3.15 GEOHAZARDS

This section provides information currently available regarding geological hazards (geohazards) in the vicinity of the proposed project. Geohazards include geophysical processes (e.g., earthquakes, volcanoes), surficial or geomorphological processes (e.g., landslides) and other hazards (e.g., ice effects, erosion, tsunamis). Regional-scale descriptions of the geohazards are presented in this section, followed by local descriptions enhanced with information gathered from geotechnical engineering studies where available. The project area is in a region of active tectonic (geophysical) processes, and the potential for multiple types of geohazards across the project area depends on location, topography, natural materials present, and proximity to hazard sources. The Environmental Impact Statement (EIS) analysis area for geohazards ranges from the immediate vicinity of the project footprint for each alternative (e.g., slope instability) to regional areas with geohazards that could affect project facilities from long distances (e.g., earthquakes, volcanoes).

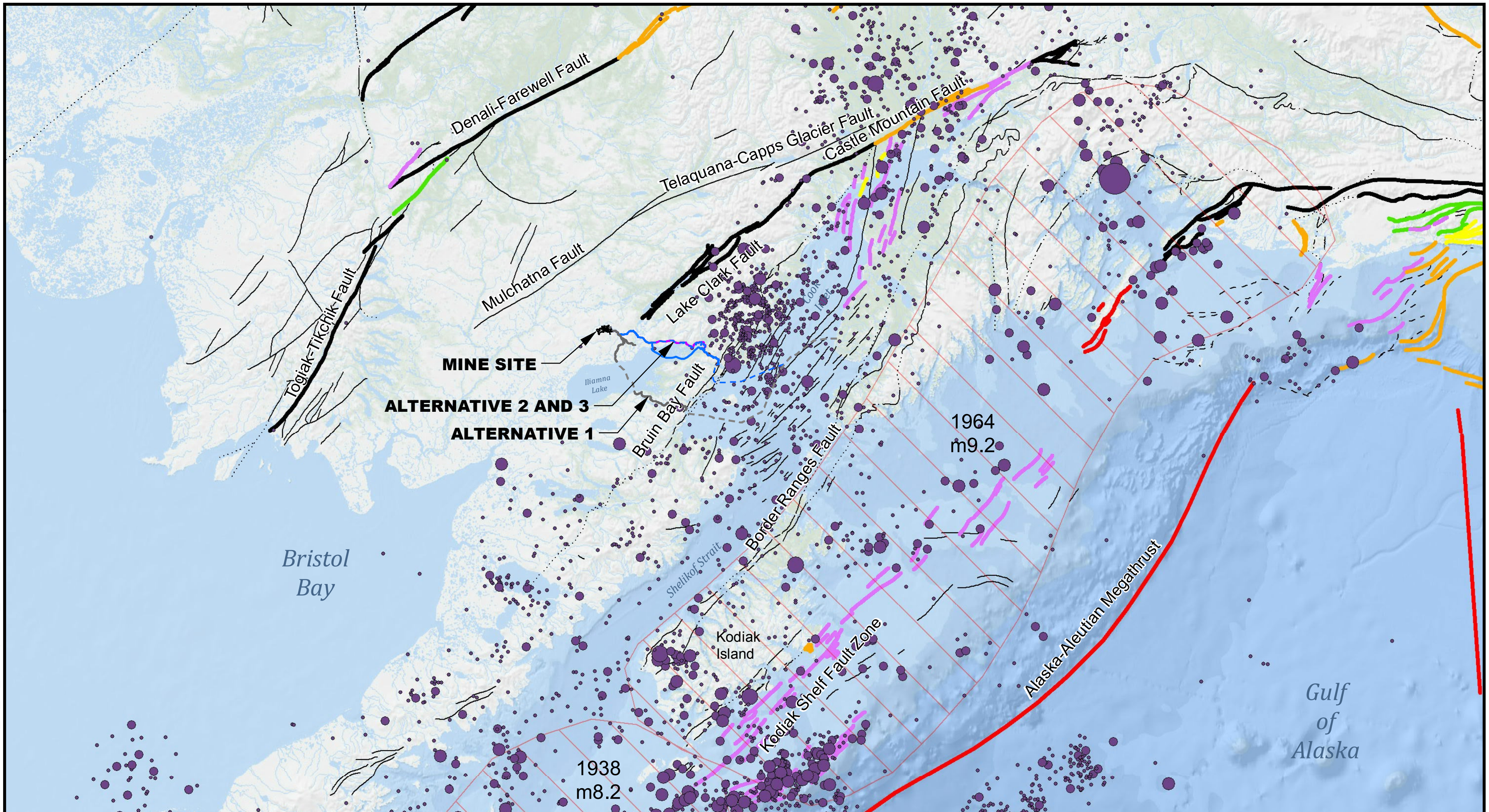
3.15.1 Earthquakes

3.15.1.1 Active Faults

The Pebble Project is in a tectonically active region of southern Alaska near the subduction zone between the Pacific and North American plates. Both shallow crustal earthquakes and deeper earthquakes associated with the subduction zone megathrust affect this region.

In general, faults that have demonstrated geologic displacement and earthquakes during the Holocene epoch (the last 11,000 years) are considered to be active, and have the potential for future movement. Earthquake hazards generally increase with the magnitude (M) of the event, proximity to the site, and fault length. The likelihood of fault movement is typically described in terms of recurrence interval or return period (i.e., how