4.13 GEOLOGY

This section describes project-related impacts on the geologic resources discussed in Section 3.13, Geology, for all project alternatives and variants. The impacts include removal and relocation of rock, soil, and sediment. Appendix K4.13 presents an analysis of potential impacts on paleontological resources. The impacts of the project on other aspects of the geologic environment are described in the following sections: Section 4.14, Soils; Section 4.15, Geohazards; Section 4.17, Groundwater Hydrogeology; Section 4.18, Water and Sediment Quality; and Section 4.22, Wetlands/Special Aquatic Sites, which also describes the affected footprint of project features, and facilities of the components, for all phases of the project.

The Environmental Impact Statement (EIS) analysis area for geology includes the footprints for the mine (including material sites), port and ferry terminals, and transportation and pipeline corridors.

The impact analysis considered the following factors: magnitude, duration, geographic extent, and potential:

- Magnitude – impacts are assessed based on the magnitude of the impact as indicated by the quantified amount of geologic resources expected to be affected (e.g., cubic feet or tons affected).
- Duration – impacts are assessed based on the duration of effects on geologic resources (e.g., short-term, long-term, or permanent). Short-term effects are considered to be those impacts occurring only during the construction and operations phases; long-term effects are considered to be those impacts extending into closure; and permanent effects are considered to be those impacts extending indefinitely into post-closure, with no restorative actions planned.
- Geographic extent – impacts are assessed on the location and distribution of occurrence of the expected effects on geologic resources (e.g., mine site footprint).
- Potential – impacts are assessed based on the potential likelihood of an effect to geologic resources occurring as a result of the proposed action or alternatives.

All three action alternatives would result in a similar magnitude and potential for impacts related to geology. The primary difference between the alternatives would be the areas and volumes of associated geologic resources that would be affected.

Geotechnical investigations and studies have been completed to support engineering design (see Appendix K4.13). Additional investigations and studies are ongoing, and will continue as needed to support detailed design and ensure project compliance with all relevant regulations that are protective of the environment. Mitigation measures that would reduce project impacts to geologic resources are discussed in Chapter 5, Mitigation.

4.13.1 No Action Alternative

Under the No Action Alternative, the Pebble Project would not be undertaken. No construction, operations, or closure activities would occur. Therefore, no additional future direct or indirect effects on recreation would be expected. Though no resource development would occur under the No Action Alternative, permitted resource exploration activities currently associated with the project may continue (ADNR 2018-RFI 073). Pebble Limited Partnership (PLP) would have the same options for exploration activities that currently exist. In addition, there are many valid mining claims in the area and these lands would remain open to mineral entry and exploration. It

is possible for permitted exploration to continue under this alternative (PLP 2018-RFI 073), which could include borehole drilling and sampling.

Geology along the transportation corridor, natural gas pipeline corridor, and at the port sites would remain in its current state. There would be no effects on existing geology in the areas of these components. In summary, there would be no additional direct or indirect impacts on baseline geology conditions in the EIS analysis area from implementation of the No Action Alternative.

4.13.2 Alternative 1 – Applicant's Proposed Alternative

This section addresses the analysis of impacts from Alternative 1 on geologic resources and materials. Scoping comments related to geology requested that impacts to bedrock, surface geology, material resources, and paleontology be analyzed.

4.13.2.1 Mine Site

Removal/Relocation of Geologic Materials

The magnitude and extent of impacts on geologic materials from construction and operations at the mine site would be the removal and relocation of rock, sediment, and soil within 8,086 acres of land (Chapter 2, Alternatives, Figure 2-4 and Figure 2-5) (PLP 2018d). These impacts would be permanent and would be certain to occur if the project is permitted and constructed. Closure of some facilities and regrading of facility footprints during site closure would minimize some of these impacts (see Section 4.16, Surface Water Hydrology, Figure 4.16-2 through Figure 4.16-6).

Open Pit

Removing and relocating overburden and rock at the open pit would result in direct impacts on geologic resources, which would be permanent, unavoidable consequences of the action alternatives.

The magnitude and extent of impacts from excavating the open pit during construction and operation would be the removal and relocation approximately 1.44 billion tons (approximately 2.9 trillion pounds) of material that would include overburden, mineralized process material, and waste rock. The open pit would be approximately 8 percent of the total mine site surface area (Chapter 2, Alternatives, Figure 2-4).

The majority of rock removed from the open pit would remain at the mine site in perpetuity in the form of tailings. Bulk tailings would remain in the bulk tailings storage facility (TSF) in perpetuity. Pyritic tailings would be stored in the pyritic TSF during operations and relocated to the open pit during closure.

A relatively small fraction of the excavated rock from the open pit would make up the economic minerals that would be processed (concentrated) then exported off site. This economic mineral portion would include 7.4 billion pounds of copper, 398 million pounds of molybdenum, and 12.1 million ounces of gold (PLP 2018d).

Approximately 89.5 million tons of overburden would be removed from the open pit. Suitable rocky overburden materials would be used for embankment fill, regrading purposes, and other rockfill for the project. Appendix K4.15, Geohazards, addresses the volumes and geotechnical characteristics of the rockfill generated from the open pit and the quarries. Some overburden material would be used for regrading purposes, topsoil would be used as a growth medium during reclamation, and the remainder would be placed in the overburden stockpile.

At the end of mining, the pit would be partially backfilled with pyritic tailings and potentially acid-generating (PAG) waste rock. The partial backfilling would reduce the volume of the open pit, but a permanent void in the landscape would remain. The extent of impacts would be limited to the footprint of the excavated pit and the locations where the materials would be relocated in the mine site. These impacts would be certain to occur if the mine were permitted and built as described for Alternative 1.

Tailings Storage Facilities

A bulk TSF and pyritic TSF would store tailings and waste rock generated from the mined and processed open pit rock (Chapter 2, Alternatives, Figure 2-4). Approximately 88 percent (1,140 million tons) would be bulk tailings, and approximately 12 percent (155 million tons) would be pyritic tailings (PLP 2018d).

The bulk TSF would have the largest footprint of the mine site facilities: about 30 percent of the mine site area. The pyritic TSF would compose about 5 percent of the mine site area.

