CHAPTER 6.
GEOTECHNICAL STUDIES, SEISMICITY, AND VOLCANISM
Bristol Bay Drainages

PREPARED BY:
Knight Piésold Ltd.
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**ACRONYMS AND ABBREVIATIONS**

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<td>ASTM</td>
<td>American Standard Test Method</td>
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<tr>
<td>Frontier</td>
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<tr>
<td>GSI</td>
<td>geological strength index</td>
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<td>HQ3</td>
<td>nominal size of Boart Longyear Triple Tube Diamond drilling bit</td>
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<tr>
<td>HW</td>
<td>nominal size of Boart Longyear casing</td>
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<td>KP</td>
<td>Knight Piésold Ltd.</td>
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<tr>
<td>M</td>
<td>magnitude of earthquake</td>
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<td>‘N’ value</td>
<td>number of blows necessary to advance a sampler a specified distance</td>
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<td>Northern Dynasty Mines Inc./Northern Dynasty Minerals Ltd.</td>
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<td>PQ3</td>
<td>nominal size of Boart Longyear Triple Tube Diamond drilling bit</td>
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<tr>
<td>PVC</td>
<td>polyvinyl chloride</td>
</tr>
<tr>
<td>PW</td>
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<td>standard penetration test</td>
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<td>UCS</td>
<td>unconfined compressive strength</td>
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6. GEOTECHNICAL STUDIES, SEISMICITY, AND VOLCANISM

6.1 Introduction

This chapter describes the baseline geotechnical characteristics for the mine study area and the seismicity characteristics of the Bristol Bay drainages study area. There are no active volcanoes located within the Bristol Bay drainages study area which encompasses the mine study area and the transportation corridor study area as shown on Figure 6-1, but the study area could be affected by volcanoes located near Cook Inlet. Regional volcanism associated with the Cook Inlet volcanoes is presented in Chapter 30.

The description of geotechnical conditions within the mine study area is based on geotechnical site investigations up to the end of 2008. No geotechnical information has been collected on the transportation corridor study area to date. The description of seismicity characteristics is based on a desktop overview study of available regional information. To avoid confusion, it should be noted that the geotechnical site investigations conducted within the mine study area have included seismic geophysical techniques. The results of these seismic site investigations should not be confused with the overview study of regional seismicity.

Geotechnical characteristics comprise aspects of surficial geology, overburden and bedrock geology, hydrogeology, physiography, topography, and soils as they pertain to engineering design. Geotechnical information of interest includes rock mass characterization and classification of bedrock; the depth, composition, and characteristics of overburden (surficial materials and organic soils); and the presence and movement of water within these materials. Related overview studies are presented in Chapters 3, 4, 5, and 8.

6.2 Study Objectives

The objective of this study is to provide baseline geotechnical and seismicity information to characterize the mine study area and the transportation corridor study area.

6.3 Study Area

The Bristol Bay drainages study area lies on the north side of Iliamna Lake and extends from the North Fork Koktuli River in the west to the Cook Inlet drainage divide in the east. The northern boundary is defined by the Lake Clark National Park and Preserve, while Iliamna Lake defines the southern boundary. The extent of the study area is shown on Figure 6-1. The mine study area encompasses the Pebble Deposit Area in the western part of the Bristol Bay drainages study area. The transportation corridor study area runs eastward from the mine study area toward Cook Inlet.

The mine study area was subdivided into 10 smaller reference areas based on geographical locations, including the Pebble West and Pebble East Areas that comprise the Pebble Deposit Area. The approximate boundaries of these reference areas are shown on Figure 6-2a. The reference area boundaries.
have been updated; the boundaries and area names shown on Figure 6-2a supersede previous reference areas presented in the Knight Piésold Ltd. (KP) 2004, 2005, 2006, and 2007 site investigation reports. The 10 reference areas are described below:

- Pebble West Area—occupies part of the topographic saddle between the watersheds of Upper Talarik Creek and the South Fork Koktuli River.
- Pebble East Area—occupies part of the topographic saddle between the watersheds of Upper Talarik Creek and the South Fork Koktuli River.
- Area J—tributary valley to the South Fork Koktuli River.
- Area L—tributary valley to the South Fork Koktuli River.
- Area E—tributary valley to the North Fork Koktuli River.
- Area G—tributary valley to the North Fork Koktuli River.
- Upper Talarik Creek Area—residual area within the Upper Talarik Creek drainage.
- North Fork Koktuli River Area—residual area within the North Fork Koktuli drainage.
- South Fork Koktuli River Area—residual area within the South Fork Koktuli River drainage.
- Area A—the upper valley of the South Fork Koktuli River including Frying Pan Lake.

Area A is further broken down into four geomorphic subareas that are shown on Figure 6-2b and are described below:

- Valley Bottom—lowlands extending south from the Deposit Area, including Frying Pan Lake and adjacent low terrain.
- Lower/Mid Side Slopes—lower slopes on either side of the main valley.
- Upper Side Slopes—upper slopes on either side of the main valley.
- Southern Upland—to the south of Frying Pan Lake and north of the South Fork Koktuli River Area.

The regional geology of the study area is discussed in detail in Chapter 3, but in general terms the study area is located in a small basin that was infilled by Jurassic to Cretaceous sedimentary rocks that were intruded by the Cretaceous Kaskanak Batholith. The eastern portion of the batholith was, in turn, intruded by a north-northeast trending swarm of stocks, dikes, and irregular bodies that host the mineralization of the Pebble Deposit. Tertiary to Recent volcanic rocks and associated sedimentary rocks were deposited and the region was deformed along a series of thrust and transverse faults, including the Lake Clark structure. The Pebble region was then eroded by Quaternary to Recent glaciers, and the valleys were filled with glacial deposits during glacial advance and retreat phases.

### 6.4 Scope of Work

This chapter of the environmental baseline document presents baseline geotechnical information collected in the study area from 2004 to the end of 2008 and regional seismicity information based on desktop studies and reviews of current published information. Detailed geotechnical information for the mine
study area is based on site investigations carried out by KP, hydrogeological investigations by Water Management Consultants Inc./Schlumberger Water Services (WMC/SWS), and geophysical investigations by Frontier Geosciences, Inc. (Frontier). The discussion of regional seismicity was prepared by KP.

6.5 Methods

The 2004 to 2008 geotechnical site investigation programs involved test pitting, overburden and bedrock drilling, piezometer/well installations, in situ testing, and geophysical surveys throughout the study area. The results of the site investigations were related to surficial geology and physiography to develop linkages between landscape features and subsurface characteristics. Field methods are described in this section with a more detailed description found in the following KP documents:


The 2004, 2005, and 2006 geophysical investigation reports prepared by Frontier are also appended to the respective KP site investigation reports. Hydrogeology studies were completed by WMC/SWS and SLR International Corp. (SLR) and summaries of the hydrogeological site investigations are appended to the respective KP site investigation reports. The 2004 to 2008 WMC/SWS/SLR hydrogeology studies are discussed in Chapter 8.

6.5.1 Test Pit Investigations

Test pits provide information on the characteristics of near-surface overburden materials. Three hundred and seventeen (317) test pits were excavated during the 2004, 2005, and 2008 geotechnical site investigation programs. There were no test pits excavated in 2006 or 2007. The locations of the test pits are shown on Figures 6-3 and 6-4, and a test pit summary is provided in Appendix 6A.

The test pits were excavated using a Digger 50 helicopter-portable excavator in 2004 and a lightweight, helicopter-portable bobcat excavator in 2005. A larger, helicopter-portable bobcat excavator was used for the excavation of test pits in 2008. Test pit depths generally ranged between 5 and 10 feet. The test pit locations were accessed using helicopters and care was taken to minimize environmental disturbance during the investigations. Wherever possible, the surface organic material and vegetation were stripped prior to the excavation of the test pit and stockpiled separately. The exposed soils in the test pit walls and spoil piles were logged for their geotechnical characteristics and samples were collected and sealed in bags for laboratory testing. The test pits were backfilled and the ground surfaces were re-contoured at the completion of each test pit. The final activity at each site involved the replacement of the surface material and vegetation to re-establish, as much as possible, the pre-investigation conditions.
6.5.2 Drilling Investigations

Geotechnical drilling was carried out to characterize the overburden (materials above bedrock) and the upper portion of the bedrock. The drillholes were vertical in most cases and were typically advanced approximately 100 feet into bedrock or until more competent bedrock was reached. However, some drillholes were completed solely for overburden characterization and in these cases bedrock was confirmed by drilling 10 to 15 feet past the contact. A separate set of deeper, oriented drillholes were completed in the Pebble East Area and Pebble West Area to characterize bedrock discontinuities in the deposit area.

6.5.2.1 Overburden/Bedrock Drilling

Two hundred and ten (210) KP geotechnical drillholes, not including redrills, were drilled throughout the study area from 2004 to 2008. The locations of the geotechnical drillholes are shown on Figure 6-5. The locations of the geotechnical drillholes in and around the general deposit area are shown on Figure 6-6. A summary of the geotechnical drillholes is provided in Appendix 6B.

The site investigation drilling was completed as follows:

- 2004 and 2005 drilling was completed using a helicopter portable Boart Longyear LF70 mud rotary diamond drill modified to conduct standard penetration tests (SPTs) in overburden and packer hydraulic conductivity testing in bedrock. Drilling, in situ testing, and the installation of standpipe piezometers were carried out by Quest America Drilling Inc./American Recon Drilling, with the assistance of, and under the technical supervision of, KP. The overburden portion of each drillhole was cored using HW size casing and HQ3 size core. Bentonite Quik-Gel or a biodegradable drilling mud additive, WDS-120, was used to help keep the drillholes open.

- 2006 and 2007 drilling was completed using a helicopter portable HT-700 mud rotary diamond drill rig. The drilling, in situ testing, and installation of standpipe piezometers were carried out by Foundex Pacific Inc., with the assistance of, and under the technical supervision of, KP. HW size casing and HQ3/NQ3 size core was used in these investigations. Bentonite Quik-Gel or a biodegradable drilling polymer, Poly-Drill 133X was used in 2006 and 2007 to keep drillholes open in the overburden or in highly faulted or fractured zones in the bedrock.