often the fault is expected to generate a large earthquake based on field evidence and past seismic record). This is described below under “Ground Shaking,” and in Section 4.15, Geohazards, as applied to project facilities. Active and potentially active faults in the project area are shown on Figure 3.15-1, and include the following:

- The closest active surface fault to the project area is the northeast-trending Lake Clark-Castle Mountain Fault, about 15 miles northeast of the mine site at the western end of Lake Clark (Haeussler and Saltus 2004). Studies of surficial geology and geomorphology in the mine area did not find evidence of Holocene fault activity between Lake Clark and the mine site (Hamilton and Klieforth 2010; Koehler 2010; Haeussler and Waythomas 2011; Knight Piésold 2015a). This fault exhibits evidence of Holocene activity in the Susitna Valley area, where it is considered capable of a maximum earthquake of M7.1 (Wesson et al. 2007), but shows no evidence of activity younger than Late Pleistocene along the Lake Clark segment southwest of Tyonek (Koehler and Reger 2011). This conclusion is further supported by a review of Light Detection and Ranging (LiDAR) data collected in 2004 in the vicinity of the mine site. No lineaments were observed that suggest possible fault-related movement in surficial deposits southwest of the previously mapped termination point of the Lake Clark fault (AECOM 2018m).



Sources: USGS 2018; Koehler 2013; Haeussler and Saltus 2004; Plafker et al. 1994

Earthquake Magnitude 1900 - 2018
- 4.0 - 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9
- 9.2

Fault Activity (Age of Most Recent Surface Deformation)
- Historical, <150 yrs
- Latest Pleistocene and Holocene, <15,000 yrs
- Latest Quaternary, <130,000 yrs
- Mid-Quaternary, <750,000 yrs
- Quaternary, <1,600,000 yrs
- Questionable, Class B

