the PTU (PTU Expansion project);
- Modifications/new facilities at the PBU (PBU Major Gas Sales [MGS] project); and
- Relocation of the Kenai Spur Highway.

6.1.1 Purpose of Resource Report

As required by 18 C.F.R. § 380.12, this Resource Report has been prepared in support of a FERC application under Section 3 of the NGA to construct and operate the Project facilities. The purpose of this Resource Report is to:

- Describe the existing geologic setting, mineral resources, geologic hazards, and paleontological resources in the vicinity of the Project;
- Summarize potential effects to these resources resulting from the construction and operation of the Project;
- Identify potential general mitigation measures to avoid or reduce potential adverse effects to geological and paleontological resources in the vicinity of the Project area; and
- Summarize potential strategies and techniques to mitigate effects of geohazards on the Project.

Unless specified, impacts have been assessed specific to the Project's footprint.

Appendices to this Resource Report include:

- Appendix A Extended Tables of Resource Report No. 6;
- Appendix B *Blasting Plan for the Alaska LNG Project*;
- Appendix C Project Geotechnical and Geophysical (G&G) Field Testing and results;
- Appendix D *Paleontological Unanticipated Discovery Plan*;
- Appendix E *Paleontological Resources Management Plan*;
- Appendix F *Gravel Sourcing Plan and Reclamation Measures*;
- Appendix G *Paleontological Resources Survey and Inventory Reports*; and
- Appendix H *Geological Hazard Assessments*.

Data for this Resource Report were compiled based on a review of:

- Feedback from FERC and other federal, state, and local agencies on Drafts 1 and 2 of the Environmental Report;
- Engineering design and proposed construction plans;
- U.S. Geological Survey (USGS) topographic maps;
- Recent aerial photography;
- Field survey and site investigation data;
- Agency-supplied comments and data;
- Review of data from adjacent projects;
- Scientific literature; and
- Geographic Information System (GIS) data from federal and state agencies.

Upon completion of a review of the Project footprint and available information such as previous field studies, additional field and laboratory investigations supporting engineering design and execution planning would be conducted to reduce effects of geohazards. This would include offshore hazard surveys, which are ongoing.

6.1.2 Effect Determination Terminology

The following definitions were used when assessing the duration, significance, and outcome of potential effects related to the Project:

- <u>Duration</u>**:** ***Temporary*** effects are those that may occur only during a specific phase of the Project, such as during construction or installation activities. ***Short-term effects*** could continue up to five years. ***Long-term*** effects are those that would take more than five years to recover. ***Permanent*** effects could occur as a result of any activity that modified a resource to the extent that it would not return to preconstruction conditions during the 30-year life of the Project;
- <u>Significance</u>: ***Minor*** effects are those that may be perceptible but are of very low intensity and may be too small to measure. ***Significant*** effects are those that, in their context, and due to their intensity, have the potential to result in a substantial adverse change in the physical environment; and
- <u>Outcome:</u> A ***positive*** effect may cause positive outcomes to the natural or human environment. In turn, an ***adverse*** effect may cause unfavorable or undesirable outcomes to the natural or human environment. ***Direct effects*** are "caused by the action and occur at the same time and place" (40

CFR 1508.8). ***Indirect effects*** are "caused by an action and are later in time or farther removed in distance but are still reasonably foreseeable. Indirect impacts may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density, or growth rate, and related effects on air and water and other natural systems, including ecosystems" (40 CFR 1508.8). Indirect impacts are caused by the Project, but do not occur at the same time or place as the direct impacts.

6.1.3 Agency and Organization Consultations

This section describes consultations that have been conducted with agencies and other parties interested in the Project.

6.1.3.1 Federal Agencies

Discussions were held with multiple federal agencies regarding various Project details. Table 6.1.3-1 includes meetings and correspondence (through December 2016) where discussions regarding geological resources were raised. This table will be updated in the FERC application as additional input is solicited.

A list of the required federal permits for the Project is provided in Resource Report No. 1, Appendix C. A preliminary summary of public, agency, and stakeholder engagement is provided in Resource Report No. 1, Appendix D.

TABLE 6.1.3-1

Summary of Consultations with Federal Agencies (Through December 2016)

Contact	Date	Summary
U.S. Army Corps of Engineers (USACE)	10/17/2013	Discussion regarding Cook Inlet metocean data gathering program and necessary approvals
U.S. Coast Guard (USCG)	10/18/2013	Discussion regarding Cook Inlet metocean data gathering program and necessary approvals
National Marine Fisheries Services (NMFS)	10/24/2013	Discussion regarding Cook Inlet metocean data gathering program and necessary approvals
NMFS; USCG	4/9/2014	Discussion regarding further metocean studies and geotechnical and geophysical studies permitting
USACE; USCG; Office of Fossil Energy (USDOE-OFE); U.S. Department of Interior (USDOI); U.S. Environmental Protection Agency (EPA); U.S. Fish and Wildlife Service (USFWS); National Park Service (NPS)	2/10/2015	Alaska LNG Project Web Mapper and SharePoint Overview for State and Federal Agency Representatives
USACE; USFWS	2/12/2015	2015 Nikiski and Cook Inlet Area Geophysical and Geotechnical Programs
Bureau of Land Management (BLM); FERC; Natural Resource Group; NMFS; Pipeline and Hazardous Materials Safety Administration (PHMSA); USACE; USCG; USDOI; EPA; USFWS; NPS	3/16/2015	Meeting with FERC and other agencies to review Resource Reports
FERC	5/15/2015	FERC Draft 1 Resource Report Nos. 1–12 comments and collated comments from NPS, USFWS, USACE, EPA, and BLM
FERC; USDOE-OFE; USDOI	5/28/2015	Roundtable Discussion – Federal Processes for

TABLE 6.1.3-1

Summary of Consultations with Federal Agencies (Through December 2016)

Contact	Date	Summary
		Permitting the Project
FERC	5/28/2015	Meeting with FERC on Resource Reports Nos. 6 and 13 design requirements and expectations
FERC; USDOE-OFE; USDOI	5/28/2015	Roundtable Discussion – Federal Processes for Permitting the Project
NMFS	6/5/2015	Cook Inlet Geotechnical and Geophysical (G&G) Incidental Harassment Authorization (IHA) Application – Schedule Alignment
USACE; USDOI; EPA; USFWS	6/24/2015	Discussion of large-diameter natural gas pipeline construction planning and execution as it pertains to the Project, including an overview of pipeline construction by season.
NMFS	7/1/2015	Review of NMFS questions on the Project Cook Inlet G&G Biological Assessment
FERC; NMFS; USACE; USCG; EPA; USFWS	8/12/2015	Review of the Gas Treatment Plant (GTP) Footprint
FERC; NMFS; USACE; USFWS	8/19/2015	Cook Inlet Routing and Construction Review
FERC; NMFS; USACE; USCG; USFWS	9/2/2015	Review of the LNG Footprint
FERC; NMFS; USACE; USCG; EPA; USFWS	9/3/2015	Dredging Workshop
FERC	9/9/2015 and 9/10/2015	Align on modifications to FERC's Plans & Procedures for Pipeline Construction
FERC	9/10/2015	Upland Erosion and Sedimentation Control Plan meeting with FERC
FERC	9/30/2015	Review of Liquefaction Facility/Marine Civil/Seismic/Geotechnical Design Criteria
FERC; Pipeline and Hazardous Materials Safety Administration (PHMSA) U.S. Department of Transportation (USDOT)	10/12/2015	Review of Pipeline Civil/Seismic/Geotechnical Design Criteria
USCG	10/19/2015	Review of Draft Follow-on Waterway Suitability Assessment Report
EPA	11/12/2015	Review Application Approach to Gas Treatment Plant Air Modeling “Sharp Gradients”
FERC	3/3/2016	Project Overview
PHMSA	3/15/2016	Crack Arrestor and Mainline Block Valve Special Permit analysis and Strain-Based Design Change Process
USACE; EPA	3/16/2016	Overview of Sediment Sampling Scope for Capital Dredging at Nikiski
FERC	3/24/2016	Geotechnical and Geophysical
FERC	3/31/2016	Project Review
FERC; USACE	4/14/2016	Wetlands, Plans and Procedures, Traditional Knowledge, Permits
FERC; USACE; USDOI; NPS, Alaska Regional Office	4/14/2016	Pipeline Routing through Denali National Park and Reserve
FERC; PHMSA	4/14/2016	PHMSA Pipeline Special Permit and Environmental Overview
USDOI; NPS, Alaska Regional Office		Denali National Park and Preserve Alternative with NPS

TABLE 6.1.3-1

Summary of Consultations with Federal Agencies (Through December 2016)

Contact	Date	Summary
		and ADOT&PF
NMFS	5/26/2016	NMFS Questions on Vibracoring
NMFS; USACE	5/27/2016	Vibracoring Operations and Incidental Harassment Authorization (IHA)
NPS	5/27/2016	Denali National Park geohazards
USACE	6/3/2016	Restoration Planning Group
BLM	6/13/2016	Alaska LNG and TAPS joint engineering study
USACE; EPA	6/20/2016	West Dock Sampling Program Summer Work
FERC	7/14/2016	Uplands Plan and Wetland/Waterbody Procedures
FERC	8/23/2016	Geotechnical Data Technical Review
NOAA; NMFS	8/24/2016	Construction and Execution of Cook Inlet Pipeline in the Susitna Delta Exclusion Zone
USACE	9/23/2016	Kenai Spur Highway Wetlands

6.1.3.2 State and Local Agencies/Entities

Discussions were held with multiple State of Alaska and local agencies, as well as private corporation representatives, regarding Project details. Table 6.1.3-2 includes meetings and correspondence (through April 14, 2017) where discussions of geological resources were raised. This table will be updated in the FERC application as additional input is solicited.

A list of required state permits for the Project, as well as a summary of public, agency, and stakeholder engagement, is provided in Resource Report No. 1, Appendix D.

TABLE 6.1.3-2

Summary of Consultations with Alaska State and Local Agencies/Entities (December 2016through April 4, 2017)

Contact	Date	Summary
State of Alaska Pipeline Coordinator's Section (SPCS)	10/16/2013	Review Cook Inlet metocean data gathering program and necessary approvals
Alaska Department of Natural Resources (ADNR) Division of Geology & Geophysical Surveys (DGGS); SPCS	4/9/2014	Discussion regarding fault survey plans and potential sharing of information
SPCS	4/24/2014	Discussion regarding further metocean studies and geotechnical and geophysical studies permitting
Alaska Department of Transportation and Public Facilities (ADOT&PF)	6/30/2014	Discussion regarding permit requirements for G&G studies
ADOT&PF; Office of Project Management and Permitting (OPMP); SPCS	8/24/2014	Pre-application meeting regarding Liquefaction Facility G&G survey program
ADOT&PF; OPMP; SPCS	10/28/2014	Discussion regarding geotechnical studies along the Mainline corridor
Alaska Department of Environmental Conservation (ADEC); OPMP; SPCS	12/5/2014	Discuss 2015 Cook Inlet G&G survey program

TABLE 6.1.3-2

Summary of Consultations with Alaska State and Local Agencies/Entities (December 2016through April 4, 2017)

Contact	Date	Summary
ADNR	1/6/2015	General discussion on National Environmental Policy Act (NEPA) coordination processes
Alaska LNG Project; SPCS; **exp** Energy Services	1/6/2015	NEPA Coordination Meeting
ADOT&PF; Paragon Partners Ltd (Paragon); SPCS	1/14/2015	Kenai Spur Highway Reroute
ADOT&PF; North Slope Gas Commercialization Permitting Coordination Team (NSGCPCT)	2/10/2015	Project Web Mapper and SharePoint Overview for State and Federal Agency Representatives
Alaska Department of Fish and Game (ADF&G); Kenai Peninsula Borough (KPB); NSGCPCT	2/12/2015	2015 Nikiski and Cook Inlet Area G&G Programs
ADOT&PF	2/17/2015	2015 Nikiski Onshore G&G Pre-Application Meeting
ADEC; ADF&G; ADNR; ADOT&PF; State Historic Preservation Office; SPCS	3/16/2015	Meeting with FERC and other agencies to review Resource Reports
Alaska Gasline Development Corporation (AGDC)	4/1/2015	Discuss Alaska Stand Alone Pipeline (ASAP) Project Scope for 2015 for Multiple Disciplines
ADF&G	4/12/2015	ADF&G Wildlife Training for G&G Survey Team
KPB	4/20/2015	2015 Permitting for Activities in the KPB
Alaska LNG Project; North Slope Borough (NSB)	5/1/2015	General overview of the Project, focusing on portions within the NSB (Pipelines and GTP)
Alaska Ocean Observing System; Cook Inlet Regional Citizens Advisory Council; University of Alaska – Anchorage	5/11/2015	Cook Inlet Data
ADEC	6/22/2015	Regulatory Framework for Potential Discharge from LNG Drilling Activities on the Beach, Nikiski
ADEC; ADF&G; ADNR; ADOT&PF; NSB; SPCS	6/24/2015	The objective for this workshop was to explain large-diameter natural gas pipeline construction planning and execution as it pertains to the Project, including an overview of pipeline construction by season.
SPCS	6/25/2015	The objective for this workshop was to review the proposed water crossing methods and season of construction, and to seek alignment on crossing methods and season of construction.
SPCS	7/2/2015	Debrief of June 24 and 25 Pipeline Construction Workshops with SPCS
ADF&G; ADNR; NSB; SPCS	8/12/2015	Review of the GTP Footprint
ADF&G; ADNR; KPB; Matanuska-Susitna Borough; SPCS	8/19/2015	Cook Inlet Routing and Construction Review
ADF&G; ADNR; ADOT&PF; KPB; SPCS	9/2/2015	Review of the LNG Footprint
ADNR; SPCS	9/3/2015	Dredging Workshop
ADOT&PF	11/20/2015	Uniform Relocation Act Applicability, Nikiski Growth Rate Projections
ADNR	12/11/2015	IHA and Subsistence Discussion, Resource Report Schedules
ADOT&PF	2/26/2016	Highway Crossings, Pipeline
ADNR; ADEC	3/16/2016	Overview of Sediment Sampling Scope for Capital Dredging at Nikiski
ADOT&PF; AGDC	4/14/2016	Pipeline Routing through Denali National Park and Reserve
ADNR; North Slope Gas Commercialization Permitting	4/14/2016	PHMSA Pipeline Special Permit and Environmental Overview

TABLE 6.1.3-2

Summary of Consultations with Alaska State and Local Agencies/Entities (December 2016through April 4, 2017)

Contact	Date	Summary
Coordination Team;		
Alaska Gasline Development Corporation		Denali National Park and Preserve Alternative with NPS and ADOT&PF
West Dock Users Group	5/9/2016	Summer Field Work
Alyeska Pipeline Service Company; BLM, Alaska State Office; JPO	6/13/2016	Alaska LNG and TAPS joint engineering study
ADNR	8/16/2016	Compensatory Mitigation Strategies
ADNR	9/1/2016	Section 106 and Mitigating Adverse Effects to NRHP-Eligible Sites

6.2 ECOREGIONS AND GEOLOGIC SETTING

The following sections summarize the ecoregions, topography, and geology transected by the footprint of the Project. Information presented here is intended to be an overview of surficial and subsurface characteristics based upon publicly accessible information and available field information.

The study area includes the geological resources within or immediately adjacent to the Project footprint. Geologic hazards are discussed as identified within relevant proximity (miles) of facility locations.

6.2.1 Ecoregion

Alaska comprises the far northwestern extent of the North American continent. The state is bordered by the Arctic Ocean to the north, the Bering and Chukchi seas to the west, the Pacific Ocean to the south, and Canada to the east. The southern border of the state lies on the edge of the tectonic boundary between the Pacific Plate, which underlies the Pacific Ocean, and the North American Plate, upon which Alaska resides. The Pacific Plate is being subducted (thrust) beneath Alaska within a subduction zone, or megathrust, at variable rates between 2.2 inches to 3 inches per year (see Section 6.4.1). This convergent boundary is responsible for Alaska's geologically active landscape, most notably producing the Aleutian chain of volcanoes and abundant earthquakes across the state (seismicity is addressed in Section 6.4.1).

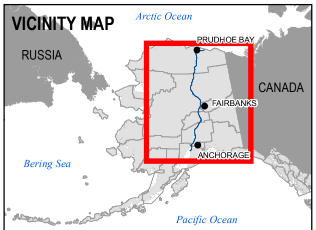
Alaska contains two massive east-west trending mountain ranges—the Brooks Range in the north and the Alaska Range in the south. The Brooks Range is the oldest mountain range in Alaska. These mountains are an extension of the Canadian Rockies and serve as the Continental Divide, which separates watersheds that drain into the Arctic Ocean to the north from watersheds that drain into the Pacific Ocean and the Bering Sea to the south. The Alaska Range is a young, actively uplifting mountain range forming from the convergence of the Pacific Plate, North American Plate, and various exotic or accreted terranes. Between the mountain ranges are extensive stretches of lowlands drained by major river systems.

Throughout the recent ice age and up through today, valley glaciers and massive ice sheets have shaped the terrain, carving out valleys and depositing thick blankets of glacial sediments in low-lying regions. Freeze and thaw cycles, erosion by water and wind, and mass wasting processes continue to shape the geomorphology of the landscape. However, though glaciers have modified much of Alaska, much of the low-lying terrain along the proposed corridor between the Brooks Range and the Alaska Range has not been altered.

The vast terrain of Alaska has been divided into general physiographic regions based on variation in topography and large-scale geomorphic processes (Wahrhaftig, 1965). Additionally, the state has been divided into ecoregions that are more specific to the discipline of geology, based on lithology, soil type, surficial geology, and land cover (Nowacki et al., 2001). The following sections provide a description of the ecoregions present in the Project area. The ecoregions within which the Project would be found are mapped in Figure 6.2.1-1 and described in Table 6.2.1-1. Further details regarding surface and bedrock geology can be found in Section 6.2.3. Permafrost is discussed in Resource Report No. 7.

A preliminary listing of each Project component by ecoregion, borough/census areas, and milepost is provided in Appendix A, Table 1.

VICINITY MAP



X:\AKLNG\Resource Reports\RR06\Figure 6_2_1-1 Physiographic Regions and Ecoregions.mxd

LEGEND

- Project Facility
- Existing Facility
- Alaska Place Names
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers
- Ecoregions

0 25 50 100 150 Miles

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ALASKA PHYSIOGRAPHIC REGIONS & ECOREGIONS

FIGURE 6.2.1-1

ALASKA LNG

TABLE 6.2.1-1

Physiographic Regions and Ecoregions Transected by the Project

Project Facility	Physiographic Region[a]	Ecosystem[b]	Ecoregion[c]	Borough/Census Area
LIQUEFACTION FACILITY				
LNG Plant	Cook Inlet-Susitna Lowlands	Boreal-Alaska Range Transition	Cook Inlet Basin	Kenai Peninsula Borough
Marine Terminal				
INTERDEPENDENT PROJECT FACILITIES				
Pipelines and Associated Infrastructure				
Mainline	Arctic Coastal Plain	Polar-Arctic Tundra	Beaufort Coastal Plain	North Slope Borough
Mainline	Arctic Mountains		Brooks Range Foothills	
Mainline			Brooks Range	Yukon-Koyukuk Census Area
Mainline	Interior Lowlands and Uplands	Boreal-Intermontane Boreal	Kobuk Ridges and Valleys	
Mainline	Yukon-Tanana Uplands		Ray Mountains Yukon Tanana Uplands	
Mainline	Tanana-Kuskokwim Lowlands		Ray Mountains	Fairbanks North Star Borough
Mainline			Tanana Kuskokwim Lowlands	Denali Borough
Mainline	Alaska Range			
Mainline		Boreal-Alaska Range Transition	Alaska Range	
Mainline				Matanuska-Susitna Borough
Mainline	Cook Inlet-Susitna Lowlands		Cook Inlet Basin	
Point Thomson Gas Transmission Line (PTTL)	Arctic Coastal Plain	Polar-Arctic Tundra	Beaufort Coastal Plain	North Slope Borough
Prudhoe Bay Gas Transmission Line (PBTL)				
GTP				
GTP	Arctic Coastal Plain	Polar-Arctic Tundra	Beaufort Coastal Plain	North Slope Borough
GTP and Associated Infrastructure				
Non-Jurisdictional Facilities				
PTU Expansion Project	Arctic Coastal Plain	Polar-Arctic Tundra	Beaufort Coastal Plain	North Slope Borough
PBU MGS				
KSH Relocation	Cook Inlet-Susitna Lowlands	Boreal-Alaska Range Transition	Cook Inlet Basin	Kenai Peninsula Borough

[a] Major Land Resource Regions as provided in Natural Resources Conservation Service (NRCS) Staff (2004).

[b] Physiographic regions generalized from Nowacki, G., Spencer, P., Fleming, M., Brock, T. and Jorgenson, T. 2001. Unified Ecoregions of Alaska, U.S. Geological Survey Open-File Report 02-297. 1 sheet, scale 1:4,000,000.

[c] Unified Ecoregions of Alaska (Nowacki et al., 2001).

6.2.1.1 Liquefaction Facility

The Liquefaction Facility would be located in the Cook Inlet Basin Ecoregion. A brief description of the terrain, surficial geology, and current geomorphic processes within this ecoregion is provided in the following sections. More-detailed information regarding bedrock encountered in this ecoregion is available in Section 6.2.3. Existing mineral, oil, gas, coal, and material resources are discussed in Section 6.3.

6.2.1.1.1 Cook Inlet Basin Ecoregion

The Liquefaction Facility would be located on the northeastern shore of the Cook Inlet Basin. This gently sloping lowland was buried by ice and subsequently flooded by proglacial lakes several times during the Pleistocene era, leaving behind fine-textured lacustrine deposits ringed by coarse-textured glacial tills and outwash throughout the region (Nowacki et al., 2001). Deposits and landforms associated with Naptowne glaciation include ground and recessional moraines composed of glacial till and outwash plains of gravelly sandy alluvial fan deposits that fan toward the south, away from the glacial front. Kettle holes, filled with small lakes and muskegs (bogs with shallow to deep accumulations of organic material), dot the till and outwash plains between the moraine ridges. Underlying bedrock is composed of oil and gas-bearing continental deposits, including sandstone, siltstone, claystone, conglomerate, and coal beds (ADNR Division of Geological & Geophysical Surveys [DGGS], 2011).

6.2.1.2 Interdependent Project Facilities

Ecoregions crossed by the Mainline, GTP, PBTL, and PTTL and their associated facilities are provided in Appendix A, Table 1. An overview of the terrain, surficial geology, and current geomorphic processes in each ecoregion transected by the Project is provided in the following sections. More-detailed information regarding bedrock is available in Section 6.2.3. Existing mineral, oil, gas, coal and material resources are discussed in Section 6.3.

6.2.1.2.1 Beaufort Coastal Plain Ecoregion

The northernmost portion of the Project occurs in the Beaufort Coastal Plain Ecoregion. The Mainline crosses over 60 miles of this ecoregion. This area includes Prudhoe Bay and extends east to Point Thomson, north of the confluence between the Ivishak and Sagavanirktok rivers. The Beaufort Coastal Plain includes both onshore and offshore areas along the continental shelf, which gently slopes seaward at an average gradient of 4 feet per mile. The area is drained by the Sagavanirktok River, which meanders in its northern reaches and is braided in its southern extents, creating a wide, coarse-grained floodplain near its mouth at Prudhoe Bay (Harrison and Osterkamp, 1976).

Bedrock in the Beaufort Coastal Plain Ecoregion consists of thick, gently north-dipping sequences of sedimentary rocks, including sandstone, siltstone, and shale (Mull, 1989). These sedimentary rocks contain valuable deposits of oil and natural gas, and have been the target of petroleum exploration in the Beaufort Coastal Plain Ecoregion (see Section 6.3). Depth to bedrock varies from a few feet to hundreds of feet below young overlying sediments. The overlying, unconsolidated sediments are of both marine and terrestrial origins, and reflect the rise and fall of sea levels throughout glacial and interglacial periods of the Pleistocene. These sediments extend approximately 50 miles offshore.

Permafrost is continuous throughout the Beaufort Coastal Plain Ecoregion. Because permafrost restricts downward percolation of groundwater, soils in the area are very poorly drained. Permafrost and freeze/thaw features dominate the landscape. Polygonal-shaped ground features caused by freeze-thaw cycles in ice wedges are common throughout the region, as are pingos, small ice-cored hills resulting from expansion of ground-ice masses. Permafrost features are addressed in Resource Report No. 7.

6.2.1.2.2 Brooks Range Foothills Ecoregion

The Mainline stretches 80 miles through the Brooks Range Foothills Ecoregion, along the Sagavanirktok River north of Galbraith Lake and Atigun River. These gently rolling hills and broad exposed ridges form the northern flank of the Brooks Range. Sedimentary bedrock is tightly folded and strata forms east- to west-trending ridges and mesas along the northern foothills (Nowacki et al., 2001). Irregular buttes, mesas, and ridges occur farther south along the Mainline. Bedrock is overlain in the lower areas by Pleistocene sediments, including alluvium, glacial deposits, and ice rich colluvium and loess. Many braided streams and rivers cut through surficial deposits and exposed bedrock in the region, especially along the Sagavanirktok River.

Permafrost is continuous throughout the Brooks Range, creating surficial formations similar to those occurring farther north. Additionally, some streams in the region completely freeze down to the riverbed during the winter, creating large aufeis deposits (i.e., a sheet-like mass of layered ice that forms from successive flows of groundwater during freezing temperatures) that last well into summer (Nowacki et al., 2001).

6.2.1.2.3 Brooks Range Ecoregion

The Mainline follows the Middle Fork Koyukuk, Dietrich, and Atigun river valleys for just over 150 miles in the Brooks Range Ecoregion. The east-west trending Brooks Range Mountains are the northern extension of the Rocky Mountains. The southern extent of the ecoregion is marked by the Kobuk-Malamute fault (Nowacki et al., 2001). Relief along the Mainline rises abruptly from several hundred feet in the northern foothills up to 8,000 feet above sea level in the higher peaks to the south. The high peaks of the Brooks Range form the Continental Divide. Streams drain north into the Arctic Ocean and south into the Bering Sea, following previously glaciated drainages and broad outwash river valleys.

Valley bottoms are filled with thick colluvium and coarse-grained floodplain deposits. High-energy streams and rivers continue to carve into narrow ravines, and have eroded deeply incised dendritic drainage patterns in the terrain. These actively eroding mountain valleys are lined with talus slopes, alluvial fans, outwash terraces, and colluvial deposits.

Bedrock in the northern and central Brooks Range consists of tightly folded sedimentary rocks interspersed within the other sedimentary rock sequences. Farther south, the sedimentary rocks have been intruded by Cretaceous age granitic bodies (DGGS, 2011). This area is known to be mineralized with gold, silver, antimony, and arsenic. Placer gold deposits are present in and along the southern flank of the Brooks Range (see mineral resources discussion, Section 6.3; Alaska Resource Data Files [ARDF], 2015).

Mass wasting processes are very active throughout the Brooks Range Ecoregion. The Dietrich River Valley in particular is host to abundant solifluction lobes and flow slides (see mass wasting discussion in Section

6.4.3). Solifluction lobes are particularly abundant due to the presence of continuous permafrost, particularly where bedrock is shale, phyllite, or siltstone. Abundant frozen debris lobes (FDLs), slow-moving ice-rich landslides, are also present throughout the southern reaches of the ecoregion. The rate at which these lobes are advancing has been increasing in recent years, and in some areas, they are likely to intersect the Mainline in the next decade (Daanen et al., 2012). The Dietrich River Valley is narrow and steep in its upper reaches, with abundant fans of alluvium and colluvium along tributaries.

Glacial moraines line valleys where glaciers have retreated. Glacial carving is apparent in the wide u-shaped profiles in the southern Dietrich River Valley, where the floodplain widens and the drainage becomes more braided (Brown and Kreig, 1983).

High elevation regions within the Brooks Range contain snow avalanche and slush flow deposits (see Section 6.4.3). Small valley glaciers flank the higher peaks, though no active glaciers are present immediately along the Mainline in this ecoregion.

6.2.1.2.4 Kobuk Ridges and Valleys Ecoregion

South of the Brooks Range, the Mainline briefly (4 miles) passes through the Kobuk Ridges and Valleys Ecoregion before continuing south into the Ray Mountains. The Kobuk Ridges and Valleys Ecoregion has largely been shaped by glacial activity throughout the recent ice age (Quaternary glaciation period). Glaciers repeatedly scoured down the valleys, carving wide, u-shaped valleys. Thick accumulations of glacial sediment have been deposited throughout lowlands and deltaic regions, and geomorphic features exhibit erosion by streams and wind (DGGS, 2011).

Bedrock outcrops are scarce throughout the region, as the area is masked by thick glacial deposits. Thin to moderately thick permafrost also underlies most of the area (Nowacki et al., 2001). Bedrock may outcrop along higher elevations, revealing highly faulted ridges of sandstones, shale, siltstone and conglomerate (DGGS, 2011).

6.2.1.2.5 Ray Mountains Ecoregion

The Mainline transects the Ray Mountains Ecoregion for over 170 miles. The Ray Mountains Ecoregion consists of an overlapping series of east-west trending ranges with elevations ranging from 2,000 to 4,000 feet. This region is separated from the Brooks Range Ecoregion to the north by the Kobuk-Malamute fault (see Section 6.4.1).

Pleistocene glaciation in the Ray Mountains was limited to localized alpine glaciers at upper elevations. The mountains are now deglaciated and covered with colluvial and eolian deposits. Windblown silt, or loess, remobilized from the floodplains of glacier-fed rivers is a common feature of many lowland areas throughout the ecoregion. Permafrost is discontinuous throughout the region, and ranges from thin to moderate thickness (Nowacki et al., 2001).

Bedrock in the northern areas of the Ray Mountains includes graywacke, conglomerate, siltstone, and shale. The southern portion contains predominantly bedrock of massive volcanics with thin interbeds of chert (Foster and Keith, 1994).

6.2.1.2.6 Yukon-Tanana Uplands Ecoregion

The Mainline follows a 12-mile stretch of south-trending ridges of the Yukon-Tanana Uplands Ecoregion, surrounded by the Tanana-Kuskokwim Lowlands ecoregion to the north and south. The gently sloping uplands consist of rounded hills rising 500 to 1,500 feet above adjacent valleys (up to 3,000 feet total elevation). Similar to the Ray Mountains, the Yukon-Tanana Uplands were subject to local alpine glaciation during the Pleistocene.

Bedrock is a composite of diverse metasedimentary rocks of the Yukon-Tanana terrane, which includes former volcanic islands arcs and continental shelf deposits (Nowacki et al., 2001). Bedrock is exposed along higher elevation ridges, with colluvium draping lower slopes, and alluvium present in deeply incised, narrow valleys.

Permafrost is discontinuous on north-facing slopes and valley bottoms. Permafrost along valley bottoms is thin, ice-rich, and relatively warmer than that of the northern regions (Nowacki et al., 2001).

6.2.1.2.7 Tanana-Kuskokwim Lowlands

The Mainline drops into the Tanana-Kuskokwim Lowlands along the Tanana River Valley for over 80 miles south of the Ray Mountains. This alluvial plain slopes gently north from the Alaska Range, and consists of fluvial, glaciofluvial, colluvial and eolian deposits reworked by meandering rivers and creeks. Sand dune fields and glacial moraines are also locally present (Nowacki et al., 2001).

Bedrock is buried under a thick layer of unconsolidated quaternary soils in this region. However, bedrock is likely to consist of metasedimentary conglomerate-mudstone, arenite, chert, and quartzite of the Wickersham unit as well as Fossil Creek volcanics that extend into the Ray Mountains to the northwest (Wilson et al., 1998). Additionally, bedrock may include conglomerate, mudstone, claystone, lignite, and sandstone of the Usibelli Group in the southern portions of the Lowlands, as well as abundant metavolcanic, metavolcaniclastic, and locally younger, coal-bearing sedimentary rocks that outcrop near the Yukon-Tanana Uplands to the east.

Permafrost is thin and discontinuous throughout the lowlands, with average temperatures close to melting point (Nowacki et al., 2001).

6.2.1.3 Alaska Range Ecoregion

The Mainline follows a 100-mile stretch through the Alaska Range Ecoregion. This ecoregion is composed of several accreted terranes, creating a highly diverse belt of rocks trending generally southwest-northeast along the Mainline (Wilson et al., 1998).

In the northern portion of the Alaska Range Ecoregion, the Mainline would likely intersect abundant sedimentary rocks of the Usibelli Group (Tertiary), with some intermittent metavolcanic and metavolcaniclastic rocks. Younger, possibly coal-bearing sedimentary rocks have been mapped across the Nenana River and as outcrops through colluvium in the valleys and along shallow ridges along the Mainline, especially along the Healy fault near Dry Creek and Otto Lake along the western edge of Mount Fellows (faults are discussed in Section 6.4.1). Volcanic rocks are also expected to crop out along the western edge of Mount Fellows, as well as lower sedimentary conglomerate, shale, sandstone, coal, arkose, siltstone, and argillite. Additionally, intermittent outcrops of schist, quartzite, and amphibolite are mapped throughout the area, along with traces of metasedimentary and metavolcanic rocks in the Yanert River valley.