- 2008 drilling was completed by Foundex Pacific Inc. under the supervision of KP field personnel and helicopter transportable HT-700 and HT-750 mud rotary diamond drill rigs were used. PW and HW casing was used in 2008 to try to increase recovery of the overburden. Bedrock was drilled with PQ3, HQ3, and NQ3 size core barrels. Bentonite Quik-Gel or a biodegradable drilling polymer, Poly-Drill 133X was used in 2008 to keep drillholes open in the overburden or in highly faulted or fractured zones in the bedrock.

The drills were moved to each location by helicopter in all investigation programs. Samples of disturbed soil were collected from the core barrel and placed into core boxes. Core recovery from the overburden was generally poor, because the fines were typically washed away during the drilling process. Core recovery was substantially improved when using the larger PQ3 size core but sandier materials were still easily washed away. All of the overburden was logged at the drill site by KP field personnel. Selected samples were sent to the KP geotechnical laboratory in Denver, Colorado, for further analysis.
Bedrock was mostly drilled using water as circulation fluid; drilling mud or biodegradable polymers were used as required in highly faulted or fractured zones. Packer hydraulic conductivity testing was completed in most drillholes. Any intervals where drilling mud or biodegradable polymers were used were flushed with water prior to packer testing. KP field personnel geotechnically logged the bedrock drill core and boxed it at the drill site. The geological logging of the drillhole core was conducted in Iliamna by geologists from Northern Dynasty Mines Inc./Northern Dynasty Minerals Ltd. (NDM) or by geologists from the Pebble Partnership. The drillhole sites were reclaimed by either NDM or Pebble Partnership personnel.

6.5.2.2 Oriented Bedrock Drilling

Fifteen (15) oriented geotechnical drillholes were completed by KP in the Pebble West Area from 2004 to 2005 to provide geotechnical information for the rock mass in this area. SRK completed 12 oriented geotechnical drillholes in the Pebble West Area and Pebble East Area in 2006, 2007, and 2008. The locations and azimuths of the drillholes are shown on Figure 6-7 and a summary of the oriented drilling programs are provided in Appendix 6C. The depth of the drillholes ranged from around 500 feet to over 5,000 feet. Core orientation was measured in these geotechnical drillholes to characterize the rock mass discontinuities within the deposit area. Drilling was completed using American Recon Drilling LF70 or Boart Longyear LF90 rigs using HQ3 and NQ3 triple-tube coring methods and the core was oriented using the Ballmark system or the Reflex ACT orientation system (formerly known as the ACE tool). Joint orientations and the geotechnical characteristics of the discontinuities were logged. Good core recovery allowed a high percentage of the core to be oriented. Acoustic logging and some borehole camera surveys were also completed in selected drillholes in 2006 to 2008.

Two oriented drillholes were completed in Area G in 2008 using a HT-750 rig to try to characterize a fault that had been encountered during 2007 drilling. These oriented drillholes were completed using the Reflex ACT orientation system and joint orientations and geotechnical characteristics were collected for the core in these drillholes.

6.5.2.3 Overburden and Bedrock Characterization

SPT samples were collected from those vertical geotechnical drillholes where an appreciable amount of overburden was present. The SPT samples provided material for soil characterization laboratory testwork. SPTs were typically conducted at 5 to 10 foot intervals where ground conditions permitted, until bedrock was reached. The number of blows required to advance the sampler was recorded for three 6-inch intervals of advancement up to 18 inches. The SPT ‘N’ value is the total number of blows required to advance the sampler the last two 6-inch increments (between 6 and 18 inches). The number of blows, depth interval, recovery length, photo documentation, and a soil description were routinely recorded for each SPT. Samples were sealed and double-bagged for subsequent laboratory analysis.

Representative samples were chosen from the SPT samples and sent to the KP geotechnical lab in Denver for testing. The SPT samples were analyzed for the following:

- Particle size distributions (ASTM D422-63).
- Hydrometer analysis (ASTM D422-63).
• Atterberg limits (ASTM D4318-84).

Detailed geotechnical logging of the bedrock core was carried out to characterize the rock mass quality. The following information for the bedrock was routinely collected:

• Depth interval.
• Core recovery length.
• Rock quality designation (RQD).
• Lithological description.
• Estimate of unconfined compressive strength (UCS).
• Number of discontinuities.
• Discontinuity/joint condition (roughness, aperture, alteration, infilling, etc.).
• Discontinuity type (joint, bedding, etc.).
• Discontinuity alpha and beta angles (collected for oriented drillholes).
• Orientation quality (collected for oriented drillholes).

The overburden was described by the combination of logging the recovered samples from the core tubes, monitoring of drilling characteristics and return fluid, and by comparison and calibration of these observations to physical samples recovered in the SPT sampler.

6.5.2.4 Rock Mass Classification

The rock mass characteristics observed during core logging were summarized for each core run and used to estimate the quality of the rock mass using the rock mass rating classification system (RMR89) (Bieniawski, 1989), as presented in Appendix 6D. The RMR89 system is based on determining values for the following five key rock mass parameters:

• Intact rock hardness or UCS—intact rock strength is estimated in the field.
• RQD—the RQD value was determined for each core run by summing the lengths of all core pieces greater than 4 inches in length and presenting this as a percentage of the actual drill run length.
• Fracture (joint) spacing—an estimate of fracture spacing was determined by counting the number of natural fractures encountered per length of drill run.
• Fracture (joint) condition—the fracture condition is based on an evaluation of fracture persistence, roughness, infilling, aperture, and weathering. The persistence has been conservatively assumed to have a rating of 0, consistent with high persistence. The roughness, infilling, aperture, and weathering are determined by evaluation of the drill core.
• Groundwater condition—a constant groundwater rating of 15, which corresponds to dry conditions, was used to calculate the rock mass rating (RMR). This allows the RMR to be consistent with the geological strength index (GSI) values (Hoek et al., 1995) that have also been used to estimate rock mass strengths.
There are five major RMR classes, from I—VERY GOOD to V—VERY POOR, associated with ranges of estimated RMR values between 100 (I) AND 0 (V), as summarized in Appendix 6D (adapted from Bieniawski, 1989).

6.5.3 Piezometer Installation and Hydraulic Conductivity Testing

6.5.3.1 Piezometer Installation

Two hundred and fourteen (214) standpipe piezometers were installed in the geotechnical drillholes during the 2004 to 2008 field seasons. A number of the drillholes had two piezometers installed into different completion zones in 2006, 2007, and 2008. Vibrating wire piezometers were installed in 2005 in some drillholes in the Deposit Area and in two drillholes in Area G and Area L in 2008.

The piezometer installation procedure involved:

- The depth of the piezometer completion zones were governed by several factors. A zone of interest was identified in the overburden, bedrock, or at the overburden/bedrock interface during drilling and this was used as a target for the completion zone. The depth to groundwater was also taken into consideration to ensure that the completion zone was installed below the observed water table.
- A bottom bentonite pellet seal was installed at the base of the completion zone. The bottom bentonite seal was usually 5 feet thick.
- A layer of coarse filter sand approximately 2 to 5 feet thick was then placed above the bottom bentonite seal.
- The bottom end cap of the slotted 1 or 2-inch diameter polyvinyl chloride (PVC) screen and PVC riser pipe assembly was placed upon the coarse filter sand layer which separates the well screen from the lower bentonite seal.
- A sufficient volume of filter sand was poured down the drillhole to fully encompass the screened section plus approximately 3 to 5 feet of the riser pipe above the well screen.
- A layer of bentonite pellets approximately 5 feet thick was then placed above the filter sand to form the top bentonite seal of the well completion zone.
- The open annulus above the completion zone was backfilled with either cement grout or another piezometer installation.
- Piezometers were completed by installing PVC top caps and a steel protective casing over the exposed pipe or pipes. A surface cement cap was used to seat the steel protective cover.

The vibrating wire piezometer installation method was very similar except that no bentonite or sand was used and the vibrating wire was grouted up to surface. The vibrating wire was attached to the PVC riser pipe by taping it at regular intervals until the desired depth was reached.

The groundwater levels in the standpipe and vibrating wire piezometers were monitored by WMC/SWS/SLR.
6.5.3.2 Hydraulic Conductivity Testing

Packer hydraulic conductivity testing (Lugeon method) was completed at selected depths in the majority of the geotechnical drillholes to estimate the hydraulic conductivity of the bedrock. These tests are frequently referred to as ‘packer tests’ and consist of seating an inflatable bladder (packer) in the drill bit to seal off an open hole interval for testing. Water was then pumped down the drill rods into the isolated test zone at varying controlled test pressures. The water flows were typically measured for three ascending and two descending pressure stages for each packer test.

Rising and falling head tests (Hvorslev method) were also conducted in most of the standpipe piezometers installed in the overburden and bedrock. These tests involve the addition or removal of water from the piezometer and recording subsequent changes in the water level against time until the water level returns to static equilibrium.

Hydraulic conductivity results for soil and rock typically vary with material type but results can be generally categorized into the following ranges (modified after Terzaghi and Peck, 1967):

- High \(10^{-1}\) to 10 centimeters per second
- Medium \(10^{-3}\) to \(10^{-1}\) centimeters per second
- Low \(10^{-5}\) to \(10^{-3}\) centimeters per second
- Very low \(10^{-7}\) to \(10^{-5}\) centimeters per second
- Extremely low \(10^{-10}\) to \(10^{-7}\) centimeters per second

6.5.4 Geophysical Investigations

Geophysical investigations were completed by Frontier as part of the 2004, 2005, and 2006 geotechnical investigations. Thirty-six (36) seismic refraction traverses were completed in the study. The locations of the seismic lines are shown on Figures 6-5 and 6-6.