- Pre-Quaternary Fault
- Rupture Zone of Megathrust Earthquake

Alternative 1
- Mine Site
- Natural Gas Pipeline
- Transportation Corridor

Alternative 2
- Transportation Corridor

Alternative 2/3
- Natural Gas Pipeline

Alternative 3
- Transportation Corridor

US Army Corps of Engineers®

25 0 25 50
Miles

N

EARTHQUAKES AND ACTIVE FAULTS

PEBBLE PROJECT EIS

FIGURE 3.15-1

- The Alaska-Aleutian Megathrust, associated with the subduction zone of the Pacific Plate beneath the North American Plate, is responsible for some of the largest earthquakes globally, including the 1964 M9.2 Great Alaskan (Good Friday) Earthquake and 1938 M8.3 Alaska Peninsula earthquake. The megathrust lies at the seafloor more than 200 miles southeast of the project area, and dips to the northwest beneath the project area. Its 30-mile-thick zone of seismicity ranges from 20 to 50 miles deep beneath the eastern end of the natural gas pipeline corridor, to about 90 to 120 miles deep near the mine site (Plafker et al. 1994; Knight Piésold 2015a). The Kodiak and Prince William Sound areas of the megathrust are considered capable of a maximum M9.2 earthquake every 650 years. Intraslab faults associated with the deeper part of the subduction zone are considered capable of earthquakes in the range of M7+ (Wesson et al. 2007).
- The Denali-Farewell Fault, about 120 miles northwest of the project area, was the source of the 2002 M7.9 Denali earthquake that originated along the central part of the fault in Interior Alaska. The westernmost extension of this fault system, called the Togiak-Tikchik Fault, about 140 miles west of the mine site, exhibits evidence of mid-Quaternary activity. Although evidence of Holocene activity along the western part of the fault is limited compared to that of Interior Alaska, it is considered capable of generating large earthquakes in the range of M7.5 to M8.0 (BGC 2011; Knight Piésold 2015a).
- The Telaquana-Capps Glacier and Mulchatna faults are about 40 miles north and northwest of the mine site, respectively (Haeussler and Saltus 2004; Gillis et al. 2009). Evidence of Holocene activity along these faults has not been established. If active, they are considered capable of maximum earthquakes in the range of M6.0 to M7.0 (Knight Piésold 2015a).
- The Bruin Bay Fault extends along the western shore of Cook Inlet near the Amakdedori port site. Although there is no evidence for Holocene offset at the surface, this fault is associated with several small to moderate earthquakes up to M7.3 in 1943 (Stevens and Craw 2003).
- Several fault-cored folds in Upper Cook Inlet show evidence of Quaternary-age activity and possible bending of the seafloor. The closest of these lies about 130 miles east of the mine site and 10 miles north of the eastern end of the pipeline corridor. These structures are considered capable of generating earthquakes up to M6.8 (Haeussler et al. 2000). Recent activity has not been documented on similar folds and faults in Lower Cook Inlet near the Amakdedori port and natural gas pipeline corridor submarine crossing (Haeussler and Saltus 2011; Koehler et al. 2012).
- The Kodiak Shelf fault zone, comprised of a series of northeast-trending faults, lies in the upper plate of the subduction zone. These faults, about 120 miles southeast of the closest project components, show geomorphic evidence of Holocene activity, and are considered capable of earthquakes up to M7.5 (Wesson et al. 2007; Carver et al. 2008).
- The Border Ranges Fault, extending northeasterly through Kodiak Island and Kenai Peninsula, has been inactive since the early Tertiary (65 million years ago), but contains a 3- to 6-mile-wide shear zone that is considered by some to be capable of a future earthquake in the range of M7.0 (Suleimani et al 2005; Knight Piésold 2015a).