The Denali Fault zone is located farther south, where bedrock primarily consists of the Cantwell Formation (Cretaceous) interspersed with mélange and limestone blocks to the north of the fault (see Section 6.4.1). Immediately south of the Denali Fault zone, and along the western flanks of the Reindeer Hills, the Mainline intersects flysch, and hypabyssal felsic to intermediate intrusions (Paleocene to Miocene). The Reindeer Hills are predominantly composed of Nikolai flood basalts, which crop out west of the Mainline, terminating at the mouth of Eldridge Glacier.

Peaks of the Alaska Range are separated by lowlands filled by glacial deposits (Pleistocene), including moraines and outwash. High-energy streams carry heavy sediment loads from abundant, remnant ice fields and glaciers. These rivers have incised the landscape, creating steep slopes and drainages that are highly susceptible to landslides and avalanches (see Section 6.4.3).

Permafrost is discontinuous in this region and occurs under shallow and rocky soils (Nowacki et al., 2001).

6.2.1.3.1 Cook Inlet Basin Ecoregion

South of the Alaska Range, the Mainline follows the Susitna River drainage to Cook Inlet through the Cook Inlet Basin Ecoregion for nearly 180 miles. This gently sloping lowland was buried by ice and flooded by proglacial lakes several times during the Pleistocene, creating fine-textured lacustrine deposits ringed by coarse-textured glacial tills and outwash throughout the region (Nowacki et al., 2001). Underlying bedrock is composed of oil and gas-bearing continental deposits, including sandstone, siltstone, claystone, conglomerate, and coal beds (DGGS, 2011). The land is covered in numerous lakes, ponds, and wetlands, and permafrost is sporadic or isolated throughout the ecoregion.

6.2.1.4 Non-Jurisdictional Facilities

The PTU Expansion project facilities and PBU MGS project facilities would be located in the Beaufort Coastal Plain Ecoregion, described in Section 6.2.1.2.1.

The Kenai Spur Highway relocation project would be located in the Cook Inlet Basin Ecoregion, described in Sections 6.2.1.1.1 and 6.2.1.2.9.

6.2.2 Topography

Topography in the proposed Project area varies widely, from sea level at the Beaufort Coastal Plain Ecoregion, up through the high mountain peaks of the Brooks and Alaska ranges to sea level at the Cook Inlet crossing. Figure 6.2.2-1 shows the topography throughout the proposed Project area. Table 6.2.2-1 summarizes general elevation ranges, topography, and special features across the proposed Project area by ecoregion.

Topography that would be crossed by the Project varies from low coastal plains to high mountain passes. The following sections summarize topography anticipated in each ecoregion. Associated facilities would be similar because of their proximity to Project. Topographic data for each ecoregion is from USGS topographic maps through the National Geographic Society (2011).

TABLE 6.2.2-1

Topography in the Project Area (By Ecoregion)

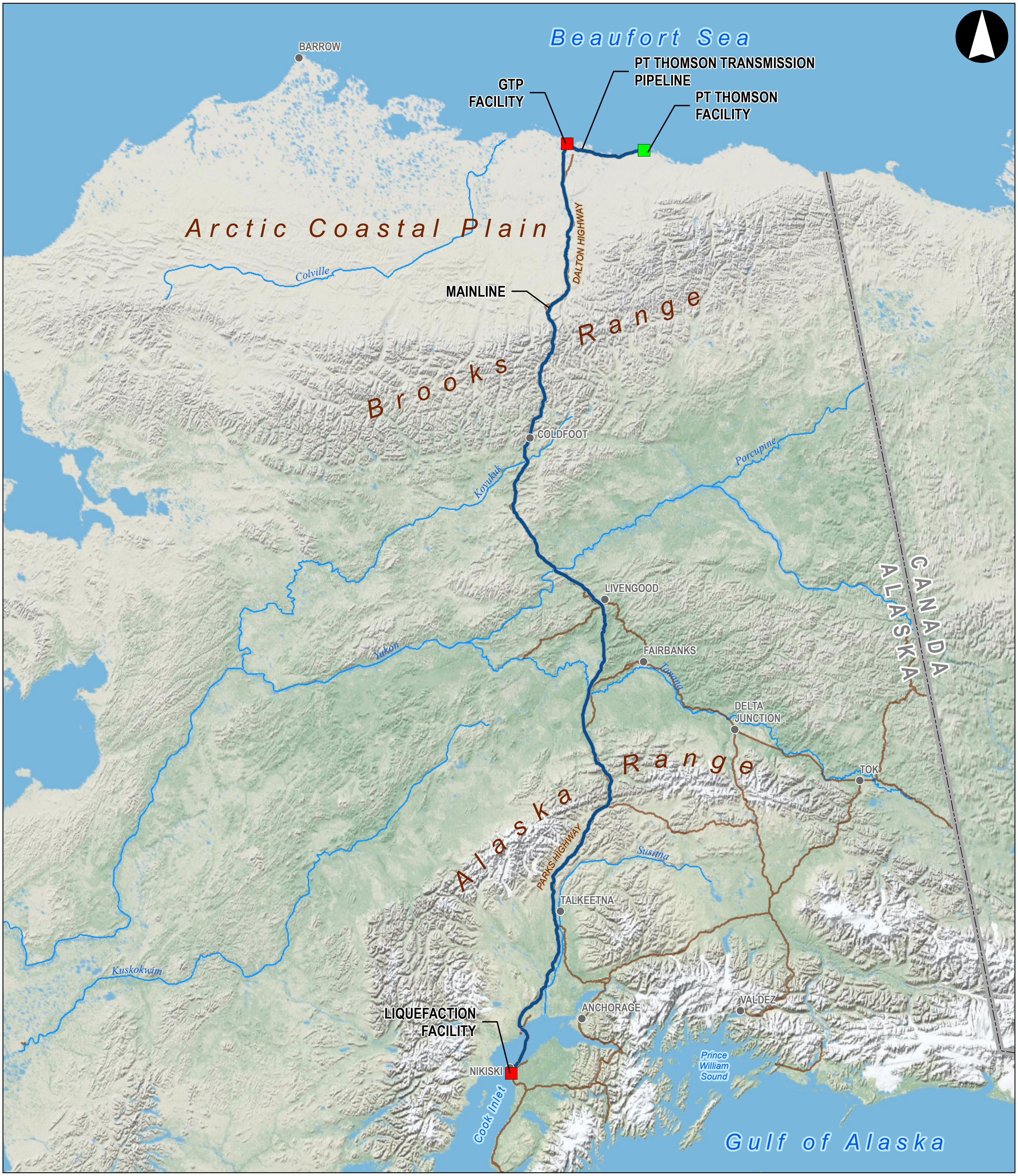
Project Facility	Approximate Milepost (MP)	Ecoregion	Average Elevation Range (feet)	Topography	Notable Features
LIQUEFACTION FACILITY					
LNG Plant	N/A	Cook Inlet Basin	100–200	Low relief	Cook Inlet
Marine Terminal	N/A	Cook Inlet Basin	0–200	Low relief	Cook Inlet
INTERDEPENDENT PROJECT FACILITIES					
Pipelines and Associated Infrastructure					
Mainline	0–60.82	Beaufort Coastal Plain	0–500	Low relief	Thermokarst formations; pingos, thaw lakes
	60.82–143.04	Brooks Range Foothills	500–2,700	Hills/Low Mountains	Ridges, valleys
	143.04-251.83	Brooks Range	600–4,700	Mountains	Rugged mountains
	251.83-256.68	Kobuk Ridges and Valleys	600–1,500	Undulating	Ridges, valleys
	257.2–430.2	Ray Mountains	600–2,000	Valley	Tolovana River valley and eastern ridgeline
	430.2–442.18; 462.52- 487.39	Tanana-Kuskokwim Lowlands	300–1,100	Valley	Tanana River valley
	442.18-460.76	Yukon-Tanana Uplands	300–700	Undulating Lowlands	Border between two ecoregions
	516.03-616.401	Alaska Range	Up to 2,700	Mountain Pass	George Parks Hwy and Nenana River valley
			Up to 3,800	Ridgeline	Reindeer Hills
			1,300–3,800	Valley	Chulitna River valley
	616.40-755.3	Cook Inlet Basin	0–1,100	Valley/Foothills	Chulitna River valley
	755.3-806.57	Cook Inlet Basin	0	Not Applicable Inlet	Not Applicable. Water
PTTL	0–62.5	Beaufort Coastal Plain	200–500	Low relief	Thermokarst formations; pingos, thaw lakes
PBTL	N/A	Beaufort Coastal Plain	200–500	Low relief	Thermokarst formations; pingos, thaw lakes
GTP					
GTP	N/A	Beaufort Coastal Plain	200–500	Low relief	Thermokarst formations; pingos, thaw lakes
GTP associated infrastructure					

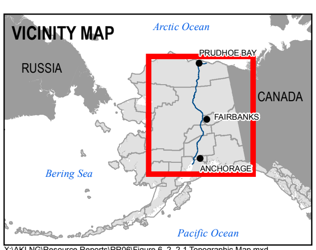
TABLE 6.2.2-1

Topography in the Project Area (By Ecoregion)

Project Facility	Approximate Milepost (MP)	Ecoregion	Average Elevation Range (feet)	Topography	Notable Features
Non-Jurisdictional Facilities					
PTU Expansion Project	N/A	Beaufort Coastal Plain	0-30 +	Low relief	Thermokarst formations; pingos, thaw lakes
PBU MGS	N/A	Beaufort Coastal Plain	200–500	Low relief	Thermokarst formations; pingos, thaw lakes
KSH Relocation	NA	Cook Inlet Basin	100–200	Low relief	Cook Inlet

Source: USGS topographic maps (National Geographic Society, 2011)





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LEGEND

- Project Facility
- Existing Facility
- Alaska Place Names
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers

0 25 50 100 150 Miles

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TOPOGRAPHIC MAP

FIGURE 6.2.2-1

ALASKA LNG

6.2.2.1 Liquefaction Facility

The Liquefaction Facility would be located in the Cook Inlet Basin Ecoregion. A brief description of the topography within this ecoregion is provided in the following sections.

6.2.2.1.1 Cook Inlet Basin Ecoregion

The Liquefaction Facility would be located along the northwestern shore of Kenai Peninsula. Relief is low in this area, which is dominated by wide, gently sloping plains of glacial outwash. Elevations range 100 to 200 feet above sea level.

6.2.2.2 Interdependent Project Facilities

A diverse geologic environment would be covered by the Interdependent Project Facilities. The topography is discussed in the following sections for the Mainline, GTP, PBTL, PTTL and the facilities associated with each.

6.2.2.2.1 Beaufort Coastal Plain Ecoregion

Topographic relief in the Beaufort Coastal Plain Ecoregion is very low. Elevations range from sea level at the coast to approximately 500 feet in the southern reaches, where the land rises toward the Brooks Range. The Mainline would slope upward to the south at a low gradient of approximately 10 feet per mile. Pingos, small ice-cored hills that result from ice growth, make up occasional modest topographic highs, rising just tens of feet from the flat plains. Streambanks carved into the lowlands represent the only other notable topography. Thermokarst formations such as polygonal tundra (discussed in Section 6.4.3 and in Resource Report No. 7) accounts for micro-topographic relief variations throughout this region. The most prominent topographical feature in the region is the intermittent coastal bluff, which reaches heights of more than 100 feet in some areas.

6.2.2.2.2 Brooks Range Foothills Ecoregion

The Mainline would enter the Brooks Range Foothills Ecoregion northwest of the confluence of the Ivishak and Sagavanirktok rivers. The northern plains gently slope upward along the Sagavanirktok River Valley south toward the Brooks Range Foothills. The Mainline would run south along the west bank of the Sagavanirktok River at approximately 1,500 feet. From there, the Mainline would steadily rise to an elevation of 2,700 feet above sea level near the north end of Galbraith Lake.

6.2.2.2.3 Brooks Range Ecoregion

Galbraith Lake marks the northern extension of the Brooks Range Ecoregion. Just south of the lake, the Project Mainline would cross the Atigun River at an elevation of 2,700 feet above sea level. The route would continue south along the eastern banks of the meandering Atigun River, maintaining an average elevation of 2,700 feet. The land would gradually rise to the south as the Mainline would approach the Continental Divide in Atigun Pass, crossing at an elevation of approximately 4,700 feet above sea level. The Mainline would then gradually descend south through the Brooks Range, passing along the Chandalar Shelf, and reaching an elevation of approximately 2,400 feet in the upper reaches of the Dietrich River

Valley. The Mainline would continue south along the Dietrich, quickly dropping in elevation. The route would begin to trend south/southwest near the upper reaches of the Middle Fork Koyukuk River Valley, at an elevation of 1,400 feet. The Mainline would maintain that approximate elevation as it would trend southwest along the eastern bank of the Middle Fork Koyukuk River, dropping elevation slightly south of the town of Wiseman. Near the southern reaches of the Brooks Range, the Mainline would pass to the west of the Cathedral Mountains and diverge from the Koyukuk as it would drop to a lower elevation, exiting the Brooks Range Ecoregion at an elevation of approximately 600 feet above sea level.

6.2.2.2.4 Kobuk Ridges and Valleys Ecoregion

After descending along the Brooks Range river valleys, the Mainline would head south through the Kobuk Ridges and Valleys Ecoregion for approximately 5 miles. The terrain in this ecoregion gently undulates between 600 and 1,000 feet. Elevations would increase as the route would approach the Ray Mountains to the south, rising to approximately 1,500 feet before exiting the Kobuk Ridges and Valleys Ecoregion.

6.2.2.2.5 Ray Mountains Ecoregion

As the Project Mainline would continue south through the Ray Mountains Ecoregion, elevations along the Mainline would increase. The Mainline would pass through a series of small valleys between 1,000 and 1,500 feet in elevation. The route would then drop to an elevation of approximately 800 feet to cross the South Fork of the Koyukuk River. From there, the Mainline would trend southwest, roughly paralleling the Jim River at approximately 1,200 feet, and passing east of the Kanuti Flats. The Mainline would turn south near Prospect Creek, passing through ridges and valleys between 1,000 and 2,000 feet.

Near the Fish Creek crossing, the Mainline would begin to trend southeast through rolling hills between 1,500 and 2,000 feet in elevation before crossing the Kanuti River at approximately 1,000 feet. The terrain would continue to undulate gently toward the southeast, with elevations ranging between 1,500 and 2,000 feet. Approaching the Yukon, the Mainline would gradually drop below 1,000 feet, finally crossing the Yukon River at approximately 300 feet. South of the Yukon River, the Mainline rises rapidly to approximately 1,000 feet in elevation, and would extend southeast through hills and valleys at 1,400 to 1,800 feet in elevation to the Cascaden Ridge. The Mainline would drop to 400 feet to cross the Tolovana River, then continue to the southeast. The route would trend south across undulating ridges between 1,200 and 1,700 feet in elevation, and then gently drop in elevation to the south as it would approach the Tanana-Kuskokwim Lowlands Ecoregion.

6.2.2.2.6 Tanana-Kuskokwim Lowlands Ecoregion (Northern Transect)

The Mainline would transect the Tanana-Kuskokwim Lowlands in two locations. The first, northern transect of the Yukon-Tanana Uplands Ecoregion would be a short 10-mile stretch along the Tatalina River Valley, averaging 300 feet in elevation. The second crossing is described separately in the following sections as the southern transect.

6.2.2.2.7 Yukon-Tanana Uplands Ecoregion

The Mainline would meander south for approximately 20 miles along the border between the Tanana-Kuskowim Lowlands to the west and the Yukon-Tanana Uplands Ecoregions. Elevations would range from 300 feet to just over 700 feet on the western flanks of the uplands.

6.2.2.2.8 Tanana-Kuskokwim Lowlands Ecoregion (Southern Transect)

After passing through the Yukon-Tanana Uplands, the Mainline would once again enter the Tanana-Kuksokwim Lowlands. Topography of the northerly crossing is described previously. The second, southern transect of the ecoregion would trend south above the banks of the Nenana River, at approximately 300 feet. Continuing south, elevations would gradually rise to approximately 1,200 feet as the Mainline would approach the Alaska Range.

6.2.2.2.9 Alaska Range Ecoregion

The Mainline would enter the Alaska Range Ecoregion along the western banks of the Nenana River at approximately 1,100 feet. The Mainline would follow the Nenana River Valley south through the northcentral Alaska Range between 1,000 and 2,000 feet in elevation. Elevations would reach approximately 3,200 feet as the Mainline would skirt the western flank of the Reindeer Hills. From the base of Reindeer Hills at 2,200 feet, the elevation would average 2,200 to 2,400 feet as the route would pass south along the eastern flanks of Broad Pass. There, the Mainline would drop to the eastern banks of the Chulitna River, and exit the Alaska Range Ecoregion at 1,100 feet in elevation.

6.2.2.2.10 Cook Inlet Basin Ecoregion

At the northern boundary of the Cook Inlet Basin Ecoregion along the Chulitna River, the Mainline would descend south from an elevation of approximately 1,100 feet near Little Coal Creek. Along the eastern banks of the Chulitna near Byers Lake, the elevation would drop to approximately 900 feet. The Mainline would then turn south and cross the Chulitna River at an elevation of 800 feet. The route would pass west of the confluence of the Chulitna and Susitna rivers, trending south at elevations between 400 and 500 feet. The Mainline would continue south/southwest along the western banks of the Susitna River, with elevations between 100 and 200 feet above sea level. Approaching Cook Inlet, the Project would cross the Yentna River at 100 feet in elevation, and then gently rise across the southern and eastern flanks of Mount Susitna to between 200 and 300 feet in elevation. The route would trend south-southeast and cross the Beluga River at nearly 100 feet in elevation. The Mainline would then run south, turning southeast along Three Mile Creek and maintaining an approximate 100- to 150-foot elevation as it would continue to the shores of Cook Inlet, north of Viapan Lake. The route would then head southeast, beneath the shallow waters of Cook Inlet (around 100 feet below sea level), and trend south-southwest to make landfall near Boulder Point in Nikishka Bay. The Mainline would then follow the eastern shore of Nikishka Bay at an elevation of 100 to 200 feet to just south of Bernice Lake at the Liquefaction Facility.

6.2.2.3 Non-Jurisdictional Facilities

The PTU Gas Expansion facilities and PBU MGS project facilities would be located in the Beaufort Coastal Plain Ecoregion near the coast. Elevation through this portion of the Beaufort Coastal Plain Ecoregion is generally low-lying and is typically less than 20 feet above sea level near the coast. Where facilities would be susceptible to potential impact from storm surge, erosion protection would be used.

The Kenai Spur Highway relocation project would be located on the northwestern shore of Kenai Peninsula. Relief is low in this area, which is dominated by wide, gently sloping plains of glacial outwash. Elevations range from 100 to 200 feet above sea level.

6.2.3 Surface and Bedrock Geology

A diverse geologic environment would be crossed by the Project. The following sections discuss surficial and bedrock geology anticipated within the Project area for the Liquefaction Facility as well as all Interdependent Project Facilities and their associated facilities.

Lands south of the Brooks Range in Alaska have been created by the accretion of composite terranes. Based on inferred lithotectonic settings and tectonic evolution, the terranes are understood to have been accreted from the north to the south (Plafker and Berg, 1994), i.e., with the oldest accreted terrane being in the north and youngest to the south. As a result of the diverse lithologies and histories of these terranes, bedrock geology of the Project area is highly variable, notably over the approximately 807-mile stretch of the Mainline. An overview of surficial geology anticipated for each ecoregion is summarized in Table 6.2.3-1 (DGGS, 2011).

TABLE 6.2.3-1

Summary of Surficial Geology by Ecoregion Anticipated in the Project Area

Ecoregion	Anticipated Surficial Geology
Beaufort Coastal Plain	Glaciofluvial, alluvium
Brooks Range Foothills	Sedimentary rock, loess, glacial deposits
Brooks Range	Metasedimentary, metaigneous and ultramafic rocks; colluvium
Kobuk Ridges and Valleys	Metasedimentary, metaigneous and ultramafic rocks
Ray Mountains	Metasedimentary to sedimentary, metaigneous, volcanic (intrusive) and ultramafic rocks; colluvium
Tanana-Kuskokwim Lowlands	Colluvium
Yukon-Tanana Uplands	Metamorphic rocks, colluvium
Tanana-Kuskokwim Lowlands	Colluvium
Alaska Range	Intrusive, metamorphic, and volcanic rocks; glacial and glaciofluvial deposits; coal-bearing, fluvial sedimentary rocks along north side of range
Cook Inlet Basin	Glacial deposits and outwash

Source: DGGS, 2013.

6.2.3.1 Liquefaction Facility

6.2.3.1.1 Cook Inlet Basin Ecoregion

Tertiary sedimentary rocks in Cook Inlet basin unconformable overlie Mesozoic sedimentary rocks throughout most of the basin (Haeussler et al., 2000). In relatively small areas within the basin and, locally along the basin margins, Tertiary strata nonconformably overlie igneous and metamorphosed igneous rocks (Hartman et al., 1972; Haeussler et al., 2000). The Tertiary basin fill and overlying Quaternary deposits, known as the Kenai Group, have a combined thickness of over 20,000 feet (Hartman et al., 1972; Shellenbaum et al., 2010). Formations include (from older to younger) the West Foreland Formation, Hemlock conglomerate, Tyonek Formation, Beluga Formation, and Sterling Formation (Hartman et al., 1972). The Sterling Formation alone is up to 11,000 feet thick in the East Foreland area (Calderwood and Fackler, 1972), so the combined thickness of Sterling plus overlying Quaternary sediments is greater than 10,000 feet. The formations and sediments are glacial and alluvial materials sourced from the Alaska and Chugach ranges and consist of massive sandstones, conglomeratic sandstones, siltstones, coal seams, and interbedded claystones (Hartman et al., 1974; Calderwood and Fackler, 1972). Near-surface deposits of Quaternary age consist of glaciofluvial materials. These deposits consist of Pleistocene glacial till and glacially derived fluvial, deltaic, and subestuarine deposits, with a veneer of Holocene eolian, lacustrine, and fluvial deposits. Based on deep seismic reflection data collected in 2015, the Quaternary deposits within the onshore site area range from 200 to 800 feet in thickness, and overlie a generally planar unconformity eroded into gently folded strata of the Pliocene Sterling Formation.

6.2.3.2 Interdependent Project Facilities

6.2.3.2.1 Beaufort Coastal Plain Ecoregion

The GTP Facility, PTTL, PBTL, and the northern-most segment of the Mainline are located in the Beaufort Coastal Plain Ecoregion area. Shallow bedrock in the ecoregion is composed of poorly consolidated Tertiary, non-marine, and shallow marine deposits of mudstone, siltstone, sandstone, and conglomerate (Mull, 1989). The Sagavanirktok Formation is particularly prominent in upper bedrock (upper 1,000 feet), which consists of poorly consolidated conglomerate, sandstone, siltstone, and lignitic coal. These distinct layers are well-exposed along of the east side of the Sagavanirktok River near Franklin Bluffs.

Depth to bedrock varies throughout the Beaufort Coastal Plain from just a few feet to several hundred feet. Quaternary to Late Pleistocene sediments of the Gubik Formation mask much of the bedrock in this area. These unconsolidated sediments include glaciofluvial deposits, braided stream alluvium, peat, deltaic sediments, shallow marine fine sand, silt, clay, and ice-rafted boulders (Osterkamp and Harrison, 1976). Mollusk Shells present within the sedimentary cover also provide evidence for at least six Cenozoic marine transgressions, with two additional marine transgressions identified in deposits of the Gubik Formation (Rawlinson, 1990).

6.2.3.2.2 Brooks Range Foothills Ecoregion

Bedrock in the Brooks Range Foothills Ecoregion predominantly consists of Lower and Upper Cretaceous sedimentary rocks including, from oldest to youngest, the Okpikruak, Kongakut, Fortress Mountain, Torok, Nanushuk, Seabee, Tuluvak, Canning, Schrader Bluff, Prince Creek, and Sagavanirktok Formations. The Okpikruak, Kongakut, lower part of the Fortress Mountain, Torok, lower part of the Seabee, and Canning Formations include sandstones and shales deposited in deep marine environments. The upper part of the Fortress Mountain, Nanushuk, upper part of the Seabee, Tuluvak, Schrader Bluff, Prince Creek, and Sagavanirktok Formations were deposited in fluvial, deltaic, and shallow marine environments and include conglomerates, sandstones, siltstone, shales, and coals. (Mull, 1989).

Bedrock outcrops are generally exposed at the surface in moderate to high elevations of the Brooks Range Foothills Ecoregion. Shallow bedrock is present throughout much of the region. Quaternary deposits of alluvium, colluvium, glacial moraine, and outwash of varied thickness are concentrated in lower elevations and along major drainages (Mull, 1989).

6.2.3.2.3 Brooks Range Ecoregion

The Mainline roughly parallels the Dalton Highway south through the Brooks Range Ecoregion. Bedrock exposed along this route is composed of Mesozoic, Paleozoic, and possibly some Precambrian-aged sedimentary, metasedimentary, and metaigneous rocks (Mull, 1989).

Portions of the route in the northern Brooks Range Ecoregion intersect Lower Cretaceous to Upper Devonian shallow marine and deltaic deposits (Mull, 1989;), including:

- Shallow marine shale and silty limestone of the Echooka Formation (Permian);
- Shallow marine shale and limestone of the Otuk Formation (Triassic and Jurassic);
- Localized shallow marine coquinoid limestone (Lower Cretaceous);
- Shallow marine carbonate rocks of the Lisburne Group (Lower Pennsylvanian and Mississippian);
- Shallow marine Kayak Shale (Mississippian);
- Deltaic complex with conglomerate, sandstone, siltstone and shale of the Kanayut Conglomerate (Lower Mississippian and Upper Devonian); and
- Prodelta Hunt Fork Shale (Upper Devonian).

Farther south in the range, Proterozoic to Paleozoic metamorphic rocks dominate, with minor granitic intrusions. The metamorphic rocks and granitic intrusions in this area are known to be mineralized with gold, silver, antimony, and arsenic. Placer gold deposits are present in and along the southern flank of the Brooks Range. The south flank of the Brooks Range is underlain by Paleozoic to Mesozoic cherts, phyllites, greenstone, and mafic and ultramafic intrusions of the Angayucham terrane. Rocks of the southern Brooks Range include:

- Limestone and other shallow marine carbonate-platform rocks of the Baird Group (Devonian to Cambrian);
- Quartz-mica schist and associated metasedimentary and metavolcanic rocks, such as Anira and Mauneluk Schists (Middle to Lower Paleozoic);
- Turbidite deposits with phyllite and greywacke, including Beaver Creek Schist (Middle Paleozoic); and

- Calc-schist, marble, quartzite, phyllite, and greenstone, such as the Kogoluktuk Schist.

Granitic intrusive bodies (Devonian) as well as volcanic rocks (Lower Paleozoic) such as basalt, andesite, tuff and agglomerate also occur in the southern portion of the Brooks Range Ecoregion.

Bedrock is exposed at the surface in much of the moderate to high elevations throughout the Brooks Range. Valley bottoms are buried by thick colluvium and floodplain deposits. High elevation valleys in the range also contain avalanche and slushflow deposits (see mass wasting discussion in Section 6.4.3).

6.2.3.2.4 Kobuk Ridges and Valleys Ecoregion

The Mainline briefly passes through the eastern-most extension of the Kobuk Ridges and Valleys Ecoregion, transecting roughly 5 miles of the ecoregion around Chapman Creek. This ecoregion is dominated by a series of parallel ridges and valleys along high-angle reverse faults that radiate south from the Brooks Range (see the Brooks Range Ecoregion Section). Much of the area was carved by glacial ice descending from the north, which left behind U-shaped valleys that now host large rivers (Nowacki et al., 2001).

Bedrock within a half-mile of the Mainline is predominantly Upper to Lower Cretaceous age, including continental deposits of shale and siltstone in the north, and graywacke, sandstones, shale, siltstone and conglomerate to the south (DGGS, 2011). Bedrock outcrops along most moderate to high ridges and peaks, while thick accumulations of alluvial and glacial sediment have been deposited throughout lowland areas.

6.2.3.2.5 Ray Mountains Ecoregion

The Ray Mountains Ecoregion transect is the longest within the Mainline, extending nearly 170 miles. Bedrock throughout the Ray Mountains is highly diverse. North of the Yukon River, the Mainline includes (Till, 2006):

- Oceanic plateau and island arc rocks of the Angayucham terrane;
- Schist, quartzite, orthogneiss, and metamorphic rocks of the Ruby terrane; and
- Granites of the Ruby Batholith.

South of the Yukon River, the Project crosses several fault-bounded terranes that include Paleozoic-Mesozoic sedimentary and mafic rocks of the Rampart-Tozitna terrane, Paleozoic sedimentary and volcanic rocks of the Livengood terrane, and Cretaceous sedimentary rocks of the Wilbur Creek terrane. These rocks are cut by Middle and Late Cretaceous-aged intrusions in the vicinity of Livengood to the north and south of the Tolovana River. Paleogene volcanic and intrusive rocks overlie and intrude the older rocks on the northern edge of the region, and along the Yukon River (DGGS, 2011).

The Ray Mountains were locally glaciated during the Pleistocene, and are presently unglaciated and covered with colluvial and eolian deposits. Windblown silt, or loess, remobilized from the floodplains of glacier-fed rivers is a common feature of many lowland areas.

6.2.3.2.6 Tanana-Kuskokwim Lowlands Ecoregion (Northern Transect)

The route passes through the Tanana-Kuskokwim Lowlands Ecoregion twice to the north and south of the Yukon-Tanana Uplands Ecoregion (see Figure 6.2.1-1). The northern transect of the Ecoregion is described here, and the southern transect is included in the following sections.

Bedrock in the northern transect of the Tanana-Kuskokwim Lowlands is buried by a thick layer of Quaternary soils and, therefore, is not well constrained. Shallow bedrock in this transect likely includes metasedimentary conglomerate-mudstone, arenite, chert, and quartzite of the Wickersham unit (Cambrian to Proterozoic), which is exposed in the Ray Mountains to the northwest. Alkali basalt, agglomerate, and volcanoclastic conglomerate of the Fossil Creek Volcanics (Ordovician) are also likely present at depth, as these units occur in the Ray Mountains Ecoregion to the northwest (Wilson et al., 1998). The Fairbanks Schist (Proterozoic), which is composed of nearly 90 percent quartzite and quartz muscovite schist, may also project under the thick Quaternary-Tertiary cover in the southern Minto Flats and the Nenana basin (Newberry et al., 1996).

6.2.3.2.7 Yukon-Tanana Uplands Ecoregion

Bedrock in the Yukon-Tanana Uplands Ecoregion is composed of felsic schist, micaceous quartzite, chloritic to actinolitic greenschist, greenstone, and marble of the Fairbanks Schist unit (Proterozoic), as well as allochthonous garnet-bearing quartz-biotite-muscovite schist and quartzite (Wilson et al., 1998). Bedrock outcrops at the surface in moderate to high elevations throughout this short segment of the proposed Mainline.

6.2.3.2.8 Tanana-Kuskokwim Lowlands Ecoregion (Southern Transect)

The southern transect the Tanana-Kuskokwim Lowlands Ecoregion is described here (see Figure 6.2.1-1).

Bedrock mapped in the southern transect of the Tanana-Kuskokwim Lowlands Ecoregion includes conglomerate, mudstone, claystone, lignite, nenana gravel, and sandstone of the Usibelli Group (Tertiary). Angular unconformities separate these rocks from older metavolcanic and metavolcaniclastic rocks (Phanerozoic) and locally younger, possibly coal-bearing sedimentary rocks. These units are further folded and juxtaposed by the Alaska Range foothills fold and thrust belt (Wilson et al., 1998).

6.2.3.2.9 Alaska Range Ecoregion

Diverse outcrops of bedrock are exposed at or near the surface through much of the Alaska Range. Bedrock diversity in this region is the result of multiple accreted terranes that trend southwest-northeast along the proposed Mainline (Wilson et al., 1998; Wilson et al., 2012). Rugged mountains and hills are separated by lowlands of moraines and outwash from Pleistocene glaciation.

In the northern portion of the Alaska Range Ecoregion, the Mainline intersects abundant non-indurated sandstone, gravel, and cobbles of the Nenana Gravel (Miocene to Pliocene). Conglomerate, mudstone, claystone, coal, lignite, and sandstone of the Usibelli Group (Tertiary), the main coal-bearing unit of the Nenana Basin, are also abundant (Wahrhaftig, 1987). Possible coal-bearing components of the Nenana Gravel have been mapped across the Nenana River, and may outcrop among colluvium deposits in lower elevations or along low ridges where present along the Mainline, especially along the Healy fault near Dry Creek and Otto Lake. The Usibelli Group unconformably overlies metavolcanic, metavolcaniclastic, and metasedimentary rocks (Proterozoic to Paleozoic), which are partially concealed by the younger rocks in the foothills of the Alaska Range.

The Park Road fault (at the intersection of the Denali Park Road and George Parks Highway) separates pelitic and quartzose schist and phyllite of the Alaska Range unit to the north (Devonian to Paleozoic) from the Cantwell Formation to the south (Late Cretaceous). The Cantwell Formation outcrops along Mount Fellows. The upper level of this formation consists of volcanic rocks (rhyolite, dacite, andesite and felsic volcanics), while the lower portion of this formation consists of sedimentary units (conglomerate, shale, sandstone, coal, arkose, siltstone, and argillite) (Csejtey, 1992). Rocks of the Cantwell Formation area include intermittent outcrops of schist, quartzite, and amphibolite (Triassic) throughout, along with traces of the Yanert Fork sequence (Late Devonian), which is a thick marine sequence of metasedimentary and metavolcanic rocks in the Yanert River valley (Csejtey, 1992).