The seismic refraction method used in these investigations was proposed by Frontier to be the most effective means of differentiating and classifying the unsaturated materials, saturated materials, glacial drift, and bedrock of the mine study area. Survey methods involved placing a geophone array (e.g., geophone cables and implanted geophones) along the survey lines, with several shot points located along and off the ends of each cable. Geophone intervals were adjusted to produce high-resolution data on subsurface layering and to ensure adequate coverage of the overburden/bedrock interface. Small, remotely detonated, explosive charges buried in shallow hand-excavated shot holes provided the source of seismic energy that was recorded by the geophone array.

The seismic-refraction investigation was carried out using a Geometrics, Geode, 24-channel, signal-enhancement seismograph and Mark Products Ltd., 48 Hertz geophones. The results of the geophysical investigations are included in the appendices of the 2004, 2005, and 2006 KP site investigation reports.
6.5.5 Seismicity

Existing information and historical data, including earthquake catalogues and technical publications on the tectonics and seismicity of the region were collected and reviewed by KP for a detailed study on the regional seismicity of the Bristol Bay drainages. The study was completed using a revised seismic hazard map for Alaska which was published by the USGS (Wesson, 2007).

An unpublished draft report Pebble Project – Report on Seismicity Assessment (Ref. No. VA101-00176/20-1) (KP, 2008c) was completed by KP in 2008 and presents the results of the detailed seismic hazard analyses for the mine study area. Technical publications published up to 2011 were also used in the evaluation of the regional seismicity.

6.6 Results and Discussion

6.6.1 Geotechnical Investigations in the Mine Study Area

Geotechnical site investigations have been completed between 2004 and 2008, and the findings are summarized in this section. Appendix 6A provides a summary of the test pits. The test pit locations are shown on Figures 6-3 and 6-4. Appendix 6B provides a summary of the geotechnical drillholes through the overburden and upper bedrock. Drillhole locations are shown on Figures 6-5 and 6-6. The piezometer completion zones, hydraulic conductivity test results, and static water levels are also presented in Appendix 6B. The test pit and geotechnical drillhole logs are included in the appendices of the corresponding KP site investigation reports.

A summary of the deeper oriented drillholes completed is presented in Appendix 6C. The locations and azimuths of these drillholes are shown on Figure 6-7, and drillhole logs for the oriented geotechnical drillholes are included as appendices in the KP 2004 and 2005 Open Pit Site Investigation Reports (KP, 2005c, 2005a) and in the SRK 2006 Preliminary Geotechnical Evaluation of the East Zone – 2006 Interim Report (SRK, 2007) and in the 2007 and 2008 Geotechnical Data Acquisition Program – Pebble East Zone Data Reports (SRK, 2008, 2009).

The depth to bedrock in each of the drillholes is shown on Figures 6-8 and 6-9. A geologic cross-section through the Deposit Area is shown on Figure 6-10. Geologic cross-sections were interpreted for most seismic lines and other areas of interest in the majority of the 10 reference areas. The section plans are presented on Figures 6-11 and 6-12 and the section profiles are presented on Figures 6-13a through 6-50.

6.6.1.1 Pebble West Area

The Pebble West Area comprises the western part of the Pebble Deposit Area, located on the drainage divide between the South Fork Koktuli River and Upper Talarik Creek, as shown on Figure 6-2a. Four vertical geotechnical drillholes, 34 test pits, and one seismic line (SL) have been completed in the Pebble West Area. The bedrock geology of the Pebble West Area is based on NDM/Pebble Partnership exploration drill core data and is illustrated on Figure 6-10. The geological section (Figure 6-13a) extending southward through the eastern half of the Pebble West Area is based on geotechnical drilling. This section provides an overview of the subsurface conditions encountered in the Pebble West Area.

The Pebble West Area is terraced with many small ponds and kettled moraine features resulting from the Brooks Lake glaciation (Detterman and Reed, 1973). A layer of topsoil less than 1 foot thick was
encountered at surface over most of the Pebble West Area. The topsoil is typically dark brown, moist, and contains varying quantities of silt, sand, and gravel. The overburden in the Pebble West Area ranges in thickness from 10 to 250 feet in the western portion and generally consists of glaciofluvial, glaciolacustrine, and glacial drift deposits.

The Pebble West Area has been roughly subdivided into the western, central, and eastern portions. These portions have not been specifically delineated as subareas, but their general locations and topographic characteristics can be described with respect to Figure 6-12. The greatest contrast in elevation within the Pebble West Area is found within the western portion, with the ground surface elevation varying from 1,000 to 1,475 feet. Surficial materials in the western portion are composed of glacial drift, predominantly silty sand with some gravel, along the gently sloping hills and ridges. The central portion of the Pebble West Area has moderate slopes and is generally characterized by well-drained glaciofluvial materials. The eastern portion of the Pebble West Area covers the upstream end of the wide valley to the north of Frying Pan Lake and generally consists of glacial drift, glaciolacustrine, and glaciofluvial materials. The topography in the eastern portion of the Pebble West Area varies from 900 to 1,075 feet. Overburden materials observed in the drillholes of the eastern portion contain varying amounts of gravel, sand, silt, and clay.

Tertiary basalt, basalt breccia, volcaniclastic matrix-supported breccia/conglomerate, and mudstone/siltstone/wackes were encountered in the Pebble West Area. The drillholes in this area had average RMR values ranging from 45 to 55 (FAIR) (Bieniawski, 1989). Bedrock conditions in the Deposit Area are described in greater detail in the KP 2004 and 2005 Open Pit Geotechnical Investigation Reports (Ref. Nos. VA101-00176/8-2 and 8-5) (KP, 2005c, 2005a) and in the SRK 2006 Preliminary Geotechnical Evaluation of the East Zone – 2006 Interim Report (SRK, 2007) and 2008 Geotechnical Data Acquisition Program – Pebble East Zone Data Report (SRK, 2009).

The piezometric surface in this area was variable, ranging from above ground level to a water level of approximately 50 feet below grade. This range represents aquifers at different elevations and variation of the topography. Some vertical drillholes were advanced 300 feet into bedrock to provide additional information on the hydraulic conductivity in the bedrock of the Pebble West Area. Packer hydraulic conductivity test results were in the low to very low range, generally decreasing with increasing depth. Falling/rising head hydraulic conductivity testing in the overburden also gave hydraulic conductivity results in the low range.

### 6.6.1.2 Pebble East Area

The Pebble East Area comprises the eastern part of the Pebble Deposit Area, located on the drainage divide between the South Fork Koktuli River and Upper Talarik Creek, as shown on Figure 6-2a. Work completed in this area included 21 geotechnical drillholes, 17 test pits, and six seismic lines to evaluate the subsurface overburden materials and to try to delineate a potential paleochannel north of Koktuli Mountain. Figures 6-14, 6-15, 6-16, and 6-17 represent cross sections along SL-25, SL-26, SL-34, and SL-38, respectively.

Surface topsoil ranges from zero to approximately 4 feet thick over most of the Pebble East Area with some areas of peat deposits up to 2.5 feet thick. The topsoil is typically dark brown, moist, and contains varying quantities of silt, sand, and gravel. The thickness of overburden in the Pebble East Area ranges from approximately 10 feet to greater than 200 feet in the eastern portion. Seismic refraction data have
revealed that there is a buried paleochannel in the eastern portion of the Pebble East Area that runs in a northeast to southwest direction along Koktuli Mountain. Several of the drillholes along this alignment did not reach bedrock. The subsurface overburden materials in the Pebble East Area consist of glaciofluvial, glaciolacustrine, and glacial drift materials composed of sand and silt with varying amounts of gravel, silt, and clay. Core recovery was generally good in the glaciolacustrine and siltier units. Several of the SPT samples in these units had a higher percentage of fines, ranging from 55 to 98 percent. Some lower SPT ‘N’ values were found near the surface and are likely attributed to peat, heaving sand, or slough in the drillholes. Several of the SPTs were refused in drillholes in the Pebble East Area; this is attributed to the abundant gravel and cobbles found in the materials of the area.

The bedrock encountered in the vertical drillholes in the Pebble East Area consisted of weathered Tertiary rhyolite, Tertiary basalt and basalt breccia, bedded andesites, and Tertiary volcaniclastic breccia/conglomerate. Some of the drillholes were terminated in the overburden or the weathered bedrock, because the primary purpose of these drillholes was for overburden characterization. Average RMR values of the drillholes in the Pebble East Area ranged from 32 to 56 (POOR to FAIR) (Bieniawski, 1989). Bedrock conditions of the Pebble East Area are described in greater detail in the SRK 2006 Preliminary Geotechnical Evaluation of the East Zone – 2006 Interim Report (SRK, 2007) and in the 2007 and 2008 Geotechnical Data Acquisition Program – Pebble East Zone Data Reports (SRK, 2008, 2009).

The piezometric surface in this area ranged from above or very near the ground surface to depths of 63 feet below surface. This range represents aquifers at different elevations and topographic variation in this area. Falling head tests were completed in the overburden materials and hydraulic conductivity results were in the low to very low range. Falling head tests completed at the overburden/bedrock contact had hydraulic conductivity results from very low to the medium range, pointing to the higher permeability material that is often encountered at the bedrock contact.

6.6.1.3 Upper Talarik Creek Area

The Upper Talarik Creek Area is located north of the Pebble Deposit Area, as shown on Figure 6-2a. The Upper Talarik Creek Area is a wide, relatively flat valley containing many streams and small, seasonal lakes that feed into the upper reaches of Upper Talarik Creek. Eleven (11) geotechnical drillholes, 29 test pits, and an extension of a seismic line from the Pebble Deposit Area were completed in this area. Figure 6-18 presents a cross section through this area based on drilling from 2008.

A surficial layer of topsoil approximately 0 to 4 feet thick was typically encountered at surface in this area. The topsoil is typically dark brown, moist to wet; consisting of silt, sand, gravel, and/or peat. The overburden of the Upper Talarik Creek Area is predominantly composed of sand with varying amounts of silt and gravel. Fine-grained sediments, primarily sand, silt, and clay, were encountered in the lower-lying area in the center of the Upper Talarik Creek valley. These materials are typically found in low-energy depositional environments, such as glaciolacustrine or very low-gradient stream reaches such as oxbows. The soil in the center of the valley contained only trace amounts of gravel to at least 8.5 feet deep. Overburden in the upland area bordering Area E was largely composed of sand and gravel materials. These coarser grained gravel and sand combinations are interpreted as glacial drift deposits.