The magnitude and extent of direct impacts on geologic materials resources would be from the removal and relocation of rock and sediment required for construction of the two TSFs. The impacts would be limited to the footprints of the facilities. During closure, the pyritic tailings would be would be backfilled into the open pit, and the footprint of the pyritic TSF would be regraded to near preexisting topography, so that its impact would be long term. The bulk TSF would be closed, recontoured, and vegetated at closure, and would remain as a new landform. The impact of the bulk TSF on the landscape would be permanent and would be certain to occur if the mine is permitted and the TSF is constructed.

Quarries

Surficial sediments and bedrock would be removed from three quarries in the western portion of the mine site to provide rockfill for the construction of embankments, roads, and other mining-related facilities (Chapter 2, Alternatives, Figure 2-4). The quarries would be developed in granodiorite bedrock, and blasting would be required to remove the rock. The combined areas of the three rock quarries would be an estimated 16 percent of the total mine site area. The magnitude and area of impacts from quarry excavation would be the removal of the following estimated volumes of material and respective dimensions (PLP 2018d) (PLP 2018-RFI 015):

- 1.7 billion cubic feet (ft^3) from Quarry A (approximately 5,000 feet by 2,900 feet)
- 3.2 billion ft^3 from Quarry B (approximately 5,800 feet by 7,000 feet)
- 1.4 billion ft^3 from Quarry C (approximately 5,200 feet by 3,300 feet).

The area of Quarry A would be covered during construction of the bulk TSF; Quarries B and C (west and east of the bulk TSF, respectively) would be backfilled and reclaimed during mine closure (see Section 4.16, Surface Water Hydrology, Figure 4.16-4). Excavation of the quarries would result in direct, long-term to permanent impacts on geologic resources. If the project is permitted and the quarries are mined as described for Alternative 1, these impacts would be certain.

Other Mine Site Facilities

Geologic materials would be removed from and/or relocated to various other facility footprints in the mine site, including water management facilities, milling and processing facilities, the power plant, water treatment plants, camp facilities, storage facilities including laydown areas, and access roads (Chapter 2, Alternatives, Figure 2-4).

The magnitude and extent of the direct impacts on geologic resources at the mine site would be the removal and relocation of geologic materials at these sites, limited to the footprints of the respective facilities. Regrading of some of these facilities at mine closure would minimize impacts on geologic materials (see Section 4.16, Surface Water Hydrology, Figure 4.16-6).

Power generation facilities, some camp and storage facilities, access roads, and the open pit water treatment plant would remain to support post-closure water treatment and site monitoring, which would likely continue beyond post-closure. Therefore, the duration of impacts of these facilities on geologic resources would be permanent. The impacts would be certain to occur if the project were permitted and built.

4.13.2.2 Transportation Corridor

Removal/Relocation of Geologic Materials

Access Roads

The construction of access and spur roads (Chapter 2, Alternatives, Figure 2-13) would require removing and relocating surficial glacial deposits and bedrock (PLP 2018-RFI 032a). The 29-mile-long mine access road from the mine site to the north ferry terminal on Iliamna Lake would be constructed in mostly surficial glacial deposits, with the potential for bedrock presence along approximately 2 miles. The spur road to Iliamna would be approximately 7 miles long and underlain by mostly surficial glacial deposits. Therefore, the road construction right-of-way (ROW) width and associated disturbed geologic resources would be similar to those for the mine access road. The port access road from the south ferry terminal to the Amakdedori port would be approximately 37 miles long and underlain mostly by bedrock.

The width of the construction ROW would vary based on the terrain and underlying geology. The estimated range of disturbed geologic resources to construct the road prism may be roughly 60 to 80 feet (PLP 2018d) (Chapter 2, Alternatives, Figure 2-16). This would include the 30-foot-wide road, embankment slopes, drainage ditches, natural gas pipeline, and cut slopes in surficial glacial deposits and bedrock. Portions of the roadbed underlain by bedrock would likely require blasting (Section 3.13, Geology, Figure 3.13-4).

Under Alternative 1, roads would include a total of 97 stream crossings. These crossing structures would consist of nine bridges and 88 culverts. Crossings designated as fish passage culverts are addressed in Section 4.24, Fish Values. All structures would require rock and riprap consisting of blasted bedrock from the geologic material sites discussed below (PLP 2018d) (Appendix K2, Figure K2-1a and Figure K2-1b).

The magnitude and extent of direct impacts on geologic resources would be the disturbance of these resources within the access road ROW, at stream crossings footprints, and at the material sites (MSs) discussed in the next subsection. The access road would be required for site maintenance and monitoring through post-closure. Therefore, impacts on geologic resources would be permanent, and would be expected to occur if the access roads are permitted and constructed as described for Alternative 1.

Material Sites

The access roads would require rockfill and aggregate for embankments and road surfacing during mine construction, operation, and closure. The rockfill and aggregate would be provided by 18 material sites adjacent to the transportation corridor (Appendix K2, Figure K2-1a and Figure K2-1b).

Footprints of the material sites would vary from 8 to 22 acres, for a total of approximately 241 acres (Appendix K2, Alternatives, Table K2-6). The total volume is estimated to be 7.9 million cubic yards (yd^3).

Two of the seven material sites along the mine access road would be situated in bedrock, and therefore would likely require blasting (Section 3.13, Geology, Figure 3.13-4; Appendix K2, Alternatives, Table K2-6). The remaining five material sites would be in surficial glacial deposits generally consisting of silt- to gravel-sized materials that would not require blasting.

No blasting is anticipated for the three material sites on the spur road to Iliamna that would be situated in surficial glacial deposits (PLP 2018-RFI 035).

All eight material sites along the port access road would be situated in bedrock and would likely require blasting.

The magnitude of direct impacts of the project at materials sites would be the removal of rock and gravel from these sites. The impact would be permanent in terms of geologic resources, but the extent would be limited to the material site footprints. The material sites would eventually be stabilized and progressively reclaimed, but generally would not be backfilled during mine closure and post-closure. These impacts to material sites would be realized if the project is permitted and built.

Ferry Terminals

Constructing the north and south ferry terminals on Iliamna Lake would require excavation of surficial glacial deposits and possibly bedrock on the combined 27 acres of the terminal footprints (Chapter 2, Alternatives, Figure 2-21 through Figure 2-26).