The Mainline crosses the Denali fault, where the Nenana River trends east, and climbs along the western edge of the Reindeer Hills. Here, the route intersects more Cantwell Formation (continued from the north), interspersed with mélange and limestone blocks north of the Denali fault. Immediately south and along the western flanks of the Reindeer Hills, the Project intersects flysch and hypabyssal felsic to intermediate intrusions (Paleocene to Miocene). The Reindeer Hills are dominantly composed of Nikolai flood basalts, which outcrop along the western edge of the George Parks Highway and the Mainline, terminating at the toe of Eldridge Glacier.

South of Eldridge Glacier, the Mainline passes through Quaternary colluvium along the eastern edge of Broad Pass and the Chulitna River, outside the boundary of Denali National Park and Preserve. The Mainline may intersect localized occurrences of highly metamorphosed flysch-like turbidites in northern portions of the pass. The route may also intersect sporadic outcrops of younger peralkaline granitic intrusions throughout this area (DGGS, 2011).

6.2.3.2.10 Cook Inlet Basin Ecoregion

A discussion of surface and bedrock geology in the Cook Inlet Basin is provided in Section 6.2.3.1.1.

6.2.3.3 Non-Jurisdictional Facilities

The PTU Expansion project facilities and PBU MGS project facilities are found in the Beaufort Coastal Plain Ecoregion near the coast with Prudhoe Bay. A description of the underlying geology of the GTP is previously described under Interdependent Project Facilities.

The Kenai Spur Highway relocation project would be found in the Cook Inlet Basin Ecoregion. A description of the underlying geology is described in Section 6.2.3.1.1.

6.3 MINERAL RESOURCE DEVELOPMENT AND MINING OPERATIONS

The Project area would either cross or be adjacent to a variety of exploitable and potentially exploitable mineral resources, including industrial (sand/gravel, rock, dimension stone), metallic (gold, silver, lead, zinc), and energy minerals (oil and gas, coal, peat). Mineral resources within at least 0.5 mile of the Project have been identified using USGS topographic maps, recent aerial photography, and available federal and state databases (ADNR, 2014, 2015; ARDF, 2015; Alaska State Geo-spatial Data Clearinghouse [ASGDC], 2015; and Bureau of Land Management Mineral Assessments [BLM], 2015). Additionally, potential industrial resource locations were identified using a combination of Google Earth imagery, USGS topographic maps, and video footage shot along the Mainline in 2014.

The following sections detail where these resources are located relative to the proposed Project area and the mitigation measures that would reduce potential impacts on metals, industrial minerals, and energy resources.

6.3.1 Non- Energy Mineral Resources

Alaska is considered one of the top three regions of the world for non-energy mineral potential, with a 2014 industry value estimated to be approximately $3.28 billion (ADNR, 2015). Exploration expenditures alone were $96 million in 2014, with 42 significant exploration projects taking place across the seven mining regions (Alaska Resource Development Council [RDC], 2015). These projects include exploration of base metals, polymetallic resources, precious metals, and industrial minerals. The proposed Project footprint overlies or is adjacent to several areas of known or potential mineral deposits (ADNR, 2015), including:

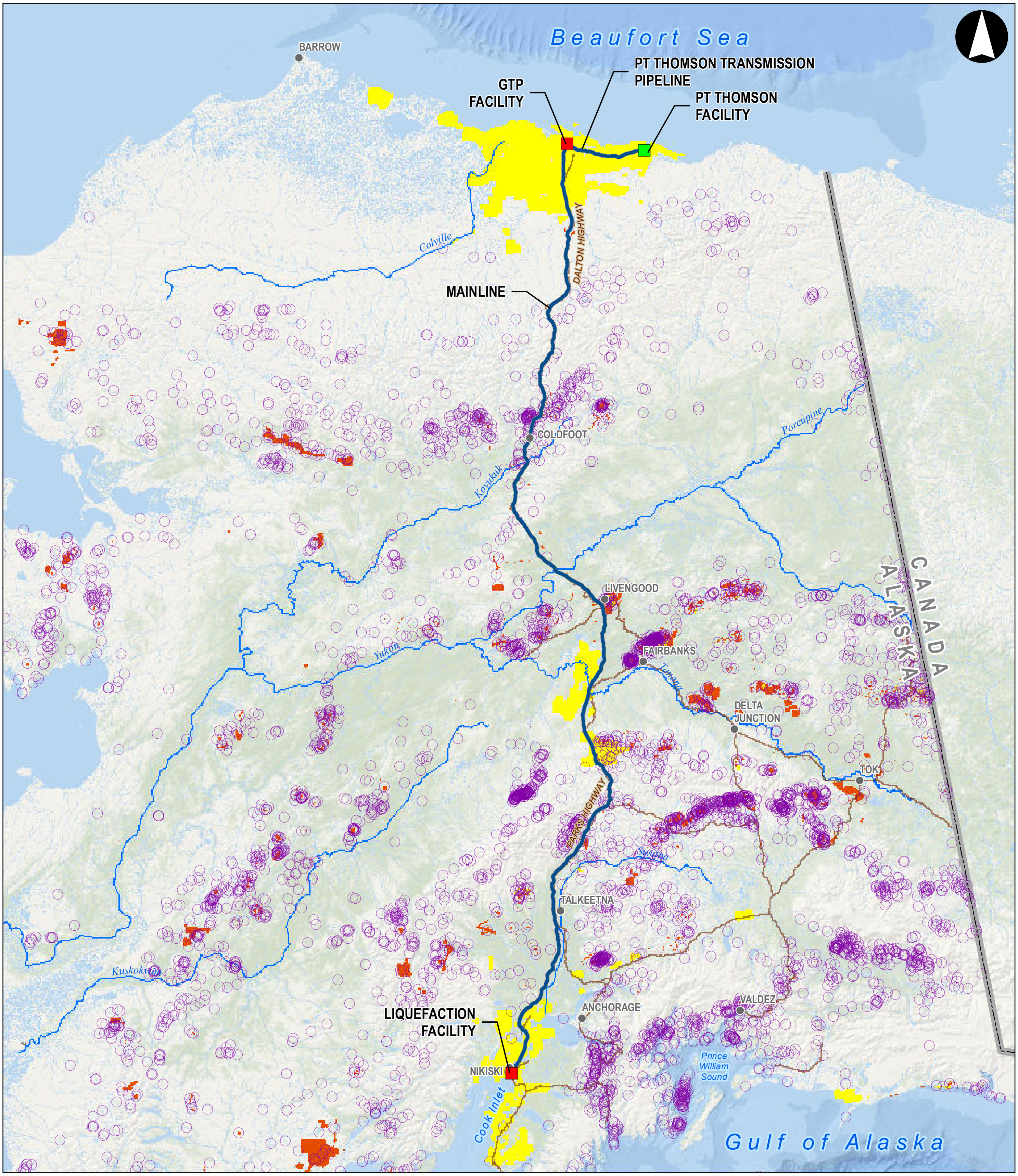
- Antimony;
- Chalcopyrite;
- Diatomaceous earth;
- Gold;
- Materials (limestone, gravel, sand, peat, and slate);
- Manganese;
- Molybdenite;
- Silver;
- Chromite;
- Tin;
- Rare-earth elements
- Sulfides (copper, nickel); and
- Titanium.

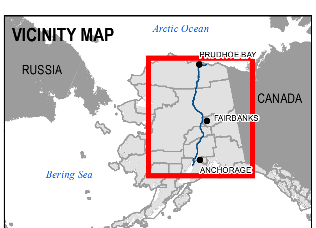
The Project area would cross four of Alaska's mining regions—the Northern, Eastern Interior, Southwestern, and Alaska Peninsula regions. Within these regions, there are no significant exploration projects currently underway, and the only major non-energy mineral production site in the vicinity of the proposed Project area is the open pit Kinross Fort Knox Gold Mine. The closest proposed Project feature to this site is the Mainline, which would be approximately 38 miles from Kinross Fort Knox Gold Mine.

The ADNR Division of Mining, Land, & Water manages the mineral exploration, development and leasing programs on nearly 92 percent of the 91 million acres of state lands. Available ADNR and USGS databases were reviewed to identify active or closed mining operations or claims within 0.5 mile of the proposed Project area. The results of this investigation are summarized in Appendix A, Tables 3 and 4, and depicted in Figure 6.3.1-1.

6.3.1.1 Liquefaction Facility

Only five (5) active mining claims registered under ADNR were identified within 0.5 mile of the proposed Liquefaction Facility. Additionally, 16 material sales sites are mapped within 0.5 mile of the Liquefaction Facility. No active mines were identified within 0.5 mile of the proposed Liquefaction Facility.





LEGEND

- Project Facility
- Existing Facility
- Alaska Place Names
- Mine Sites - USGS
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers
- Mine Leases - ADNR
- Mine Claims - ADNR

0 35 70 140 Miles

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MINERAL RESOURCES ALONG THE PROJECT FOOTPRINT

FIGURE 6.3.1-1

ALASKA LNG

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6.3.1.2 Interdependent Project Facilities

A total of 373 mineral resource sites, 158 ADNR mineral claims, 202 ADNR Mineral leases, and 14 USGS occurrences were identified within 0.5 mile of the proposed Mainline and associated facilities. The majority of these sites are on state-managed land, associated with gold deposits (Appendix A, Table 3). The proposed footprint of the Mainline pipeline and associated facilities would cross 158 ADNR mineral claims, of which all are active.

No ADNR mineral claims or USGS occurrences were identified within 0.5 mile of the proposed PBTL. PTTL (although 60 ADNR Mineral leases were identified within 0.5 mile of the PTTL) GTP, or associated facilities.

A total of 290 material sites were identified within 0.5 mile of the proposed Mainline and associated facilities (Appendix A, Table 4).

6.3.1.3 Non-Jurisdictional Facilities

A total of eight active mining claims and one mineral lease was identified within 0.5 mile of the Kenai Spur Highway relocation project. Additional mineral leases were identified within 0.5 mile of the PTU Expansion project facilities (8), and the PBU MGS project facilities (35).

A total of 30 material sites within 0.5 mile of the Non-jurisdictional facilities were identified, including 27 within 0.5 miles of the Kenai Spur Highway relocation project and one near the PTU Expansion project facilities, and two near the PBU MGS project facilities.

6.3.2 Oil and Natural Gas Resources

Over the last 40 years, the state of Alaska's oil and gas industry has produced more than 18 billion barrels of oil and 16 trillion cubic feet of natural gas (Alaska Oil and Gas Conservation Commission [AOGCC], 2016). The Project would traverse several large oil and gas lease sale tracts throughout Cook Inlet and the Beaufort Coastal Plain Ecoregion, including Prudhoe Bay—the largest oilfield in North America (AOGCC, 2013). During its peak in 1987, Prudhoe Bay oil production totaled 1,627,036 barrels per day.

The ADNR has designated five areas of the state for annual area-wide oil and gas lease sales due to moderate to high potential for energy development (ADNR, 2015). The Project would traverse four of the five designated areas:

- Beaufort Sea;
- North Slope;
- North Slope Foothills; and
- Cook Inlet.

A summary of the lease sale statistics for the four lease sale areas that would be crossed by the Project and Non-Jurisdictional Facilities are provided in Table 6.3.2-1 and 6.3.2-2 (ADNR, 2014). Figure 6.3.2-1 depicts the oil and gas lease sale areas along the proposed Project footprint.

TABLE 6.3.2-1

Area-Wide Lease Sale Tracts for the Four Areas Crossed by the Project (ADNR, 2014)

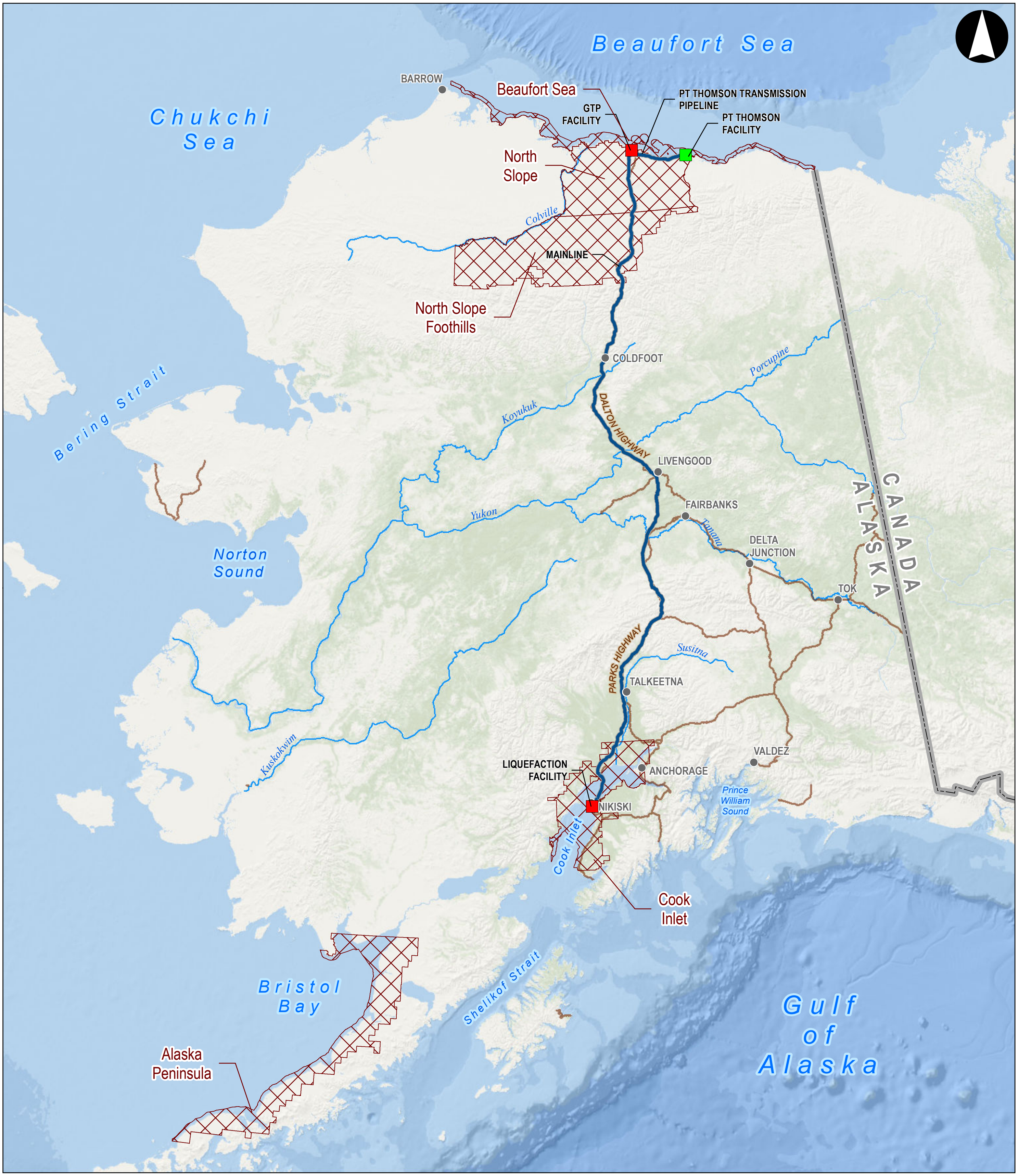
Facility	**Total Acreage of Facility Group**	**Active Lease Boundary Impacts (acres)**	**Statewide Area-wide Sale Tract Impacts by Area-wide Code (acres)**				
			Beaufort Sea	**Cook Inlet**	**North Slope Foothills**	**North Slope**	**Grand Total**
Liquefaction Facility	1,065.14	0.0	0.0	1,065.14	0.0	0.0	*1,065.14*
Mainline	12,508.87	1,453.80	24.91	966.20	1,204.45	1,693.24	3,888.80
Mainline ROW**	50,620.52	32,855.02	-	39,033.30	1,308.45	1,931.50	42,273.24
PBTL	7.31	7.31	3.93	-	-	3.38	7.31
PTTL*	349.82	342.47	63.20	-	-	286.62	349.82
PTTL ROW**	1,726.62	1,617.54	457.96	-	-	1,268.66	1,726.62
GTP	925.95	925.95	123.41	-	-	802.54	925.95
Grand Total	**67,204.33**	**37,202.09**	**673.41**	**41,064.63**	**2,512.90**	**5,985.94**	**50,236.88**

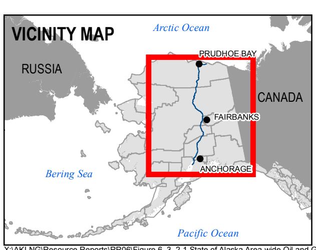
* Includes all facilities except for permanent/temporary ROW easements
** Includes all facilities permanent/temporary ROW easements

TABLE 6.3.2-2

Area-Wide Lease Sale Tracts for the Four Areas Crossed by Non-Jurisdictional Facilities (ADNR, 2014)

Facility	**Total Acreage of Facility Group**	**Active Lease Boundary Impacts (acres)**	**Statewide Area-wide Sale Tract Impacts by Area-wide Code (acres)**				
			Beaufort Sea	**Cook Inlet**	**North Slope Foothills**	**North Slope**	**Grand Total**
KSH	949.47	-	-	949.47	-	-	949.47
PBU	513.59	513.59	121.34	-	-	392.24	513.59
PTU	135.94	135.94	83.39	-	-	52.55	135.94
Grand Total	**1,598.99**	**649.53**	**204.73**	**949.47**	**-**	**444.79**	**1,598.99**





LEGEND

- Project Facility
- Existing Facility
- Alaska Place Names
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers
- Area Wide Sale Boundary

0 50 100 200 Miles

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STATE OF ALASKA AREA-WIDE OIL AND GAS LEASE SALE AREAS

FIGURE 6.3.2-1

ALASKA LNG

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The AOGCC and ADNR databases were reviewed to identify oil and gas resources (wells, active leases, and potentially leased areas) within 0.5 mile of the proposed Project area (ADNR, 2014; AOGCC, 2012). The results of these investigations are summarized in Appendix A, Table 5.

6.3.2.1 Liquefaction Facility

No actively leased areas or known oil or gas wells are within the proposed footprint of the Liquefaction Facility.

6.3.2.2 Interdependent Project Facilities

The proposed Project footprint for the Interdependent Project Facilities would cross a significant area of leased land covered by the area-wide leasing, some actively leased areas, and a several known oil or gas wells (Appendix A, Table 5).

6.3.2.3 Non-Jurisdictional Facilities

The PTU Expansion project facilities and PBU MGS project facilities would be built in North Slope oil and gas fields and within the boundaries of multiple active, state-approved oil and gas units and leases. The PBU MGS project would enable commercialization of approximately 23–26 trillion cubic feet of natural gas located in the Prudhoe Bay field. Prudhoe Bay is the largest oil field in Alaska and is surrounded by numerous other oil and gas units at various stages of exploration and development.

The PTU Gas Expansion project would enable commercialization of the natural gas resources in the Thomson Sand reservoir, which is estimated to contain approximately 8 trillion cubic feet of natural gas plus associated condensate resources. Point Thomson is the easternmost discovered major hydrocarbon reservoir in the Beaufort Coastal Plain Ecoregion, and is approximately 22 miles east of the Badami development, which is the closest oil and gas development. Point Thomson is located west of the Arctic National Wildlife Refuge 1002 Area, which was designated/recognized as an area with significant hydrocarbon potential.

On the Kenai Peninsula, the Kenai Spur Highway relocation project would not cross any actively leased areas or known oil or gas wells within the proposed Project footprint.

6.3.3 Coal Resources

Alaska coal resources are largely located in three major regions—the Alaska North Slope, Nenana Valley of Central Alaska, and Cook Inlet in southern Alaska—all which are within the proposed Project area. The combined coal resources in these regions are estimated to be 5,012 billion metric tons, which constitutes approximately 87 percent of Alaska's coal reserves and surpasses the total coal resources of the contiguous United States by 40 percent (McDowell, 2015).

Despite its enormous coal reserves, Alaska has only one active mine, the Usibelli Mine at Healy (Alaska Public Lands Information Centers [AKPLIC], 2015), which is located more than 5 miles away from the Project area.

While coal production in Alaska may not be viewed as a primary pursuit, there are several coal resources within 0.5 mile of the Project area that may present an opportunity for future development shown in Figure 6.3.3-1 and summarized in Appendix A, Table 6.

6.3.3.1 Liquefaction Facility

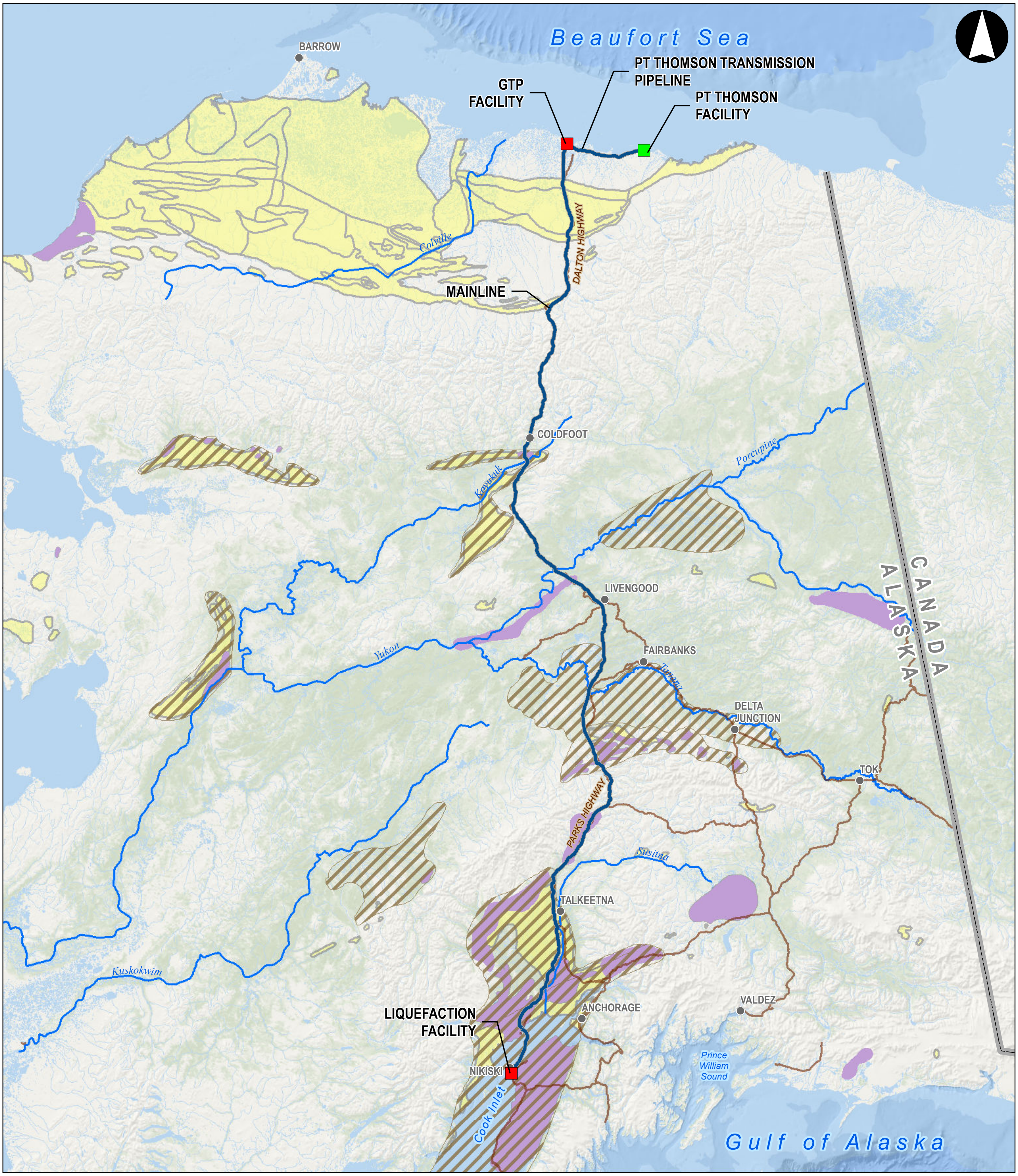
There are no active coal mines within 0.5 mile of the proposed footprint of the Liquefaction Facility.

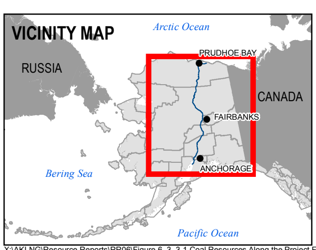
6.3.3.2 Interdependent Project Facilities

There are no active coal mines within 0.5 mile of the proposed footprint of the Mainline, PTTL, PBTL, and GTP facilities.

6.3.3.3 Non-Jurisdictional Facilities

There are no active coal mines within 0.5 mile of the proposed PTU Expansion, PBU MGS project, or the proposed Kenai Spur Highway relocation project. See Figure 6.3.3-1 for coal resources that are located proximate to the proposed Project.





X:\AKLNG\Resource Reports\RR06\Figure 6_3_3-1 Coal Resources Along the Project Footprint.mxd

LEGEND

- Project Facility
- Existing Facility
- Alaska Place Names
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers
- Coal Basins - ADGGS
- Coal Fields - ADGGS
- Coal Units - ADGGS

0 35 70 140 Miles

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COAL RESOURCES ALONG THE PROJECT FOOTPRINT

FIGURE 6.3.3-1

ALASKA LNG

6.3.4 Industrial Material Resources

The proposed Project area contains many potential material resources, including borrow sites for sand, gravel, and rock. A number of existing permitted aggregate mines as granular material sources would be planned to be used to the greatest extent practicable. However, because of the remoteness of many locations, new borrow sources would need to be developed. The *Gravel Sourcing and Reclamation Measures Plan* in Appendix F provides a listing of the potential new and existing material sites that are being explored for Project use. Potential industrial material resource sites within 35 miles of the proposed Mainline are also summarized in Appendix F. The purpose of this *Gravel Sourcing and Reclamation Measures Plan* is to provide an overview of the material needs, potential sources to meet those material needs, general extraction/transportation protocols, and reclamation methods for the extraction sites.

6.3.4.1 Liquefaction Facility

After clearing and grubbing, the Liquefaction facility would require approximately 4.7 million cubic yards of granular material for fill. The gravel, rock, and other aggregate imported for construction of the Liquefaction Facility would be sourced from local quarries where practical. Interdependent Project Facilities

6.3.4.2 Interdependent Project Facilities

The estimated need for granular material is approximately 9 million cubic yards for the work pad and an additional 1.95 million cubic yards for bedding and padding of the pipe. Minor amounts would also be needed for weight bags, as fill to protect the ditch and workspace areas, and for slope stabilization, all estimated at approximately 0.56 million cubic yards. Material sites would be developed along the Mainline ROW, particularly at hilltops, to provide work pad material within the valleys, as practicable.

Granular material for the PTTL would be needed for construction of new granular material pads for three Mainline block valves, however the construction camps and pipe storage yards would be located on existing sites or ice pads.

Approximately 6.9 million cubic yards of material would be required for the construction of GTP features including: Dock Head 4, the GTP Facility Pad, the Integrated Construction and Operations Camp Pad, access roads, upgrades along the West Dock causeway, and other supporting infrastructure. Granular material requirements for construction of the PBTL are anticipated to be minimal and are accounted for in the granular material requirements described for the GTP.

The PTTL, PBTL and GTP facilities' primary source of material for construction would be a new mine (quarry) site located southwest of the GTP site and just north of the Putuligayuk River.

6.3.4.3 Non-Jurisdictional Facilities

The Point Thomson Gas Expansion, PBU MGS projects, and the Kenai Spur Highway relocation project would determine the sources of their granular materials at a later date. The PTU Expansion Project would develop and rehabilitate a new granular mine site to provide the approximately 1–2 million cubic yards of granular material required for Project development."

6.3.5 Potential Construction Impacts and Mitigation Measures

Potential construction impacts of the Project on mineral resources such as claims and leases, active mines, oil and gas wells, access, and commercial viability could include:

- Blasting for the installation of some facilities;
- Extraction of granular resources required for construction, including blasting to loosen resources;
- Short-term restrictions on exploration and development within a certain distance to the Project for activities deemed a safety hazard;
- Short-term restrictions to access of claims or leases within the construction ROW during construction activities in a specific area;
- Short-term disruption of the land surface within the construction ROW during construction activities, which may disturb surface or subsurface mineral resources; and
- Limitations on the recovery of mineral sources because of the physical presence of the Project; this impact depends on the location of the Project within the boundaries of the lease relative to the location of the mineral resources.

Preliminary assessments show that the subsurface estate of oil and gas resources would not be impacted and that the proposed footprint does not currently overlap with any entry points. Although the Project footprint would cross areas that could potentially be used for oil and gas development, it is not anticipated to inhibit development because the pipeline would require shallow excavation and would not be buried deep enough to directly or indirectly impact the relatively deep oil and gas resources.

Preliminary assessment also indicates construction would not impact the subsurface estate of coal resources and that the proposed footprint does not currently overlap with any entry points. Although the Project footprint would cross areas currently used or that could potentially be used for coal development, it is not anticipated that development would be inhibited because the pipeline would not be buried deep enough to directly or indirectly impact a coal operation.

A reasonable effort to maintain communications with parties affected by construction activities would be made to reduce adverse effects of construction on energy resources. Work with parties associated with energy resource claims and leases in an attempt to preserve the mining and commercial viability of these resources while protecting the integrity of the Project facilities would be done. If third-party facilities are located within construction work areas, well or pipeline sites would be avoided or appropriate precautions would be taken to protect the integrity of such facilities.

A reasonable effort would be made to maintain communications with parties affected by construction activities to reduce adverse effects of the Project on industrial resources and extraction activities. Work with parties associated with future industrial resource leases would be done in an attempt to preserve the commercial viability of such leases and permit the mining of these resources while protecting the integrity of the Project.

Material resources, such as gravel and sand, would be used during construction. Appendix F provides a summary of material resources, including impacts and mitigation measures, as well as reclamation procedures.

6.3.5.1 Liquefaction Facility

6.3.5.1.1 Non-Energy Mineral Resources

The Liquefaction Facility would not be located on or within 0.5 mile of any known active or abandoned producing surface or underground mines, or advanced exploration projects. However, 5 mining claims are within 0.5 mile of the Liquefaction Facility.

6.3.5.1.2 Oil and Natural Gas Resources

No actively leased areas or known oil or gas wells are within the proposed footprint of the Liquefaction Facility. Potential geohazards and associated mitigation measures are discussed below in Section 6.3.5.2.1.

6.3.5.1.3 Coal Resources

There are no active coal mines within 0.5 miles of the proposed footprint of the Liquefaction Facility.

6.3.5.1.4 Industrial Materials

Potential granular material and other industrial material sources needed for construction of the proposed Liquefaction Facility would be identified in the *Gravel Sourcing and Reclamation Measures Plan*.

6.3.5.2 Interdependent Project Facilities

6.3.5.2.1 Non-Energy Mineral Resources

The Mainline, GTP, PBTL, and PTTL would not cross any known active or abandoned producing surface, underground mines, or advanced exploration projects. However, 170 mining claims are within 0.5 mile of the proposed Mainline pipeline and associated facilities, 56 of which are within the proposed Project footprint.

Potential geohazards associated with being in the close and immediate proximity of mineral claims could include, but would not be limited to, ground subsidence, contaminated water or soils, toxic gas, mud pits, tailings, open boreholes, and the presence of waste chemicals, shock-sensitive materials, and explosives. Evaluation of the potential hazards associated with active and abandoned mine claims within the proposed Project area suggests tailings are likely to be the only significant potential hazard. Contamination from these tailings would have a significant adverse effect, but would be temporary, if procedures for isolation and cleaning of the contaminated sites would be followed. If tailings would be found within the Project footprint during construction, or if it would be determined that runoff from these deposits could impact the

Project area, their presence would be reported to the appropriate federal and/or state regulatory agency, and further actions would be complied with as necessary.

6.3.5.2.2 Oil and Natural Gas Resources

The proposed Project footprint for the Interdependent Project Facilities crosses a significant area of leased land covered by the area-wide lease tract program (236 tracts), some actively leased areas (128 tracts), and a few known oil or gas wells (12) (Appendix A, Table 4). The Mainline would be designed to avoid all known wells and oil and gas surface facilities.

Oil and gas are generally produced from depths of more than 1,000 feet, as a result of this, construction of the proposed Interdependent Project Facilities is not anticipated to inhibit development because the pipeline would not be buried deep enough to directly or indirectly impact an oil and gas field. In the unlikely event of construction-related damages to unknown oil and gas wells, impacts would 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 ground-disturbing activities, underground utilities in the construction area would be identified by contacting Alaska's One-Call system. If facilities were to be located within construction work areas, well or pipeline sites would be avoided or appropriate precautions would be taken to protect the integrity of such facilities. Mitigation measures would be implemented as necessary to avoid damage to oil and gas wells during construction of the Project. However, if unexpected damage to oil and gas well facilities were to occur during construction of the Project, all facilities would be repaired to preconstruction condition or better. Communication would be maintained with parties affected by construction activities to reduce adverse effects of the Project on energy resources. Work would be done with all parties associated with energy resource claims and leases in an attempt to preserve the mining and commercial viability of these resources while protecting the integrity of Project facilities.

6.3.5.2.3 Coal Resources

There are no active coal mines within 0.5 mile of the proposed footprint of the Mainline, PTTL, PBTL, and GTP facilities.