3.15.1.2 Ground Shaking

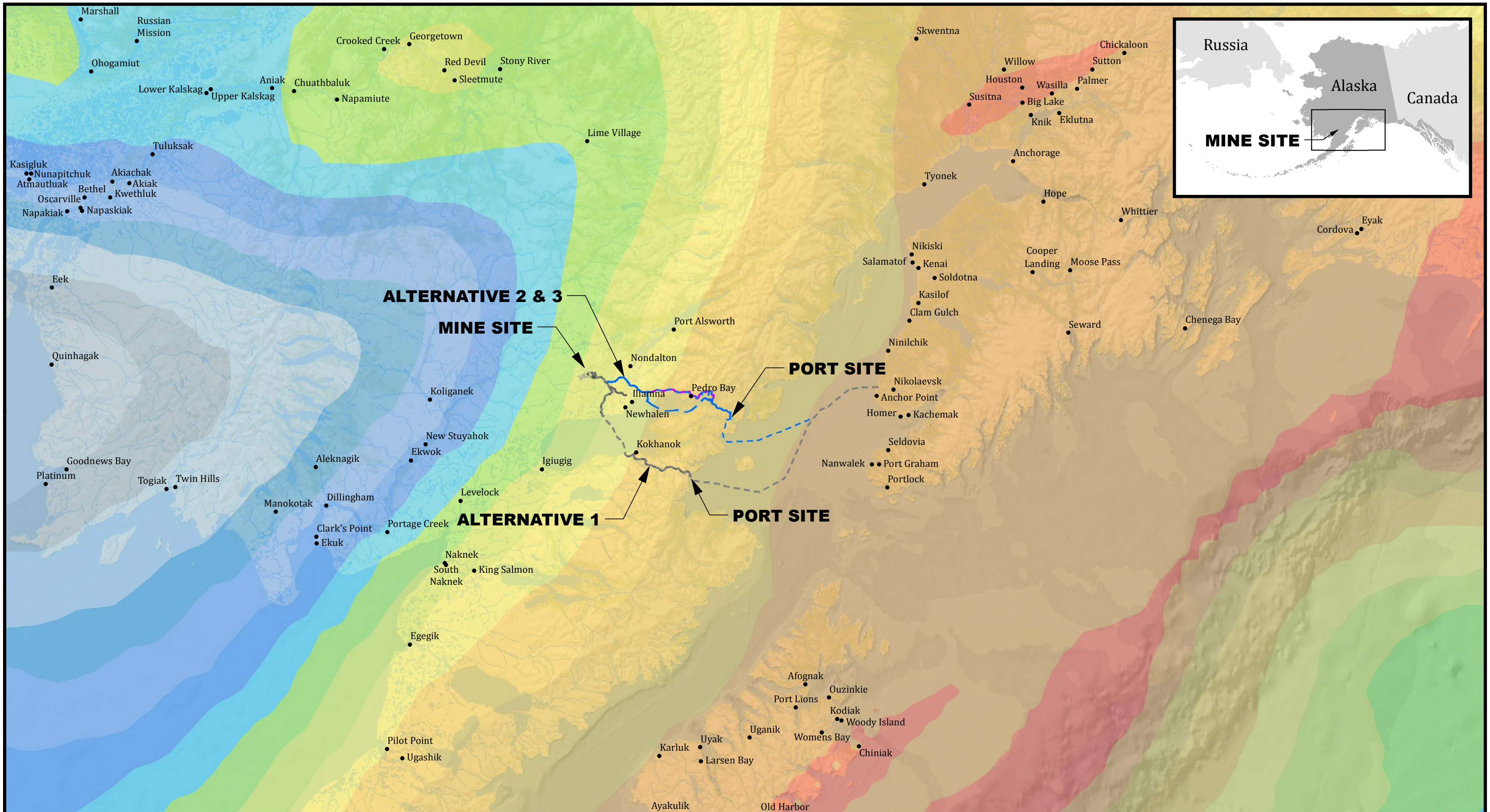
Earthquake-induced ground shaking is typically expressed in terms of peak ground acceleration (pga), measured as a fraction of gravity (g), with a probability of exceeding a certain level over a specific period of time in the future. For example, a pga of 0.1g in bedrock is considered the approximate threshold at which damage occurs in buildings that are not specially constructed to withstand earthquakes. An earthquake with a 10 percent probability of exceedance in 50 years (about a 500-year return period) is the most common event used in building codes for seismic design (e.g., Gould 2003). Larger, more infrequent seismic events, such as those with a 2,500-year return period (a 2 percent probability of exceedance in 50 years) are typically used for design of critical structures such as dams (ADNR 2017a).