The magnitude of impacts due to ferry terminal construction on geologic features would be the removal and relocation of geologic materials. The extent of direct impacts would be limited to the footprints of the facilities. The ferry terminals would be closed and the sites would be reclaimed during closure. Impacts related to geology would be permanent and certain to occur if the project is permitted and the terminals are constructed.

4.13.2.3 Amakdedori Port

Removal/Relocation of Geologic Materials

The Amakdedori port would be approximately 14 acres, and would require construction of a port terminal, a truck route and causeway, and a barge berth (Chapter 2, Alternatives, Figure 2-28 and Figure 2-29).

Surficial glacial deposits and possible alluvium (mostly of sand and gravel) would be affected during construction of the port terminal.

The truck route and causeway would be constructed of an earthfill embankment. The barge berth would be constructed using an enclosed steel sheet-pile wall wharf structure filled with earthfill. The combined area of the causeway and barge berth would be approximately 13 acres (Chapter 2, Alternatives, Figure 2-28) (PLP 2018-RFI 071). The source of the earthfill would likely be the nearest geologic materials site, MS-A08, and possibly the footprint of the port terminal.

The rockfill access causeway would be constructed in nearshore sediment deposits on the bottom of the bay (see Section 4.16, Surface Water Hydrology, for impacts on marine water; see Section 4.18, Water and Sediment Quality, for impacts on marine water quality). Dredging would not be required.

The magnitude of impacts on geologic features due to Amakdedori port construction would be the removal and relocation of geologic materials. The extent of direct impacts would be limited to the footprints of the port (14 acres) and the cause way and barge berth (13 acres). The port would be closed, and undergo reclamation after completion of the off-site transport of concentrate. Therefore, the duration of impacts would be long-term, and certain to occur if the project is permitted and the Amakdedori port is constructed.

4.13.2.4 Natural Gas Pipeline Corridor

Removal/Relocation of Geologic Materials

Construction of the shoreline component of the pipeline west of the compressor station at Anchor Point would use horizontal directional drilling (HDD) (see Section 4.15, Geohazards, for a more detailed discussion). From the eastern nearshore, portions of the pipeline would be installed beneath the seafloor to a depth determined to avoid navigational hazards, then the pipeline would be laid on the seafloor (PLP 2018-RFI 011). The segment of pipeline placed on the Cook Inlet seafloor would not affect geologic resources.

From the western landfall near Amakdedori port, the magnitude of impacts from pipeline construction on upland geologic features would be the removal of both surficial glacial deposits and bedrock (depending on the location along the corridor) to bury the pipeline. Much of this material would be used to backfill the excavation. Upland pipeline construction would be integrated with access road construction in the ROW where practicable and the extent of impacts would generally be limited to the immediate vicinity of the construction ROW and in established areas used for material laydown and staging of equipment.

Installing the pipeline would likely require drilling and blasting for those segments mapped as underlain by bedrock (Section 3.13, Geology, Figure 3.13-4). Where the pipeline installation is coincident with access road construction, the extent of pipeline-related impacts on geologic resources would be considered part of the impact of the access road ROW (Chapter 2, Alternatives, Figure 2-15).

Where the pipeline installation is not coincident with access road construction, the magnitude and extent of impacts from pipeline installation on geologic resources within the ROW and the related corridor would be approximately 100 feet (Chapter 2, Alternatives, Figure 2-54). However, the disturbed area would be reclaimed after installation of the pipeline. Therefore, the impact on geologic resources beyond the installation trench would be short term, lasting only though the construction phase. However, these impacts would be certain to occur if the project is permitted and the pipeline is constructed as described for Alternative 1.

For the crossing of Iliamna Lake, the pipeline would be buried nearshore in sediments to prevent inadvertent damage, but would then be placed on the floor of the lake (PLP 2018d). The pipeline segment placed on the lake floor would not affect geologic resources.

The natural gas pipeline would be required to support mine site maintenance and monitoring through post-closure. Therefore, the impact on geologic resources would be permanent, because of the displacement of materials required to accommodate the pipeline.

4.13.2.5 Alternative 1 – Summer-Only Ferry Operations Variant

Mine Site Concentrate Storage

During the winter, concentrate would be stored in a 38-acre shipping storage container laydown area constructed of rock and gravel fill northeast of the pyritic TSF (Chapter 2, Alternatives,

Figure 2-56). The magnitude and extent of impacts due to construction of the concentrate storage site on geologic features would be the removal and relocation of geologic materials from these 38 acres. The facility would be removed and the sites would be reclaimed during closure. Therefore, impacts related to geology would be long term and certain to occur if the Summer-Only Ferry Operations Variant is chosen, the project is permitted and the storage area is constructed.

Amakdedori Port

The Summer-Only Ferry Operations Variant would require the Amakdedori port to include an expanded storage yard. The extent of impacts on geologic resources would be limited to the construction footprint. The port would be closed and undergo reclamation after completion of the off-site transport of concentrate for the project. Impacts would therefore be long term and certain to occur if the Summer-Only Ferry Operations Variant is chosen and the project is permitted and built.

4.13.2.6 Alternative 1 – Kokhanok East Ferry Terminal Variant

The Kokhanok east ferry terminal would be constructed east of Kokhanok (Chapter 2, Alternatives, Figure 2-41 and Figure 2-42). Construction of the ferry terminal under this variant would encounter similar geology as construction of the Kokhanok ferry terminal.

The Kokhanok east ferry terminal would require approximately 64 percent more rockfill material than the Kokhanok ferry terminal (PLP 2018d). Also, because the natural gas pipeline alignment would not coincide with the road corridor in the northern portion of the alignment, installing the pipeline would result in additional disturbance of geologic materials in the ROW (Chapter 2, Alternatives, Figure 2-41).

Three of the material sites for the Kokhanok East Ferry Terminal Variant would change from MS-A01 through MS-A0 (totaling approximately 39 acres) to MS-K01 through MS-K03 (totaling approximately 163 acres). This would result in an approximately 70 percent increase in the area of material sites needed to construct the Kokhanok East Ferry Terminal Variant.