6.3.5.2.4 Industrial Materials

Potential granular material and other industrial material sources needed for construction of the proposed Mainline, PTTL, and PBTL would be identified in the *Gravel Sourcing and Reclamation Measures Plan*.

6.3.5.3 Non-Jurisdictional Facilities

6.3.5.3.1 Non-Energy Mineral Resources

No mining claims registered under ADNR or USGS were identified within 0.5 mile of the proposed PTU Expansion, PBU MGS project, or the proposed Kenai Spur Highway relocation project.

6.3.5.3.2 Oil and Natural Gas Resources

The PTU Expansion project facilities and PBU MGS project facilities are located within the PTU and PBU, respectively. The purpose of these projects is the development and commercialization of natural gas resources located within these units. Drilling activities associated with subsurface development and maintenance would be conducted responsibly using prudent technology and industry practice and according to regulations. Construction activities that occur at the surface would not affect the oil and gas resources located beneath the surface.

6.3.5.3.3 Coal Resources

There are no active coal mines within 0.5 mile of the proposed PTU Expansion, PBU MGS project, or the proposed Kenai Spur Highway relocation project.

6.3.5.3.4 Industrial Materials

Granular material required for the PTU Expansion project would be obtained from a new material site as described in Resource Report No. 1. The PTU operator would develop and submit a Gravel Mining and Rehabilitation Plan to applicable regulatory agencies. Potential Operational Impacts and Mitigation Measures

6.3.5.4 Liquefaction Facility

6.3.5.4.1 Non-Energy Mineral Resources

No anticipated impacts would be expected to non-energy mineral resources during the operation of the Liquefaction Facility. Gravel, sand, and other resources would be excavated within the footprint of the facility for construction on site.

6.3.5.4.2 Oil and Natural Gas Resources

No anticipated impacts would be expected to oil and natural gas resources during the operation of the Liquefaction Facility.

6.3.5.4.3 Coal Resources

No anticipated impacts would be expected to coal resources during the operation of the Liquefaction Facility.

6.3.5.4.4 Industrial Resources

Activities outside the Liquefaction Facility's fenced areas during operations would be very limited and non-intrusive in nature. These activities should be of very little consequence to any industrial or mineral resource undertaking.

6.3.5.5 Interdependent Project Facilities

6.3.5.5.1 Non-Energy Mineral Resources

The potential operational impacts of the Interdependent Project Facilities on mineral resources include:

- Restrictions on exploration and development within a certain distance for activities deemed a safety hazard;
- Temporary disruption of the land surface within the pipeline ROW during maintenance activities, which may disturb surface or subsurface mineral resources;
- Limitations on the mining process that can be used to recover minerals because of considerations of Project safety (e.g., vibration impacts on the pipeline);
- Limitations on the recovery of mineral sources because of the physical presence of the Project; and
- Potential expansion of existing extraction activities due to proximity to pipeline and associated facilities.

Potential operational impacts and mitigation associated with geohazards within mineral resource areas are addressed in Section 6.4.

6.3.5.5.2 Oil and Natural Gas Resources

No anticipated impacts would be expected to oil and natural gas resources during the operation of the Interdependent Project Facilities.

6.3.5.5.3 Coal Resources

No anticipated impacts would be expected to coal resources during the operation of the Interdependent Project Facilities.

6.3.5.5.4 Industrial Resources

Activities outside of the fenced areas of the Interdependent Project Facilities during operations would be very limited and non-intrusive in nature. These activities should be of very little consequence to any industrial or mineral resource undertaking.

On the occasions that the pipeline or its ROW would require maintenance, Project personnel and contractors would mobilize with construction equipment to very specific areas of the ROW. Among the activities to potentially be performed could be the placement of granular materials as fill to improve the access and working surfaces.

A reasonable effort would be made to maintain communications with parties affected by operational activities to reduce adverse effects of the Project on resource exploration and development activities. Work would be done with parties associated with future resource leases in an attempt to preserve the commercial viability of such leases and permit the mining of these resources while protecting the integrity of the Project.

6.3.5.6 Non-Jurisdictional Facilities

6.3.5.6.1 Non-Energy Mineral Resources

Because non-energy mineral resources are not known to be located in proximity to both the PBU MGS and PTU Expansion projects, no impacts to non-energy mineral resources are anticipated from the development projects.

6.3.5.6.2 Oil and Natural Gas Resources

No anticipated impacts would be expected to oil and natural gas resources during the operation of the PBU MGS project, or the proposed Kenai Spur Highway relocation project. PTU Expansion project development would result in approved depletion of the Thomson Sand reservoir via production of natural gas and natural gas condensate. PBU MGS project development would result in approved depletion of reservoirs via production of natural gas.

6.3.5.6.3 Coal Resources

Because coal resources are not known to be located in proximity to PTU Expansion project, no impacts to coal resources are anticipated from this development.

6.3.5.6.4 Industrial Materials

Following construction, the proposed PTU Expansion, PBU MGS project, and the proposed Kenai Spur Highway relocation project are anticipated to have no impacts to industrial material resources.

6.4 GEOLOGIC HAZARDS

Geologic hazards are naturally occurring events or conditions arising from the geologic environment or geological processes that can lead to damage of property, injury to people, and/or modification of landscapes. Geologic hazards addressed in this Resource Report include:

- Seismic Hazards;
- Volcanic Hazards;
- Mass Wasting/Slope Stability;
- Acid Rock Drainage and Metal Leaching (ARD/ML);
- Naturally Occurring Asbestos (NOA); and
- Hydrologic Processes (Erosion and Scour).

A discussion of potential geologic hazards encountered in the proposed Project area is provided in the following sections. Related permafrost hazards are addressed in Resource Report No. 7.

6.4.1 Seismic Hazards

Southern Alaska (including the Southcentral, Southeast, and Southwest regions as defined by ADNR) is located adjacent to the plate boundary between the North American and Pacific tectonic plates. This makes Alaska a geologically active region, which includes volcanic and seismic activity. Historically, seismic hazards are greatest in southern Alaska, although seismic activity also extends north into Interior Alaska and is distributed across the Brooks Range (see Figure 6.4.1-1). Distributed seismicity north of the Alaska Range along poorly understood faults poses additional potential earthquake hazards. Seismic activity in the northern part of the state, north of the Brooks Range, is less frequent and less severe than in the south.

The strength of an earthquake is measured using seismometers and reported as an earthquake magnitude. The most commonly used magnitude scale is the Moment Magnitude, denoted M_w, which is a logarithmic scale with no upper limit. The effects of an earthquake in relation to its magnitude are described in Table 6.4.1-1 (Gupta, 2012; USGS, 2014). Earthquake magnitudes are an objective measurement, based on the energy of the seismic waves, the amount of motion along faults, and other related quantitative factors. Magnitudes given herein are moment magnitudes, unless otherwise noted. The impact that an earthquake has on human society is a subjective ranking, called the intensity of the earthquake. Earthquake intensity takes into account any damage to infrastructure, injury to people, and localized variations in impact. The Modified Mercalli Intensity scale assigns ranks of intensity on a scale of I to XII. Human perceptions or structural response to earthquakes of various levels of intensity are described in Table 6.4.1-1 (USGS, 2015a). The subsection of the Modified Mercalli Intensity scale most pertinent to the Project is detailed in this Table 6.4.1-2(IV and higher).

TABLE 6.4.1-1

Earthquake Effects in Relation to Magnitude

Earthquake Magnitude (MW)	Perception or Effect[a]	Typical Maximum Modified Mercalli Intensity[b]
Less than 2.0	Micro earthquakes, not felt	I
2.0–2.9	Generally not felt, but recorded	I
3.0–3.9	Often felt, but rarely causes damage	II–III
4.0–4.9	Noticeable shaking of indoor items, rattling noises; Significant damage unlikely	IV–V
5.0–5.9	Can cause major damage to poorly constructed buildings over small regions; at most slight damage to well-designed buildings	VI–VII
6.0–6.9	Can be destructive in areas up to about 100 miles across in populated areas	VII–IX
7.0–7.9	Can cause serious damage over larger areas	VII or higher
8.0–8.9	Can cause serious damage in areas several hundred miles across	VII or higher
9.0–9.9	Devastating in areas many hundreds to several thousand miles across	VII or higher
10.0+	Never recorded; widespread devastation across very large areas	VII or higher

[a] Source: Gupta, 2012.

TABLE 6.4.1-1

Earthquake Effects in Relation to Magnitude

Earthquake Magnitude (MW)	Perception or Effect[a]	Typical Maximum Modified Mercalli Intensity[b]

[b] Source: USGS, 2014.

TABLE 6.4.1-2

Human Perceptions or Structural Responses to Maximum Modified Mercalli Intensities

Maximum Modified Mercalli Intensity	Human Perception or Structural Response
IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Source: USGS, 2015a

Historic earthquakes greater than intensity IV are summarized in Appendix A Table 7.

Seismicity in Alaska is generated by four main sources:

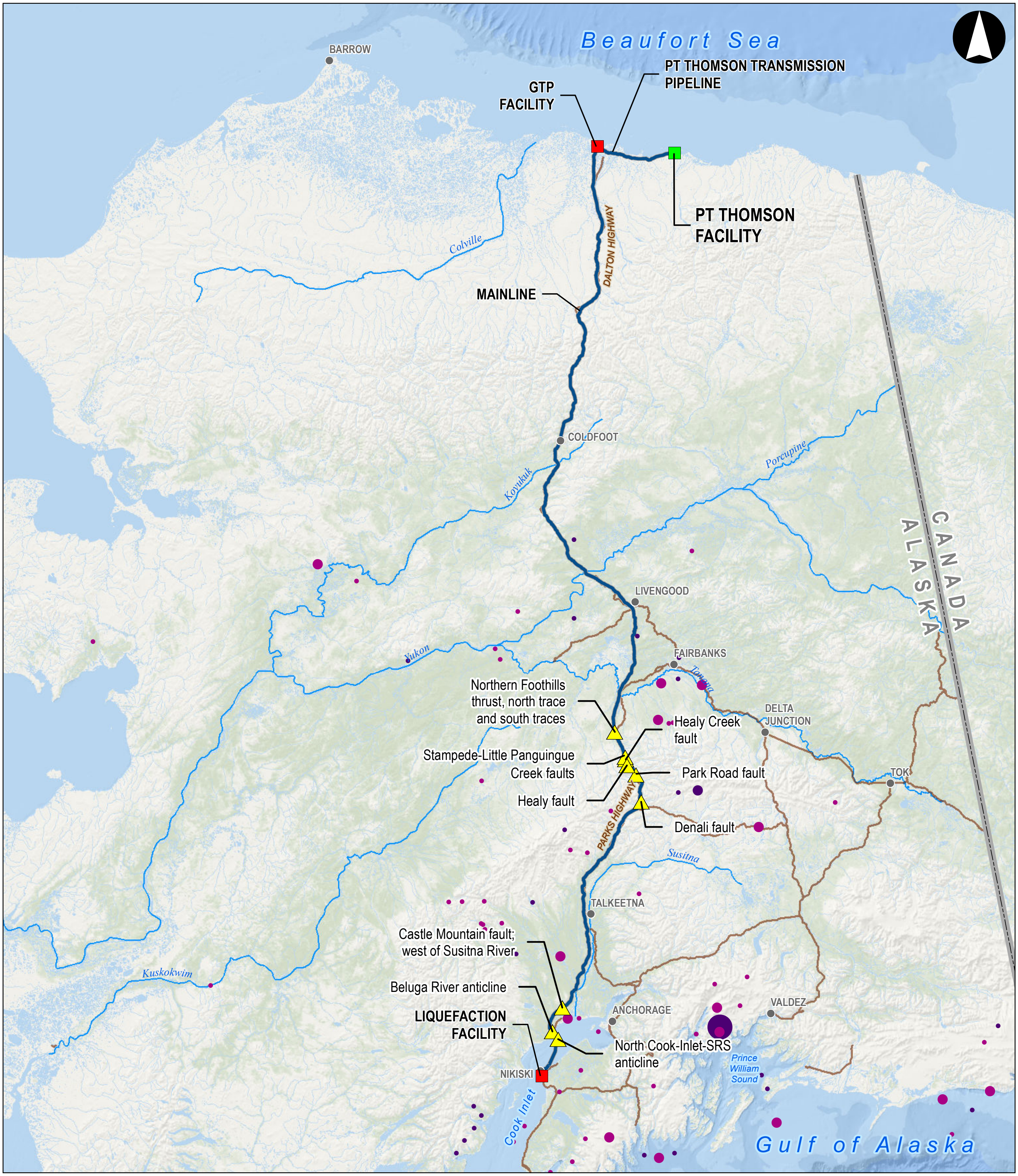
- Aleutian Subduction Zone – The Aleutian Subduction Zone is located along the southwestern border of the state, where the dense, Pacific oceanic plate is subducting below the relatively buoyant North American continental plate. Subduction zone earthquakes, also known as megathrust earthquakes, are the strongest, most-severe earthquakes in the state. This area is where many of Alaska's earthquakes originate. They can be generated by directed oblique convergence between the oceanic Pacific Plate and the western edge of the Southern Alaska block along the Aleutian megathrust, at a rate of 2 (Perry et al., 2009) to 2.1 inches/year (Bruhn and Haeussler, 2006). Due to the geometry of plate convergence, relative plate motions along the Aleutian trench vary from normal in the east to transform in the west (Ruppert et al., 2007). Consequently, the maximum depth of seismicity varies from 155 miles in the east, along the Alaska-Aleutian arc, to 31 miles in the west, where active volcanism diminishes (see volcanism discussion in Section 6.4.2). The Liquefaction Facility would be within relatively close proximity (90 miles) to the Aleutian Subduction Zone.

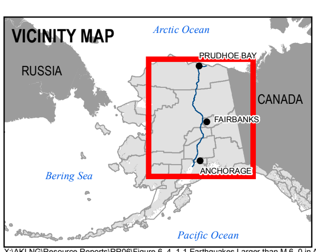
- Southeast Alaska Transform Boundary- The plate boundary in southern Alaska transitions from a convergent boundary along the Aleutian subduction zone to a transform boundary in Southeast Alaska. These plate boundaries are also capable of generating significant seismicity, such as that at the well-known San Andreas Fault system in California. In Southeast Alaska, the Pacific Plate is moving in a northwesterly direction relative to the North American plate. There have been several notable earthquakes recorded: a magnitude 8.0 in 1899, a magnitude 7.1 in 1927, a magnitude 8.1 in 1949, a magnitude 7.9 in 1958, and a magnitude 7.4 in 1972 (Alaska Earthquake Information Center [AEIC], 2014). The Great Alaska Earthquake of 1964, with a magnitude of 9.2, triggered avalanches and structural damages. These large-magnitude earthquakes are concentrated along the Fairweather and Queen Charlotte strike-slip faults, which are part of a larger fault system resulting from the transform boundary (Figure 6.4.1-2, Koehler et. al., 2012).

- Crustal faults – Where the tectonic boundary transitions from transform to convergence (i.e., where plates move toward one another and collide), the ongoing collision of accreted terranes transfers stress into Interior Alaska. The Yakutat block is an exotic terrane displaced some 373 miles north since the Cenozoic (Freymueller et al., 2002). Its presence in this transitional plate boundary complicates the subduction pattern of the Pacific Plate, and stresses from the collision result in transpressional deformation in Southcentral Alaska, compression across the Alaska Range, and strike-slip deformation in Interior Alaska. This transfer of energy results in an abundance of crustal faults and active mountain building. Many of these crustal faults are concentrated within the Alaska Range (Figures 6.4.1-3a and 6.4.1-3b), which is crossed by the Mainline. Transpressional deformation is accommodated by dextral slip along the Denali fault and oblique reverse slip on the Castle Mountain fault. Crustal faults were the source of an earthquake with a magnitude of 7.9 in 2002 (Denali fault earthquake).

- Aleutian Arc Volcanoes – The Aleutian Arc is a large volcanic arc within Alaska that consists of a number of active and dormant volcanoes that have formed by an eruption of magma that ascends to the surface due to subduction processes. Volcanic processes are associated with earthquakes generated by the upward movement of magma, however, these earthquakes are generally small in magnitude and rarely larger than a magnitude of 5 (USGS, 2011). During significant eruptions, large magnitude earthquakes can be triggered by rapid rates of eruption and/or collapse of the volcanic edifice. Potential hazards from volcanic earthquakes are generally localized in close proximity to the volcano. The exception would be in cases where flank collapse/landslides during large eruption can cause tsunami waves that propagate great distances across open water. Such waves have been recorded from the Augustine volcano in Cook Inlet (Alaska Volcano Observatory [AVO], 2014). The Liquefaction Facility and the southern portion of the Mainline would be within relative close proximity of the Aleutian Arc.

An overview of Alaska seismicity is depicted in Figure 6.4.1-3.





LEGEND

- Project Facility
- Existing Facility
- Holocene-Active Fault
- Alaska Place Names
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers

Pre 1964	Post 1964
6.0 - 6.9	6.0 - 6.9
7.0 - 7.9	7.0 - 7.9
	9.0 or Larger

Source: ADGGS Quaternary Faults and Folds Database

0 25 50 100 150 Miles

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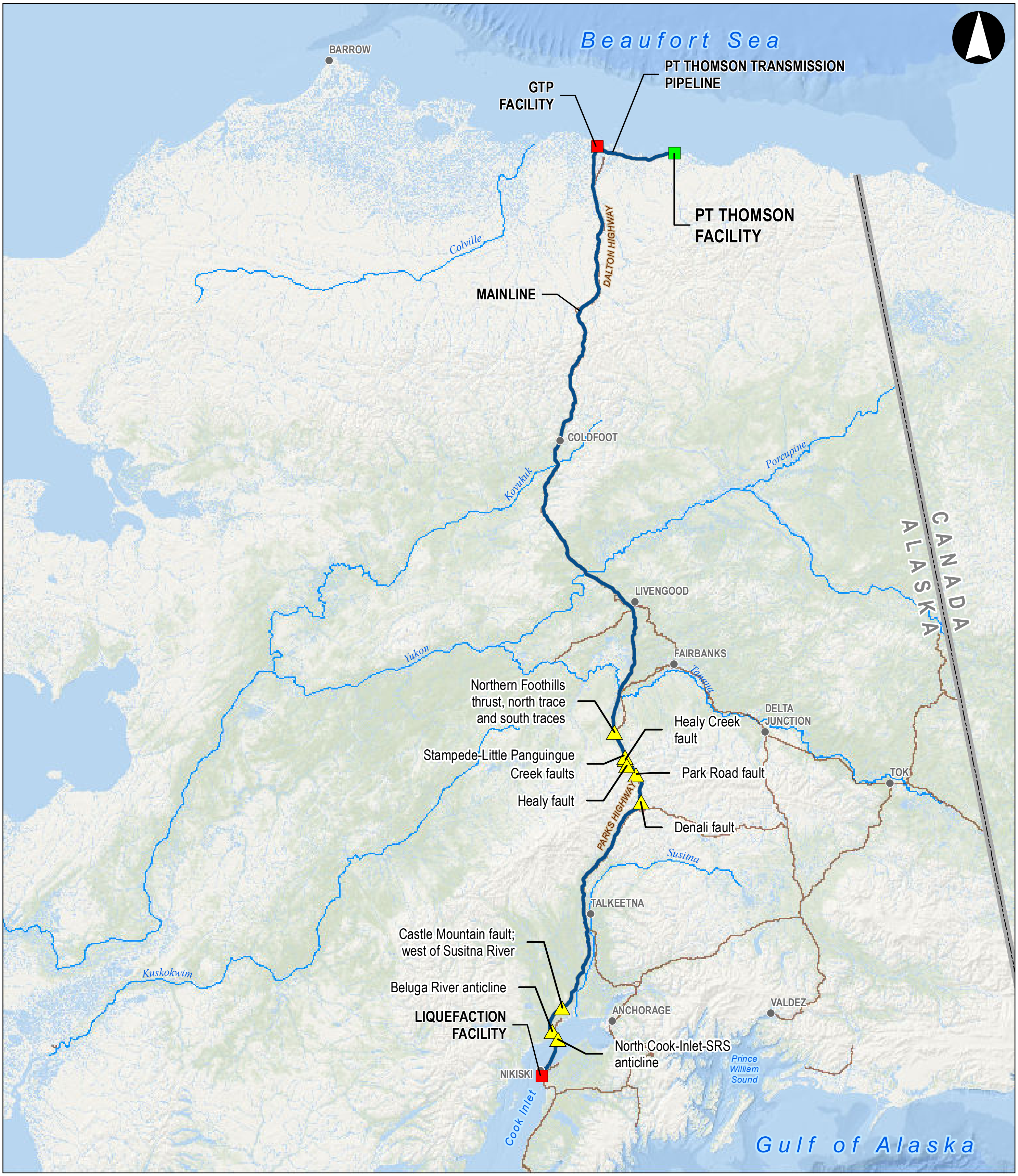
EARTHQUAKES LARGER THAN M 6.0 IN ALASKA

FIGURE 6.4.1-1

ALASKA LNG

X:\AKLNG\Resource Reports\RR06\Figure 6_4_1-1 Earthquakes Larger than M 6_0 in Alaska.mxd



X:\AKLNG\Resource Reports\RR06\Figure 6_4_1-2 Major Faults and Seismic Zones.mxd

LEGEND

- Project Facility
- Existing Facility
- Holocene-Active Fault
- Alaska Place Names
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers

Source: ADGGS Quaternary Faults and Folds Database

0 25 50 100 150 Miles

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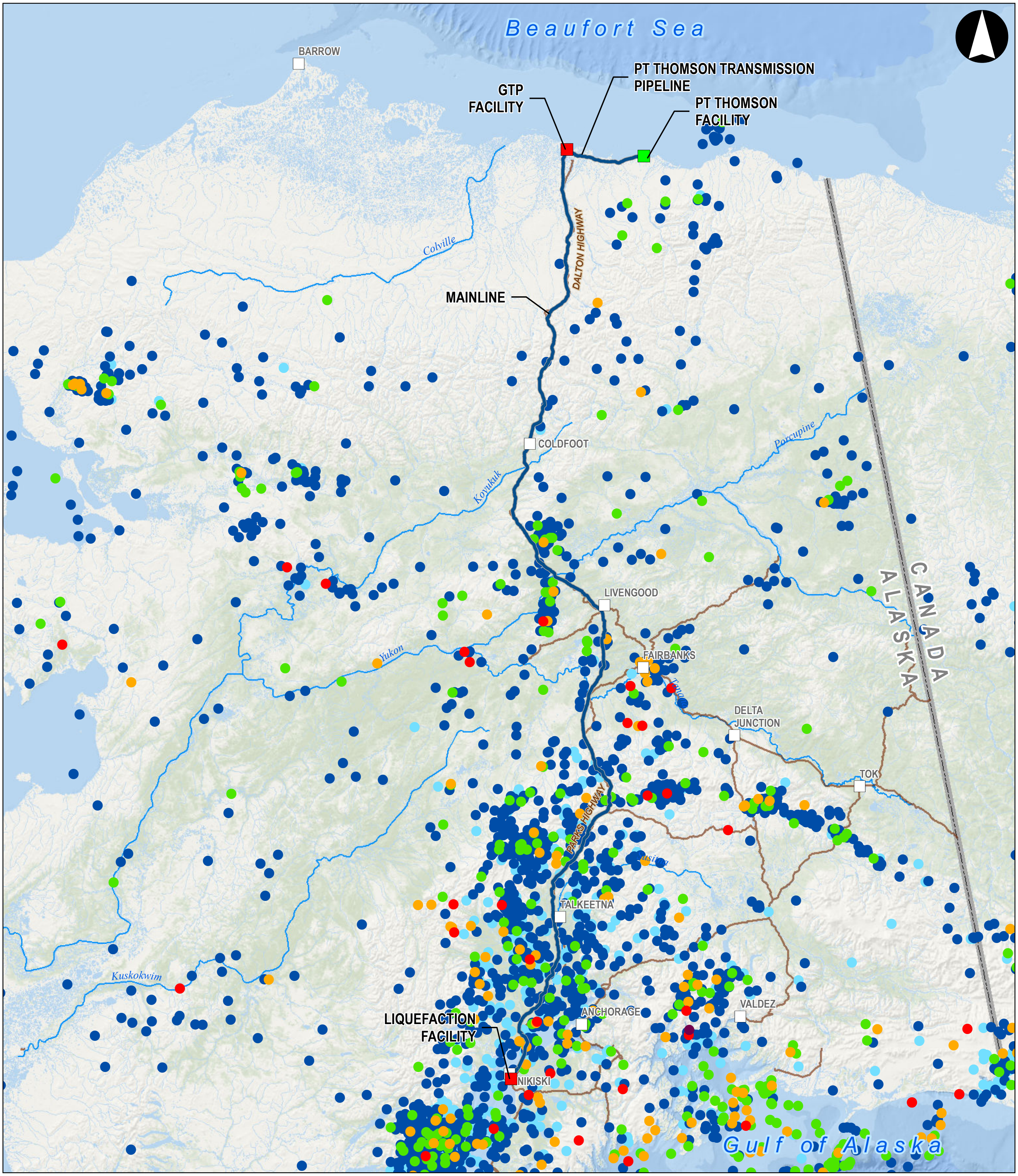
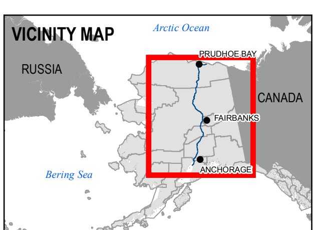
MAJOR FAULTS AND SEISMIC ZONES

FIGURE 6.4.1-2

ALASKA LNG



VICINITY MAP



X:\AKLNG\Resource Reports\RR06\Figure 6_4_1-3a Alaska Seismicity (1898-2012) - Earthquake Magnitudes.mxd

LEGEND

- Project Facility
- Existing Facility
- Alaska Place Names
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers

Earthquake Magnitude

- M = 1.0-3.9
- M = 4.0-4.9
- M = 5.0-5.9
- M = 6.0-6.9
- M = 7.0-7.9
- M > 8.0

Source: ADGGS Quaternary Faults and Folds Database

0 25 50 100 Miles

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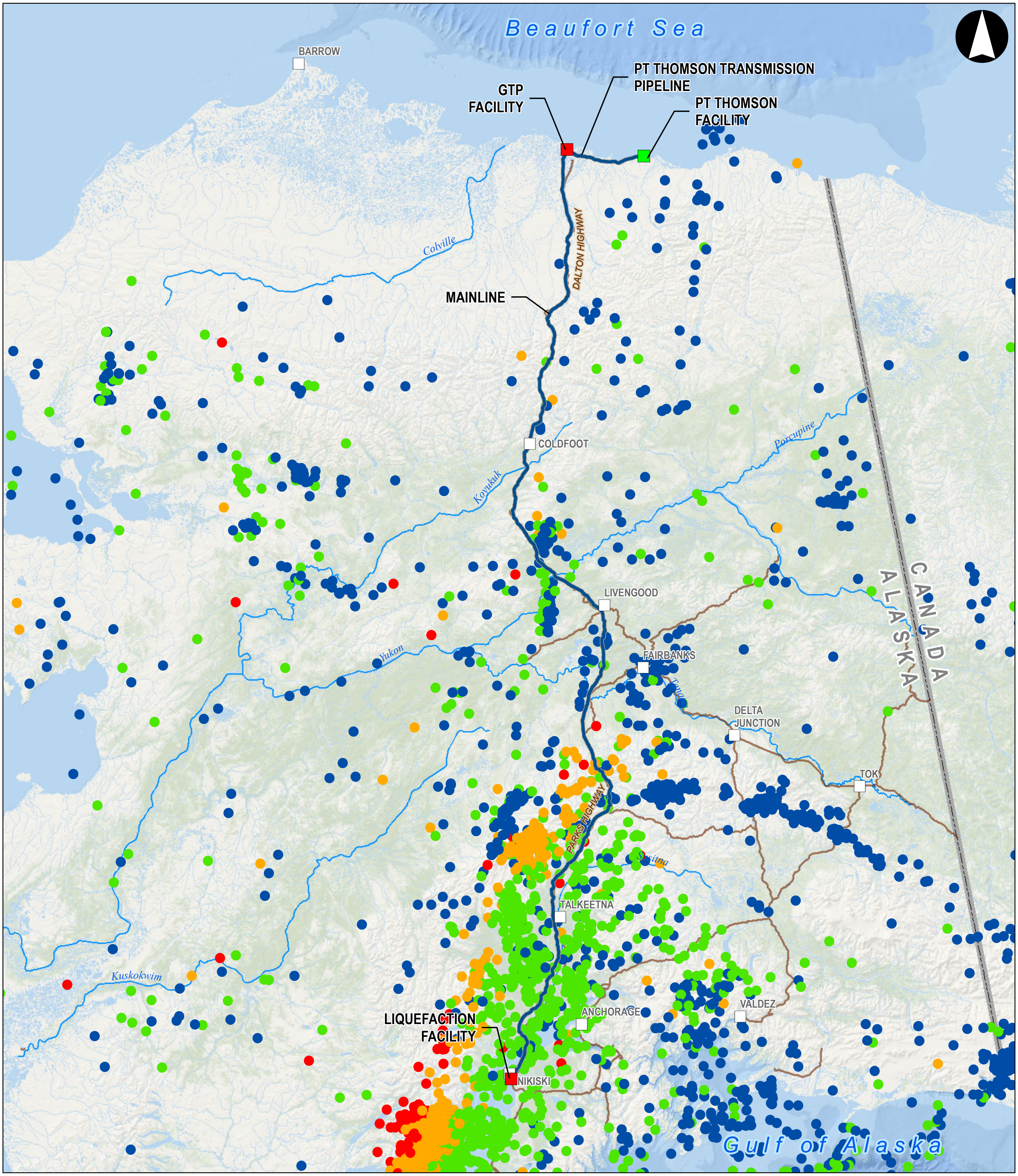
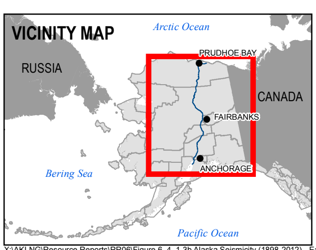
ALASKA SEISMICITY (1898-2012) - EARTHQUAKE MAGNITUDES

FIGURE 6.4.1-3A

ALASKA LNG



VICINITY MAP



LEGEND

- Project Facility
- Existing Facility
- Alaska Place Names
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers

Earthquake Depth

- 0-30 km
- 31-100 km
- 101-150 km
- >150

Source: ADGGS Quaternary Faults and Folds Database

0 35 70 140 Miles

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ALASKA SEISMICITY (1898-2012) - EARTHQUAKE DEPTHS

FIGURE 6.4.1-3B

ALASKA LNG

X:\AKLNG\Resource Reports\RR06\Figure 6_4_1-3b Alaska Seismicity (1898-2012) - Earthquake Depths.mxd

6.4.1.1 Fault Rupture Displacement and Seismic Wave Propagation

Fault rupture displacement occurs when the ground surface moves due to slip along a fault. Following the initial fault rupture, seismic waves cause shaking of the ground surface. The ground shaking that occurs during an earthquake is usually responsible for the most damage to overlying structures. Large magnitude earthquakes, such as megathrust earthquakes, tend to have the longest duration of shaking.

Fault displacement could occur where Project areas intersect faults. Earthquakes along nearby or distant crustal faults and subduction zone earthquakes could all produce significant ground shaking in the Project area. Potentially active faults (a fault that has been observed or has evidence of seismic activity during the last 10,000 years) are a significant consideration in the design engineering of an LNG facility and natural gas pipeline.

The January 24, 2016, Magnitude 7.1 earthquake southwest of Anchorage occurred as the result of strike-slip faulting at intermediate depths within the subducted lithosphere of the Pacific plate. Earthquakes like this event, with focal depths between 43 (70 kilometers) and 186 miles (300 kilometers), are commonly termed “intermediate-depth” earthquakes. Intermediate-depth earthquakes represent deformation within subducted slabs rather than at the shallow plate interfaces between subducting and overriding tectonic plates. They typically cause less damage on the ground surface above the foci than is the case with similar magnitude shallow-focus earthquakes, but large intermediate-depth earthquakes may be felt at greater distance from their epicenters.

The locations of known faults within the Project area are depicted in Figure 6.4.1-1 (Koehler, 2013). Appendix A, Table 8 provides a preliminary list of the faults that would be crossed by the Project.

Although megathrust earthquakes do not originate within the proposed Project area, their massive scale can generate strong ground motions for hundreds of miles in all directions. The most significant earthquake to have impacted the southernmost portion of the proposed Project area was Great Alaska Earthquake of 1964. The Pacific Plate interface during this earthquake is estimated to have advanced approximately 30 feet along the Alaska-Aleutian subduction zone. Significant damage occurred throughout southern Alaska, including ground displacement, shaking, landslides, soil liquefaction, and ensuing tsunamis. Other significant historical earthquakes have occurred along the megathrust as well, including earthquakes with a magnitude of 7.5 in 1979, a magnitude of 7.8 in 1988, and a magnitude of 7.9 in 1987 and 2002 (AEIC, 2014).