The bedrock encountered in the Upper Talarik Creek Area consists of Tertiary sandstone/wacke/conglomerate, Tertiary volcaniclastic breccia/conglomerate, Tertiary basalt, Cretaceous
siltstone (bedded andesite), granodiorite, and diorite. The rocks in this area had average RMR values ranging from 29 to 54 (POOR to FAIR).

The piezometric surface throughout the Upper Talarik Creek Area ranged from above ground to a depth of approximately 40 feet below ground surface. This range represents aquifers at different elevations and topographic variation throughout this area. Falling head hydraulic conductivity testing results of the overburden/bedrock contact were in the low range.

6.6.1.4 Area E

Area E consists of a broad valley located immediately west of the Pebble Deposit Area, as shown on Figure 6-2a. Site investigations in Area E included 18 geotechnical drillholes, 66 test pits, and 10 seismic lines. Work completed from 2004 to 2006 largely concentrated on a knoll in the eastern portion of Area E. Geologic sections corresponding to the SL-13 (which also extends into Area A) to SL-15 (2004) , SL-27 to 33 (2006) are presented on Figures 6-19, 6-20, 6-21, 6-22, 6-23, 6-24, 6-25, 6-26, 6-27, and 6-28, respectively. A geologic section through the northwestern part of Area E is shown on Figure 6-29.

A layer of topsoil, 0 to 1 foot thick, was encountered at surface over most of Area E. The topsoil was typically medium to dark brown, moist, and contained varying quantities of organic material, sand, and gravel. The overburden consists of a veneer of glacial drift, predominantly sands and gravels with varying amounts of silt. Frost shattered bedrock (felsenmeer) is present on the hill tops.

Bedrock was encountered at depths of 0 to 8 feet in the drillholes on top of the knoll in the eastern part of Area E. Overburden thicknesses ranging from 6 to 111 feet were found in the drillholes in the valley and on the valley side slopes in the central part of Area E. The bedrock in Area E varied from Cretaceous monzonite/granodiorite and siltstone to Tertiary sediments and intrusives. Tertiary rocks found in Area E include Tertiary volcaniclastic breccia/conglomerate, basalt, brecciated basalt, and siltstone. The average RMR values ranged from 30 to 58 (POOR to FAIR) (Bieniawski, 1989). POOR bedrock encountered in Area E was generally more fractured, or the bedrock was weathered to a considerable depth.

The piezometric surface in Area E ranged from above ground to 84 feet below surface and was usually coincident with, or close to the top of the fractured bedrock unit. This range represents aquifers at different elevations and variation of the topography throughout this area. Packer hydraulic conductivity tests were conducted in the more competent bedrock and results were in the low to very low range. Hydraulic conductivities obtained for the piezometer completion zones using rising/falling head tests were also in the low to very low range. Hydraulic conductivity values are typically higher in the overburden or at the overburden/bedrock contact where the bedrock is usually more broken.

6.6.1.5 North Fork Koktuli River Area

The North Fork Koktuli River Area is a wide, relatively flat valley located approximately four miles northwest of the Pebble Deposit Area, as shown on Figure 6-2a. The area has many streams and small, seasonal lakes that feed into the upper reaches of the North Fork Koktuli River. Four geotechnical drillholes and the excavation of nine test pits were completed in the area.

A 0.5 to 2 foot thick layer of organic topsoil was found in this area. The topsoil is typically dark brown, moist, and consists of silt, sand, and gravel. The overburden was 148 feet deep in the north, which sharply
contrasted with the overburden thicknesses of 22 to 40 feet encountered farther to the south and closer to
the edge of the valley. The overburden materials encountered throughout the North Fork Koktuli River
Area are generally compact, with gravel and cobbles present. Material variations are the result of
the numerous glaciations and localized depositional environments.

The bedrock types encountered in the North Fork Koktuli River Area were Tertiary andesite, Tertiary
basalt, and Tertiary mudstone/siltstone/wacke. The bedrock in the North Fork Koktuli River Area
demonstrated average RMR values ranging from 36 to 60 (POOR to FAIR) (Bieniawski, 1989). The
bedrock in the northern portion of the area was comprised of Tertiary andesite and was highly fractured,
weak to medium strong rock. The Tertiary basalt was generally strong, though the Tertiary basalt in a
drillhole near the southern edge of the area was weaker and was fractured to approximately 130 feet deep.
Tertiary mudstone/siltstone/wacke encountered in this area was medium strong and highly fractured to the
depth of the drillhole (133 feet).

The ground was generally frozen near the surface in the North Fork Koktuli River Area during the
excavation of the test pits in 2004 because they were completed in the early months of the summer. Aside
from this frozen moisture there was no other noted groundwater present in any of the test pits. Site
reconnaissance conducted in late August 2004, encountered a number of dry, rocky depressions (several
feet deep) that had obvious high water lines from earlier in the season, indicating that the area is fairly
well drained from spring to fall. The piezometric surface ranged from approximately 14 to 31 feet below
ground surface. The range is a result of aquifers encountered at different elevations and topographic
variation. A falling head test was completed in the overburden materials with a resulting hydraulic
conductivity in the low range. Falling head tests were also completed at the overburden/bedrock contact
with hydraulic conductivities in the very low range. Hydraulic conductivities were in the very low range
for falling head tests and packer tests completed in the more competent bedrock. Packer tests could not be
performed in a drillhole in the southwestern part of the North Fork Koktuli River Area where highly
fractured rock was encountered because of the risk of the inflatable bladder being damaged; this rock is
expected to have hydraulic conductivity in the low to medium range.

6.6.1.6 Area G

Area G is a valley surrounding a northward-draining tributary of the North Fork Koktuli River, located
approximately five miles west of the Pebble Deposit Area, as shown on Figure 6-2a. Site investigation
programs included 45 geotechnical drillholes, 42 test pits, and two seismic lines in this area. Geologic
sections for the north, upstream north, northwest, southwest, south, and east parts of the valley are shown
on Figures 6-30, 6-31, 6-32, 6-33, 6-34, and 6-35. SL-23 and SL-24 correspond to the sections on Figures
6-30 and 6-34, respectively.

The topsoil in Area G varies from a thin veneer at higher elevations, where it is often mixed with
felsenmeer, to approximately 4 feet thick at lower elevations. There are frost-heaved bedrock blocks with
interstitial topsoil between the blocks; this surficial portion of felsenmeer is often classed as overburden.
Relict felsenmeer is encountered at depth and can be coincident with the zone of altered and fractured
rock at the bedrock contact but is very difficult to distinguish. Felsenmeer exists on the ridges, valley
slopes, and hill tops in the east and west of Area G with many large boulder-size fragments at the higher
elevations. The topsoil in Area G is typically dark brown, moist, and consists of silt, sand, and gravel.
Peat up to 10 feet thick is found in the bottom of the valley with thinner peat found in some poorly
drained areas on the valley slopes.
Overburden materials in Area G are complex with rapidly changing composition and numerous layers that are not easily extrapolated between drillholes. The overburden is largely composed of sand and gravel with varying proportions of silt and is largely felsenmeer, glacial drift, and colluvium deposits. The geotechnical drillholes in northern Area G encountered bedrock at 2 to 51 feet below surface. In lower elevation areas, the overburden generally had a higher amount of fines, and was predominantly composed of silty sand. Overburden in the valley bottom was up to 15 feet of combined peat, sands, and gravels. Deeper overburden, in the northern part of the valley, was encountered on the eastern and western mid-valley slopes.

The overburden along the western ridges is generally thin with less than 5 feet present in the saddles. In contrast, the depth of overburden in the east saddle, north of Kaskanak Mountain, was approximately 50 feet deep. The depth of overburden on the eastern side slopes is typically less than 15 feet. Volcaniclastic fragmented breccia has been identified in drillholes in this area and the degree of weathering may make it difficult to distinguish this rock type from bedrock. The overburden on the eastern slopes is largely composed of sand with varying amounts of gravel and fines.

Bedrock in the northern part of Area G is primarily of volcanic origin and mostly composed of monzonite/monzodiorite of the Kaskanak Batholith with some basalt, gabbro, pyroxenite, and Tertiary sediments. Bedrock in the southern and eastern part of Area G includes Cretaceous granodiorite/monzonite, Tertiary rhyolite, basalt, volcaniclastic fragmented rocks, and brecciated Tertiary sediments and volcanics. Weathered bedrock was encountered up to 80 feet deep in some of the drillholes in the southern portion of Area G. The average RMR values of the bedrock in Area G ranged from 35 to 66 (POOR to GOOD) (Bieniawski, 1989). The drillholes in Area G encountered zones of highly weathered, fractured bedrock. Some fault zones were encountered in drillholes in the northwest part of Area G.

The groundwater conditions of Area G are variable and the groundwater table varies seasonally throughout the area. The piezometric surface in the northern portion of Area G is either at or close to the ground surface, ranging from above ground to 41 feet below surface at 1700 feet elevation. The piezometric surface was observed to be close to or above the ground surface in most drillholes in the southern portion of Area G with a few drillholes at higher elevations exhibiting lower piezometric levels up to 85 feet below ground surface. The range is a result of the variation in topography and aquifers encountered at different elevations throughout Area G.

A number of falling head tests (Hvorslev method) were conducted in piezometers installed at the overburden/bedrock contact. A fractured/weathered bedrock zone is generally observed at the overburden/bedrock contact throughout Area G. This zone has a generally low to medium hydraulic conductivity. The hydraulic conductivity in the bedrock in the northern and northwestern parts of Area G is medium to low. A number of small fault zones and zones of heavily fractured rock with clay in the joints were encountered; these zones have low hydraulic conductivity in the same order of magnitude as the surrounding bedrock. The bedrock of the southern portion of Area G exhibited generally low hydraulic conductivity, however, occasional intervals of medium hydraulic conductivity ranging from were identified near the valley bottom and in the eastern saddle slopes.
6.6.1.7  Area L

Area L is a southward-draining tributary valley to the South Fork Koktuli River, located approximately six miles southwest of the Pebble Deposit Area, as shown on Figure 6-2a. The site investigation programs included 32 geotechnical drillholes and the excavation of 43 test pits in this area. Geologic sections through Area L are shown on Figures 6-36, 6-37a, and 6-37b.