The magnitude of impacts on geological features due to construction of the Kokhanok east ferry terminal site would be the removal and relocation of geologic materials in the construction footprints of the ferry terminal site, the natural gas pipeline alignment, and the access road to the ferry terminal. The extent of impacts due to the removal of geologic material would be greater than those estimated for the Kokhanok ferry terminal (Alternative 1 without this variant) because more fill would be required to construct the terminal at the east location.

The closure-related impacts of the Kokhanok East Ferry Terminal Variant would be similar to those for the south ferry terminal site. Both ferry terminal sites would be closed, and reclaimed in closure, so that the duration of impacts would be long term. These impacts on geologic resources would be certain to occur if the Kokhanok East Ferry Terminal Variant were chosen, permitted, and built.

4.13.2.7 Alternative 1 – Pile-Supported Dock Variant

The Pile-Supported Dock Variant (Chapter 2, Alternatives, Figure 2-43) would include approximately 518 piles that would disturb approximately 6,500 square feet of area (less than 2 acres) (PLP 2018-RFI 071). This would compare with an estimated 27 acres for the port without the pile-support design (Chapter 2, Alternatives, Figure 2-28). Therefore, the magnitude of impacts on geologic resources due to construction of the Pile-Supported Dock Variant would be

approximately 94 percent less on than the earthfill causeway and sheet pile wall wharf structure described for Alternative 1.

As described above for the earthfill causeway and sheet pile wall wharf, the Pile-Supported Dock Variant would be closed, and undergo reclamation after completion of the off-site transport of concentrate, as described under Alternative 1. Therefore, the duration of impacts would be long term.

Closure of the pile-supported port facility would be similar to closure of the port without pile support. However, instead of removing the earthfill from the footprint of the causeway and from behind the sheet pile wall berth and wharf structure, closure would involve removing the steel piling and disposing of it off site (PLP 2018d). Therefore, closure-related impacts would also be approximately 98 percent less than the closure-related impacts of the earthfill causeway and sheet pile wall wharf design. These impacts would be certain to occur if the Pile-Supported Dock Variant were to be chosen, permitted, and built.

4.13.3 Action Alternative 2 – North Road and Ferry with Downstream Dams

The analysis of impacts from Alternative 2 on geologic resources is presented below.

4.13.3.1 Mine Site

Removal/Relocation of Geologic Materials

Impacts of Alternative 2 on geologic resources at the mine site would be similar to impacts of Alternative 1. The difference is that the bulk TSF main embankment would be developed by downstream construction with downstream buttresses under Alternative 2, compared to centerline construction with downstream buttresses under Alternative 1 (Chapter 2, Alternatives, Figure 2-45 through Figure 2-47). The magnitude and extent of impacts to geologic resources would increase from 78 million yd^3 for Alternative 1 to 124 million yd^3 for Alternative 2 (PLP 2018-RFI 075a). This is because the footprint for the bulk TSF main embankment would increase by approximately 119 acres, requiring additional embankment fill. This would be an increase in direct impacts on geologic resources under Alternative 2 of approximately 5 percent for the bulk TSF main embankment, and approximately 1 percent for the overall mine site (PLP 2018-RFI 075a) as compared to Alternative 1. The impacts would be permanent because the bulk TSF would be closed, and reclaimed in place. The impacts would be expected to occur if the Alternative 2 is chosen as the preferred alternative and the project is permitted and built.

4.13.3.2 Transportation Corridor

Removal/Relocation of Geologic Materials

Access Road

Alternative 2 would involve constructing and operating an access road that would total approximately 54 miles (Chapter 2, Alternatives, Figure 2-48; PLP 2018d). An estimated 5 miles of the Alternative 2 access road would use an existing road; and the remainder would require new road construction, or widening of the existing road.

The mine access road to the ferry terminal at Eagle Bay would be approximately 36 miles long and underlain by geology similar to that of the mine access road under Alternative 1, including possible blasting for approximately 2 miles of the corridor (Chapter 2, Alternatives, Figure 2-49; Figure 3.13-4). A spur road to Iliamna would not be required under Alternative 2.

The access road from the Pile Bay ferry terminal to Williamsport would generally follow the existing road (Chapter 2, Alternatives, Figure 2-50; PLP 2018d). However, the road would need to be expanded and possibly bypassed in places to make the road suitable for use by haul trucks. This would have the potential to result in fewer impacts on geologic resources than constructing a new road. However, material sites would still be needed for both construction and maintenance of the road surface (see "Material Sites," below).

Portions of the corridor are underlain by surficial glacial deposits where there may be less need for blasting. However, if the existing road were to be bypassed or widened to accommodate the requirements for a haul road, it is possible, and in places likely, that bedrock would be encountered outside the ROW of the existing road. For example, several material sites are likely in bedrock.

A new, approximately 3-mile-long access road from Williamsport to Diamond Point would be constructed. Constructing this road would require removing and relocating mostly bedrock. Blasting would likely be required because of the type of bedrock (competent igneous intrusive rock) (Section 3.13, Geology, Figure 3.13-4).

The magnitude of direct impacts on geologic resources from constructing the access road would be the removal of geologic materials. The extent of impacts would be limited to the access road ROW. The total road distance for Alternative 2 would be approximately 19 percent less than under Alternative 1. If the 5 miles of existing road are considered, the net impact on geologic resources under Alternative 2 would be approximately 26 percent less than the impact under Alternative 1.

As described for Alternative 1, the Alternative 2 road would be required for site maintenance and monitoring through post-closure. Therefore, the impact on geologic resources would be permanent. The impacts would occur if Alternative 2 is chosen and the transportation system associated with it is permitted and built.

Material Sites

Road construction and operational maintenance under Alternative 2 would require material sites to provide required aggregate for road surfacing during mine construction, operation, and closure (Chapter 2, Alternatives, Figure 2-48 through Figure 2-50; and Appendix K2, Table K2-6).

For Alternative 2, 17 material sites (including the existing Diamond Point quarry) would be required versus 15 sites under Alternative 1. The footprints of the Alternative 2 material sites would vary from approximately 8 acres to 54 acres, for a total of approximately 431 acres (Appendix K2, Table K2-12). This would be approximately 179 percent more area than needed under Alternative 1.