Earthquakes are much less frequent in northern Alaska, and seismicity is low throughout the northern Project area (Koehler et al., 2012). The seismicity of northeast Alaska is characterized by widespread, but relatively weak, activity as far north as the northern boundary of the Brooks Range; a broad zone of diffuse activity extending from the northeast Brooks Range, across the coastal plain and onto the Beaufort Shelf; and a notable quiescence beneath the North Slope. Within 50 miles of the proposed Project area in the northernmost ecoregions (Beaufort Coastal Plain, Brooks Range Foothills, and Brooks Range Ecoregions), there have only been four earthquakes in the last 50 years that had a magnitude greater than 5.0 (AEIC, 2014).

6.4.1.2 Soil Liquefaction

Soil liquefaction is defined as "the transformation of a granular soil from a solid state to a liquefied state as a consequence of increased pore water pressure and reduced effective stress (Committee on Soil Dynamics, 1978)." Liquefaction occurs as seismic waves propagate through saturated, loosely deposited fine granular sediment layers, causing cyclic shear deformation and collapse of loose particulate structures followed by transfer of intergranular effective stress to the interstitial porewater. When the pore pressure reaches a critical level, the effective stress approaches zero, and the granular sediment begins to behave as a viscous liquid rather than as a solid, i.e., liquefaction has occurred. The liquefied condition is temporary with the material reverting to a solid state as pore pressures dissipate over time, usually within hours to days. Affected soils can sink downward in the process of dynamic settlement and can spread out in the process of lateral spreading. Infrastructure can suffer significant damage when relying on support from liquefaction-susceptible soils that liquefy during a seismic event. Large magnitude earthquakes with long duration shaking are most likely to induce soil liquefaction.

Areas that generally contain saturated, loosely deposited granular sediments are often found along rivers, streams, lakes, and ocean shorelines. Younger sediments that have not yet experienced significant compaction are the most susceptible. If a soil is frozen, it is not liquefiable.

6.4.1.3 Tsunamis and Seiches

With the extensive coastlines and high seismicity throughout the southern portion of the state, Alaska has a high potential for tsunami and seiche hazards. Tsunamis are massive water waves that propagate through any depth of water, and become particularly hazardous when passing through shallow water and onto shorelines. Seiches are oscillating standing waves that can occur within any enclosed or partially enclosed waterbody, and are also most hazardous when they intersect shorelines. Tsunamis are generated by vertical fault displacement offset in the seafloor, such as thrust or reverse faults, while the largest seiches are more often generated by submarine landslides in confined waterbodies such as fjords.

Large magnitude earthquakes in southern Alaska, particularly those that originate along the tectonic plate boundary, can generate both tsunami and seiche waves. Such waves can inundate coastal areas, endangering lives and infrastructure in low-lying areas for several miles inland. Coastal areas in southern Alaska are also susceptible to tsunami waves generated from earthquakes in distant locales around the North Pacific.

Ground displacement, liquefaction, and resulting landslides during the Great Alaskan Earthquake of 1964 generated tsunamic waves of up to 220 feet in height (Stover et. al., 1993), the largest ever recorded in North America. The earthquake also generated seiche waves triggered by submarine landslides in the deep waters of Prince William Sound. The run-up of these waves destroyed coastal infrastructure in the port towns of Valdez, Seward, Chenega, and Kodiak (AEIC, 2014).

6.4.1.4 Liquefaction Facility

Seismicity is a primary concern in the southern portion of the state, where motion along the tectonic plate boundary and a variety of active faults produces abundant earthquakes. Earthquakes can be, in turn, the cause of other secondary hazards, such as landslides, tsunamis, soil liquefaction, ground settlement, and strong ground motions, among others. The Liquefaction Facility would be located within zones of elevated seismic risk. The Project area's location along northern Cook Inlet would provide significant protection from large-scale earthquake-generated tsunamis. Cook Inlet is a narrow inlet separated from the main body of the Pacific Ocean. Any large amplitude tsunami waves intersecting southern Alaska would be greatly diminished as they passed through the narrow entrance to the Inlet. Tsunami waves would be dispersed and lose most of their energy as they passed north through the Inlet. The Project area would also be unlikely to experience significant landslide-generated tsunamis. The shallow bathymetry of Cook Inlet reduces the submarine landslide hazard that is such a great threat to shorelines along the deep waters of the Prince William Sound (Gardner et al., 2008).

6.4.1.4.1 Fault Rupture Displacement and Seismic Wave Propagation

The potential for surface faulting was evaluated for the Liquefaction Facility and found to be low. No geomorphic evidence of surface faulting was identified within the 5-mile site radius, investigated through review of available geologic map data, geomorphic analysis of LiDAR from 2008, 2012, and land-based topographic surveying performed in 2015, and geologic field mapping efforts in 2014 and 2015. The Killey stade (17,500 to 18,500 years old) glacial deposits that underlie the ground surface show no evidence of lineaments or linear scarps consistent with a surface faulting origin. All lineaments observed can be attributed to a glacial or glaciofluvial origin.

Mapping of the stratigraphic boundary zone between the Killey and Moosehorn stade deposits in the onshore LNG Plant area shows no discernible displacement of bedding consistent with a surface faulting origin. Small surface faults documented by previous studies in the bluff face north of the site are interpreted to have resulted from lateral spreading, either as a result of kettle margin failure after melting of the ice block, or failure due to earthquake-related ground shaking. The faults are located adjacent to a kettle depression and many kettles in the site area show clear evidence of shore-parallel slope failures that could have a similar origin. Seismic reflection data show no displacement of Tertiary reflectors beneath these faults, precluding a tectonic origin.

Interpretation of deep seismic reflection data collected in 2015 and archival data from the oil and gas industry show that faults nearest the site in the Cook Inlet Basin are blind-thrust faults displacing Mesozoic and Tertiary strata. Fault tips do not reach the ground surface. The tip of the blind thrust fault associated with the Middle Ground Shoal anticline is located approximately 4.3 miles west from the onshore site center, at an average depth of approximately 6,750 feet. The tip of the blind thrust fault associated with the Kenai Cannery Loop monocline is located approximately 4.9 miles east from the onshore site center, at an average depth of about 6,350 feet. Seismic reflection data provide positive evidence of an absence of tectonic faulting beneath the site. The site lies in a synclinal flat between seismogenic blind-thrust faults. The Tertiary strata beneath the site, imaged by 2015 seismic reflection data, are planar-bedded and gently dipping, with no observed disruption of bedding to a depth of 150 feet. Seismic reflection imaging of the Tertiary strata shows continuous planar reflectors underlying the marine facilities area. These data provide positive evidence of the absence of faulting. In addition, no geomorphic features consistent with a surface faulting origin were observed in the bathymetric data (Fugro Consultants, Inc. [Fugro]. 2015a. Alaska LNG Facilities Geohazard Report. Report No. USAL-FG-GRHAZ-00-002015-002.).

The potential for tectonic folding that could cause ground tilting in excess of FERC (2007, 2015) guidelines is judged to be very low. Tilting documented from the 1964 Great Alaskan earthquake was an order of magnitude lower than permitted by the guidelines. A similar result was computed for hypothetical tilting from an earthquake event on a Cook Inlet style fold within the 5-mile site radius.

Geologic and geomorphic features were assessed for their potential to record long-term tectonic deformation. No positive evidence for tilting was observed.

Paleo-shorelines around kettle lakes were found to be a mappable strain marker, but the small size of the lakes, the possible confusion of paloe-shorelines with slump scarps, and the low expected magnitudes of tilting given the likely age of the shorelines, resulted in the uncertainties being comparable to the magnitude of potential tilting.

The Moosehorn-Killey contact, exposed in the coastal bluff face and imaged in seismic profiles, was found to be generally planar with some gentle local warping. The warping may be the result of glacial processes.

The top-of-Tertiary unconformity, as mapped from marine seismic reflection data, exhibits a gentle tilt to the east-southeast. This tilt may be related to continued growth of the Middle Ground Shoal fold. The magnitude of tilting is relatively low and occurred over a relatively long time period post the erosion of the Tertiary unconformity, therefore does not pose a hazard to the marine facilities.

6.4.1.4.2 Soil Liquefaction

Soil liquefaction potential evaluation was conducted in accordance with the requirements of both NFPA 59A 2006 and ASCE 7-05 for the onshore area. Per NFPA 59A 2006 requirements, liquefaction triggering hazard assessment was performed for the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE) shaking levels. OBE corresponds to a 475-year return period event. SSE requirements are the same as the MCE requirements per ASCE 7-05. Liquefaction triggering hazard assessment using the NCEER (Youd et al., 2001) and the Boulanger and Idriss (2014) empirical relationships was performed for the 87 onshore borings. Based on these evaluations, generally, continuous potentially liquefiable soil layers were not identified at the site.

Liquefaction-induced reconsolidation settlements are estimated in the range of approximately 0 to 0.5 inch for the onshore borings during both the OBE and the SSE /MCE shaking level, with negligible estimated settlements at most locations.

A screening assessment of the liquefaction susceptibility of fine-grained soils for the onshore borings was performed based on the procedures of Bray and Sancio (2006). Results showed that some sublayers classified as sandy silts (ML) and lean clays (CL) might be susceptible to liquefaction. However, these layers are thin and discontinuous and hence, soil liquefaction would likely be localized and discontinuous if it would occur (Fugro Consultants, Inc. [Fugro]. 2015b. Alaska LNG Facilities Seismic Engineering Report. Report No. USAL-FG-GRZZZ-00-002015-003).

Liquefaction potential evaluation was conducted in accordance with the requirements of both NFPA 59A 2006 and ASCE 7-05 for the nearshore area. Per NFPA 59A 2006 requirements, a liquefaction hazard assessment was performed for OBE and SSE shaking levels. OBE corresponds to a 475-year return period event. SSE requirements are the same as the MCE requirements per ASCE 7-05. A liquefaction triggering hazard assessment using the NCEER (Youd et al., 2001) and the Boulanger and Idriss (2014) empirical relationships was performed for the 25 nearshore borings. Based on these evaluations, in general, potentially liquefiable soil layers are encountered at approximately the top 2 to 10 feet in the nearshore area. Within the proposed construction area, estimated settlements are generally less than 0.5 inch.

A screening assessment of the liquefaction susceptibility of fine-grained soils for the nearshore borings was performed based on the procedures of Bray and Sancio (2006). Results showed that some sublayers classified as sandy silts (ML) and lean clays (CL) might be susceptible to liquefaction. However, these layers are thin and discontinuous and hence, soil liquefaction would likely be localized and discontinuous if it would occur.

6.4.1.4.3 Tsunamis and Seiches

A deterministic tsunami hazard assessment was conducted for the proposed Liquefaction Facility to define a range in wave height by defining tsunami sources. and model the wave propagation across the local bathymetry; the primary facility and structures would be constructed on a coastal bluff at an elevation of approximately 125 feet above mean sea level. The analysis included an assessment of potential tsunamigenic sources; the three sources judged to be the most likely to cause a significant tsunami at the site were evaluated using a deterministic analysis. They include:

- A submarine landslide in Cook Inlet;
- The 1964 Great Alaskan Earthquake; and
- Volcanic flank collapse and debris flow at Augustine Volcano.

The submarine landslide scenario produced maximum wave heights of 16 to 20 feet for mean sea level conditions. The maximum wave height during highest astronomical tide (HAT) conditions is calculated to be 30 to 33 feet. Flank collapse of the Augustine volcano is expected to create a maximum wave height of approximately 3.3 feet or less during mean sea level conditions and a maximum wave height of ~16 feet or less during the HAT based on published results in literature (Kienle et al., 1987; Kienle et al., 1996; Waythomas, 2000; Waythomas and Waitt, 1998; Beget and Kowalik, 2006; and Waythomas et al., 2006).

The simulated results from the 1964 Great Alaskan Earthquake created a maximum wave height of about 2.6 feet, which at a HAT of 14 feet would rise to an elevation of about 16 feet. The data suggests that the tsunami hazard at the planned Nikiski site is very low. The site is located on a coastal bluff ranging in height from approximately 90 feet up to approximately 150 feet, and neither simulated maximum wave heights, nor historical observations of wave heights (National Oceanic and Atmospheric Administration/National Geophysical Data Center), exceeds the bluff height.

Historical accounts and modeled scenarios are in agreement that tsunami waves are generally attenuated during their passage from the Gulf of Alaska and the southern Cook Inlet into the central Cook Inlet due to shallow water depth and other factors. Two previous qualitative studies, the Kenai Peninsula Borough All-Hazard Mitigation Plan (KPB, 2014) and the 1978 Nikiski site hazard assessment (Pacific AK LNG Assoc., 1978), also conclude with low tsunami hazard estimates for the site and areas of the central Cook Inlet near the site.

6.4.1.5 Interdependent Project Facilities

Potential seismic hazards along the Mainline were evaluated through multiple comprehensive pre-FEED, geohazard assessments. These assessments, provided in Appendix H, *Geological Hazard Assessments*, include:

- *USAP-WP-GRZZZ-00-000020-000 Onshore Geohazard Assessment Methodology and Results Summary;*
- *USAP-GP-YRZZZ-10-000006-000 Probabilistic Seismic Hazard Analysis;*
- *USAL-FG-GRZZZ-00-002016-008 Alaska LNG Facilities Seismic Engineering Report;*
- *USAP- WP-GRZZZ-00-000051-000 Seismic Liquefaction and Fault Displacement Hazard Assessment; and*
- *USAP-WP-GRZZZ-00-000050-000 Slope Stability and Mass Movement Assessment Update (Route C).*

These attachments to Appendix H are being submitted as business confidential and will not be released into the public domain as privileged and confidential information.

6.4.1.5.1 Fault Rupture Displacement and Seismic Wave Propagation

The assessment of fault displacement hazards along the Mainline identified several major faults with Holocene surface displacement and/or shallow seismicity trends toward or across the pipeline route. While most of these faults are likely to be inactive, there is a possibility one or more may have Holocene displacement near the pipeline crossing. Additionally, unrecognized or unmapped active faults that cross the pipeline route may also be present in the region. A summary of possible fault crossings is shown in Table 6.4.1-3.

An investigation to delineate fault location, orientation, slip characteristics, and the zone of disturbance caused by potential displacement was conducted by geotechnical engineers. Fault delineation for the Project has involved desktop evaluations of available published maps and imagery, LiDAR data analysis, and two summer fault delineation field programs (2014 and 2015). In advance of the 2014 field work, the published literature was reviewed to identify pertinent geological maps and reports on faults that cross or are close to the pipeline corridor. From this review, a collection of geologic maps that cover much of the pipeline route was compiled. The scales and vintages of the maps span a large range, but all were found to be useful sources of information to complement analysis of the LiDAR data.

In addition, the interactive, on-line ADGGS Quaternary fault-and-fold databases (Koehler, 2013) provided locations and key characteristics of known and well-studied faults and folds throughout Alaska. Faults in the databases are assigned to one of five categories based on the age of the most recent surface deformation:

- Historic, less than 150 years;
- Latest Pleistocene and Holocene, less than 15,000 years;
- Latest Quaternary, less than 130,000 years;
- Mid-Quaternary, less than 750,000 years; and
- Quaternary, less than 1,800,000 years.

Within this categorization, structures that show evidence of deformation in Pleistocene and Holocene timeframes are of particular interest as these faults likely pose the most significant hazard to the pipeline (that is, they have the highest likelihood of experiencing a fault rupture event in the lifetime of the Project).

Geohazard parameters were assigned to each fault listed in Table 6.4.1-3 based on the activity level and likelihood of the fault intersecting the pipeline. Frequency was based on an assumed 500-year recurrence interval for fault rupture events (future characterization of fault displacement parameters will be used to refine the frequency parameter). Development rate was assumed to be rapid. Vulnerability was assumed to be total loss of containment in the event of a fault displacement event. In all cases except the last three faults listed in Table 6.4.1-3, the estimated susceptibility indicated that geohazard mitigation is required, consistent with the direct observational method (Appendix H Geological Hazard Assessments).

TABLE 6.4.1.-3

Possible Holocene-Active Fault Crossings for the Mainline

Start MP	End MP	Fault Name	Fault Type	Activity Level	Intersects Pipeline
500.04	500.61	Northern Foothills thrust, north trace and south traces	Thrust fault	Active	Yes
519.96	520.96	Stampede–Little Panguingue Creek faults	Thrust fault	Possibly active	Maybe
522.41	522.52	Healy Creek fault	Right-lateral strike slip	Active	Uncertain
526.91	527.02	Healy fault	Reverse fault	Active	Uncertain
538.01	538.24	Park Road fault	Reverse fault	Active	Yes
560.31	561.49	Denali fault	Right-lateral strike-slip	Highly active	Yes
743.21	743.40	Castle Mountain fault; west of Susitna River	Right-lateral strike slip	Active	Yes
765.35	767.08	Beluga River anticline	Thrust-fault cored anticline?	Possibly active	Yes
773.20	773.30	North Cook Inlet–SRS anticline	Right-lateral strike slip	Possibly active	Yes; in center of Cook Inlet

Source: WorleyParsons (2016).

6.4.1.5.2 Soil Liquefaction

A multi-level, systematic liquefaction assessment approach combining a focused observational evaluation of watercourses and floodplains with a system-wide statistical landform-based approach was used to determine potential for lateral spread and buoyancy for the entire Mainline. Seismic potential was considered as an initial screen to identify locations with sufficient ground motion to liquefy soils, assuming liquefiable soils are present. This was accomplished by calculating lateral spread displacement for a credible worst-case soil type, and identifying locations with predicted displacement more than 0.1 m (0.3 ft.). Data from the AKLNG Project and ASAP Project boreholes were used to estimate relative density and other soil conditions. In areas where borehole data was not available, conservative assumptions were made with respect to each landform layer, screening out only those landforms not susceptible to liquefaction (for example, bedrock and organics). These results are included in the Liquefaction/Fault Report USAP_WP_GRZZZ-00-000051-000 Seismic Liquefaction and Fault Displacement Hazard Assessment (Route Rev. C).

As shown in Table 6.4.1-4, a total of 38.1 miles of the route was identified to have significant exposure to lateral spread hazard. Of this total, 9.6 miles was characterized as High lateral spread potential and 28.5 miles as Moderate lateral spread potential. For buoyant rise, the reconciled results indicate 56.4 miles of the route with significant hazard of exposure of the pipe with buoyant soils, of which 22.9 miles has High potential and 33.6 has Moderate potential for liquefaction-induced buoyant rise. Table 6.4.1-4 provides locations of potential liquefaction throughout the Project.

TABLE 6.4.1-4

Potential Soil Liquefaction with the Project Area (Route Revision C)

Borough/Census Area	**Ecoregions**	**MP (from)**	**MP (to)**	**Length of Lateral Spread Potential (miles)**			**Length of Buoyancy Potential (miles)**		
				High	**Moderate**	**Low**	**High**	**Moderate**	**Low**
LIQUEFACTION FACILITY									
LNG Plant	Cook Inlet Basin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marine Terminal				N/A	N/A	N/A	N/A	N/A	N/A
INTERDEPENDENT PROJECT FACILITIES									
Pipelines and Associated Infrastructure									
Mainline									
North Slope	Beaufort Coastal Plain Ecoregion	0.00	63.92	0.00	0.00	0.00	0.00	0.00	0.00
	Beaufort Coastal Plain Ecoregion	63.92	145.37	0.00	0.00	0.00	0.00	0.00	0.00
Yukon-Koyukuk	Beaufort Coastal Plain Ecoregion/ Brooks Range/	145.37	182.29	0.00	0.00	0.00	0.00	0.00	0.00
	Kobuk Ridges and Valleys/ Ray Mountains	182.29	262.70	0.00	0.00	0.00	0.00	0.00	0.00
Fairbanks North Star		262.70	421.87	0.00	0.00	0.00	0.00	1.50	3.84
Yukon-Koyukuk		421.87	424.21	0.00	0.00	0.00	0.00	0.28	0.00
		424.21	448.26	0.00	0.00	0.00	0.00	3.55	5.12
	Ray Mountains/ Tanana Kuskokwim Lowlands	448.26	487.08	0.00	0.00	0.00	10.66	9.07	6.99
Denali		487.08	501.85	0.00	0.00	0.00	10.45	0.60	1.55
	Tanana	501.85	564.76	2.32	7.76	5.74	0.13	8.22	6.20

TABLE 6.4.1-4

Potential Soil Liquefaction with the Project Area (Route Revision C)

Borough/Census Area	Ecoregions	MP (from)	MP (to)	Length of Lateral Spread Potential (miles)			Length of Buoyancy Potential (miles)		
				High	Moderate	Low	High	Moderate	Low
Matanuska-Susitna	Kuskokwim Lowlands/ Alaska Range	564.76	575.44	0.28	5.13	0.24	0.00	0.78	1.67
	Alaska Range	575.44	755.43	1.20	11.10	27.29	1.63	9.24	25.33
Kenai Peninsula	Cook Inlet Basin	755.43	806.57	5.81	4.48	0.78	0.00	0.35	3.93
PTTL									
North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PBTL									
North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GTP									
North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Non-Jurisdictional Facilities									
PTU Expansion Project	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PBU MGS		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
KSH Relocation	Cook Inlet Basin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Source: WorleyParsons (2016).									

Seismicity hazards near the GTP, PTTL, and PBTL facilities were determined to be low to moderate. Liquefaction and lateral spread are not anticipated to be a concern; therefore, a detailed liquefaction assessment was not conducted for this part of the Project.

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6.4.1.5.3 Tsunamis and Seiches

Findings and outcomes from future studies, including tsunamis and seiches studies associated with the Interdependent Project Facilities, will be included in the FERC application.

6.4.1.6 Non-Jurisdictional Project Facilities

Both the proposed PTU Expansion and the PBU MGS projects are found in an area of Alaska that has a low seismic risk and hazard associated with earthquakes, including soil liquefaction, tsunamis, and propagated waves.

The Kenai Spur Highway relocation project area is similar to the area described for the Liquefaction Facility.

6.4.2 Volcanic Hazards

Southern Alaska is a volcanically active region with most of the volcanoes lying along the Aleutian Arc, which runs the length of the Alaska Peninsula and the Aleutian Islands. The Aleutian Chain is approximately 2,000 miles long and contains approximately 100 volcanoes, half of which have been historically active (AVO, 2014). The northern portion of the Aleutian Chain includes Cook Inlet, with active volcanoes located along the west side of the Inlet (Figure 6.4.2-1).

Volcanoes in the vicinity of the Project area are listed in Table 6.4.2-1 (AVO, 2014). The closest active volcanoes to the Project area include the following:

- Mount Spurr, located approximately 40 miles west of the Mainline.
- Redoubt Volcano, located approximately 50 miles southwest of the Liquefaction Facility;
- Iliamna Volcano, located approximately 75 miles southwest of the Liquefaction Facility; and
- Augustine Volcano, located approximately 115 miles south-southwest of the Liquefaction Facility.

All four of these volcanoes are active stratovolcanoes, having been built up through explosive eruptions of ash and pyroclastics, and thick, viscous lava flows.

VICINITY MAP

X:\AKLNG\Resource Reports\RR06\Figure 6_4_2-1 Cook Inlet Volcanoes.mxd

LEGEND

- Project Facility
- Alaska Place Names
- Volcanoes
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers
- State and Federal Conservation Lands

0 15 30 60 Miles

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COOK INLET VOLCANOES

FIGURE 6.4.2-1

ALASKA LNG

TABLE 6.4.2-1

Volcanoes in the Vicinity of the Project Area

Project Facility	Segment/Borough or Census Area	Volcanic Feature	Approximate MP	Distance to Volcano (miles) and Direction	Most Recent Activity
LIQUEFACTION FACILITY					
LNG Plant	Kenai Peninsula Borough	Redoubt	N/A	48/W-SW	2009
		Iliamna	N/A	72/SW	1953
		Augustine	N/A	115/S-SW	2005
Marine Terminal	Kenai Peninsula Borough	Redoubt	N/A	48/W-SW	2009
		Iliamna	N/A	72/SW	1953
		Augustine	N/A	115/S-SW	2005
INTERDEPENDENT PROJECT FACILITIES					
Pipelines and Associated Infrastructure					
Mainline	Kenai Peninsula Borough	Hayes Volcano	715	51/W	N/A
		Mount Spurr	754	38/W	1992
		Crater Peak	754	37/W	N/A
		Double Glacier	800	43/W	N/A
		Redoubt Volcano	804	48/SE	N/A
		Iliamna Volcano	804	74/SW	N/A
		Augustine Volcano	804	116/SW	N/A
PTTL	North Slope Borough	None	N/A	N/A	N/A
PBTL	North Slope Borough	None	NA	N/A	NA
GTP					
GTP	North Slope Borough	None	N/A	N/A	N/A
GTP associated infrastructure	North Slope Borough	None	N/A	N/A	N/A
NON-JURISDICTIONAL FACILITIES					
PTU Expansion Project	North Slope Borough	None	N/A	N/A	N/A
PBU MGS	North Slope Borough	None	N/A	N/A	N/A
KSH Relocation	Kenai Peninsula Borough	TBD	TBD	TBD	TBD

Source: AVO, 2014

TABLE 6.4.2-2

Summary of Documented Volcanic Eruption Cycles and Thickness of Ash Fallout of Major Active Volcanos.

Volcano	Start of Documentation	Eruption Cycle[a]	Thickness	Notes
Novarupta Volcano	1912	103 years	>40 inches to <0.40 inches	12 inches at Kodiak, 0.40 inches at Homer
Mount Spurr	1953	39 years	0.06 to 0.25 inches	Light dusting as far south as Valdez and Cordova
Redoubt Volcano	1902	64 years, 21 years, 19 years	0.03 to 0.07 inches	Drifted across Alaska to Canada and as far south as Texas
Iliamna Volcano	1741	Frequent	> 0.10 inches[b]	Regularly emits steam plumes/clouds and gas along with noticeable small shallow earthquakes
Augustine Volcano	1812	71 years, 25 years, 27 years, 28 years, 12 years, 10 years, 20 years	Trace	Deposited on southern Kenai Peninsula

[a] Eruption cycle is defined by the duration in years between documented eruptions

[b] Prehistoric eruption of Iliamna Volcano; not from recent documented activity

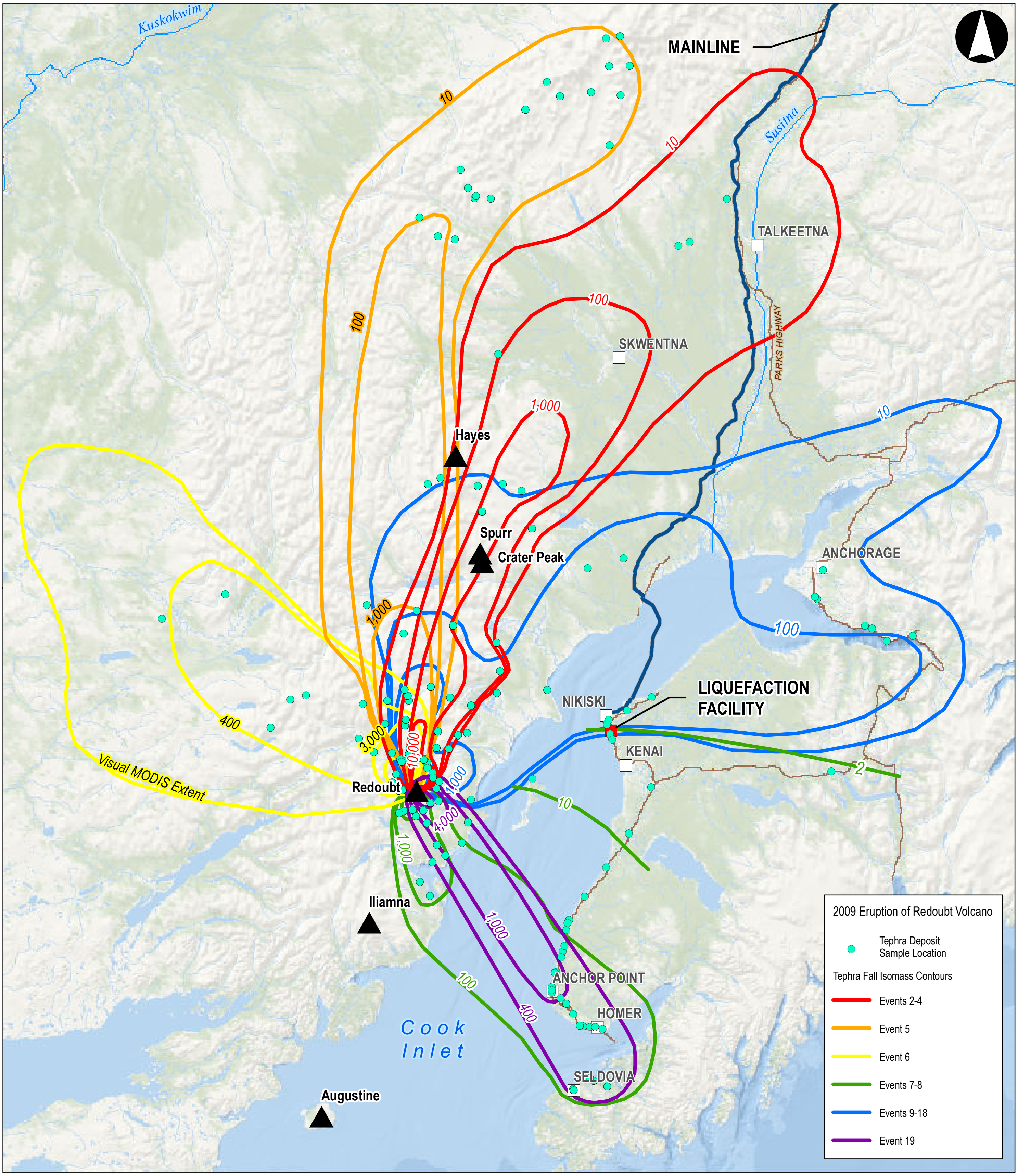
6.4.2.1 Ashfall

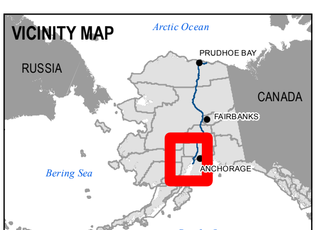
Explosive volcanic activity produces tephra, which includes any airborne volcanic ejecta, from tiny particles of ash up through moderate-sized cinders and large volcanic bombs (i.e., mass of molten rock larger than 2.5 inches in diameter). Volcanic ash becomes suspended in the air and can travel great distances, including circling the earth in the upper atmosphere. Volcanic ash and the associated volcanic gases can be highly corrosive to metallic machinery. Volcanic ash is also composed of sharp particles that can abrade hard surfaces.

Larger volcanic tephra from Cook Inlet volcanoes, including cinders and bombs, would fall close to the volcanic vent, and would not be capable of reaching the proposed Project area (Figure 6.4.2-2). There is potential for ashfall to reach the Liquefaction Facility and some of the Mainline Aboveground Facilities and for ash to reach machinery through air intake valves or other openings and damage or destroy machines.

6.4.2.2 Lahars

Lahars are volcanic mud flows, made up of fresh volcanic ash and other rock debris, and mobilized by rain water or melted snow and ice. Lahars are a typical volcanic hazard close to stratovolcanoes, particularly along drainages. For example, eruptions in 1989–1990 and again in 2009 from Mount Redoubt, some 50 miles southwest of the proposed Liquefaction Facility, sent lahars downstream of the volcano, reaching to the shores of Cook Inlet via the Drift River (Schaefer, 2012; Waythomas et al., 1997). Potential lahars from Mount Spurr are capable of traveling to the shores of Cook Inlet, but would likely follow drainages well south of the western proposed Project area into the Chakachatna River (Waythomas and Nye 2002).





LEGEND

- Project Facility
- Alaska Place Names
- Volcano
- Alaska LNG Rev C2 Route
- Major Highways
- Major Rivers

0 12.5 25 50 Miles

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ISOMASS CONTOURS OF TEPHRA FALL DEPOSITS FROM THE 2009 ERUPTION OF REDOUBT VOLCANO

FIGURE 6.4.2-2

ALASKA LNG

X:\AKLNG\Resource Reports\RR06\Figure 6_4_2-2 Map Showing Isomass Contours of tephra fall deposits from the 2009 eruption of Redoubt Volcano.mxd

Lahars would be unlikely to be a significant hazard to the Project area. Although lahars can travel for tens of miles from a volcanic vent, Cook Inlet lies between the volcanoes and the Project area. Any massive scale lahars from the west side of Cook Inlet would flow into the inlet and disperse, and would pose no threat to the Project area.

6.4.2.3 Pyroclastic Flows

Pyroclastic flows are high-speed, extremely hot flows of volcanic ash, gas, and other debris. Pyroclastic flows destroy anything in their path without warning, and are typical of Cook Inlet volcanoes. Pyroclastic flows, however, would be unlikely to be a significant hazard to the Project area. These flows would typically travel only a few miles from the volcanic vent, although they are capable of traveling tens of miles from a vent during a catastrophic eruption (USGS Volcano Hazards Program, 2014). Cook Inlet lies between the volcanoes and the Project area. Any massive catastrophic eruption, pyroclastic flows on the west side of Cook Inlet would flow into the inlet and disperse. There is no evidence to suggest that a pyroclastic flow would reach the Project area.

6.4.2.4 Lava Flows

Lava flows from Cook Inlet volcanoes tend to be slow-moving, high viscosity flows, typically only advancing several yards per day. Lava flows from Cook Inlet volcanoes rarely travel beyond the flanks of the erupting volcano (AVO, 2014). In the unlikely event that a highly mobile lava flow was to erupt, the lava flow would intersect Cook Inlet before reaching the Project area and would immediately be quenched and cooled, posing no threat to the Project.