The topsoil in Area L ranges from 0 to 5 feet thick and consists of dark brown silt, sand, gravel, and cobbles. The overburden varies from 0 to 105 feet with the thicker overburden in the valley bottom areas. Most overburden deposits are within 30 feet of surface. The overburden deposits consist of sand and/or gravel with varying amounts of finer materials. Glacial drift, colluvium, felsenmeer, and bedrock are found at surface in this area.

The bedrock encountered in Area L is of igneous and volcanosedimentary origin. Bedrock types encountered include granodiorite, monzonite, and monzodiorite of the Kaskanak Batholith; and Tertiary siltstone, rhyolite, andesite, dacite, volcaniclastic breccia, basalt, and brecciated basalt. The bedrock was strong, with average RMR values of 39 to 66 (POOR to GOOD) (Bieniawski, 198 Hydraulic conductivity testing was conducted in the bedrock and the results ranged from low to medium values. 9).

Groundwater was observed to be seeping into many of the test pits excavated in the northern and eastern regions of the valley. Numerous groundwater seeps were noted in these same areas during site reconnaissance in late August 2004. The piezometric level varies from above ground to approximately 200 feet below ground surface. The range is largely due to topographic variation in this area and is also attributed to encountering aquifers at different elevations.

6.6.1.8  South Fork Koktuli River Area

The South Fork Koktuli Area is located approximately six miles south to southwest of the Pebble Deposit Area, as shown on Figure 6-2a. It consists of the main valley of the South Fork Koktuli River, downstream of the Pebble Deposit Area and Area A, and also receives drainage from the tributary valleys of Areas J and L. Site investigations included the excavation of 22 test pits and 23 geotechnical drillholes in this area. Seven seismic survey lines were also completed in this area. Figures 6-38a, 6-38b, 6-39, 6-40, and 6-41 represent geologic sections along SL-6, SL-7, SL-8, and SL-19, respectively.

A surficial layer of topsoil up to 4 feet thick covers most of the area. The topsoil is typically dark brown and consists of silt, sand, gravel, and cobbles. There were also some areas of peat encountered. The overburden thickness is highly variable in the South Fork Koktuli River Area, with recorded thickness ranging from 12 feet to greater than 390 feet. The shallower overburden tends to occur in elevated areas along the sides of the valley. The overburden composition is predominantly sand and gravel, with greater proportions of sand interbedded in the east, and greater quantities of silt in the west. The materials consist of glacial drift, alluvial, and colluvial deposits. Multiple glaciations with ice sheets of varying thicknesses affected the area and resulted in a complex depositional history with numerous glacial advances and retreats reworking the glacially derived sediments and resulting in the burial of old stream channels and ponds.

The bedrock composition is variable in the South Fork Koktuli River Area. The bedrock types encountered were granodiorite, monzonite, basalt, sandstone, siltstone/mudstone, dacite, and andesite.
The rock strength was highly variable between drillholes. The average RMR values ranged from 39 to 64 (POOR to GOOD) (Bieniawski, 1989).

The presence of groundwater was not noted in any of the test pits excavated in the South Fork Koktuli River Area; however, the ground was frozen in March and April when these test pits were excavated. The groundwater levels measured in the piezometers ranged from 5 to 136 feet below ground surface. The range represents aquifers at different elevations and topographic variation throughout this area. The area is underlain by predominantly sand and gravel with high hydraulic conductivity. Portions of the South Fork Koktuli River flow subsurface through the more permeable strata during dry periods.

A limited number of hydraulic conductivity packer (Lugeon) tests were conducted in the bedrock of the area and hydraulic conductivity values were in the low range. Rising head hydraulic conductivity tests were conducted in some of the piezometers with completion zones located in overburden material; however, the groundwater recovery was too rapid to obtain accurate results, which is indicative of medium to high hydraulic conductivity. Additional information has been collected on the hydrogeology of this area by WMC/SWS/SLR and is presented in Chapter 8.

### 6.6.1.9 Area J

Area J is a long, narrow, steeply incised valley that drains southward into the South Fork Koktuli River, southwest of the Pebble Deposit Area, as shown on Figure 6-2a. The site investigation of Area J included 15 geotechnical drillholes, 13 test pits, and three seismic lines distributed along the valley. A geologic section through Area J is presented on Figure 6-42.

Topsoil covers much of the surface of the valley and is up to 4 feet thick. The topsoil is composed of silt, sand, and gravel. Felsenmeer is prevalent at higher elevations and ranges from 0 to approximately 15 feet depth in the drillholes throughout Area J. Overburden thickness in Area J ranged from approximately 0 to 70 feet. The overburden in Area J is predominantly composed of sand, grading to sandy gravel, with varying proportions of silt. Gradational layering and particle orientation, consistent with fluvial deposition, was noted in some coarser-grained deposits. The bedrock most commonly encountered in this area is Cretaceous granodiorite/diorite of the Kaskanak Batholith, Tertiary basalt and minor Cretaceous siltstone. The bedrock is strong with average RMR values of 40 to 65 (FAIR to GOOD) (Bieniawski, 1989).

Groundwater was encountered at depths ranging from above ground to approximately 40 feet below surface, but was mostly less than 25 feet below ground surface. The depth of groundwater ranges as a result of varying topography and aquifers at different elevations. Hydraulic conductivity values of the bedrock were in the low range.

### 6.6.1.10 Area A

Area A is located directly to the south of the Pebble Deposit Area, as shown on Figure 6-2a. Area A has been subdivided into four geomorphic subareas, as shown on Figure 6-2b, each of which is described in the following sections. A north to south geological cross section through Area A is shown on Figures 6-13a and 6-13b.
**Valley Bottom**

The Valley Bottom of Area A consists of the valley south of the Pebble Deposit Area extending to the southern end of Frying Pan Lake, as shown on Figure 6-2b. The eastern and western extents of the Valley Bottom are governed by the elevation on the side slopes. Six geotechnical drillholes, 10 test pits, and one seismic line were completed in this area. Cross sections along SL-2 and across the northern portion of the valley are shown on Figures 6-43 and 6-44, respectively.

The Valley Bottom is characterized by relatively flat topography with extensive swamp/wetlands present. Based on relict beaches evident along the valley sides, the water elevation of the glacial lake in this area was approximately 1,000 feet. The thickness of the overburden across the Valley Bottom varied between approximately 100 and 185 feet, with the thickest deposits found along the western side of the valley. The peat thickness varied between 1 and 15 feet, while the thickness of the more recent glaciofluvial deposits varied between 15 and 30 feet. A glaciolacustrine silt layer was encountered approximately 30 to 40 feet below the existing ground elevation and was variable in thickness. Glacial drift, including some relatively thin, discontinuous glaciolacustrine and glaciofluvial layers, extends from the bottom of the glaciolacustrine layer to the bedrock. The materials encountered in the drillholes in the Valley Bottom consist primarily of sand and gravel with varying amounts of silt, clay, and cobbles.

The bedrock in the Valley Bottom is primarily igneous in origin, varying from granodiorite/diorite to Tertiary rhyolite and Tertiary dacite/latite. Bedded andesites were also encountered in this area. The bedrock ranged from medium to very strong rock and average RMR values ranged from 44 to 63 (FAIR to GOOD) but generally were in the FAIR range (Bieniawski, 1989).

The piezometric surface in the Valley Bottom was encountered above or within 10 feet of the ground surface, evidenced by the numerous swamp/wetland areas in this area. The range is a result of encountering aquifers at different elevations and varying topography. The wet, boggy composition of this area is indicative of a groundwater discharge zone.

**Southern Upland**

The Southern Upland of Area A lies to the south of Frying Pan Lake, as shown on Figure 6-2b, and is distinguished from the Valley Bottom by elevated topography. Seventeen geotechnical drillholes, 10 test pits, and three seismic lines were completed in this area. Cross sections along SL-3, SL-4, SL-5, and a transverse section through this area are shown on Figures 6-45, 6-46, 6-47, and 6-48, respectively.

The Southern Upland is kettled and characterized by deep deposits of moraine and outwash of the Brooks Lake glaciation (Detterman and Reed, 1973). The overburden is predominantly composed of glacial drift and glaciofluvial deposits, with some sorting consistent with reworking by water. Materials encountered include sand and gravel, with varying cobble and silt content. Some thin, discontinuous silt and/or clay layers were also encountered. This material is anticipated to be moderately to highly permeable based on results of grain size analyses and observed difficulties in maintaining circulation of the drilling fluid during drilling. The overburden depth ranged between approximately 7 and 390 feet below existing grade, increasing southward.

The bedrock encountered in the Southern Upland was comprised of both sedimentary and volcanic units. The sedimentary units varied from mudstone/siltstone to breccia. Andesite, monzodiorite, latite,
granodiorite, diorite, and basalt dikes are the volcanic units encountered in this part of Area A. The bedrock ranged from weak to very strong rock, though most of the drillholes encountered medium to strong rock. The drillholes in this area had average RMR values ranging from 42 to 63 (FAIR to GOOD) (Bieniawski, 1989), with most bedrock in the area in the FAIR range.

The groundwater levels in the piezometers installed in this area ranged from approximately 30 to 140 feet below surface. The range of groundwater depth is a result of encountering aquifers at different elevations and topographic variation. Hydraulic conductivity (Lugeon) tests were conducted in the bedrock, and the results for the bedrock are generally low. Falling head tests (Hvorslev method) were also conducted, and the hydraulic conductivity values for the overburden were also in the low range. Some of the overburden materials have medium to high hydraulic conductivities as indicated by recovery rates that were too fast for accurate measurements to be made with a water level meter.