Blasting would likely be required to remove bedrock from five of the 17 Alternative 2 material sites (Section 3.13, Geology, Figure 3.13-4). No blasting is anticipated for the 10 material sites associated with the mine access road to the Eagle Bay ferry terminal. Five of the seven material sites between Pile Bay and the port would likely require blasting. This would result in approximately 66 percent less blasting than under Alternative 1.

As under Alternative 1, the magnitude of direct impacts on geologic resources at material sites under Alternative 2 would be the removal and relocation of geologic materials for road surfacing. The extent of direct impacts would be limited to the footprints of the material sites. The material sites would be eventually stabilized and progressively reclaimed, but generally would not be backfilled during mine closure and post-closure. Therefore, impacts would be permanent. They would be certain to occur as described in Alternative 2 was chosen, permitted, and built.

Ferry Terminals

The transportation corridor under Alternative 2 would require ferry terminals at Eagle Bay and Pile Bay, which would be approximately the same size as the ferry terminals described for Alternative 1 (Chapter 2, Alternatives, Figure 2-48 through Figure 2-50). The geology at the ferry terminals under Alternative 2 would be similar to the geology at the ferry terminals under Alternative 1.

The magnitude, extent, duration, and likelihood of impacts of construction of the Alternative 2 ferry terminals on geologic resources would be similar to the impacts of the ferry terminals under Alternative 1.

4.13.3.3 Diamond Point Port

Removal/Relocation of Geologic Materials

The Diamond Point port facility would use the same design concept as the Amakdedori port under Alternative 1. The total footprint of the Diamond Point port would be larger than that of the Amakdedori port. The Diamond Point port would encompass an estimated 102 acres (PLP 2018-RFI 071). The estimated dredged area would be an additional estimated 60 to 70 acres. The entire port area would total roughly 162 to 172 acres of affected geologic resources, compared to the roughly 27 acres at the Amakdedori port under Alternative 1.

Dredging would create approximately 650,000 yd^3 of geologic materials to deepen the channel adjacent to and near the port wharf structure. Most dredged material (615,000 yd^3) would be used as earthfill behind the sheet pile wall. Any remaining material would be placed in the Dredged Materials Storage Area west of the port terminal (Chapter 2, Alternatives, Figure 2-52).

The magnitude of direct impacts on geologic resources would be the removal and relocation of geologic materials to construct the Diamond Point port. Because the Diamond Point port site is much larger than the Amakdedori port site, these impacts would be more than five times the geographic extent of the impacts described under Alternative 1. As described for the Alternative 1 Amakdedori port site, the earthen access causeway would affect the nearshore sediment deposits of Iliamna Bay (see Section 4.16, Surface Water Hydrology, for impacts on marine water; see Section 4.18, Water and Sediment Quality, for impacts on marine water quality).

The Diamond Point port would be closed, and would undergo reclamation after the completion of off-site transport of concentrate, as described for Alternative 1. Therefore, the duration of impacts would be long term, and would be certain to occur if this alternative was chosen and the port was permitted and built.

4.13.3.4 Natural Gas Pipeline Corridor

Removal/Relocation of Geologic Materials

Construction of the natural gas pipeline under Alternative 2 would require disturbing both surficial glacial soils and bedrock for all upland portions of the pipeline (Chapter 2, Alternatives, Figure 2-52), as described for Alternative 1 above. The corridor route, length, and respective geologic resources would differ from those of Alternative 1. See Chapter 2, Alternatives, for the Alternative 2 pipeline corridor route.

Pipeline construction materials and methods for Alternative 2 would be similar to those for Alternative 1. However, the pipeline segment between the Pile Bay road intersection and the mine site would require an installation corridor independent of the transportation system. The pipeline installation equipment would require a corridor or ROW estimated at 100 feet wide; the

actual width would vary depending on the terrain and underlying geology (Chapter 2, Alternatives, Figure 2-55).

For the pipeline segment between the Pile Bay road intersection and about Pedro Bay, the corridor is underlain by bedrock with relatively steep topography for portions of the alignment. From Pedro Bay to the western portion of Knutson Bay, the geology would consist mostly of surficial glacial deposits, and then bedrock similar to that found near Pedro Bay. From Knutson Bay to the mine site, the geology would generally consist of surficial glacial deposits, similar to the geology of the Alternative 2 transportation corridor to the Eagle Bay ferry terminal.

The total length of the upland section of the pipeline from Ursus Cove to the mine site would be approximately 88 miles. Blasting would be required during installation of an estimated 20 to 25 miles of the pipeline, an estimated 20 to 40 percent less blasting than Alternative 1.

The magnitude of direct impacts on geologic resources from installation of the natural gas pipeline would be the removal and placement of geologic materials for construction. The extent of impacts would be limited to within the construction ROW for pipeline installation. As described for Alternative 1, the natural gas pipeline would be required for site maintenance and monitoring through post-closure. Therefore, the duration of the impact on geologic resources would be permanent and certain to occur if this pipeline as described for Alternative 2 were permitted and built.

4.13.3.5 Alternative 2 – Summer-Only Ferry Operations Variant

Impacts would be the same as those described above for Alternative 1 during summer-only ferry operations.

4.13.3.6 Alternative 2 – Pile-Supported Dock Variant

A Pile-Supported Dock Variant (Chapter 2, Alternatives, Figure 2-58) with a total of 253 steel piles would replace the earthfill causeway, sheet pile wall, and earthfill wharf structure of Alternative 1. The magnitude of the impact would be the disturbance of about approximately 3,200 square feet of geologic resources (PLP 2018-RFI 072). Impacts on geologic resources would be direct, and the extent of impacts would be limited to the footprint of the piling. As described above for the non-pile-supported dock, the Pile-Supported Dock Variant would be closed, and would undergo reclamation after the completion of off-site transport of concentrate, as described for Alternative 1. Therefore, the duration of the impacts would be long term, and they would be expected to occur if Alternative 2 were chosen as the preferred alternative and the Pile-Supported Dock Variant was permitted and built.