6.4.2.5 Flank Collapse

During a massive, catastrophic eruption, portions of a volcano's flank can collapse into a landslide, similar to what occurred at Mount Saint Helens in 1980 (Brantly and Myers, 2000). If a similar event were to occur at Cook Inlet, landslide debris, lahars, and/or pyroclastic flows would likely travel south and/or east to the Inlet along existing drainage pathways and likely disperse into the Chakachatna River valley.

An additional hazard that may result from volcanism is that of a flank collapse into the Cook Inlet, generating a tsunami. Augustine, as it is an island in the Cook Inlet, is the only one of the four nearby active volcanoes capable of such a flank collapse. The hazard to the LNG site from a tsunami generated by an Augustine flank collapse was evaluated and the results presented in Section 6.4.1.4.3 (Fugro Consultants, Inc. [Fugro]. 2015a. Alaska LNG Facilities Geohazard Report. Report No. USAL-FG-GRHAZ-00-002015-002.).

6.4.2.6 Volcanic Gases

Carbon dioxide, hydrogen sulfide, and sulfur dioxide are all dangerous and potentially lethal volcanic gases that can be released in massive quantities during an eruption. If the gases were erupted in sufficient quantity, and the winds blew to the east/northeast, concentrated gases could create hazardous conditions for people in the Project area. This would only occur in the event of a rare, massively catastrophic eruption.

6.4.2.7 Liquefaction Facility

The volcanoes are on the western shore of Cook Inlet opposite from the Kenai Peninsula, where the Liquefaction Facility would be located. The most significant potential hazard that these volcanoes could pose to the Project area is ashfall. Many of the other volcanic hazards, such as lahars, lava flows, or pyroclastic flows, are not a significant concern in the Project area due to (1) the distance from the volcanoes and (2) the separation provided by Cook Inlet. The most likely extent of ash fallout from future eruptions would be based on the prevailing winds at the time of eruption. Generally, the prevailing winds as observed in recent times are westerly, reducing the risk of significant ash deposits at the proposed Liquefaction Facility site. Deposits at the Nikiski site would most likely approximate the levels as documented in Table 6.4.2-2, unless there were to be a major cataclysmic event such as the eruption at Novarupta. While ash deposits are not anticipated to be large, historical frequency of eruptions indicates consideration of protective measures for air intakes of sensitive machinery and facilities where practical to prevent damage due to minor ash fallout events.

6.4.2.8 Interdependent Project Facilities

The nearest volcanoes are located in the Kenai Peninsula Borough, more than 40 miles from the proposed Mainline. Potential hazards for the Mainline (from MP 715 to MP 804) are discussed in Section 6.4.2.7.

No volcanoes are located near the GTP, PTTL, or PBTL facilities and associated infrastructure.

6.4.2.9 Non-Jurisdictional Project Facilities

There are no active volcanoes within 100 miles of the proposed PTU Expansion and the PBU MGS project.

The Kenai Spur Highway relocation project area is similar to the description for the Liquefaction Facility and also susceptible to similar hazards, particularly ashfall.

6.4.3 Mass Wasting and Slope Stability

Slope stability is the likelihood that a given slope would resist imposed forces and erosion to remain intact. Mass movement is a geologic hazard in which slope stability is overcome and slopes fail. Mass movement events are classified into categories depending on the type of materials involved, the speed at which the materials are mobilized, and the way the material moves downslope. Mass movement involves the large-scale movement of geological materials, including rocks, sediments, soils, water, ice, and snow. The movement process can occur on a variety of timescales, from rapid and catastrophic, to slow movement over decades. Mass movements types can be, in general, divided into falls, slides, and flows (McRoberts and Morgenstern 1974; Cruden and Varnes 1996).

Gravity is the dominant force behind mass movement events, but they can also be triggered by the motion of water or wind, significant rainfall, or disturbance such as earthquakes. Water and ice present in the material can exacerbate activity, as can a change in climatic factors, such as degradation of permafrost/pore ice.

Based on the terrain that would be traversed by the Project, there are two types of potential instability and mass movement:

- Permafrost Terrain Related Instability; and
- Unfrozen Terrain Related Instability.

6.4.3.1 Permafrost Terrain-Related Instability

Slopes in northern terrain are differentiated from those in temperate areas by the existence of permafrost. If thermal equilibrium is disrupted by human activities, weather conditions, or fire, the seasonal thaw depth (active layer) may increase with time, which may induce slope instability. Because much of the Project pipeline traverses permafrost areas, special measures are considered to account for the effect of permafrost thawing on slope stability along the pipeline route. Permafrost-related instability is addressed in more detail in Resource Report No. 7.

6.4.3.1.1 Solifluction

Solifluction is defined as "the slow, downslope flow of saturated, unfrozen earth materials" (National Research Council of Canada, 1988; van Everdingen, 2005). Solifluction movements are favored in permafrost zones where movements are restricted to the active layer (McRoberts, 1978). Solifluction occurs as a result of freezing in winter sealing the sloping ground surface preventing drainage of excess pore water pressure to surface. This lack of drainage causes soil water content to reach levels of saturation. The saturated zone warms in spring and summer, causing the slope to slowly creep downward. As the upper zone thaws and drains, it becomes more stable, but continues to move on top of ice-rich materials, which remain frozen (Tart, 1996). McRoberts (1978) reported cases of slopes failing at angles as low as 3 degrees.

6.4.3.1.2 Frozen Debris Lobes

Frozen debris lobes are a form of mass movement unique to cold climates. They are a mixture of frozen soil, sediment, rock, ice, often with trees growing in the upper layers. They are considered to have a slow to moderate speed for landslides. They may advance from inches to feet per year.

In Alaska, frozen debris lobes are found throughout the southern Brooks Range, where they are locally composed of a dominantly silty matrix. Most of these features in Alaska move downslope on the order of 10–30 feet per year, though one in particular has been measured at some 150 feet of advancement per year for multiple years (Daanen et al., 2012). Frozen debris lobes have become a concern in Alaska, as some of the lobes are encroaching upon the Dalton Highway and Mainline route.

6.4.3.1.3 Thaw Layer Detachment

Thawed layer detachment is a mechanism that refers to "several forms of slope failures or failure mechanisms commonly occurring in the active layer overlying permafrost" (van Everdingen, 2005). Thawed layer detachment involves flow of a shallow layer of saturated soil and vegetation, forming long, narrow flows moving on the surface but over the underlying permanently frozen soil (Highland and Botrowsky, 2008). This type of movement may expose buried ice lenses that, when thawed, may develop into retrogressive thaw flows (larger features with a bimodal shape of a steep headwall and low angle tongue of saturated soil) or, possibly, debris flows. McRoberts (1973) reported the development of thawed layer detachment on slopes as shallow as 6 degrees.

6.4.3.1.4 Rock Glaciers

Rock glaciers are common in northern Alaska, particularly within the valleys of the Brooks Range. Rock glaciers are mass movements involving immature, coarse talus with a high proportion of interstitial ice. Rock glaciers occur on blocky fracturing rocks that have large interconnected voids in which ice can accumulate (Wahrhaftig et. al, 1959). They are rare on platy or schistose rocks whose talus moves rapidly by solifluction. Seasonal thaw allows for creep in the interstitial ice and the rock glaciers slowly advance downslope. Such movements can form lobate flows. Seasonally, rock glaciers advance downslope on top of bedrock or sediments, or alternatively may be located on top of a deeper valley glacier. In areas of retreating glaciers, rock glaciers may be left behind when the ice beneath them melts.

6.4.3.2 Unfrozen Terrain Related Instability

6.4.3.2.1 Deep landslide

A deep landslide is generally a rotational mass movement where the surface of rupture is spoon-shaped and the rotational movement is about an axis parallel to the contour of the slope (Highland and Botrowsky, 2008). A deep landslide in soil can result from intense or sustained rainfall that leads to saturation of the slope and an elevated groundwater level. It can also occur near streams or lakes due to rapid water level changes and toe erosion. Deep translational landslides are also possible, such as in the case of a soil/rock interface that acts as a failure surface. For this assessment, slump-type failure of unconsolidated material that deforms as single or multiple units along a markedly curved and concave-upward slip surface is considered as a deep landslide.

6.4.3.2.2 Shallow Landslide

A debris slide in this assessment is considered to be a shallow landslide. Slides involve downslope movement of rock or sediment along a discrete surface. They are subdivided into translational and rotational types, although many slides are complex phenomena, involving both types of movement.

6.4.3.2.3 Slope Creep

Slope creep involves progressive failure and is a very slow earth flow caused by changes in shear stress due to such events as rainfall, physical weathering, and poor drainage (Highland and Botrowsky, 2008). Creep is common on slopes consisting of fine-grained cohesive soils or some weathered or pre-sheared bedrock, or both. Soil movements in glaciomarine clay areas are considered as slope creep, although rapid flow failures involving sensitive glaciomarine sediments are also possible under certain conditions in areas of high sensitivity.

6.4.3.2.4 Debris flow

Debris flows may occur where loose soil, rock, and sometimes organic materials combine with water to form a mass that flows rapidly downslope (Highland and Botrowsky, 2008). The water content of debris flows may range from 10 percent to more than 50 percent by volume. Debris flows may transport large boulders for great distances down gentle slopes (van Everdingen, 2005). Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt that erodes and mobilizes loose soil or rock on steep slopes (USGS, 2004). Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. A mudflow is an earthflow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles.

6.4.3.2.5 Rock Fall

A rock fall could originate from bedrock exposures (i.e., source zones) adjacent to the proposed Project route if these exposures are located above the elevation of the ROW. Rock fall may occur very rapidly and with little warning. Falls may develop due to degradation of the rock mass, heavy rainfall increasing water level in fissures and cracks, freeze-thaw effects (e.g., ice-wedging), and seismic activity.

6.4.3.2.6 Avalanches (Snow/Rock)

Avalanches are mass movement events involving mostly snow and ice, which may also entrain other debris such as rocks, soil, and vegetation. Most severe avalanches originate on slopes between 30 and 45 degrees, as slopes steeper than 45 degrees, or shallower than 25 degrees, rarely experience avalanches (U.S. Department of Agriculture [USDA], 2004). Snow avalanches are capable of moving at extremely high speeds, and can be a significant threat to infrastructure and people.

When snow absorbs significant meltwater during the annual spring thaw season in the Arctic and Subarctic, the saturated snow is susceptible to a mass wasting failure called a “slushflow.” These wet snow avalanches are common on slopes in the Arctic and Subarctic during the spring and early summer. Slushflows are generally slower than dry snow avalanches and do not have the ability to override high topography. The high water and debris content of the slushflows allows them to generate considerable momentum, with potential for long run-out distances, even along very gentle slopes (Onesti, 1985).

Rock avalanches involve gravitational movement of a very large volume of fragmented rock that may contain little or no water. Dynamic fluidization through high-energy particle interactions contributes to the potential for very rapid movement and long run-out distance. Rock avalanches are the fastest of all landslides, in some cases achieving speeds of 300 feet per second or more, and may travel long distances where unimpeded by topography. Large rock avalanches are far less common than other types of landslides, but are important because of their large volumes and long travel distances.

Sackung (German for “sagging slope”) is a deep-seated downslope movement of a large, internally broken rock mass with no single well-defined basal failure plane. Movement is manifested at ground surface by cracks, trenches, and scarps at mid and upper slope positions, and by bulging of the lower slope.

Rock slides are a type of landslide occurring when a mass of rock moves quickly downslope. Sliding describes the motion of a mass that remains under-formed except along its base. In slides, a rupture surface separates the displaced mass of rock from the rock over which it moves.

6.4.3.3 Liquefaction Facility

The proposed Liquefaction Facility would be sited on the shore of the Cook Inlet, at the top of a coastal bluff that rises approximately 120 to 125 feet above mean sea level. Analysis of historical aerial photography combined with LiDAR and geologic field mapping (documented in Fugro Report No. 04.1010094-2) indicate that the bluffs are eroding by a combination of wave erosion, which undermines the toe of the slope, followed by landsliding, debris flows, raveling, and gullying on the face of the bluff. No evidence of large, deep-seated, mass wasting events was observed during the field activities or in the LiDAR topographic data. All slides, including slumps, are relatively shallow and involve materials from the bluff face above sea level.

Bluff erosion occurs episodically, typically in association with major storm events. Episodic coastal retreat from storm events has been reported up to approximately 50 feet in a single event (USACE, 2011). Reger et. al. (2007) note significant bluff retreat after a powerful storm in October of 2002.

Reported annual rates of coastal retreat vary, but generally range from 1 to 3 feet per year. Anecdotal information collected by Reger et. al. (2007) suggests a rate of bluff retreat in the Salamatof area of about 2 feet per year. Kenai Peninsula (Kenai Peninsula Borough, 2013) estimated rates of erosion within the area of the planned onshore LNG Plant at 1 to 3 feet per year, with one portion estimated at around 5 feet per year. Long-term measurements of coastal bluff retreat based on a comparison of aerial photographs from 1980 and 2012 showed that average rates of bluff retreat in that 22-year time span generally did not exceed 0.6 foot/year). However, localized areas have experienced as much as 2 feet/year (+/- 0.5 feet).

In summary, the coastal bluffs are eroding and retreating as a response to wave erosion at the toe of the bluff followed by removal of material from the over-steepened slope. Bluff retreat is most rapid following major storm events. Bluff retreat associated with a single storm may be as great as 50 feet. Average rates of retreat of the bluff crest vary from 1 to 3 feet per year. Existing erosion protection measures adjacent to the proposed facility location including sheet pile walls, gabions, and large rip-rap appear to have proved effective at greatly reducing erosion due to wave action.

6.4.3.4 Interdependent Project Facilities

Potential natural mass movement features within the Mainline corridor were identified and evaluated by a slope stability and mass movement assessment. This report, *Slope Stability and Mass Movement Assessment Update (Route Revision C)*, is included in Appendix H. The assessment considered natural existing landslides and potential slope instability during pipeline construction and operation. Data sources included:

- Digital and hardcopy regional geology maps;
- DEM and LiDAR data;
- Aerial photographs;
- Borehole and test pit logs and databases;
- Legacy data from applicable Projects;

- Helicopter electromagnetic data;
- Government reports and databases; and
- Field Investigations.

To assess and analyze slope stability, the data was intersected with the Mainline route to produce linearly-referenced tabular data sets (such as depth to bedrock and bedrock type). These data sets were evaluated to characterize and assess slope stability and mass movement along the Mainline route. Results from this assessment were grouped according to landslide and mass movement type and are summarized in Table 6.4.3-1.

TABLE 6.4.3-1

Mass Wasting along Mainline– Potential Static[a] and Dynamic Instability[b] During Construction and Operation and Potential Existing Landslides

Project Facility	Borough/Census Area	MP (from)	MP (to)	Landslide Category /Type of Movement	Mass Wasting Type	Impacted Pipeline Length (miles)	Impacted Pipeline (% of segment)
LIQUEFACTION FACILITY							
LNG Plant	Kenai Peninsula Borough	Cook Inlet Basin	N/A	N/A	Potential landslides/slump along coastal bluff	N/A	N/A
Marine Terminal	Kenai Peninsula Borough	Cook Inlet Basin	N/A	N/A	Potential landslides/slump along coastal bluff	N/A	N/A
INTERDEPENDENT PROJECT FACILITIES							
Pipelines and Associated Infrastructure							
North Slope Borough	Arctic Coastal Plain/Arctic Borough	0.00	63.92	N/A	N/A	0.0	0.0
North Slope Borough	Arctic Foothills/Arctic Borough	63.92	145.37	Existing Natural Landslides/thaw flow	Existing Natural Landslides	2.74	3.4%
North Slope Borough	Arctic Foothills/Arctic Mountains Borough	145.37	182.29	N/A	N/A	0.0	0.0%
				Existing Natural Landslides/ avalanche	Existing Natural Landslides	0.8	2.2%
				Existing Natural Landslides/ debris flow	Existing Natural Landslides	7.65	20.7%
				Existing Natural Landslides/earth flow	Existing Natural Landslides	0.25	0.7%
				Existing Natural Landslides/rock fall	Existing Natural Landslides	1.64	4.5%
				Existing Natural Landslides/rock glacier	Existing Natural Landslides	0.36	1.0%

TABLE 6.4.3-1

Mass Wasting along Mainline– Potential Static[a] and Dynamic Instability[b] During Construction and Operation and Potential Existing Landslides

Project Facility	Borough/Census Area	MP (from)	MP (to)	Landslide Category /Type of Movement	Mass Wasting Type	Impacted Pipeline Length (miles)	Impacted Pipeline (% of segment)
				Existing Natural Landslides/rock slide	Existing Natural Landslides	2.12	5.7%
				Existing Natural Landslides/ slump	Existing Natural Landslides	0.39	1.0%
				Existing Natural Landslides/ Solifluction	Existing Natural Landslides	0.16	0.4%
				Existing Natural Landslides/thaw flow	Existing Natural Landslides	1.52	4.1%
Yukon-Koyukuk Census Area	Arctic Foothills/Arctic Mountains Borough	182.29	262.70	N/A	N/A	0.00	0.0%
				Existing Natural Landslides/ debris slide	Existing Natural Landslides	0.25	0.3%
				Existing Natural Landslides/ solifluction	Existing Natural Landslides	0.64	0.8%
Yukon-Koyukuk Census Area	Intermontane/ Northern Plateaus Borough	262.70	421.87	N/A	N/A	0.00	0.0%
				Existing Natural Landslides/ debris slide	Existing Natural Landslides	0.14	0.1%
				Existing Natural Landslides/ slump	Existing Natural Landslides	0.19	0.1%
				Existing Natural Landslides/ solifluction	Existing Natural Landslides	0.29	0.2%
				Potential Dynamic Slope Instability	Potential Dynamic Instability During Construction and Operations	0.02	0.0%
				Potential Static Slope Instability	Potential Static Instability During Construction and Operations	1.41	0.9%
Yukon-Koyukuk Census Area	Intermontane/ Northern Plateaus Borough	448.26	487.08				
				Potential Static Slope Instability	Potential Static Instability During Construction and Operations	0.03	0.1%

TABLE 6.4.3-1

Mass Wasting along Mainline– Potential Static[a] and Dynamic Instability[b] During Construction and Operation and Potential Existing Landslides

Project Facility	Borough/Census Area	MP (from)	MP (to)	Landslide Category /Type of Movement	Mass Wasting Type	Impacted Pipeline Length (miles)	Impacted Pipeline (% of segment)
Denali Borough	Pacific Mountain/Alaska Aleutian Borough	501.85	564.76				
				Existing Natural Landslides/ debris flow	Existing Natural Landslides	1.06	1.7%
				Existing Natural Landslides/ debris slide	Existing Natural Landslides	0.75	1.2%
				Existing Natural Landslides/earth flow	Existing Natural Landslides	0.34	0.3%
				Existing Natural Landslides/rock fall	Existing Natural Landslides	2.89	4.9%
				Existing Natural Landslides/rock slide	Existing Natural Landslides	1.81	1.2%
				Existing Natural Landslides/ sackung	Existing Natural Landslides	0.81	1.3%
				Existing Natural Landslides/ slump	Existing Natural Landslides	1.03	1.6%
				Existing Natural Landslides/thaw flow	Existing Natural Landslides	0.21	0.3%
				Potential Dynamic Slope Instability	Potential Dynamic Instability During Construction and Operations	0.04	0.1%
				Potential Static Slope Instability	Potential Static Instability During Construction and Operations	0.57	0.9%
Matanuska-Susitna Borough	Pacific Mountain/Coastal Trough Borough	575.44	755.43				
				Existing Natural Landslides/ debris flow	Existing Natural Landslides	0.45	0.3%
				Existing Natural Landslides/ debris slide	Existing Natural Landslides	0.16	0.1%
				Potential Dynamic Slope Instability	Potential Dynamic Instability	0.33	0.2%

TABLE 6.4.3-1

Mass Wasting along Mainline– Potential Static[a] and Dynamic Instability[b] During Construction and Operation and Potential Existing Landslides

Project Facility	Borough/Census Area	MP (from)	MP (to)	Landslide Category /Type of Movement	Mass Wasting Type	Impacted Pipeline Length (miles)	Impacted Pipeline (% of segment)
					During Construction and Operations		
				Potential Static Slope Instability	Potential Static Instability During Construction and Operations	0.80	0.4%
Kenai Peninsula Borough	Pacific Mountain/Coastal Trough Borough	755.43	806.57				
				Existing Natural Landslides/ slump	Existing Natural Landslides	0.26%	0.5%
PTTL	North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A
PBTL	North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A
GTP							
GTP	North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A
GTP Associated Infrastructure	North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A
NON-JURISDICTIONAL FACILITIES							
PTU Expansion Project	North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A
PBU MGS	North Slope Borough	Beaufort Coastal Plain	N/A	N/A	N/A	N/A	N/A
KSH Relocation	Kenai Peninsula Borough	Cook Inlet Basin	N/A	N/A	TBD	TBD	TBD

Source: WorleyParsons, 2015.

[a] For potential static instability, the potential for landslides and mass movement along the pipeline route during construction and operation was assessed through slope stability analysis for longitudinal slopes assuming rotational and planar failure mechanisms under static loading. No detailed site specific assessment was conducted and only data available to the Project as of September 2015 was used in this screening process.

[b] For seismically induced dynamic loading, a planar failure mechanism was considered in the slope stability analysis. Slopes with a dynamic Factor of Safety less than unity were further investigated to estimate potential soil displacement. A preliminary threshold of 3.3 feet (1 meter) was used as the allowable displacement under seismic loading that stresses and strain developed on the pipe would remain within the allowable limits. Seismic data for 2,475 years was used in this assessment.

Solifluction – Mass wasting slope process related to freeze-thaw activity, occurring in permafrost; Sackung – slow, deep-seated gravitational deformation of slopes.

TABLE 6.4.3-1

Mass Wasting along Mainline– Potential Static[a] and Dynamic Instability[b] During Construction and Operation and Potential Existing Landslides

Project Facility	Borough/Census Area	MP (from)	MP (to)	Landslide Category /Type of Movement	Mass Wasting Type	Impacted Pipeline Length (miles)	Impacted Pipeline (% of segment)
"Information provided in this table is based on preliminary geotechnical analysis completed with available route data, and is subject to change as further field work and analyses are completed. This information should not be released to agencies or a third party without the explicit consent and guidance of WorleyParsons Geotechnical team."							

Findings and outcomes from geotechnical work, both intrusive and non-intrusive, are included in Appendix H. Preliminary findings for the Mainline are shown in Table 6.4.3-1.

6.4.3.5 Non-Jurisdictional Facilities

There are no known features that have the potential to cause mass wasting processes at or near the proposed PTU Expansion, PBU MGS project, or the Kenai Spur Highway relocation project.

6.4.4 Acid Rock Drainage and Metal Leaching

Acid Rock Drainage and Metal Leaching (ARD/ML) are naturally occurring processes resulting from the release of acidity, chemical constituents, and metals during oxidation or leaching of rocks containing sulfide minerals, secondary acidic minerals, or coal. When these rocks or soil formations are exposed to weathering conditions (e.g., water and oxygen), sulfide minerals present in the rocks or buried coal may be oxidized or leached releasing acidic, sulfate, and metal-rich drainage. This acidic drainage may contain elevated concentrations of toxic metals and can negatively impact aquatic life, and subsequently affect wildlife and humans. Pyrite is an ubiquitous sulfide in nature and is the main mineral responsible for ARD/ML, but other sulfide minerals can also release acid or metals and metalloids into the environment. Therefore, mitigations and control measures are required to prevent and mitigate ARD/ML where the potential is elevated.

Carbonate minerals, such as calcite, dolomite, and most reactive alumino-silicates like anorthite, are effective in neutralizing acid. Where these minerals coexist with sulfide minerals in sufficient amounts in exposed rock, they can dissolve and buffer the acidity generated from sulfide oxidation, raising the pH and inducing the precipitation of metals out of the drainages. Although the solubility of metals decreases under near-neutral pH conditions, several metals, metalloids and constituents including arsenic, molybdenum, selenium sulfate, etc., can reach elevated and environmentally damaging concentrations under near-neutral to slightly alkaline conditions.

Overburden and sediments that have been reworked by water over thousands of years generally do not contain sulfide minerals, and therefore do not tend to pose a risk of ARD/ML. Major sections of the Project area are covered with thick deposits of glacial sediments. In most of these areas, bedrock is deep and is unlikely to be excavated or exposed during construction. These regions are expected to have a very low to no potential for ARD/ML.

In areas where construction activities are expected to excavate, disturb, or expose the bedrock, there could be a potential for ARD/ML. Based on previous investigations and the geological and mineralogical of the rock types and alteration encountered along the Mainline, several rock types may be sulfide-bearing or contain coal seams.

Rock types encountered in the Project area capable of hosting sulfide minerals include:

- Mesozoic and Cenozoic-aged shale;
- Mudstone;
- Schist;
- Claystone;
- Coal and shale; and
- Igneous rocks.

To assess the potential for ARD/ML within the Project area, a phased ARD/ML characterization was undertaken by WorleyParsons (2015). Initially, a preliminary desktop assessment was conducted to identify and rank the Mainline according to the potential for ARD/ML using publicly available geological and mineralogical and geochemical data as well as qualitative data collected during field investigations. The primary objective of this study was to strategically select sites for field investigation, sampling, and testing.

Following initial desktop studies, two field investigation programs were completed in 2014 and 2015. During these field investigations, 75 sites were visited and 42 samples were collected using a portable drill and tested for their ARD/ML potential. The tests included acid base accounting, solid-phase metal analysis, net acid generation test, shake flask extraction test and mineralogy by x-ray diffraction. The result of laboratory test results indicated a generally low potential for ARD/ML at sampled sites with the exception of one area where the potential is high.

The results of laboratory testing were later integrated with the desktop assessment results into an ARD geohazard framework for route Revision C. The result was a Project-wide ARD/ML profile ranking of the route into high, moderate, low, and no ARD/ML potential. The ARD geohazard assessment involved a detailed assessment of rock units based on their geological characteristics, types and amount of sulfides and carbonates present, mineral associations, reactivity, presence of known or presumed mineralized regions, geochemical test results from past investigations (by USGS, DGGS, etc.), and mapping of bedrock depth.

6.4.4.1 Liquefaction Facility

The Liquefaction Facility does not have the potential to encounter ARD/ML due to the depth of bedrock in the area and absence of outcrops.

6.4.4.2 Interdependent Project Facilities

Results of the ARD/ML Mainline assessment are based on geotechnical analysis completed in May 2016 and June 2016. The result of the ARD/ML assessment shows the Mainline has the potential to encounter ARD/ML and that:

- 4.49 miles of the route is classified as high ARD/ML; and
- 19.84 miles is classified as moderate.

Classifying areas into "low potential" and "no potential" does not necessarily eliminate the potential for elevated ARD/ML during construction. This assessment is limited by: sampling limitation; use of regional geological, mineralogical and geochemical characteristics of rocks; and depth of bedrock from terrain mapping.

The GTP, PBTL, and PTTL facilities do not have the potential to encounter ARD/ML. Preliminary pipeline locations with an elevated (high or moderate) ARD/ML potential are summarized in Table 6.4.4-1.

TABLE 6.4.4-1

Potential for Elevated ARD/ML Hazards along the Project Mainline (Route Revision C)

Borough/ Census Area	Division/ Physiographic Province	Start MP	End MP	Bedrock Geology			ARD/ML Potential
				Bedrock Code	Length (miles)	Geological Description of Formation	
North Slope Borough	Arctic Coastal Plain/Arctic Province	0.00	63.92	N/A	N/A	N/A	N/A
North Slope Borough	Arctic Foothills/Arctic Province	63.92	145.37	N/A	N/A	N/A	N/A
North Slope Borough	Arctic Foothills/Arctic Mountains Province	145.37	182.29	Dhw	0.17	Grey-green manganiferous shale and silstone; thin bedded, orange weathering subgreywacke, coquina lenses	Moderate
Yukon-Koyukuk Census Area	Arctic Foothills/Arctic Mountains Province	182.29	262.70	MzPzv	0.01	Pillow basalt, dark greenish grey and dark greenish black, fine grained, medium grained and locally coarse grained porphyritic, amygdaloidal and variolitic basalt, pillow baslt and pillow breccia with local blastoporphyritic albite	Moderate
Yukon-Koyukuk Census Area	Intermontane/Northern Plateaus Province	262.70	421.87	Tb	0.30	Basalt flows	Moderate
				TRPv	1.62	Extrusive and intrusive basaltic and doleritic rocks, tuff, chert, argillite, slate and rarely clastic limestone	Moderate
				Tvs	0.32	Conglomerate, sandstone, shale and basalt	Moderate
				TRMrs	0.75	Argillite, chert, greywacke, shale and limestone	Moderate
				TRMrv	0.01	Intrusive and extrusive mafic igneous rocks; a few intermixed sedimentary rocks	Moderate
				TRMrv	2.02	Intrusive and extrusive mafic igneous rocks; a few intermixed sedimentary rocks	High

TABLE 6.4.4-1

Potential for Elevated ARD/ML Hazards along the Project Mainline (Route Revision C)

Borough/ Census Area	Division/ Physiographic Province	Start MP	End MP	Bedrock Geology			ARD/ML Potential
				Bedrock Code	Length (miles)	Geological Description of Formation	
				CZwa	0.06	Maroon and green argillite, phyllite, quartzite, greywacke, siltite and phyllite	Moderate
				SZa	1.25	Siliceous dolomite, chert and basaltic greenstone and minor limestone, shale and siltstone	High
				CZum	0.16	Serpentinite and greenstone intruded by gabbro and diorite	High
				Kwc	11.60	Shale, siltstone, greywacke, conglomeritic greywacke and conglomerate	Moderate
Fairbanks North Star Borough	Intermontane/Northern Plateaus Province	421.87	424.21	Kwc	0.05	Shale, siltstone, greywacke, conglomeritic greywacke and conglomerate	Moderate
				TRm	0.66	Gabbro and dolerite sills and dykes	Moderate
Yukon-Koyukuk Census Area	Intermontane/Northern Plateaus Province	424.21	448.26	TRm	0.39	Gabbro and dolerite sills and dykes	Moderate
				Ofv	0.15	Alkali basalt, agglomerate and gabbro. Also includes shale, chert and limestone all intruded by gabbro	Moderate
Yukon-Koyukuk Census Area	Intermontane/Western Alaska Province	448.26	487.08	bc	0.17	Quartzite-sericite schist, quartzite, quartz-sericite-carbonate schist, locally green chloritic and epidotic schist and impure marble. Locally contains disseminated pyrite	Moderate
Denali Borough	Intermontane/Western Alaska Province	487.08	501.85	N/A	N/A	N/A	N/A
Denali Borough	Pacific Mountain/Alaska Aleutian Province	501.85	564.76	ss	0.03	Generally fine grained yellow, pale green and maroon schist and slate	Moderate
				Tn	0.01	Buff to reddish-brown, poorly consolidated, pebble to boulder conglomerate and coarse sandstone with interbedded mudflow feposits, thin claystone layers and local thin lignite beds	High
				Tcu	0.15	Coal bearing group, undivided	High
				bc	0.75	Quartzite-sericite schist,	Moderate

TABLE 6.4.4-1

Potential for Elevated ARD/ML Hazards along the Project Mainline (Route Revision C)

Borough/ Census Area	Division/ Physiographic Province	Start MP	End MP	Bedrock Geology			ARD/ML Potential
				Bedrock Code	Length (miles)	Geological Description of Formation	
						quartzite, quartz-sericite-carbonate schist, locally green chloritic and epidotic schist and impure marble. Locally contains disseminated pyrite	
				Tcv	0.05	Volcanic rocks sub unit	High
				TRbd	0.02	Basalt, dolerite and subordinate sedimentary rocks	Moderate
				Kms	0.24	Melange south of McKinley fault; limestone	High
Denali Borough	Pacific Mountain/Coastal Trough Province	564.76	575.44	N/A	N/A	N/A	N/A
Matanuska-Susitna Borough	Pacific Mountain/Coastal Trough Province	575.44	755.43	Qs	0.22	Surficial deposits	Moderate
				Kag	0.05	Argillite and Lithic Graywacke - Intercalated marine flysch-like sequence	Moderate
				Qm	0.61	Major moraine and kame deposits	High
				Kgd	2.50	Granodiorite	Moderate
Kenai Peninsula Borough	Pacific Mountain/Coastal Trough Province	755.43	806.57	N/A	N/A	N/A	N/A

6.4.4.3 Non-Jurisdictional Facilities

Neither the proposed PTU Expansion, nor the PBU MGS project, nor the Kenai Spur Highway relocation project impact areas with potential to encounter ARD/ML.

6.4.5 Naturally Occurring Asbestos (NOA)

NOA has recently become a concern in Alaska, and it has impacted state projects over the past several years. The term ‘asbestos’ refers to a variety of magnesium silicate minerals that naturally occur in fibrous form or ‘asbestiform.’ Accidental inhalation or ingestion of asbestos particles is known to cause or contribute to fibrosis and malignancies of the lung and other organs (Perkins et al., 2009).

Geologic environments that can host NOA minerals (Van Gosen 2007) include:

- Metamorphosed ultramafic rock;
- Metasomatized mafic volcanic and plutonic rocks;

- Metamorphosed dolostones;
- Metamorphosed iron formations; and
- Metasomatized alkaline igneous rocks.

Spatial distribution of bedrock in Alaska with the potential for NOA was recently published by USGS (Solie and Athey, 2015). Results of this study indicate that there are no known NOA hazards within the Project area.