**Lower/Mid Side Slopes**

The Lower/Mid Side Slopes of Area A refer to the lower and middle elevations of the side slopes along the Frying Pan Lake valley, and part of the South Fork Koktuli River valley downstream of Frying Pan Lake, as shown on Figure 6-2b. Site investigations in this area include one seismic line, 12 geotechnical drillholes and 19 test pits that were completed in this area. Cross sections through SL-20 and through the north valley are shown on Figures 6-49 and 6-44, respectively.

The thickness of the overburden on the Lower/Mid Side Slopes varied from 18 to 91 feet. Overburden materials encountered in the drillholes typically consisted of sand and gravel with varying amounts of silt.

The bedrock of the Lower/Mid Side Slopes was primarily diorite and granodiorite. However, dacite, andesite, Tertiary basalt, volcaniclastic breccia, siltstone/mudstone, and wackes were also encountered. The bedrock varied from a medium strong to strong rock including altered, highly fractured rock near the top of the drillholes. The bedrock in this area had average RMR values of 44 to 63 (FAIR) (Bieniawski, 1989).

The piezometric surface of this area was variable, ranging from above ground to depths of approximately 38 feet below surface. The variability of the piezometric surface is a result of topographic variation over the area and aquifers encountered at differing elevations.

Packer hydraulic conductivity (Lugeon) tests were conducted in the bedrock, and the hydraulic conductivity values determined for the bedrock were in the low range. Falling head tests (Hvorslev method) were conducted in some of the piezometers, and the hydraulic conductivity values ranged from low to medium for tests conducted in completion zones at the overburden/bedrock contact and in the bedrock.

**Upper Side Slopes**

The Upper Side Slopes of Area A are situated at upper elevations along the Frying Pan Lake valley, and part of the South Fork Koktuli River valley downstream of Frying Pan Lake, as shown on Figure 6-2b. Seven geotechnical drillholes, three test pits, and one seismic line have been completed in this area. A cross section through SL-21 is shown on Figure 6-50.
The subsurface conditions in this area can be summarized as a veneer of colluvium or glacial drift over shattered bedrock. Overburden thickness varied between 10 and 130 feet, but was mostly within 50 feet of ground surface. Minor frost sorting of the loose colluvium on the surface has produced thin solifluction lobes across much of this area.

The bedrock along the Upper Side Slopes consists of granodiorite/diorite/monzonite, and bedded andesites. The bedrock ranged from strong to very strong rock and average RMR values ranged from 44 to 68 (FAIR to GOOD) (Bieniawski, 1989).

The piezometric surface was typically found within the weathered bedrock in the Upper Side Slopes, approximately 0 to 92 feet below the ground surface. The range is a result of aquifers at different elevations and topographic variation. Packer testing was performed in the bedrock and the values ranged from extremely low to medium hydraulic conductivity. Falling head hydraulic conductivity testing results in the bedrock tests were in the low to medium range.

### 6.6.2 Regional Seismicity and Faulting

Alaska is the most seismically active state in the United States, and in 1964 it experienced the second largest earthquake recorded worldwide. The seismicity of southern Alaska is associated with interplate subduction earthquakes, intraplate earthquakes in the subducted oceanic plate, and shallow crustal earthquakes within the North American continental plate. The historical seismicity, regional tectonics, and related fault systems of southern Alaska are shown on Figure 6-51.

#### 6.6.2.1 Alaska-Aleutian Megathrust Subduction Zone

Historically, the level of seismic activity is highest offshore along the south coast of Alaska, where earthquakes are generated by the Pacific (oceanic) plate subducting under the North American plate at an average rate of approximately 2 to 3 inches per year. Evidence suggests that these tectonic plates are locking as they pass each other, building up pressure that can sometimes be released as large Magnitude 8 to 9+ earthquakes. These large interplate subduction (thrust) earthquakes typically occur at relatively shallow depths of 10 to 25 miles. This seismic source region, known as the Alaska-Aleutian Megathrust (shown on Figure 6-51), has been responsible for several of the largest earthquakes recorded globally, including the 1964 Prince William Sound Magnitude 9.2 (M9.2) earthquake. There is potential for future large interplate subduction earthquakes (M8 to M9+) along the southern coast of Alaska. The recurrence period for these great megathrust earthquakes along the subduction zone is estimated to be about 650 years (Wesson et al., 2007). Unlike shallow crustal earthquakes or deeper intraplate subduction earthquakes that typically produce shaking for a minute or less, interplate subduction zone earthquakes produce shaking that can last for several minutes.

The distribution of recorded earthquakes by focal depth (depth to earthquake source) is shown on Figure 6-51. Several deeper earthquakes (focal depth > 25 miles) have been recorded along the south coast of Alaska and northwards in addition to the shallow earthquakes associated with the subducting plate boundary and crustal faulting. Many of these events correspond to the greater depth of the northwestward dipping Pacific plate beneath the North American plate. Very few of the recorded earthquakes are deeper than 130 miles, indicating that the subducting plate does not penetrate deeply into the mantle. This suggests that the Pacific plate is subducting at a relatively shallow angle beneath the overriding North
American plate, causing these two tectonic plates to be strongly coupled. This results in the potential for large magnitude earthquakes.

Intraplate (in subducting slab) subduction earthquakes are typically generated by a normal faulting mechanism in the subducted oceanic lithosphere, often occurring deep within the subducting Pacific plate as it moves northward beneath the North American plate. These deep earthquakes have potential to cause large ground motion, typically affecting a large area and producing a distinctive rolling motion, in contrast to the sharper jolts from shallower earthquakes on near-surface crustal faults. Several moderate to large magnitude intraplate subduction earthquakes have been recorded in southern Alaska over the last century, including M7 earthquakes in 1999 and 2001 and a M6.5 earthquake in 2000. These three events were located on or close to Kodiak Island. There is potential for future large magnitude (M7+) intraplate subduction earthquakes in the region.

A schematic section through the Alaska subduction zone is presented on Figure 6-52. The section includes all earthquakes within a zone along Section A-A, which is delineated on Figure 6-51. The section illustrates the approximate location of potential interplate subduction (megathrust) and intraplate subduction earthquakes relative to the Pebble Deposit Area.

### 6.6.2.2 Active Fault Systems

A fault is defined as a planar fracture or discontinuity in a volume of rock that can range from less than an inch in length to many miles long as is often found along the boundaries of tectonic plates. Active faults are moving over time due to building stresses. Inactive faults had movement along them at one time with no evidence of movement or associated seismic activity within the Holocene epoch. There are a number of active and potentially active fault systems in southern Alaska related to the tectonic pressures and crustal flexure caused by the subducting Pacific plate. Several of the active faults have generated large crustal earthquakes within the last century. The most important active and potentially active fault systems in the Bristol Bay and Cook Inlet drainages are shown on Figure 6-51 and are discussed below. Cook Inlet faults are included in this chapter because their seismicity may affect the Bristol Bay drainages study area. However, the effect of an earthquake dissipates with increasing distance from the epicenter.

A M7.9 earthquake occurred along a part of the Denali fault in 2002, with the epicenter located approximately 44 miles south of Fairbanks. This event was the largest inland earthquake in North America in almost 150 years. The western portion of the Denali fault trends in a northeast-southwest direction, approximately 125 miles north of the mine study area. The western portion of the Denali fault system is capable of generating large earthquakes of up to about M8.0.

The western end of the northeast-southwest trending Lake Clark-Castle Mountain fault system is located northeast of the mine study area. Published information indicates that the Lake Clark fault terminates at the western end of Lake Clark, over 15 miles from the eastern edge of the mine study area. This distance is based on a recent study by Haeussler and Saltus (2004) who used aeromagnetic data to refine the position of the western end of the fault. The study implies that the fault previously was mismapped in the remote and mountainous region. Recently, Haeussler (via personal communication with KP, April 2007) indicated that the reason for terminating the Lake Clark fault at the western end of Lake Clark was because of the lack of bedrock exposures southwest of the lake. Bedrock exposures are required for conventional fault mapping techniques. Haeussler suggested that the fault may extend farther to the southwest, based on a preliminary review of regional aeromagnetic data developed by the USGS.
Haeussler also indicated that there may be a southerly splay of the fault along the Newhalen River valley (east of the mine study area) toward Iliamna Lake.

A detailed study of the surficial geology and geomorphology at the mine study area was carried out in 2007 by consulting geologist Thomas Hamilton, formerly with the USGS in Anchorage, at the request of the Pebble Partnership. The findings of this study did not demonstrate any surficial evidence of fault activity (e.g., linear features or disturbance of surficial deposits) in the vicinity of the mine study area. The mine study area is located on plutonic outcrops (some of batholithic scale) that likely provide resistance to crustal fracture. The surficial study indicated that large glaciers during the Pleistocene glacial advance followed zones of crustal fracture (weakness) associated with the Lake Clark fault (Hamilton et al, 2010). The mapped direction of primary glacial advance, shown on Figure 6-53, suggests that any potential extension of the Lake Clark fault may pass north and/or east of the mine study area, and would not cross the mine study area.

The Castle Mountain fault system is capable of generating large earthquakes with magnitudes of about M7.0+. There is surficial geologic evidence of Holocene movement along this fault (Haeussler et al., 2000). There have been two instrument-recorded earthquakes on the Castle Mountain fault zone, a M5.7 earthquake in 1984 and a M4.6 earthquake in 1996. An earthquake of approximately M7 that was likely associated with the Castle Mountain Fault also occurred in 1933. Research studies by the USGS (Haeussler et al., 2002) indicated that major earthquakes have occurred along this fault about every 700 years, on average, over the last 2,700 years, and that a major (M6 to M7) earthquake may occur on the fault in the next 50 to 100 years. A recent study indicates that there is potential for a M6.9 to M7.3 earthquake on the western segment of the fault, based on geologic findings relating to fault slip rates. The USGS has adopted a maximum earthquake magnitude of M7.1 for the Castle Mountain fault in the recently revised seismic hazard model (Wesson et al., 2007). The potential for earthquakes of similar magnitude may also exist along the Lake Clark fault. However, unlike the Castle Mountain fault, Haeussler and Waythomas (2011) have found no known evidence of movement along the currently mapped Lake Clark fault since the last glaciation (the Holocene epoch) and no evidence of historical seismicity during the last 1.8 million years, indicating that the Lake Clark fault is not active. The Lake Clark fault is now classified by the USGS as inactive. (Haeussler et al., 2011).