Closure of the pile-supported dock port would be similar to closure of the port without pile support. However, instead of removing the earthfill from the footprint of the causeway and from behind the sheet pile wall berth and wharf structure, the closure would include removing the steel piling and disposing of it off site (PLP 2018d). Therefore, the closure-related impacts would also be less than the closure-related impacts of the earthfill causeway and sheet pile wall wharf design.

4.13.4 Action Alternative 3 – North Road Only

The analysis of impacts from Alternative 3 on geologic resources is presented below.

4.13.4.1 Mine Site

Impacts of Alternative 3 on geologic resources at the mine site would be the same as those described for Alternative 1.

4.13.4.2 Transportation Corridor

Removal/Relocation of Geologic Materials

Access Road

Impacts on geologic resources resulting from the construction and operation of the Alternative 3 access road (Chapter 2, Alternatives, Figure 2-61) would be generally the same as the impacts of the natural gas pipeline corridor described for Alternative 2. The differences in potential related impacts are summarized below.

From the mine site to near Knutson Bay, the geology would consist of surficial glacial deposits, similar to the geology of the Alternative 2 transportation corridor to the Eagle Bay ferry terminal. From the western portion of Knutson Bay to Pedro Bay, the geology would consist mostly of bedrock and surficial glacial deposits. From Pedro Bay to the Pile Bay road intersection, the corridor is mapped as underlain by bedrock and relatively steep topography for portions of the alignment.

The access road from the Pile Bay road intersection to Williamsport would generally follow the existing road (Chapter 2, Alternatives, Figure 2-61), which is underlain by a combination of bedrock and surficial glacial deposits. The last approximately 3 miles of new road from Williamsport to the Diamond Point port would be underlain by bedrock.

The magnitude of direct impacts on geologic resources from constructing the access road would be the placement of geologic materials, and the extent of impacts would be limited to the access road ROW. Alternative 3 would require removing and relocating approximately 25 percent more geologic material for the access road than under Alternative 1, and 54 percent more than under Alternative 2. As with Alternatives 1 and 2, the road would be required for site maintenance and monitoring through post-closure. Therefore, the duration of the impact on geologic resources would be permanent. These impacts would be certain to occur if Alternative 3 is chosen as the preferred alternative and the project is constructed and built.

Material Sites

As with Alternative 1 and Alternative 2, access road construction and operational maintenance under Alternative 3 would require material sites, to provide required aggregate for road surfacing during mine construction, operation, and closure (Appendix K2, Figure K2-3; and Table K2-16).

Twenty-seven material sites (including the existing Diamond Point quarry) would be required for Alternative 3, versus 15 sites under Alternative 1, and 12 sites under Alternative 2. The footprints of the Alternative 3 material sites would vary from 8 acres to 54 acres, for a total of an estimated 808 acres (PLP 2018-RFI 035). This would be 208 percent more than needed under Alternative 1, and 72 percent more than needed under Alternative 2.

Blasting would likely be required to remove bedrock from seven of the Alternative 3 material sites (Section 3.13, Geology, Figure 3.13-4). All other material sites would be in surficial glacial deposits. Therefore, approximately 72 percent less blasting would be required under Alternative 3 than under Alternative 1, and 227 percent more than under Alternative 2.

As under both Alternatives 1 and 2, the magnitude an extent of direct impacts to material sites under Alternative 3 would be the removal of rock and gravel. The extent of the impact would be limited to within the footprints of the material sites; the sites would be eventually stabilized and progressively reclaimed, but not backfilled, during mine closure and post-closure. Therefore, the

duration of impacts to the sites would be permanent. These impacts would be expected to occur if Alternative 3 is chosen, permitted and built.

Ferry Terminals

No ferry terminals would be needed under Alternative 3. Therefore, no impacts on geologic resources would occur.

4.13.4.3 Diamond Point Port

Impacts on geologic resources at the Diamond Point port site would be the same as those described above for Alternative 2.

4.13.4.4 Natural Gas Pipeline Corridor

Removal/Relocation of Geologic Materials

As described for Alternative 1 and Alternative 2, construction of the natural gas pipeline under Alternative 3 would require removing and relocating geologic resources to bury the pipeline in an excavated trench for all upland portions of the pipeline.

The Alternative 3 pipeline route would be the same as the route under Alternative 2. However, the Alternative 3 corridor may be an average of approximately 10 to 20 percent narrower, because the access road would be available for staging materials during pipeline installation, instead of needing an estimated 100-foot-wide ROW for pipeline installation when not adjacent to an access road (Chapter 2, Alternatives, Figure 2-54).

Therefore, the magnitude of impacts to geological resources would be less than that for Alternative 2. The extent of impacts would be within the pipeline and access road corridors. As described for both Alternatives 1 and 2, the natural gas pipeline under Alternative 3 would be required for site maintenance and monitoring through post-closure. Therefore, the duration impact on geologic resources would be permanent and expected to occur if Alternative 3 is chosen as the preferred alternative and the project is permitted and built.

4.13.4.5 Alternative 3 – Concentrate Pipeline Variant

The Alternative 3 Concentrate Pipeline Variant would involve installing and operating a concentrate pipeline from the mine site to the Diamond Point port. The pipeline would be installed in the same trench as the natural gas pipeline, and in a ROW estimated to be 100 feet wide (Chapter 2, Alternatives, Figure 2-63). Therefore, impacts would be the same as those for the Alternative 2 natural gas pipeline corridor.

From Williamsport to Diamond Point, the concentrate pipeline would be installed in the transportation corridor, which would still be required for construction and maintenance of the Diamond Point port (Chapter 2, Alternatives, Figure 2-63). The port would be modified to accommodate a concentrate pipeline filter plant and bulk storage building. This would not change the overall footprint of the port. The impact on geologic materials, however, would be similar to that of the port terminal without concentrate-related facilities.

The Concentrate Pipeline Variant would also require a pump house at the mine site. The magnitude and extent of impacts on geologic resources would be limited to a footprint of about 0.7 acre (Chapter 2, Alternatives, Figure 2-62). The concentrate pipeline would be decommissioned in place at mine closure; however, to avoid further ground disturbance, the pipeline would not be removed. Therefore, the duration of impact on geologic materials would

be permanent. Impacts would be certain to occur at this magnitude if Alternative 3 was chosen and the pipeline is permitted and built.