6.4.5.1 Non-Jurisdictional Facilities

Neither the proposed PTU Expansion, nor the PBU MGS project, nor the Kenai Spur Highway relocation project would be within areas known for NOA.

6.4.6 Hydrologic Processes (Vertical Scour)

Hydrologic processes in both onshore and offshore environments cause erosion, which is the removal of earth materials such as soil, rocks, and sediments from a surface. When erosion occurs adjacent to constructed infrastructure, it is referred to as scour. Significant scour can lead to infrastructure failures through the destabilization of foundations or other impacts to a built environment. Other geologic hazards from hydrologic processes (erosion and scour) include channel migration, avulsion, and rapid lake drainage. The following sections discuss these processes and associated hazards as they relate to the Project.

6.4.6.1 Liquefaction Facility

Subsea erosion and scour could be a particular hazard in Cook Inlet due to extreme tidal fluctuations, strong currents, and high sediment loads (Thurston and Choromanski, 1995). Seafloor features in Cook Inlet undergo geomorphic processes that are highly influenced by these strong currents, including:

- Lag gravel: Residual deposit of coarse material that has had the finer fraction removed by a transporting agent, usually wind or water;

- Sand Ribbons: Strips of sand oriented parallel to prevailing tidal currents;

- Sand waves: Regular, repeated mounds or hills of sand typically oriented perpendicular to prevailing currents; and

- Comet marks: Erosional tail of lag gravel behind a seafloor obstruction.

Onshore erosion due to surface drainage can damage slopes, roads, stormwater infrastructure, and, in extreme cases, buried facilities; this risk is managed through site grading and drainage infrastructure (e.g. ditches, culverts, and erosion control best management practices [BMPs]). Erosion and scour hazards anticipated in Cook Inlet are discussed further in Resource Report No. 2.

6.4.6.2 Interdependent Project Facilities

Preliminary locations within the Mainline where the potential for damaging hydrologic processes is anticipated to be high are summarized in Table 6.4.6-1.

TABLE 6.4.6-1

Areas Susceptible to Vertical Scour, Channel Migration, Avulsion and Rapid Lake Drainage in the Project Area

Borough/Census Area	Ecoregion	Start MP	End MP	Length (miles)	Length (percent)
North Slope	Beaufort Coastal Plain	0.00	63.92	0.25	0.4%
	Beaufort Coastal Plain	63.92	145.37	1.10	1.4%
	Beaufort Coastal Plain	145.37	182.29	9.10	24.6%
Yukon-Koyukuk	Kobuk Ridges and Valleys	182.29	262.70	3.20	4.0%
	Ray Mountains	262.70	421.87	3.00	1.9%
Fairbanks North Star	Ray Mountains	421.87	424.21	0.00	0.0%
Denali	Tanana-Kuskokwim Lowlands	501.85	564.76	0.29	1.2%
	Tanana-Kuskokwim Lowlands/Alaska Range	564.76	575.44	0.92	2.4%
	Alaska Range	575.44	755.43	0.21	1.4%
Kenai Peninsula	Cook Inlet Basin	755.43	806.57	0.99	1.6%

Source: WorleyParsons, 2016.

Multiple stream channel crossings occur along the proposed Mainline, as described in Resource Report No. 2. Bank and channel erosion are naturally occurring processes that can pose a hazard to pipeline infrastructure. Additionally, channel migration is a natural process that may be exacerbated by the burial of a pipeline, as this can promote the mobilization of loosened sediments. The scour of sediments around a buried pipeline or underlying pipe bridge supports can, in extreme cases, lead to undercutting the pipeline, leaving the pipeline unsupported (spanning).

Typically, pipelines are buried at sufficient depth to avoid most terrestrial erosion concerns. However, seasonal or flash flooding (e.g., catastrophic increase in stream discharge) can lead to extensive scour, exposing buried pipe, or undercutting pipe bridge supports, unless facilities are properly designed. Flooding hazards exist during the spring thaw, when melting snow and ice combines with increased precipitation, leading to high stream discharges and increased stream loads. Ice dams are also common during spring thaw, and their failure can lead to flash flooding. Mobilized stream ice from the breakup of an ice dam or aufeis (ice overflow) poses an additional threat due to potential ice scour.

Table 6.4.6-2 summarizes preliminary lengths of the Mainline where flooding is anticipated (WorleyParsons, 2015). Additional discussions on flooding are addressed in Section 2.5 of Resource Report No. 2.

TABLE 6.4.6-2

Flooding Hazards along the Project Mainline Route C

Borough/Census Area	Ecoregion	MP (from)	MP (to)	Flooding Hazard Length (miles)
North Slope	Beaufort Coastal Plain	0	63.92	0.00%
		63.92	145.37	0.00%
	Beaufort Coastal Plain/Brooks Range	145.37	182.29	0.00%
Yukon-Koyuk	Kobuk Ridges and Valleys/	182.29	262.7	1.13
	Ray Mountains	262.7	421.87	0.00%
Fairbanks North Star		421.87	424.21	0.00%
Yukon-Koyuk		424.21	448.26	0.00%
		448.26	487.08	4.61
		487.08	501.85	0.71
Denali	Ray Mountains/Tanana Kuskokwim Lowlands	501.85	564.76	2.78
		564.76	575.44	0.00%
	Tanana Kuskokwim Lowlands	575.44	755.43	0.67
	Alaska Range	755.43	806.57	0.00%
Matanuska-Susitna	Alaska Range	0	63.92	0.00%
	Alaska Range/Cook Inlet Basin	63.92	145.37	0.06
Kenai Peninsula	Cook Inlet Basin	145.37	182.29	00.00%
Source: WorleyParsons, 2015.				

With the exception of three open-cut river crossings, the PTTL would be elevated above the floodplain, thereby limiting potential impacts from hydrologic processes such as scour or erosion. Similarly, the PBTL is unlikely to be inundated during most flood events and would likely not be impacted by hydrologic processes. Additional discussions on flooding are addressed in Section 2.5 of Resource Report No. 2.

The GTP would not be located in a 500-year (0.2 percent annual probability) floodplain, and there are no waterbodies located at the site. It is not anticipated that floodplain processes or hydrologic processes such as scour or erosion would be affected by construction or that the construction footprint would be prone to flooding. Additional discussions on flooding are addressed in Section 2.5 of Resource Report No. 2.

6.4.6.3 Non-Jurisdictional Facilities

Both the PTU Expansion project and the PBU MGS project would be located within the Beaufort Coastal Plain Ecoregion and the Flaxman Island Sub-basin. This area does experience seasonal local flooding (shallow sheet flow) during spring thaw ("break-up"). No Federal Emergency Management Agency floodplain delineation exists for this area, and other sources of information on site-specific flooding are limited. Existing and new facilities at Point Thomson have been designed to address hydrologic conditions documented in multi-year, site-specific studies to ensure natural cross and stream flows are maintained throughout the year. Additional information related to potential impacts associated with flooding in the Beaufort Coastal Plain Ecoregion are provided in Section 2.5 of Resource Report No. 2

The Kenai Spur Highway relocation project area is similar to the description for the onshore Liquefaction Facility and susceptible to similar hazards.

6.4.7 Potential Construction Impacts and Mitigation Measures

Adverse effects to the Project resulting from geologic hazards, or increases to geologic hazard risks due to construction, would be avoided or greatly reduced through route selection, engineering design, monitoring, and agency consultation. In addition to these reports, industry BMPs and engineering design would be used to prevent or mitigate adverse effects wherever possible. Overarching construction environmental management plans and operations environmental management plans would be prepared for the Project.

The following sections briefly summarize construction impacts and mitigations for geohazards anticipated at the Liquefaction Facility and Interdependent Project Facilities.

6.4.7.1 Liquefaction Facility

6.4.7.1.1 Surface and Subsurface Geology

Adverse effects to surface and subsurface geology would occur during site development. Impacts would be minor, including displacement of sediment changes to drainage patterns, but would remain during operation of the Liquefaction Facility. Facility design would consider site surface and subsurface geology, including sediment structure and texture and drainage patterns.

6.4.7.1.2 Seismicity Hazards

6.4.7.1.2.1 Fault Rupture Displacement

The Liquefaction Facility would not be located above any known active faults, and thus fault rupture displacement is not anticipated to be a hazard for this facility. However, mitigation strategies would be considered in the design of the Liquefaction Facility to reduce fuel spills. These strategies may include use of thick reinforced concrete mat foundations to prevent damage from underlying ground movements and increasing the flexibility of fuel storage facilities rigid attachments.

6.4.7.1.2.2 Seismic Wave Propagation

Ground shaking from seismic wave propagation is a significant potential hazard during construction of the Liquefaction Facility. Potential exists for damage to facility components, equipment, and construction personnel if a major earthquake would strike during the construction process. Ground shaking can occur from earthquakes on proximal crustal faults, as well as earthquakes from the Aleutian subduction zone.

The facilities would be designed to withstand the anticipated forces based on the probabilistic seismic hazard analysis (Fugro Consultants, Inc. [Fugro]. 2015c. Alaska LNG Facilities Seismic Hazard Analysis. Report No. USAL-FG-GRHAZ-00-002015-001).

6.4.7.1.2.3 Soil Liquefaction

All potential adverse soil liquefaction effects caused by an earthquake during construction would likely be localized and discontinuous. Soil liquefaction could potentially occur on a local scale due to vibratory construction activities. Areas known to be prone to soil liquefaction would be assessed in advance. Areas found to be susceptible to soil liquefaction would be avoided to the extent possible. If it is necessary to construct on soils prone to liquefaction, the Liquefaction Facility structures would be constructed using piles for settlement-sensitive structures with high lateral loads (Fugro Consultants, Inc. [Fugro]. 2015b. Alaska LNG Facilities Seismic Engineering Report. Report No. USAL-FG-GRZZZ-00-002015-003).

6.4.7.1.2.4 Tsunamis and Seiches

Tsunamis and seiches are not anticipated to be significant hazards during Liquefaction Facility construction, except for initial marine facility construction along the beach and in nearshore water. A tsunami's impact is dependent on basin bathymetries and coastline configurations and can, in particular, depend on tsunami-tide interactions (Kowalik and Proshutinsky, 2009). Cook Inlet's strong tides may intensify or dampen a tsunami, depending on mean basin depth, which is regulated by tides.

6.4.7.1.3 Volcanism

The volcanoes in the vicinity of the Project area are listed in Table 6.4.2-1. Cook Inlet separates these four volcanoes from the Kenai Peninsula, where the Liquefaction Facility would be located. The most significant potential hazard that these volcanoes could pose to the Project is ashfall. Many of the other volcanic hazards, such as lahars, lava flows, or pyroclastic flows, are not a significant concern to the Liquefaction Facility area due to (1) the distance from the volcanoes and (2) the separation provided by Cook Inlet.

In the event of ashfall due to a volcanic eruption, every precaution would be taken to reduce damage to equipment, facilities, and personnel, including use of personal protective equipment or even evacuation of personnel, as necessary. The effects of this hazard would be temporary as it could cause delays to the Project construction schedule.

6.4.7.1.4 Mass Wasting

6.4.7.1.4.1 Falls, Slides and Slumps

The Liquefaction Facility would be located on fairly flat and stable ground where falls and slides are not considered a hazard. Slumps from coastal erosion processes along the western edge of the site are possible, though not considered a significant threat to the Project as the facilities would be located sufficiently inland from the bluff to allow for both natural erosion or sluffing due to seismic activity. Design of the heavy haul road in this area would take into consideration the potential for slumps with any required ground improvements.

6.4.7.1.4.2 Flows

The Liquefaction Facility would be located on fairly flat and stable ground without major topographical features. Therefore, mudflows are not considered to be a risk at this location.

6.4.7.1.4.3 Avalanches

The Liquefaction Facility would be located on fairly flat and stable ground without major topographical features. Therefore, avalanches are not considered to be a risk at this location.

6.4.7.1.4.4 Creep and Solifluction

Creep and solifluction are not anticipated to be a hazard at the Liquefaction Facility, because permafrost is absent in this location. Solifluction is addressed in more detail in Resource Report No. 7.

6.4.7.1.4.5 Rock Glaciers

The Liquefaction Facility would be located on fairly flat and stable ground without major topographical features. Therefore, rock glaciers are not considered to be a risk at this location.

6.4.7.1.4.6 Frozen Debris Lobes (FDLs)

FDLs are not a potential hazard in the vicinity of the proposed Liquefaction Facility.

6.4.7.1.4.7 Subsidence

Subsidence hazards are not expected to be a concern at the Liquefaction Facility during construction. Regional subsidence is unlikely to occur in the Project area and the potential for localized collapse features to develop in the Project area is low. In the unlikely event of a collapse structure developing beneath any pipelines in the Liquefaction Facility, the strength and ductility of the pipeline could allow it to span over short distances without threatening the integrity of the pipeline. Thaw-settlement may occur in localized areas, as discussed in Resource Report No. 7.

Based on geologic origins and supported by geologic field mapping, no karst collapse hazards occur in the vicinity of the Project; therefore, karst collapse around the Liquefaction Facility would be unlikely.

Subsidence hazards are addressed in more detail in Resource Report No. 7.

6.4.7.1.5 Acid Rock Drainage

Preliminary research and field reconnaissance has shown that ML/ARD is not a concern for the Liquefaction Facility area.

6.4.7.1.6 Hydrologic Processes (Vertical Scour)

There are no identified flowing waterbodies within the proposed footprint of the LNG Plant. Therefore, vertical scour is not considered to be a risk at this location.

Risks due to coastal erosion processes would be assessed and standard coastal engineering shoreline protection measures such as breakwaters, rip-rap, armor stone blankets, or beach nourishment would be considered as potential alternatives to address any risk of shoreline erosion that may endanger the Liquefaction Facility.

6.4.7.2 Interdependent Project Facilities

Interdependent Project Facilities considered in the following discussions include pipelines (PTTL, PBTL, and Mainline) and the GTP.

6.4.7.2.1 Seismicity Hazards

6.4.7.2.1.1 Fault Rupture Displacement

Fault zones have been identified near the proposed Project area considered critical for potential facility strain and stress from dynamic ground motion associated with earthquakes. The pipeline would be realigned to cross active faults in the safest manner possible. All pipelines and associated facilities would be designed to withstand the predicted levels of ground deformation and incorporate current seismological engineering standards where applicable. Aboveground facilities would be sited to avoid known faults or features that would propagate impacts from a fault (see Resource Report No. 10 on facility siting).

Fault crossings for the Mainline will be constructed aboveground in an unrestrained configuration on sliding supports to avoid complications presented by frozen soil and chilled gas operation. However, for certain faults with relatively minor design displacements, it may be feasible to cross them with a berm constructed with well drained uniform-graded gravel or crushed rock backfill. In other cases, an aerial crossing would be recommended. Proposed mitigation ranges from above-ground crossing on sleepers using sliding pipe shoes (similar to the design of the Denali Fault crossing on TAPS) to aerial crossing of a steep ravine near Lynx Creek. These fault-crossing designs are expected to reduce fault displacement hazard to an acceptable level.

A commentary on possible design strategies for each confirmed or potential fault crossing would be as follows:

- Northern Foothills Thrust fault (~MP 500.04 to 500.61). Current characterization of this fault defines multiple splays distributed over a pipeline crossing width of approximately 3,000 ft. Unless the fault splays can be located rather precisely (within about 50 to 100 ft.), design of a trapezoidal aboveground configuration similar to TAPS is expected. If the fault splays can be located with precision, a berm crossing may be feasible.

- Stampede-Little Panguingue Creek faults (~519.96 to 520.96). This fault is potentially active, but whether or not it intersects the pipeline is uncertain. Further field investigation is required to be undertaken, and if determined to be active and intersect the route, a crossing design will be required.

- Healy Creek fault (~MP 522.41 to 522.52). Investigation to date has failed to confirm that this fault extends to the pipeline route. Further field investigation is required to be undertaken, and if determined to be active and intersect the route, a crossing design will be required.

- Healy fault (~526.91 to 527.02). Investigation to date has failed to confirm that this fault extends to the pipeline route. Further field investigation is required to be undertaken, and if determined to be active and intersect the route, a crossing design will be required.

- Park Road fault (~MP 538.01 to 538.24). The current route alignment would cross this fault near Lynx Creek, which is incised in a deep canyon. Based on current knowledge, an aerial crossing, likely a suspension bridge similar to the TAPS crossing at the Tazlina River, would be designed. A route alternative west of the Nenana River alongside the Parks Highway through Denali Park is under consideration which would simplify the fault crossing design if adopted. The fault is well-constrained in DNP at that location and crosses the highway near Riley Creek.

- Denali fault (~560.31 to 561.49). The fault is crossed east of the Nenana River where the location of the fault is well-established, and the crossing zone can be minimized to a length of about 1000 ft. To ensure that the crossing zone would span the possible surface location, it would be necessary to extend an aboveground crossing over a length of about 2,600 feet. The aboveground crossing configuration would be similar to TAPS.

- Castle Mountain fault (~MP 743.21 to 743.40). Based on geologic investigation completed thus far, the most likely intersection point is near MP 743.3. A crossing configuration would be aboveground in a configuration similar to TAPS Denali crossing.

The remaining onshore faults are much shorter in length with associated reduced rupture hazard. The two offshore fault features do not require special design. Additional mitigation strategies would be decided on a case-by-case basis and would be outlined in more detail in Appendix G.

If a fault rupture occurs during construction of the Mainline, no significant impacts to the existing environment from the Project are anticipated. After an earthquake occurs, the integrity of completed portions of the line would need to be inspected and repairs made as necessary to ensure that it would still be structurally sound prior to regular operations. The effects of the Project on the natural environment due to this hazard would be minor to nonexistent and temporary, so long as inspections and repair procedures are followed.

There are no known Holocene active fault lines north of the Brooks Range where the GTP facility and PTTL and PBTL would be located. The risk of a fault rupture occurring underneath one of these facilities would be extremely low. However, in the event of a contaminable fuel or fluids spill caused by fault rupture displacement, general mitigation measures to limit or control impacts would be followed, including the construction and operations of structures to provide edge containment to prevent large lateral spreading.

6.4.7.2.1.2 Seismic Wave Propagation

Very small strains on the pipeline from seismic wave propagation during construction are predicted. Seismic waves that could affect the Interdependent Project Facilities during construction could cause safety concerns or delays to the Project, but no significant impacts to the existing environment would result due to the Project. The integrity of completed portions of pipelines and structural facilities would need to be inspected and repairs made as necessary to ensure that they would still be structurally sound after an earthquake.

6.4.7.2.1.3 Soil Liquefaction

Liquefaction could cause catastrophic loss of strength along any of the Interdependent Project Facilities. The Project area was characterized to identify potential areas of significant lateral spreading and/or buoyancy, discussed in Section 6.4.1.5.2 (Table 6.4.1-3). Susceptible areas identified are primarily in floodplains associated with waterbodies. The mitigation options selected to address lateral spread at watercourse crossings may involve modified burial depth and crossing geometry at conventional trenched crossing locations. To address areas of potentially liquefiable materials, mitigation may include techniques such as interceptor ditches and vertical drains. Techniques would be developed on a case-by-case basis as additional data becomes available and engineering design is refined.

All potential adverse soil liquefaction effects caused by a large and prolonged earthquake during construction could be considered significant.

Soil liquefaction could potentially occur on a local scale due to vibratory construction activities. These effects would likely be minor and temporary. General mitigation measures would be adhered to in order to limit or control impacts caused by liquefiable soils including:

- In situ stabilization by ground densification;
- Construction of structures to provide edge containment to prevent large lateral spreading;
- Construction of deep foundations; and
- Reinforced shallow foundations.

Soil liquefaction is not believed to be a risk in the Beaufort Coastal Plain Ecoregion due to lower earthquake frequency and intensities, as well as widespread continuous bonded permafrost. Therefore, this hazard would have no effect on the GTP, PTTL, and PBTL facilities or associated infrastructure.

6.4.7.2.1.4 Tsunamis and Seiches

Tsunami/seiche may affect the Mainline in the vicinity of the Cook Inlet crossing. Details will be provided prior to the DEIS issuance.

Tsunamis and seiches are not anticipated to be significant hazards within the GTP, PTTL, or PBTL facilities and associated infrastructure area.

6.4.7.2.2 Volcanism

The volcanoes in the vicinity of the Project area are listed in Table 6.4.2-1. Given the distance of these volcanoes from the Project, most adverse effects of volcanism are not expected. The most-significant potential hazard that these volcanoes could pose to the Project is ashfall. Should there be ashfall related to an eruption, every precaution would be taken to reduce damage to equipment, facilities, and personnel, including use of personal protective equipment or even evacuation of personnel, as necessary. The effects of this hazard would be temporary, because it could cause delays to the Project construction schedule.

The nearest volcanoes are located in the Kenai Peninsula Borough, more than 40 miles from the proposed Mainline at the closest point, and are not considered a hazard to the proposed GTP, PTTL, or PBTL facilities and associated infrastructure.

6.4.7.2.3 Mass Wasting

Pipeline milepost ranges prone to mass wasting are listed in Table 6.4.3-1. To the extent practicable, general mass wasting avoidance measures would be adhered to, including:

- Avoiding preexisting landslides;
- Avoiding cutting into steep, sidelong ground;
- Ensuring that permanent stabilization and drainage measures are constructed where cuts are required;
- Maximizing the use of stable ridgelines and plateaus;
- Routing preferentially along ridges by using slopes with steep ascents and descents along stable spurs; and
- Ensuring that the design of river and stream crossings account for possible river bank undercutting.

When crossing identified potential landslide areas, to the extent practicable:

- Construction impacts to slope stability would be mitigated;
- Drainage would be installed to lower the water table in the slope, thereby reducing the driving force in the slide; and
- Engineered structures would be constructed to provide additional resistance against movement, if deemed necessary.

Additionally, the area would be monitored using visual techniques, surface monuments, inclinometers, piezometers, and/or aerial photography.

6.4.7.2.3.1 Falls, Slides, and Slumps

To reduce the effects from landslides, the pipeline route selection criteria includes avoiding steep slopes, minimizing exposure to unstable landforms, and following the fall line (perpendicular to the slope contour) when traversing a slope, as discussed in Resource Report No. 10 Section 10.1.1.1 Feasibility Analysis. By following existing or previously studied corridors, the large majority of potential slope instability hazards have been avoided. If areas prone to these effects are unavoidable, the primary risk during construction would be to personnel and equipment. Safety plans would be in place to protect workers from exposure.

The risk of the Project causing a fall, slide, or slump is low. Environmental impacts from falls, slides, and slumps during construction are limited to areas of potential static and dynamic instability. The effects of this occurrence would be temporary, but likely significant to the immediate area of occurrence. Appropriate erosion control measures would be installed during and following construction to mitigate landslides and slope instability. Mitigation plans for areas prone to deep-seated landslides would be included in Appendix G.

Falls, slides, and slumps are not considered to be a serious risk to the proposed GTP, PTTL, or PBTL facilities located in the Beaufort Coastal Plain Ecoregion due to low relief. Risks due to coastal erosion processes would be assessed and standard coastal engineering shoreline protection measures such as breakwaters, rip-rap, armor stone blankets, or beach nourishment would be considered as potential alternatives to address the risk of shoreline erosion that may endanger the GTP, PTTL, and PBTL. The only infrastructure with offshore contact associated with the GTP would be West Dock, which would be protected from coastal erosion through the placement and use of bags filled with granular material along the shoulder of the causeway as discussed in Resource Report No. 10 Section 10.5.7.1 West Dock.

6.4.7.2.3.2 Flows

Debris flows and mudflows can mobilize due to heavy and/or prolonged rainfall events. If these occur, they can pose a risk to Project personnel and equipment. Areas prone to these flows would be evaluated and construction activities postponed (or other safety measures enacted as necessary) if weather conditions create an increased risk of flows. Additional mitigation strategies are outlined in Appendix H.

Pipeline associated facilities could be at risk due to mudflows, as these flows could potentially damage aboveground facilities. This effect would be significant, adverse, and direct. To mitigate this, every precaution would be taken to minimize exposure to possible flows by locating and designing facilities outside of potential high-risk mudflow and debris flow areas.

Construction of the Mainline is not anticipated to increase the risk of a flow event occurring.

Flows are not considered to be a risk to the GTP, PTTL, or PBTL facilities on the shallow and flat coastal plains of the Beaufort Coastal Plain Ecoregion.

6.4.7.2.3.3 Avalanches

Snow avalanche chutes and slushflow avalanche chutes (some of which are collocated) cross the Project area, as identified in Table 6.4.3-1. Avalanches are a potential hazard in all mountainous regions where the pipeline or aboveground facilities would be located near the bottom of an avalanche chute. Specific areas, such as Atigun Pass, would be addressed in the design process to incorporate appropriate mitigation measures. Avalanches can occur naturally or can be initiated by human activities. Vibrations, such as those caused by blasting or heavy machine work, may act to trigger avalanches during construction.

For those areas along the proposed Mainline that are avalanche-prone, precautions would be taken to ensure that personnel would be protected. These precautions would include constructing only in the summer, inspecting snow conditions with snow pits or other means to assess current risk conditions, or intentionally attempting to set off avalanches prior to beginning work in the runout area. If the Project crosses through avalanche-prone zones in populated areas, additional precautions would be taken to ensure that the public are kept out of harm’s way during construction activities.

The potentially large run-out distances for snow avalanches during selection of sites for aboveground facilities, parking and storage areas, and materials sites in mountainous terrain would be considered.

The effects of an avalanche would be significant and direct, but temporary. Additional avalanche risk mitigation techniques are discussed in Appendix H.

Avalanches are not considered to be a risk to the GTP, PTTL, or PBTL facilities.

6.4.7.2.3.4 Creep and Solifluction

During the summer thaw season in the Arctic and Subarctic, thawing ice-rich soils on slopes may be susceptible to creep and solifluction. For a full discussion of this and other frozen soils-related geohazards for the Project, see the Permafrost discussion in Resource Report No. 7.

6.4.7.2.3.5 Rock Glaciers

Based on preliminary assessments, known rock glaciers along the Mainline would not have an impact due to the slow rate of movement.

Rock glaciers are not considered to be a risk to the GTP, PTTL, or PBTL facilities located in the Beaufort Coastal Plain Ecoregion.

6.4.7.2.3.6 Frozen Debris Lobes

The advance of FDLs could become a geologic hazard in the Mainline in certain segments of the southern Brooks Range. At least one FDL in particular is currently within 200 feet of the Dalton Highway, and has been advancing toward the highway/Mainline at approximately 150 feet per year for multiple years (Daanen et. al., 2012). If an FDL reaches the Mainline, environmental impacts may include the deposition of many tons of rock, sediment, soil, and debris on the corridor daily. The Project representatives would work with the ADOT&PF on routing through this area and the measures to take to protect the pipeline.

No known FDLs exist within the vicinity of the GTP, PTTL, or PBTL facilities.

6.4.7.2.3.7 Subsidence

Subsidence hazards are addressed in more detail in Resource Report No. 7, including thaw-settlement anticipated throughout the northern portions of the Project corridor.

Review of available route data indicates no evidence of shallow karst features prone to collapse beneath the Mainline. Likewise, there are no known underground mines along the route that may pose a collapse hazard. In the unlikely event of a collapse structure developing beneath the pipeline, the strength and ductility of the pipeline could allow it to span a short distance without threatening the integrity of the pipeline.

Review of available data indicates no evidence of shallow karst features or known underground mines within the area of the GTP, PTTL, or PBTL facilities located in the Beaufort Coastal Plain Ecoregion.

Specific geotechnical studies would be conducted as necessary to characterize subsurface conditions, and ground would be compacted as necessary as part of the construction process of buildings and associated infrastructure. Due to these standard engineering precautions and design and construction process, any effects from subsidence hazards caused by the Project facilities would likely be of minor significance, although they may develop over a long-term or permanent timespan.

6.4.7.2.4 Acid Rock Drainage

Preliminary pipeline locations with an elevated (high or moderate) ARD/ML potential are summarized in Table 6.4.4-1. Construction activities along the Mainline, infrastructure, and facilities (e.g., roads, compressor stations, etc.) may be affected to different degrees by ARD/ML if these activities expose or disturb the bedrock or formation containing coal seams. For example, environmental impacts from the effect of ARD/ML on construction on the North Slope would be negligible to null because the bedrock is deep and is unlikely to be exposed during construction or operation. Conversely, construction activities in areas classified as high or moderate ARD/ML would be impacted where it is found during pre-construction sampling.

ARD/ML mitigations and control measures would be based on the geochemical characteristics and behavior of the rock excavated and may include the following:

- Segregation of rocks with potential for ARD/ML from benign rock;
- Protection (cover) of the grade, ditch, and exposed slopes at ARD sites with low permeability clay, soil, or impervious layer (or a combination of these) to prevent water and oxygen contact with reactive rock;
- Design and construction of stockpiles for the long-term storage of excavated ARD/ML material;
- Diversion of surface runoffs away from ARD/ML sites and stockpile and the collection and testing of contact water before release into the environment; and

- Monitoring measures at ARD/ML sites.

Potential ARD/ML effects due to construction of the Mainline and associated facilities would generally be temporary in duration, as excavation would be filled back in as the pipeline construction is completed. As previously stated, ARD/ML effects are expected to be negligible to null on the North Slope, so are not considered to be a hazard for the GTP, PTTL, PBTL, or associated facilities.

6.4.7.2.5 Hydrologic Processes (Vertical Scour)

Areas susceptible to vertical scour, channel migration, avulsion and rapid lake drainage along the Mainline are summarized in Table 6.4.6-1. Potential flooding hazards along the Mainline are also summarized in Table 6.4.6-2. The Applicant's *Plan* and *Procedures* would be adhered to during construction of the Pipeline Facilities to avoid and mitigate the potential for erosion and scour. In addition, site-specific waterbody crossing plans would be developed, as applicable. Further details can be found in Resource Report No. 2, Appendix I (Site-Specific Waterbody Crossing Plans).

Vertical scour is not considered a hazard to the GTP, PTTL, or PBTL facilities.

6.4.7.3 Non-Jurisdictional Facilities

Both the PTU Expansion project and the PBU MGS project have a low risk of construction-related geologic hazards associated with seismic hazards, volcanism, mass wasting, and acid rock drainage. Potential erosion and scour impacts associated with flooding in the Beaufort Coastal Plain Ecoregion are provided in Section 2.5 of Resource Report No. 2.

The Kenai Spur Highway relocation project area is similar to the area described for the Liquefaction Facility and susceptible to the same geohazards.

6.4.8 Potential Operational Impacts and Mitigation Measures

Adverse effects to the operation of the Project (design life 30 years) resulting from geologic hazards, or increases to geologic hazard risks due to operation of the Project, would be avoided or greatly reduced through engineering design and monitoring.

Completed geological hazard assessments (Appendix H) detail potential operational impacts and mitigations for the Project associated with geohazards. In addition to these plans, industry BMPs and engineering design would be used to prevent or mitigate adverse effects wherever possible.

The following sections briefly summarize operational impacts and mitigations for geohazards anticipated at the Liquefaction Facility and the Interdependent Project Facilities and associated infrastructure).

6.4.8.1 Liquefaction Facility

6.4.8.1.1 Seismicity Hazards

Site-specific seismic hazard design criteria specific to the Liquefaction Facility are included in Resource Report No. 13. This includes measures to mitigate the potential loss of containment.

6.4.8.1.1.1 Fault Rupture Displacement

The Liquefaction Facility would not be located above any known active fault lines; therefore, this is not anticipated to be a hazard for this facility. However, mitigation strategies would be included in the design of the Liquefaction Facility. These strategies may include use of thick reinforced concrete mat foundations to prevent damage from underlying ground movements.

6.4.8.1.1.2 Seismic Wave Propagation

Ground shaking from seismic wave propagation is a significant potential hazard during operation of the Liquefaction Facility. The potential exists for damage to facility components, equipment, and personnel if a major earthquake struck during operation. Ground shaking can occur from earthquakes on proximal crustal faults, as well as earthquakes from the Aleutian subduction zone.

Site-specific structural engineering analysis would be performed to ensure that all buildings and infrastructure associated with the Liquefaction Facility would meet current design codes (International Building Code [IBC] for buildings and the American Association of State Highway and Transportation Officials) for seismic wave propagations associated with design-level seismic events in the Nikiski area (ASCE 7-05 and Marine Oil Terminal Engineering and Maintenance Standards (MOTEM)). These codes ensure that buildings are able to withstand the forces associated with these seismic events. If a large earthquake would occur such that inspections are warranted, all facilities associated with the Liquefaction Facility would be inspected for structural integrity and repairs made as necessary. Any effects that would occur could be significant, but temporary, in nature, as long as all appropriate repairs are made if damage occurs.

6.4.8.1.1.3 Soil Liquefaction

It is not anticipated that operational activities at the Liquefaction Facility would cause soil liquefaction. Soil liquefaction may occur as a result of a large or prolonged earthquake event. Site-specific structural and geotechnical engineering analyses would be performed to ensure that all buildings and infrastructure associated with the Liquefaction Facility are designed to meet current design codes for liquefaction effects associated with seismic events. If soil liquefaction associated with a large earthquake occurs, all facilities associated with the Liquefaction Facility would be inspected for structural integrity and repairs made as necessary. Additional measures may be developed as engineering design progresses and may be included in Appendix H (Geological Hazard Assessments).