Ground shaking prediction in Alaska has been studied both regionally by the US Geological Survey (USGS) (Wesson et al. 2007) and for the Pebble Project area by Knight Piésold (2011c, 2015a, 2018c). Based on published USGS data for the 2,500-year event, Figure 3.15-2 depicts a general trend from high ground shaking near the subduction zone offshore of Kodiak to less ground shaking further inland. Predicted ground shaking for the 2,500-year event ranges from a pga of about 0.3g near the mine site to 0.6g at the eastern end of the natural gas pipeline corridor. In comparison, predicted ground shaking for a smaller 500-year earthquake ranges from about 0.2g near the mine site to 0.4g at the eastern end of the natural gas pipeline corridor (Wesson et al. 2007). Site-specific seismic hazard analyses conducted for project facilities are discussed in Section 4.15, Geohazards.

3.15.1.3 Liquefaction

Liquefaction is an earthquake-caused phenomenon that reduces the strength and stiffness of a soil by ground shaking. Where the groundwater table is near surface, or the ground is otherwise saturated, the pore space between soil particles containing water can increase (i.e., increase pore pressure), changing the physical character of the landform and weakening the natural material; in essence, the ground temporarily behaves like a liquid. Liquefaction generally affects unconsolidated, fine-grained (sand and silt) deposits in lowland areas. The susceptibility of an area to liquefaction is a consideration in design and construction in earthquake-prone areas because the loss of strength of the foundational material can cause structural damage. The potential for liquefaction from ground shaking at the mine site is less for features built where bedrock is near the surface, than in lowland areas underlain by unconsolidated material. A more detailed explanation of liquefaction is provided in Appendix K3.15. Areas believed to be susceptible to liquefaction in the project area are described below.

Areas susceptible to liquefaction are typically found along rivers, streams, lake shorelines, and in areas with relatively shallow groundwater. Lateral spread of liquefied soil up to a few feet can occur on gentle slopes or in areas near a free face, such as an incised river channel. Section 3.18, Water and Sediment Quality, provides a description of sediment types in areas of the project that could be subject to liquefaction. These include portions of the mine site with shallow groundwater and fine-grained soils, such as the glacial lake deposits in the eastern part of the mine site (Section 3.13, Geology), and in project facilities that contain fine-grained saturated tailings (bulk and pyritic tailings storage facilities [TSFs]). Wide stream crossings along the road and pipeline corridors and marine sediment at port sites that contain predominantly sand and silt, such as along the northern portion of the mine access road, protected bays in Iliamna Lake, and Cottonwood and Iliamna bays in Cook Inlet, may be subject to liquefaction. Other sediment with high gravel content, such as at the north ferry terminal, high-energy stream crossings along the port access road and north road route (Alternative 2 and Alternative 3), and nearshore Kamishak Bay are less likely to liquefy (PLP 2018-RFI 036; PLP 2018-RFI 039).



Sources: Wesson et al. 2007

Project Components

Alternative 1	Alternative 2	Alternative 3
Natural Gas Pipeline	Natural Gas Pipeline	Natural Gas Pipeline
Transportation Corridor	Transportation Corridor	Transportation Corridor
Project Features	Ferry Route	

Peak Ground Acceleration (% g[1])

5 - 6	9 - 11	17 - 21	32 - 40	61 - 76
6 - 7	11 - 14	21 - 26	40 - 49	76 - 94
7 - 9	14 - 17	26 - 32	49 - 61	94 - 117

US Army Corps of Engineers®

N

20 0 20 40

Miles

1. Ground shaking expressed as the probability of exceeding a certain amount of peak ground acceleration (PGA), measured in % of gravity (g), over a 2,500-year time period (return period), which is equivalent to a 2% probability of exceedance in 50 years.

SEISMIC HAZARD MAP

PEBBLE MINE EIS

FIGURE 3.15-2