4.13.5 Summary of Key Issues

Table 4.13-1 provides a summary of the key issues and impacts from the project on geologic resources.

Table 4.13-1: Summary of Key Issues for Geology

Impact-Causing Project Component	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variants
Mine Site			
Mine Site Construction and Operations	Construction and operation of the mine site would result in removal and/or replacement of geologic resources in conjunction with all facilities. Impacts would occur from blasting of most bedrock in construction areas. All impacts would be direct, and limited to footprints of facilities. No change in impacts for variants.	Impacts similar to those of Alternative 1, except the bulk TSF main embankment, would be downstream; constructed with downstream buttresses, which would result in an ~5% increase in the total mine site footprint, and resulting direct impacts on geologic resources. No change in impacts for variants.	Impacts similar to those of Alternative 1. **Concentrate Pipeline Variant:** Increased project footprint by less than 1 acre, and associated impacts.
Mine Site Closure	All embankments other than those at the bulk TSF would be removed and the areas reclaimed at closure, resulting in direct, long-term impacts. Pyritic TSF: Material would be placed in the open pit, resulting in long-term direct impacts. Open Pit: Would be partially backfilled, resulting in permanent direct impacts. Bulk TSF: Would be closed and reclaimed in place, resulting in permanent direct impacts. No change in impacts for variants.	Impacts would be the same as those for Alternative 1, except with a larger bulk TSF footprint. No change in impacts for variants.	Impacts would be the same as those for Alternative 1. No change in impacts for variants.
Transportation Corridor			
Transportation Corridor Construction and Operations	Access Road: Total 75 miles. Mine Access Road: 27 miles to north ferry terminal, mostly surficial glacial deposits. Bedrock ~2 miles; likely blasting impacts. Iliamna Spur Road: 7 miles, mostly surficial glacial deposits. Port Access Road: 32 miles, mostly bedrock, likely blasting. Geologic MSs: 18 MSs, 241	Access Road: Total 54 miles (~5 miles using existing road). Mine Access Road: 36 miles to Eagle Bay, mostly surficial glacial deposits. Bedrock ~2 miles, likely blasting. Iliamna Spur Road: N/A Port Access Road: 32 miles mostly shallow	Access Road: Total 82 miles. Mine Access to Port Road: Mostly surficial glacial deposits from mine site to Knutson Bay, then a combination of glacial deposits and bedrock to the port. Blasting likely for northwestern Knutson Bay, Pedro Bay to Pile

Table 4.13-1: Summary of Key Issues for Geology

Impact-Causing Project Component	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variants
	acres. Mine Access Road MSs: 7 total and 2 blasting. Iliamna Spur Road MSs: 3 total, and no blasting. Port Access Road MSs: 8 total and all blasting. Ferry Terminals: 27 acres of direct impacts. Kokhanok East Ferry Terminal Variant: Direct impact ~70% more geologic resources to construct than the Alternative 1 terminal, and indirect impact of wider gas pipeline ROW where not adjacent to road.	bedrock blasting. Geologic MSs: 17 MSs, 431 acres. Mine Access Road MSs: 10 total & 0 blasting. Iliamna Spur Road MSs: N/A. Port Access Road MSs: 7 total & 5 blasting. Ferry Terminals: 27 acres, direct impacts. Variants N/A	Bay road intersection, and Williamsport to the port. Geologic MSs: 27 MSs, 808 acres. Mine Access Road to Port MSs: 27 total and 7 blasting. Iliamna Spur Road MSs: N/A. Port Access Road MSs: N/A. Ferry Terminals: N/A. Concentrate Pipeline Variant: Same impacts as those for Alternative 1 for the gas pipeline.
Transportation Corridor Closure	Geologic MSs: Progressively reclaimed but not backfilled, so there would be permanent impacts. Ferry Terminals: Decommissioning and reclamation at mine closure, so long-term impacts. **Kokhanok East Ferry Terminal Variant:** Same as for Alternative 1.	Geologic MSs: Same as for Alternative 1. Ferry Terminals: Same as for Alternative 1. **Variants** N/A	Geologic MSs: Same as for Alternative 1. Ferry Terminals: Same as for Alternative 1. **Concentrate Pipeline Variant:** Same impacts as those of Alternative 2 gas pipeline.
Ports			
Port Construction and Operation	Amakdedori Port: Earthfill embankment causeway and steel sheet pile wall wharf with earthfill design. Port Terminal +Causeway/ Barge Wharf: 27 acres. No dredging. **Pile-Supported Dock Variant:** Reduce causeway/barge wharf to ~0.1 acre **Summer-Only Ferry Variant:** Expanded port terminal by 28 acres.	Diamond Point Port: Earthfill embankment causeway and steel sheet pile wall wharf with earthfill design. Port Terminal Causeway/ Barge Wharf: 101 acres. Dredging: ~60 to 70 acres (most dredged material used as earthfill). **Pile-Supported Dock Variant**: Reduce causeway/barge wharf to ~2 acres.	Same as for Alternative 2. **Concentrate Pipeline Variant:** Modify port terminal, but footprint nearly the same as for Alternative 2.
Port Closure	Amakdedori Port: Structures and earthfill removed after mine closure, so impacts would be long-term. **Pile-Supported Dock Variant**: Same as above, but the impact would be less because of smaller piling footprint and no causeway and wharf earthfill.	Diamond Point Port: Same as for Alternative 1, but with an area about four to five times larger. **Pile-Supported Dock Variant**: Larger area of impact on seafloor. Long-term impacts.	Impacts same as those of Alternative 2. **Concentrate Pipeline Variant**: Minimal impact difference. Long-term impacts.