6.4.8.1.1.4 Tsunamis and Seiches

Tsunamis and seiches are not anticipated to be a hazard during operation of the Liquefaction Facility. The anticipated design tsunami wave run-up at Nikiski is estimated to be the +35 foot mean lower low water contour. The bluff along the Liquefaction Facility site's shoreline would be affected by a tsunami run-up.

6.4.8.1.2 Volcanism

Ashfall is the only likely volcanic hazard that poses a threat to Project operations near the Liquefaction Facility, and this has been factored into the design. Should there be ashfall related to an eruption during operations, every precaution would be taken to reduce damage to equipment and facilities and injury to personnel. If very heavy ashfall is expected during a particular volcanic eruption, certain nonessential operations may be temporarily and partially shut down at the Liquefaction Facility. There is potential for ashfall to reach the Liquefaction Facility and for ash to reach machinery through air intake valves or other openings and damage or destroy machines.

6.4.8.1.3 Mass Wasting

6.4.8.1.3.1 Falls, Slides and Slumps

In accordance with the *Upland Erosion Control, Revegetation, and Maintenance Plan* (the Applicant's *Plan*), appropriate erosion control measures would be installed as required to mitigate slope instability (see Appendix H – Geological Hazard Assessments). However, the Liquefaction Facility would be located on relatively flat, stable ground and this is not expected to pose a risk to operations.

A geotechnical analysis was completed to assess the risk from deep-seated landslides. Any risks to the Liquefaction Facility due to deep-seated landslides will require a site-specific plan, which is included in Appendix H (Geological Hazard Assessments).

In accordance with the Applicant's *Plan*, appropriate erosion control measures would be installed during and following construction to mitigate landslides and slope instability. During operations, an Integrity Management Program would be implemented, as identified in Resource Report No. 11.

6.4.8.1.3.2 Flows

The Liquefaction Facility would be located on fairly flat and stable ground without major topographical features. Therefore, debris flows and mudflows are not considered to be a risk at this location.

6.4.8.1.3.3 Avalanches

The Liquefaction Facility would be located on fairly flat and stable ground without major topographical features. Therefore, avalanches are not considered to be a risk at this location.

6.4.8.1.3.4 Creep and Solifluction

Creep and solifluction are not anticipated to be a hazard during operation of the Liquefaction Facility, as no permafrost conditions exist at this proposed location.

6.4.8.1.3.5 Rock Glaciers

The Liquefaction Facility would be located on fairly flat and stable ground without major topographical features. Therefore, rock glaciers are not considered to be a risk at this location.

6.4.8.1.3.6 Frozen Debris Lobes

There are no FDLs in the vicinity of the proposed Liquefaction Facility, so they are not a potential hazard.

6.4.8.1.3.7 Subsidence

There is no known history of subsidence in the proposed Liquefaction Facility area. Geophysical and geotechnical investigations indicate the majority of the subgrade materials are dense sands and gravels not generally susceptible to subsidence. Subsidence is not anticipated to represent a potential hazard.

6.4.8.1.4 Acid Rock Drainage

Preliminary research and field reconnaissance has shown that ML/ARD is not a concern for the Liquefaction Facility area.

6.4.8.1.5 Hydrologic Processes (Vertical Scour)

There are no identified flowing waterbodies within the footprint of the Liquefaction Facility. Therefore, vertical scour is not considered to be a risk at this location.

Impacts to operations from coastal erosion could include delays to marine or other terminal processes. If this were to occur, the effect would be significant and adverse, but depending on severity and the required repair measures that would result, the effect duration could range from temporary to long-term, especially if the erosion is a recurring problem. However, risks due to coastal erosion processes would be assessed as part of the design process to elevate the Marine Terminal above storm wave heights and standard coastal engineering shoreline protection measures such as breakwaters, rip-rap, armor stone blankets, or beach nourishment would be considered as potential alternatives to address any risk of erosion of the shoreline that may endanger the Liquefaction Facility. Erosion and scour risks are further discussed in Resource Report No. 2 and in Appendix G.

6.4.8.2 Interdependent Project Facilities

Interdependent Project Facilities considered in the following discussions include Pipelines (PTTL, PBTL, and Mainline) and GTP.

6.4.8.2.1 Seismicity Hazards

A discussion of site-specific seismic hazard design specific to the Pipeline, including consultations with PHMSA, is included in Resource Report No. 11.

6.4.8.2.1.1 Fault Rupture Displacement

If an earthquake would occur along a fault during operation of the Mainline and the pipeline ruptures, then a significant, direct, adverse effect would occur due to a gas leak or the spilling of stored fuel at the pipeline aboveground facilities into the existing environment. Depending on the severity of the rupture and the amount of spilled liquids, the effect could be temporary to short-term. The primary mitigation for this potential effect is proper engineering design to withstand these forces, storage tanks set on firm foundations, and protective berms around the fuel storage facilities to prevent this from occurring at all. Clean-up activities conducted in accordance with the *Spill Prevention, Control, and Countermeasure Plan* (see Resource Report No. 2), along with repairs to the storage facility and further engineering to prevent a repeat occurrence would complete this mitigation strategy.

A fault displacement rupture along the Mainline would be primarily mitigated by avoidance. Facilities would be intentionally located at sites with very low likelihood of surface fault rupture. However, in the instances in which the Mainline pipeline must cross areas where surface fault rupture is more likely, designs, including pipeline above ground on sleepers, as well as route optimization for proper orientation of pipe relative to fault movement would be used as mitigation tools. These designs would be included in Appendix H (Geological Hazard Assessments).

The risk of a fault rupture occurring underneath the GTP, PTTL and PBTL facilities s would be extremely low.

During operations, monitoring of seismic ground motions would be developed or arranged in accordance with the Integrity Management Program.

6.4.8.2.1.2 Seismic Wave Propagation

Seismic waves are a risk to the Mainline during operations due to the potential for sudden and large vertical and horizontal accelerations that may occur. Risks due to seismic wave propagation are similar to those posed by fault ruptures. Site-specific structural engineering analysis would be performed to ensure that the Mainline, GTP, PTTL, PBTL, and all buildings and infrastructure associated with these facilities meet current design codes for seismic wave propagation associated with design-level seismic events. These codes ensure that facilities are able to withstand the forces associated with these seismic events.

6.4.8.2.1.3 Soil Liquefaction

Liquefaction causes ground strains and movement transferred to the buried pipeline, potentially resulting in a pipeline rupture. Refer to Section 6.4.7.2.1.1 Fault Rupture Displacement for the discussion of pipeline rupture risk during operations and associated mitigation techniques.

Operations of the Mainline and associated infrastructure are not expected to cause any local liquefaction effects. Mitigation of soil liquefaction hazard to the pipeline is achieved through routing and design.

Soil liquefaction is not a risk in the Beaufort Coastal Plain Ecoregion due to lower earthquake frequency and intensities, and widespread continuous bonded permafrost, as such, this hazard would have no effect on the GTP, PTTL, and PBTL facilities or associated infrastructure.

6.4.8.2.1.4 Tsunamis and Seiches

Tsunamis and seiches would not be a potential hazard during operation of the Interdependent Project Facilities. There are no water bodies capable of sustaining such waves in the Project corridor.

6.4.8.2.1.5 Volcanism

Ashfall is the only potential volcanic hazard that poses a threat to Mainline aboveground facilities near Cook Inlet. There is potential for ashfall to reach machinery through air intake valves or other openings and damage or destroy machines. Every precaution would be taken to reduce damage to equipment and facilities and injury to personnel.

Volcanism does not pose any risk to the Mainline pipeline, GTP, PTTL, or PBTL.

6.4.8.2.2 Mass Wasting

6.4.8.2.2.1 Falls, Slides and Slumps

In accordance with the Applicant's *Plan*, appropriate erosion control measures would be installed during and following construction to mitigate slope instability. During operations, an Integrity Management Program would also be implemented, as identified in Resource Report No. 11.

By following existing or previously studied corridors, the large majority of potential slope instability hazards in the Project area have been avoided. Falls, slides, and slumps are not considered to be a risk to the GTP, PTTL, or PBTL facilities located in the Beaufort Coastal Plain Ecoregion.

6.4.8.2.2.2 Flows

Mudflows and debris flows are depositional in nature where they cross the Mainline, therefore, are not considered a threat to the underground pipeline. However, pipeline associated facilities could be at risk due to mudflows, as these flows could negatively impact aboveground facilities. This effect would be significant, adverse, and direct. To mitigate this, every precaution would be taken to minimize exposure to possible flows by locating and designing facilities outside of potential high-risk mudflow and debris flow areas.

Flows are not considered to be a risk to the GTP, PTTL, or PBTL facilities located in the Beaufort Coastal Plain Ecoregion.

6.4.8.2.2.3 Avalanches

Avalanches are a potential hazard in all mountainous regions where the pipeline or aboveground facilities would be located near the terminus of an avalanche run-out zone. Avalanches can occur naturally or can be initiated by human activities. The potentially large run-out distances for snow avalanches during selection of sites for all aboveground facilities, infrastructure (i.e., camps, storage areas) and materials sites in mountainous terrain would be considered.

For those areas along the Mainline that would be avalanche-prone, precautions would be taken to ensure that personnel would be protected by avoiding these areas during high-risk periods or by triggering avalanches intentionally prior to activities such as inspections and maintenance.

None of the aboveground facilities are sited in an avalanche prone or susceptible areas.

Avalanches are not considered to be a risk to the GTP, PTTL, or PBTL facilities located in the Beaufort Coastal Plain Ecoregion.

6.4.8.2.2.4 Creep and Solifluction

Creep and solifluction would be a significant, long-term concern during operation of northern portions of the Pipeline, GTP, PTTL, and PBTL. During the summer thaw season in the Arctic and Subarctic, thawing ice-rich soils on slopes may be susceptible to solifluction. Table 6.4.3-1 provides a preliminary summary of locations in which creep and solifluction are likely to occur along the Mainline. For a full discussion of this and other frozen soil-related geohazards for the Project, see the Permafrost discussion in Resource Report No. 7.

6.4.8.2.2.5 Rock Glaciers

Based on preliminary assessments, known rock glaciers in the Mainline area would not have an impact due to the slow rate of movement.

Rock glaciers are not considered to be a risk to the GTP, PTTL, or PBTL facilities located in the Beaufort Coastal Plain Ecoregion.

6.4.8.2.2.6 Frozen Debris Lobes (FDLs)

The advance of FDLs could become a geologic hazard in the Mainline in certain segments of the southern Brooks Range. At least one FDL in particular is currently within 200 feet of the Dalton Highway, and has been advancing toward the highway/Mainline at some 150 feet-per-year for multiple years (Daanen et. al., 2012). If an FDL reaches the Mainline, it would be capable of depositing many tons of rock, sediment, soil and debris on the corridor daily. The Project representatives would work with the ADOT&PF on routing through this area and the measures to take to protect the pipeline. FDLs are not a potential hazard in the vicinity of the GTP, PTTL, or PBTL facilities.

6.4.8.2.2.7 Subsidence

Review of available route data indicates no evidence of shallow karst features prone to collapse beneath the Mainline. Likewise, there are no underground mines along the route that may pose a collapse hazard (see Section 6.3.1). In the unlikely event of a collapse structure developing beneath the pipeline, the strength and ductility of the pipeline could allow it to span a short distance without threatening the integrity of the pipeline.

Specific geotechnical investigations would be completed as necessary to characterize subsurface conditions, and ground would be compacted as necessary as part of the construction process of buildings and associated infrastructure. Due to these standard engineering precautions and design and construction process, any effects from subsidence hazards caused by the Project facilities are likely to be of minor significance, although they could likely develop over a long-term period.

Gradual subsidence due to building loads may occur over the lifetime of the various structures and is normal. However, a site-specific geotechnical investigation to determine soil characteristics, combined with stabilization methods, can greatly reduce the risk or magnitude of subsidence during operations. These studies are underway for the GTP, Liquefaction Facility, and compressor station locations.

Subsidence hazards are addressed in more detail in Resource Report No. 7, including thaw-settlement anticipated throughout northern portions of the Project corridor.

6.4.8.2.3 Acid Rock Drainage

Preliminary pipeline locations with an elevated (high or moderate) ARD/ML potential are summarized in Table 6.4.4-1. ARD/ML mitigations and control measures during operations may be required for ongoing operations, especially near borrow material sites, and would be handled with the same procedures described previously under construction impacts (Section 6.4.7.2).

ARD/ML effects are expected to be negligible to null in the Beaufort Coastal Plain Ecoregion and are not considered to be a hazard for the GTP, PTTL, or PBTL or associated facilities.

6.4.8.2.4 Hydrologic Processes (Vertical Scour)

Areas susceptible to vertical scour, channel migration, avulsion and rapid lake drainage along the Mainline are summarized in Table 6.4.6-1. Potential flooding hazards along the Mainline are also summarized in Table 6.4.6-2. The Pipeline Facilities would be designed and constructed in accordance with 49 CFR § 192 as well as in accordance with the Applicant's *Procedures* to provide adequate protection from bank erosion, scour, and/or channel migration. Further details can be found in Resource Report No. 2 Appendix I Site-Specific Waterbody Crossing Plans.

6.4.8.3 Non-Jurisdictional Facilities

Both the PTU Expansion project and the PBU MGS project would have low risk of operations geologic hazards associated with seismic hazards, volcanism, mass wasting, and acid rock drainage. Potential erosion and scour impacts associated with flooding in the Beaufort Coastal Plain Ecoregion are provided in Section 2.5 of Resource Report No. 2.

The Kenai Spur Highway relocation project area is similar to the area described for the Liquefaction Facility and susceptible to the same geohazards.

6.5 BLASTING

Blasting would be required in areas where competent shallow bedrock or numerous boulders are encountered at or near the ground surface and in certain permafrost terrain conditions that cannot be removed by conventional mechanized excavation with a trencher, bulldozer, hydraulic hammer, or rocksaw. Blasting would be conducted in accordance with the *Blasting Plan* found in Appendix B.

The *Blasting Plan* lists areas where shallow or exposed bedrock is expected to be encountered along the Mainline facilities and may require blasting. It includes certain soil conditions with boulders, cobbles, or granular materials in permafrost, which may also require blasting depending on the proportion of coarse granular materials and the nature of the permafrost. In addition to these locations, blasting may also be required at some borrow sites to loosen material that may be frozen or in dense, consolidated state (see Appendix F, *Gravel Sourcing Plan and Reclamation Measures*).

Blasting has the potential to impact nearby structures, including buildings, wells, unstable slopes, undiscovered paleontological resources, and existing third-party facilities. Blasting activities would be performed in accordance with manufacturers' prescribed safety procedures and industry practices, and comply with all laws, regulations, and permits. The *Blasting Plan* would also specify measures for storage, transport, and handling of explosives. The *Blasting Plan* would be finalized by each construction contractor for the measures specific to their assigned work area. However, the structure of the *Blasting Plan* included with this Resource Report identifies the procedures that would be included, such as:

- Identification and compliance with state, federal, and local blasting regulations;
- Provisions for pre-blasting investigations;
- Measures to mitigate flyrock and vibrations;
- Determination of appropriate charge type, weight, and configuration;
- Depth and spacing of charges;
- Detonation delays;
- Procedures for notifying nearby residents;
- Procedures for pre- and post-blasting monitoring; and
- Procedures for blast mat placement.

6.5.1 Potential Construction Impacts and Mitigation Measures

The following discussion provides an overview of the potential impacts of blasting to geological resources and the general mitigation measures that would be used. Potential impacts and mitigation for other resources (e.g., water resources, wildlife, etc.) related to the need for blasting during Project construction, are addressed in the appropriate Resource Report.

6.5.1.1 Liquefaction Facility

Bedrock is deep enough that no blasting would be required.

6.5.1.2 Interdependent Project Facilities

Appendix B lists areas where shallow or exposed bedrock is expected to be encountered along the pipeline facilities that may require blasting. Certain soil conditions with boulders, cobbles, or granular materials in permafrost may also require blasting depending on the proportion of coarse granular materials and the nature of the permafrost. These locations are labeled "Potential Blasting" and are also listed in this Appendix. In addition to these locations, blasting may also be required at some borrow sites to loosen material that may be frozen or in dense, consolidated matrix with ice.

The estimated total length of blasting along the Mainline varies between 256.7 miles and 314.2 miles, when considering those locations listed as requiring "Blasting" and areas of "Potential Blasting", as defined in Appendix B. There are another 65.4 miles of ROW that may require blasting during grading and before any ditching is done. No bedrock is anticipated along the PTTL or PBTL based on available information.

Table 6.5.1-1 provides a preliminary summary of potential blasting lengths of the pipeline anticipated during construction of the Project.

TABLE 6.5.1-1

Potential Blasting Locations During Construction of the Mainline

Borough/Census Area	Ecoregion	Start MP	End MP	Length of Blasted Ditch (miles)	Length of Blasted Ditch (%)	Length of Blast-assisted Trenching (miles)	Blast-assisted Trenching (%)
North Slope	Beaufort Coastal Plain Ecoregion/Brooks Range	0.0	61.8	28.1	45.4%	0.0	0.0%
		61.8	176.2	78.0	68.1%	2.0	1.7%
Yukon-Koyukuk	Kobuk Ridges and Valleys	176.2	260.9	62.8	74.1%	5.7	6.8%
	Ray Mountains	260.9	421.8	78.6	48.8%	2.5	1.5%
Fairbanks North Star	Northern Plateaus Province	421.8	424.3	0.0	0.0%	1.1	43.3%
Yukon-Koyukuk	Ray Mountains	424.3	429.9	0.0	0.0%	0.5	8.3%
		429.9	442.7	0.0	0.0%	0.0	0.0%
		442.7	443.6	0.0	0.0%	0.0	0.0%
		443.6	450.3	0.0	0.0%	0.0	0.0%
		450.3	450.5	0.0	0.0%	0.0	0.0%
		450.5	472.6	0.0	0.0%	0.0	0.0%
	Tanana-Kuskokwim Lowlands	472.6	473.1	0.0	0.0%	0.0	0.0%
		473.1	488.6	0.0	0.0%	7.1	45.5%
Denali	Tanana-Kuskokwim Lowlands	488.6	500.6	0.0	0.0%	10.1	84.8%
	Tanana-Kuskokwim Lowlands/Alaska	500.6	576.4	7.3	9.6%	14.0	18.4%

TABLE 6.5.1-1

Potential Blasting Locations During Construction of the Mainline

Borough/Census Area	Ecoregion	Start MP	End MP	Length of Blasted Ditch (miles)	Length of Blasted Ditch (%)	Length of Blast-assisted Trenching (miles)	Blast-assisted Trenching (%)
	Range						
Matanuska-Susitna	Alaska Range	576.4	639.7	0.1	0.1%	7.9	12.5%
	Alaska Range/Cook Inlet Basin	639.7	754.2	0.0	0.0%	6.7	5.8%
Kenai Peninsula	Cook Inlet Basin	754.2	804.3	1.8	3.6%	0.0	0.0%

[a] Source: WorleyParsons, 2015.

Blasting has the potential to damage nearby structures, including buildings and wells, unstable slopes, undiscovered paleontological resources, and existing third party pipelines and facilities. All blasting would be carried out in accordance with the *Blasting Plan*. A preliminary version of the *Blasting Plan* is included as Appendix B.

Prior to construction, the *Blasting Plan* would be finalized, including the confirmation of the locations where blasting impacts could be a concern to nearby resources or infrastructure. Examples include:

- Buildings and structures;
- Roadways and railroads;
- Utilities (aboveground and belowground);
- Water supply wells and springs;
- Sensitive terrestrial and aquatic habitats; and
- Geologically unstable areas.

In those locations, site-specific blasting measures would be developed with the contractor to mitigate impacts to infrastructure and land. These measures would include provisions for pre-blast baseline testing and post-blast monitoring and reporting.

6.5.1.2.1 Pipeline Aboveground Facilities

Further field studies are required to determine if any blasting would be required for the construction of pipeline aboveground facilities. Generally, sites would be chosen to avoid the presence of shallow rock or large boulders, but that level of detail is not known at this time. If any blasting becomes necessary, the procedures identified in the *Blasting Plan* would be implemented.

6.5.1.2.2 Pipeline Associated Infrastructure

Siting for the pipeline associated facilities would also avoid rock or large boulders, making the need for blasting highly unlikely. Only work at material (borrow) sites may involve blasting. If any blasting is needed, the procedures identified in the *Blasting Plan* would be implemented.

6.5.1.2.3 GTP

Blasting would not be required for the GTP site. Only work at material (borrow) sites would involve blasting. When blasting is required, the procedures identified in the *Blasting Plan* would be implemented.

6.5.2 Potential Operational Impacts and Mitigation Measures

While blasting impacts are mostly of concern during construction of the Project, there may be some ongoing operational impacts to consider. Any operational impacts and mitigation measures from blasting would be addressed in a manner similar to the procedures outlined in the *Blasting Plan*.

6.6 PALEONTOLOGICAL RESOURCES

Paleontological resources are the remains of former living organisms, such as plants and animals, that are preserved in rocks and/or unconsolidated sediment. These resources include fossils, imprints, molds, casts, traces, or frozen remains. Paleontological resources are distinct from cultural resources (Resource Report No. 4) which deal with archaeological findings specific to human history and prehistory. Cultural resources are relatively younger than most paleontological resources, and are found at shallower depths within the Earth's substrata.

Fossils of plants and animals, both marine and terrestrial, are a valuable scientific resource which document the history of life on the planet. Fossils are protected under the following laws:

- Antiquities Act (any fossil which is considered of scientific value);
- The Omnibus Public Land Management Act of 2009, Public Law 111-011. Title VI Subtitle D Paleontological Resources Preservation Act;
- Alaska Historic Preservation Act;
- Federal Land Policy and Management Act;
- Federal Cave Resources Protection Act; and
- Archaeological Resources Protection Act.

Some rock formations present in the Project area are either known to contain paleontological resources or have the potential to contain them. Most sedimentary rocks contain some microfossils, including bacteria, algae, planktonic plants, and invertebrates (e.g., insects, worms). These microfossils are common and widespread around the world and are not necessarily considered scientifically significant. Larger and more scientifically significant fossils that may be present in the Project area include those of Mesozoic age dinosaurs. A wide variety of Pleistocene (ice age) remains may be found in the Project vicinity, including Pleistocene vertebrates (e.g., mammoth, horse, and bison). However, mammoth, horse, and bison remains are rare, not commonly found intact, and considered scientifically significant. Extremely rare and scientifically valuable specimens of other less common organisms may be encountered during Project excavations, but such findings are unpredictable. Rock and sediment formations which are most likely to contain large vertebrate fossils are of the greatest concern.

Sedimentary rocks are the most likely formations in which to find vertebrate fossils. Sediments which have been deposited and not yet lithified into solid rock are considered unconsolidated sediments, such as alluvial, fluvial, glaciofluvial, and eolian deposits. These sediments may also contain vertebrate remains, particularly more recent remains, such as Pleistocene animals. Well-preserved Pleistocene vertebrate remains are most notably found in unconsolidated sediments in areas of permafrost.

Known paleontological resources were identified by Project field assessments in 2015. The results of these assessments, in combination with previous investigations, are listed in the *Paleontological Resources Survey and Inventory Report* (Appendix G). Field surveys identified a total of 12 new paleontological sites (Appendix G). Seven of these contain marine invertebrates only, and are recommended as not significant paleontological resources. Five sites contain significant vertebrate fossils. Three of the five are outside the Project footprint, but attest to the high potential of geologic units crossed by the Project footprint. These locations are delineated in Appendix G and filed as privileged and confidential to prevent the resources from loss and/or damage by the public.

The following sections briefly summarize known or potential paleontological resources by ecoregion along the proposed Project footprint.

6.6.1 Liquefaction Facility

Bedrock beneath the proposed Liquefaction Facility is composed of upper Tertiary continental deposits (sandstone, siltstone, claystone, conglomerate, and coal) of the Kenai Group (DGGS, 2011). Due to lack of bedrock outcropping in this area, little is known about the local abundance of Tertiary age fossils. Kenai Group rocks also outcrop on the west side of Cook Inlet, however, where they are known to contain abundant Tertiary plant fossils (Wolfe et al., 1966).

6.6.1.1.1 Cook Inlet Basin Ecoregion

The Cook Inlet Basin Ecoregion is well known for its fossiliferous sedimentary rocks. Terrane accretion throughout the Tertiary has introduced diverse crustal blocks to the area, contributing diverse outcrops of Mesozoic, Tertiary, Late Miocene, and Early Pliocene age rocks. Much of the Cook Inlet area is overlain by young glacial sediments, but where bedrock outcrops occur, some areas yield abundant marine invertebrate and terrestrial plant fossils of Mesozoic and Tertiary age. The Liquefaction Facility has a low probability of encountering fossil-bearing rocks near the surface of the site. If excavations during foundation construction of the LNG tanks would encounter any fossil-bearing rock, the *Paleontological Resources Unanticipated Discovery Plan* (Appendix D) would be implemented.

6.6.2 Interdependent Project Facilities

6.6.2.1.1 Beaufort Coastal Plain Ecoregion

Potentially fossil-bearing rocks in the Beaufort Coastal Plain Ecoregion include marine sandstone, limestone, shale, and siltstone. In some places along the Beaufort Coastal Plain Ecoregion, these fossil-bearing marine sedimentary rocks are up to 20,000 feet thick. Sedimentary rocks of Middle Devonian age (approximately 380-390 Ma) contain the oldest known fossils in the area. Devonian and post-Devonian age fossils include mostly small invertebrate marine animals, such as brachiopods, cephalopods, gastropods, pelecypods, sponges, bryozoans, corals, and crinoids (Lindsey, 1986).

Twelve varieties of dinosaur fossils have been recovered from Late Cretaceous age strata (65–100 Ma) in the Beaufort Coastal Plain Ecoregion. Approximately 50 miles west of Prudhoe Bay, dinosaur fossils of adult and young hadrosaur, tyrannosaur, and troodons have been found along the Colville River (BLM, 2014). No dinosaur fossils have been discovered within the Project area, although the Late Cretaceous sandstone present there could possibly contain them. Middle Jurassic through Cretaceous rocks in the Beaufort Coastal Plain Ecoregion also contain terrestrial plant fossils.

Quaternary age strata west of the Project area contain abundant remains of both marine and terrestrial mammals, including otter, seal, whale, mammoth, moose, caribou, musk ox, bison, antelope, camel, horse, and mountain lion, as well as birds. Windblown silt remobilized from the floodplains of glacier-fed rivers is known as loess, and is a common feature of many lowland areas in Alaska. Reworked loess in the region may contain the well-preserved remains of Pleistocene vertebrates.

6.6.2.1.2 Brooks Range Foothills and Brooks Range Ecoregions

Potentially fossil-bearing bedrock in the Brooks Range includes marine sedimentary rock and metamorphosed marine rocks. Overlying sediments include glacial deposits, colluvium, alluvium, lacustrine deposits, and eolian deposits, some of which may also be fossil-bearing. In various locales throughout the Brooks Range, faulting has exposed fossil-bearing strata at the surface. In the northeastern Brooks Range, marine sedimentary rocks have yielded fossils of marine invertebrates, coral, gastropods, and bivalves (Reifenstuhl, 1991). Similar rock types occur within the Mainline, and thus, fossils are potentially present where the Project area traverses the Brooks Range.

6.6.2.1.3 Kobuk Ridges and Valleys Ecoregion

The Mainline passes very briefly through the Kobuk Ridges and Valleys Ecoregion. Bedrock in the area is composed of late Cretaceous continental deposits, overlain by deep deposits of Quaternary glacial, glaciofluvial, outwash, and lacustrine, alluvial, and eolian sediments. Pleistocene fossils, such as mammoth and mastodon, have been found in unconsolidated deposits throughout the region, especially well-preserved in permafrost areas. Fossils from prior to the Quaternary are either lacking or very uncommon in this area.

6.6.2.1.4 Ray Mountains Ecoregion

Sedimentary rocks in and around the Ray Mountains Ecoregion contain abundant Paleozoic marine fossils. The oldest fossils in the area are Early Cambrian trace fossils. Abundant Ordovician fossils from the Fossil Creek volcanics and Tolovana limestone include gastropods, trilobites, bryozoans, brachiopods, and corals. Silurian and Devonian fossils of the Tolovana, Cascaden, and Skajit limestones include brachiopods, corals, gastropods, and other bivalves. Mississippian age bryozoan, crinoid, coral, gastropod, and brachiopod fossils are present in marine sedimentary rocks within the Ray Mountains Ecoregion. Additionally, there is a wide assortment of well-preserved Cretaceous plant fossils which outcrop along the Yukon River (Lindsey, 1986).

Abundant remains of Pleistocene vertebrates have also been found in the region, including mammoth, mastodon, bison, saiga antelope, horse, musk oxen, and birds (Lindsey, 1986).

6.6.2.1.5 Tanana-Kuskokwim Lowlands and Yukon Tanana Uplands Ecoregions

South of Livengood, fossils of freshwater mollusks, insects, and vertebrates are abundant. In addition, fossils of extinct Pleistocene vertebrates have also been found in the area, including mammoth, mastodon, bison, saiga antelope, horse, musk oxen, and birds.

6.6.2.1.6 Alaska Range Ecoregion

The Alaska Range is composed of several different accreted terranes, and thus rock types in the area are extremely diverse. There are many known and potential fossil-bearing strata within the Alaska Range Ecoregion. Rocks of the Chulitna Terrane in particular contain abundant fossil species, including Triassic-age bivalves, gastropods, ammonites and conodonts, and Paleozoic-age radiolarian, bivalves, and crinoids. Strata of the West Fork Terrane contain Upper Jurassic radiolarians, and rocks of the Kahiltna Flysch Terrane bear Lower Cretaceous-age bivalve and belemnite fossils (Blodgett and Clautice, 2000).

Rocks of the lower Cantwell Formation correlates in age with the famous dinosaur-bearing rocks of the Prince Creek Formation of the North Slope of Alaska, as well as the dinosaur-bearing Chignik Formation of Aniakchak National Park in southwestern Alaska. The lower Cantwell Formation is abundantly fossiliferous, and consists of numerous successions of conglomerate, sandstone, mudstone and, locally, thin coal seams and altered tuffs. The sedimentary rocks rest uncomfortably on weakly metamorphosed and locally, intensely folded Late Jurassic to Cretaceous flysch deposits that may be correlative to the Kahiltna assemblage (see Csejtey et al., 1992; Ridgway et al., 2002).

6.6.2.1.7 Cook Inlet Basin Ecoregion

Bedrock beneath the southernmost Mainline is composed of upper Tertiary continental deposits (sandstone, siltstone, claystone, conglomerate, and coal) of the Kenai Group (DGGS, 2011). Due to lack of bedrock outcrops in this area, little is known about the abundance of Tertiary age fossils in the area. The same rocks of the Kenai Group, however, outcrop on the west side of Cook Inlet, and are known to contain abundant Tertiary plant fossils (Wolfe et al., 1966).

6.6.3 Non-Jurisdictional Facilities

The paleontological record of the PTU Expansion and PBU MGS project area ranges in age from the Paleozoic through Cenozoic. Bedrock underlying the area consists of thousands of feet of fossil-bearing sedimentary strata. These sedimentary rocks are overlain by fossil-bearing unconsolidated fluvial and eolian deposits. Fossils found in these rocks elsewhere in the Beaufort Coastal Plain Ecoregion range from single-celled organisms to large vertebrates. Marine invertebrate fossils include: bryozoans, brachiopods, pelecypods, gastropods, ostracods, crinoids, trilobites belemnites, ammonites, and coral. The occurrence of fossils in the Project area is limited to those taxa found in such materials across the Beaufort Coastal Plain Ecoregion. The Kenai Spur Highway relocation project area is similar to the area described for the Liquefaction Facility.

6.6.4 Potential Construction Impacts and Mitigation Measures

As detailed in *Paleontological Resources Survey and Inventory Report* (Appendix G), the Liquefaction Facility, GTP, PTTL ROW and off-ROW facilities, the PTU Expansion, PBU MGS project, and the Kenai Spur Highway relocation project could be constructed without further paleontological resources assessment, survey, or monitoring. Ground-disturbing activities at each of these Project components have little potential to impact significant paleontological resources. Potential impacts to unanticipated significant paleontological resources would be mitigated by providing workforce paleontological sensitivity training and adhering to the *Paleontological Resources Unanticipated Discovery Plan* (Appendix D).

The Mainline and off-ROW Project footprint intersect geologic units with a high probability of significant paleontological resources like vertebrate remains, both from the Cretaceous period (dinosaurs) and Pleistocene (Ice Age). Construction activities for the Mainline and off-ROW work areas listed in Table 4-1 of the *Paleontological Resources Management Plan* (Appendix E), have the potential to adversely impact significant paleontological resources.

Paleontological resources could be damaged or destroyed during construction activities in areas where the resources are present. Potential impacts could result from construction activities including:

- Excavation and earthmoving activities;
- Erosion of the fossil-bearing strata from slope grading, vegetation clearing, etc.;
- Increased public access to the area leading to a higher risk for being removed or damaged; and/or
- Blasting.

Potential construction impacts and mitigation measures would be addressed in Appendix E, *Paleontological Resources Management Plan*, as well as Appendix D, *Paleontological Resources Unanticipated Discovery Plan*.

6.6.5 Potential Operational Impacts and Mitigation Measures

In general, sensitive paleontological resources could be damaged or destroyed during maintenance activities that cause ground disturbance, however, the probability is extremely low. Following the *Paleontological Resources Unanticipated Discovery Plan* would mitigate any impacts during operations.

6.7 REFERENCES

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