The findings of Haeussler and Saltus (2004) also imply the presence of another fault northwest and parallel to the Lake Clark fault and name it the Telaquana fault. The Mulchatna fault is farther north, trending parallel to the Lake Clark fault. The maximum potential magnitude for earthquakes generated on these two faults would likely be similar or smaller (in the range of M6 to M7) compared to the longer Lake Clark and Castle Mountain fault system.

The Bruin Bay fault runs northeast-southwest along the west shore of Cook Inlet starting from Mt. Susitna, near Anchorage, to the south shore of Becharof Lake. The fault is a major reverse (thrust) fault, dipping to the northwest and is predominantly buried under Quaternary deposits. It is thought to have been active during the late Jurassic period (around 150 million years ago) and again about 25 million years ago in the middle to late Tertiary. A source characterization study conducted by Woodland-Clyde Consultants in 1978 indicated that the Bruin Bay fault has experienced a small number of earthquakes, the largest of which was a M7.3 event in 1943 (Stevens and Craw, 2003).

The Border Ranges fault is a major, but currently inactive, north-northwest trending fault system that crosses the Kenai Peninsula and continues southwest through Afognak Island. The last movement on this
fault occurred during the Cretaceous or early Tertiary, about 65 million years ago, producing a strike-slip system that can be traced as a continuous structure for over 400 miles, from southeast Alaska to south-central Alaska. The Border Ranges fault system consists of a 3 to 6-mile-wide zone of ductile shear zones and brittle faults, known as the Border Ranges shear zone. This fault system likely has the potential for generating future large earthquakes greater than M7.0.

The Kodiak Island and Narrow Cape faults are part of a series of northeast-trending strike-slip faults (subparallel to the megathrust subduction zone) that extend across southeastern Kodiak Island and into the northwestern Gulf of Alaska. The geomorphic expression of these faults suggests that displacement occurred during Holocene time. These faults are considered to be active and capable of producing earthquakes of up to M7.5 (Wesson et al., 2007).

### 6.6.3 Regional Volcanism

There are no active volcanoes located within the Bristol Bay drainages study area, but the study area could be affected by volcanoes located near Cook Inlet. Regional volcanism associated with the Cook Inlet volcanoes is presented in Chapter 30.

### 6.7 Summary

The study area for the geotechnical studies in the Bristol Bay drainages is limited to the vicinity of the mine study area. No geotechnical information has been collected in the transportation corridor study area to date. The geotechnical information presented here is based on site investigations completed in 2004 to 2008, which consisted of test pitting, drilling, piezometer/well installations, hydraulic conductivity testing, and geophysical investigations. The site investigations were completed to assess the subsurface conditions of the mine study area, including the rock mass characterization and classification of bedrock; the depth, composition and characteristics of overburden (surficial materials and organic soils); and the presence and movement of groundwater within these materials.

Alaska is the most seismically active state in the United States, with earthquakes generated by the Pacific plate subducting under the North American plate. Historically, the level of seismic activity is highest offshore along the south coast of Alaska where the Pacific (oceanic) plate is subducting under the North American plate at an average rate of approximately 2 to 3 inches per year. Several moderate to large magnitude intraplate subduction earthquakes have been recorded over the last century. There is potential for future large magnitude (M8 to M9+) interplate subduction earthquakes and (M7+) intraplate subduction earthquakes in the region. The western end of the northeast-southwest trending Lake Clark-Castle Mountain Fault system is located east of the mine study area at the end of Lake Clark. The Castle Mountain Fault system is capable of generating large earthquakes with magnitudes in the range of 7 that could affect the Bristol Bay drainages study area. The Lake Clark fault is considered inactive by the USGS. The seismic hazard associated with crustal faults in the mine study area is not considered to be significant as the ground accelerations generated by earthquakes decrease the farther the distance from the epicenter.

### 6.8 References


### 6.9 Glossary

Aeromagnetic survey—a geophysical survey of the earth’s magnetic field carried out using a magnetometer either onboard or towed behind an aircraft in a grid-like pattern.

Alluvium—sediment and detritus transported by a stream or river and deposited as the river floodplain.

Alpha angle—the maximum dip vector of a fracture plane with respect to the core axis.

Andesite—a type of fine-grained volcanic rock.

Annulus—the space between the drill string and sides of the drillhole or surface casing.

Aperture—measurement of the size of the opening on a fracture surface that would allow water to pass through.

Asthenosphere—A zone of the earth's mantle that lies beneath the lithosphere and consists of several hundred kilometers of deformable rock.

Atterberg limits—series of thresholds which are observed when the water content of a soil is steadily changed.

Azimuth—the angle measured between a reference vector and the plane of the meridian, measured clockwise to 360 degrees.
Basalt—a dark-colored, fine-grained, extrusive igneous rock containing no more than 53 percent by weight of quartz.

Batholith—a large (more than 100 square kilometers) igneous intrusion; most are granitic in composition, and their genesis is linked with plate tectonics; batholiths are generally discordant with the surrounding rocks.

Bedding—layering of sheet like units, called beds or strata.

Bentonite—montmorillonite rich clay formed by the breakdown and alteration of volcanic ash and volcanic tuffs.

Beta angle—the angle between the maximum dip vector of a fracture plane with respect to a core reference line in a clockwise direction.

Breccia—a coarse, clastic sedimentary or volcanosedimentary rock with angular constituent clasts.

Brittle behavior—the manner in which competent rocks lose their internal cohesion along certain surfaces when the elastic limit is exceeded under an applied stress, gives rise to fractures, faults or joints.

Clast—fragment of sediment or rock that was formed by the deterioration of larger rocks.

Clastic—sediment composed of fragments of pre-existing rocks.

Colluvium—material transported by gravity, typically deposited and accumulated on lower slopes and/or at the base of slopes.

Competent—a measure of the amount of intact rock and the strength of the rock in a rock mass.

Completion zone—the zone of filter sand surrounding the screened section of a piezometer.

Cretaceous—approximately 145.6 to 65 million years ago, the third of the three periods included in the Mesozoic Era.

Crustal—term applied to the thin outermost solid layer of the earth.

Dacite—a light colored, fine-grained, igneous rock containing 63 to 70 weight percent of silicon dioxide.

Dike—discordant or cross cutting, tabular intrusion, most are vertical or near vertical, having pushed their way through the overlying rock.

Diorite—an intermediate, coarse-grained igneous rock with up to 10 percent quartz.

Discontinuity—a boundary or layer marked by substantial change or break in sedimentation, or a joint (fracture), vein, etc., in rock mechanics.

Ductile behavior—response to stress where permanent deformation occurs without fracturing.

Epicenter—the point on the earth’s surface immediately overlying an earthquake focus.
Fault slip rate—the rate of relative displacement that occurs between the blocks along a fault zone.

Felsenmeer—coarse, angular, frost-shattered rock debris in environments that are or were formerly at the immediate margins of glaciers.

Flexure—the lateral deflection from a datum line of a planar feature as it is shortened.

Fluvial—term applied to material transported by moving water, typically deposited in a stream channel, along a stream bank, or on a floodplain.

Gabbro—a type of coarse-grained, basic igneous rock that results from slow crystallization of basaltic magmas.

Geological cross-section—a diagram which displays a vertical section of the earth’s subsurface.

Geological strength index—an estimate of the average strength of a rock mass taking lithology, structure, and discontinuity surface conditions into consideration.

Geomorphology—the scientific study of the landforms on the earth’s surface and of the processes that have fashioned them.

Geophone—a rugged device employed during seismic surveys to measure ground displacement by detecting the arrival of seismic waves by transforming the ground motion into an electric voltage.

Geotechnical—of or pertaining to practical applications of geological science in civil engineering, mining, etc.

Glacial wasting—erosion and/or melting of glacier ice.

Glacial drift—any sediment laid down by, or in association with, glacial ice activity.

Glacial outwash—the stratified sands and gravels deposited at or near ice margins.

Glacial till—collective term for the group of sediments laid down by the direct action of glacial ice without the intervention of water.

Glaciofluvial sediments—material transported and deposited by meltwater streams flowing from glaciers.

Glaciolacustrine—term for materials produced by or involving a lake which received meltwater from glacial ice.

Granodiorite—a type of coarse-grained igneous rock.

Heaving sand—term for sand that pushes up inside the drill string during drilling because of greater pressure conditions within the formation outside the drill string than those pressures inside the drill string.

Holocene—epoch that covers the last 10,000 years, often referred to as Recent or post-glacial.
Hydraulic conductivity—a measurement of the flow rate of water, by volume, through a cross-sectional unit of a porous subsurface medium.

Hydrogeology—the study of the occurrence and movement of groundwater and its effects on earth materials.

Hydrometer—a device used to measure specific gravity or relative density of a liquid.

Igneous rocks—rocks or minerals that were formed when molten material (magma) solidified; one of three main classifications of rock.

Interplate—relating to or occurring between two tectonic plates.

Intraplate—relating to or occurring within the interior of a tectonic plate.

Intrusive—applied to a body of rock, usually igneous, that is intrudes into pre-existing rocks; intrusions are classified according to size, shape, and geometrical relationship to the surrounding rock.

Jurassic—from 208 to 145.6 million years ago, the Mesozoic period following the Triassic and preceding the Cretaceous.

Kettle depression—a depression that forms in the surface of glacial sediment as a result of the melting of an included ice mass; a depression may fill with water, forming a small lake.

Latite—a type of porphyritic extrusive igneous rock.

Lithology—physical characteristics of a rock such as color and texture.

Lithosphere—the outermost layer of the solid earth, comprising all crustal rocks and the brittle part of the uppermost mantle.

Magnitude—the magnitude of an earthquake based on the amplitude of seismic waves.

Mantle—the zone lying between the earth’s crust and core.