Table 4.13-1: Summary of Key Issues for Geology

Impact-Causing Project Component	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variants
	Long-term impacts. **Summer-Only Ferry Variant:** Same as for Alternative 1, but larger area and long-term impacts.		
Natural Gas Pipeline Corridor			
Gas Pipeline Construction and Operations	Total Upland Length: 66 miles Kenai Peninsula: HDD at Anchor Point to safe depth in Cook Inlet, then on seafloor. Amakdedori Port to Mine Site: Generally installed within access road alignment, so same geological resources affected. 66 miles upland (plus lake crossing, pipeline on lake floor). Impacts are the same as for Alternative 1 access road. **Variants** N/A	Total Upland Length: 88 miles Kenai Peninsula: Same as for Alternative 1. Ursus Cove to Mine Site: Independent alignment from Ursus Cove to Diamond Point port. Installed in access road to Pile Bay road intersection. Then independent ROW to mine site. Impacts for ROW independent of access road about 10 to 20% more because of design width. Would directly affect geologic resources consisting of surficial glacial deposits for about 63 to 68 miles, and bedrock for the remainder, which would likely require blasting. **Variants** N/A	Same as for Alternative 2 except installed in access road ROW. **Variants** N/A
Gas Pipeline Closure	Required through post-closure, resulting in permanent impacts. **Variants** N/A	Same as for Alternative 1. **Variants** N/A	Same as for Alternative 1. **Variant** N/A

MS = material site N/A = not applicable

4.13.6 Cumulative Effects

The cumulative effects analysis area for geologic resources encompasses the footprint of the proposed project, including alternatives and variants. In this area, a nexus may exist between the project and other past, present, and reasonably foreseeable future actions (RFFAs) that could contribute to cumulative effects on geologic resources. Section 4.1, Introduction to Environmental Consequences, details the comprehensive set of past, present, and RFFAs considered for evaluation as applicable. A number of the actions identified in Section 4.1, Introduction to Environmental Consequences, are considered to have no potential of contributing to cumulative effects on geologic resources in the analysis area. These include offshore-based developments, activities that may occur in the analysis area but are unlikely to result in any appreciable impact on geologic resources (such as tourism, recreation, fishing, and

hunting), or actions outside of the cumulative effects analysis area (e.g., Donlin Gold, Shotgun, Johnson Tract).

Past, present, and RFFAs that could contribute cumulatively to geologic resource impacts, and are therefore considered in this analysis, include:

- Pebble Project buildout—develop 55 percent of the resource over a 78-year period
- Pebble South/PEB*
- Big Chunk South*
- Big Chunk North*
- Fog Lake*
- Groundhog*
- Diamond Point Rock Quarry

**Indicates exploration activities only.*

4.13.6.1 Past and Present Actions

Past and present actions that have impacted geologic resources in the analysis area include transportation development where existing roads intersect the project footprint, and mineral exploration in locations where past or current activities have impacted geologic resources (e.g., drill sites). Although these actions affect localized areas, they are additive to other actions that may occur, slightly increasing the total cumulative effect on geologic resources. Past exploration at the Pebble deposit has included drilling of over 1,600 boreholes. Similarly, there have been boreholes drilled associated with exploration at other deposits in the analysis area. However, for approved exploration activities on state lands, there are requirements with regard to stabilizing boreholes and site remediation. Overall, the cumulative effects on geologic resources from past and present actions are minimal in extent and minor in magnitude for all action alternatives.

4.13.6.2 Reasonably Foreseeable Future Actions

No Action Alternative

The No Action Alternative would not contribute to cumulative effects on geologic resources.

Alternative 1 – Applicant's Proposed Alternative

Pebble Mine Expanded Development Scenario – An expanded development scenario for this project, as detailed in Section 4.1, Introduction to Environmental Consequences, Table 4.1-2, would include an additional 58 years of mining (for a total of 78 years) over a larger mine site footprint, and would include increases in port and transportation corridor infrastructure. The mine site footprint would have a larger open pit and new facilities to store tailings and waste rock (Section 4.1, Introduction to Environmental Consequences, Figure 4.1.1), which would contribute to cumulative effects on geologic resources through removal of overburden, waste rock, and ore.

The mine-expanded development scenario project footprint would impact approximately 34,790 acres, compared to 12,371 acres under Alternative 1.

Other Mineral Exploration Projects – Mineral exploration is likely to continue in the analysis area for the mining projects listed previously in this section. Exploration activities, including additional borehole drilling, road and pad construction, and development of temporary camp and other support facilities, would contribute to the cumulative effects on geologic resources, although impacts would be expected to be limited in extent and low in magnitude.

Road Improvement and Community Development Projects – Road improvement projects could have limited impacts on geologic resources, and therefore contribute to cumulative effects

in the analysis area. The most likely road improvements in the area would be in the development footprint of existing communities, with only Iliamna and Newhalen being considered to be in the analysis area for geologic resource cumulative effects. Some limited road upgrades could also occur in the vicinity of the natural gas pipeline eastern terminus near Stariski Creek. None of the anticipated transportation development in the geologic resources analysis area would contribute greatly to cumulative effects on those resources.

Additional RFFAs that have the potential to affect geologic resources in the analysis area are limited to the Diamond Point rock quarry. That RFFA would include the excavation of geologic resources, which would represent a direct and cumulative effect. The estimated total rock reserve of the proposed quarry source is approximately 10 to 15 million cubic yards (USFWS 2012g).

Alternative 2 – North Road and Ferry with Downstream Dams

Pebble Mine Expanded Development Scenario – Expanded mine site development and associated contributions to cumulative effects would be the same for all action alternatives. Under Alternative 2, project expansion would use the existing Diamond Point port facility; would use the same natural gas pipeline; and would use the constructed portion of the North Road. A concentrate pipeline and a diesel pipeline from the mine site to Iniskin Bay would be constructed, both having potentially limited impacts on geologic resources due to trenching and burial. Cumulative effects on geologic resources would be similar to those discussed under Alternative 1.

Other Mineral Exploration Projects, Road Improvement and Community Development Projects – Cumulative effects of these activities on geologic resources would be similar to those discussed under Alternative 1.

Alternative 3 – North Road Only

Pebble Mine Expanded Development Scenario – Expanded mine site development and associated contributions to cumulative effects on geologic resources would be very similar for all action alternatives. Under Alternative 3, project expansion would use the Diamond Point port facility; would use the same natural gas pipeline and diesel pipeline; and would use the same north access road and Concentrate Pipeline Variant as described under Alternative 2, but extend the concentrate pipeline with a service road to Iniskin Bay.

Other Mineral Exploration Projects, Road Improvement, and Community Development Projects – Cumulative effects of these activities on geologic resources would be similar to those discussed under Alternative 1.