Monzodiorite—a type of coarse-grained igneous rock.

Monzonite—a type of coarse-grained igneous rock.

Moraine—an accumulation of material that has been transported on the surface of ice, within ice, or beneath ice.

Oriented drilling—drilling of a hole with a known azimuth and inclination in order to collect orientation measurements of the discontinuities in the rock mass.

Outcrop—exposed bedrock.

Overburden—the material that lies above the bedrock.
Oxbow—a crescent-shaped body of water formed when a wide meander from the main stream of a river is cut off to create a lake.

Packer or Lugeon test—a pressure test of a sealed zone, used to determine hydraulic conductivity.

Paleochannel—unconsolidated sediments deposited in ancient currently inactive river or stream bed.

Permeability—the ability of a rock, sediment, or soil to permit fluids to flow through it.

Persistence—the continuation of a discontinuity beyond the limits of the drill core.

Physiography—the study of the physical features of the earth’s surface.

Piezometer—an observation or monitoring well designed to measure the hydraulic head of the groundwater at a particular depth below the ground.

Piezometric level—the elevation representing the static hydraulic head of groundwater at a site.

Plate—a segment of the lithosphere with little volcanic or seismic activity that is bounded by continuous belts of earthquakes and volcanic activity.

Pleistocene—from 1.64 million years ago to about 10,000 years ago, the first of two epochs of the Quaternary sub-era.

Plutonic—a loosely defined term to describe igneous rock bodies which have crystallized at great depth, or to describe a large intrusion, also used to describe the origin of magmas and gas derived from near the base of the crust or in the upper mantle.

Porphyry—medium-grained rock containing large, well-formed grains of any mineral.

Pyroxenite—a type of igneous rock with a silica content of less than about 45 percent.

Quaternary—a sub-era of the Cenozoic Era that covers the past 1.64 million years and comprises the Pleistocene and Holocene epochs.

Relict—used to describe a feature that has persisted through time.

Response test—a particular type of aquifer test where water is quickly added or removed from a piezometer, and the change in hydraulic head is monitored through time, to determine the near-well aquifer characteristics.

Reverse fault—a low-angle fault in which the relative displacement of the hanging wall is upwards; thrust faults are a type of reverse fault.

Rhyolite—a type of fine-grained extrusive igneous rock.

Rock mass rating system (RMR89)—system developed by Bieniawski to classify a rock mass.
Rock quality designation (RQD)—core recovery percentage which incorporates only solid core pieces that are greater than four inches in length.

Seismicity—the frequency or magnitude of earthquake activity in a given area.

Seismic refraction—a geophysical survey method that uses the refraction of seismic waves on soil and rock units to characterize subsurface geologic conditions and structure.

Seismograph—a device which records seismic information.

Shear zone—a narrow region in which rocks have undergone intense deformation.

Shot point—the point from which a source of seismic shock waves is produced for experimental purposes.

Slough—material that sheds from the sides of an excavation and falls down to the bottom of the hole.

Solifluction—the slow creeping of fragmented material down a slope as a result of the alternate freezing and thawing of the water contained in the material.

Splay—one of a series of branching faults near the termination of a major fault which spread the displacement over a large area.

Spoil pile—earth and rock removed when excavating.

Standard penetration test—an in situ dynamic penetration test designed to provide data regarding soil properties.

Static equilibrium—the point at which the water level becomes static during a response test.

Strata—lithological term applied to materials that form layers or beds.

Strike—the compass direction of a horizontal line on an inclined plane.

Strike-slip fault—also known as a transverse fault, a fault where the major displacement is horizontal and parallel to the strike of a vertical or subvertical fault plane.

Stock—an igneous intrusion, approximately circular in plan with steep contacts to the country rock and a surface area of 20 square kilometers or less.

Subduction—the action of a tectonic plate descending below another plate at a convergent margin.

Tertiary—from 65 million years ago until 1.64 million years ago, the first sub-era of the Cenozoic Era; the Tertiary comprises five epochs: Paleocene, Eocene, Oligocene, Miocene, and Pliocene.

Test pit—a shallow excavation dug either by hand or a mechanical device to observe and sample shallow subsurface materials.
Thrust fault—a low-angle (commonly less than 45 degrees) reverse fault where the hanging wall overhangs the footwall.

Transverse fault—also known as a strike-slip fault, a fault where the major displacement is horizontal and parallel to the strike of a vertical or subvertical fault plane.

Triconed—drilling that is completed with a tricone bit.

Unconfined compressive strength—the strength of a rock or soil sample when crushed in one direction (uniaxial) without lateral restraint.

Vibrating wire piezometer—a piezometer that converts water pressure to a frequency signal via a diaphragm, a tensioned steel wire, and an electromagnetic coil. The piezometer is designed so that a change in pressure on the diaphragm causes a change in tension of the wire. When excited by the electromagnetic coil, the wire vibrates at its natural frequency. The vibration of the wire in the proximity of the coil generates a frequency signal that is transmitted to a readout device.

Volcaniclastic—a sedimentary rock composed of pre-existing fragments, particles or clasts of volcanic origin.

Wacke—a sandstone which contains between 15 and 75 percent mud matrix.

Weathering—the breakdown of rocks and minerals at and below the earth’s surface by the action of physical and chemical processes.
FIGURES
Figure 6-1
Geotechnical, Seismicity, and Volcanism
Study Area
Bristol Bay Drainages

Legend
- General Deposit Location
- Bristol Bay Study Area
- Geotechnical Study Area
- Population Centers
- National Park and Preserve Boundary
- BB/CI Drainages Boundary
- Existing Roads

Notes
1. BB/CI refers to Bristol Bay/Cook Inlet drainages.

File: B36_r0.mxd Date: October 15, 2010
Version: 2008-2
Author: Knight Piesold Ltd.
Figure 6-5
Geotechnical Drillhole
and Seismic Line Locations
Mine Study Area
2004 - 2008

Legend

- Mine Study Area Boundary
- Reference Area Boundary
- General Deposit Location
- 2004 to 2006 Geotechnical Drillholes
- Older/used Geotechnical Drillholes
- Seismic Line
- Other Geotechnical Drillhole

Notes
1. See Figure 6-6 for detail.

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: IS4.Dwg
Date: October 16, 2010
Version: 2006-1
Author: Knight Piëck & Partners
Figure 6-6
Detail Geotechnical Drillhole and Seismic Line Locations
Mine Study Area
2004 - 2008

Legend
- Mine Study Area Boundary
- Reference Area Boundary
- General Deposit Location
- 2004 to 2008 Geotechnical Drilling
- Oriented Geotechnical Drillhole
- Seismic Line
- Other Geotechnical Drillhole

Notes
1. See Figure 6-5 for Drill Hole Location

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 98215pap
Date: September 14, 2010
Version: 2006-1
Author: Knight Piesold Ltd.
Figure 6-9
Detail Geotechnical Drillholes
Depth to Bedrock
Mine Study Area
2004 - 2008

Legend
- Mine Study Area Boundary
- Reference Area Boundary
- General Deposit Location
- 2004 to 2008 Geotechnical Drillhole
- Censored Geotechnical Drillhole

Notes
1. Numbers in parentheses denote the depth of the overburden in feet.
2. See Figure 6-4 for detail trend location.

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 8022.dwg
Date: September 14, 2010
Version: 2009-1
Author: Knight Ferry Ltd.
Figure 6-11
Geologic Section Plan
Mine Study Area
2004 - 2008

Legend
- Mine Study Area Boundary
- Reference Area Boundary
- General Deposit Location
- 2004 to 2008 Geotechnical Drilling
- Oriented Geotechnical Drillhole
- Seismic Line
- Other Geotechnical Drillhole
- Location and Direction of Geologic Sections

Notes
1. See Figure 6-12 for detail.
Figure 6-13a
Geologic Section
Frying Pan Valley
Sheet 1 of 2

Notes
1. For section locations, see Figures 6-11 and 6-12.
2. Groundwater levels may vary seasonally. Measurements are
   from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types encountered in the drillholes. The elevation of the
   strata is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
   are found in OP, 2008b, 2009, 2008e, and 2009 respectively.
6. Sediment data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were infilled and have
   minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is
   unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-13b
Geologic Section
Frying Pan Valley
Sheet 2 of 2

SECTION 1 - FIGURE 6-11
SECTION ALONG FRYING PAN VALLEY
Horizontal Scale 1:4 Vertical Scale 1:8

Legend
- Gravel
- Sand
- Silt
- Clay
- Organic Deposit
- Alluvium
- Glaciofluvial Deposit
- Glacial Drift Deposit
- Fill deposits
- Cut

1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major depositional units encountered in the drillholes. The stratigraphy of the soils is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Sediment data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were informally and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6.15
Geologic Section
Seismic Line-26
Pebble East Area

Notes
1. For section locations, see Figures 6.11 and Figure 6.12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The striations indicated represent the major deposit hypsometric lines encountered in the drillholes. The gradation of the scale is also shown to vary. The contract between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were untested and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

SECTION 2/FIGURE 6-12
SECTION ALONG SEISMIC LINE - 26
Horizontal Scale A, Vertical Scale B

Legend
- Gravel
- Sand
- Silt
- Clay
- Organic Deposit
- Alluvial
- Blockfield Deposit
- Blackshale Deposit
- Glacial Drift Deposit
- Feathers
- Clay

- Tertiary Sediments and Volcanics; Typically consist of Mudstone/Shale, Volcanics, Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Latite, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics; Typically consist of Mudstone/Shale, Conglomerate, Sandstone, and Basalt
- Cretaceous Intrusive; Typically consist of Granodiorite, Monzonite, Monocidrite, Porphyritic Microdiorite, Diorite, and Gabbro
- Fault Zone
- Piezometer completion zone, measured groundwater level (GW) and date of measurement
- Hand excavated
- Ground surface
- Interpreted groundwater level from seismic data
- Interpreted bedrock surface from seismic and drillhole data

Scale: 1:25,000

Map Location

File: B15dep
Date: September 17, 2010
Version: 2008-1
Author: Knight Piesold Ltd.
Figure 6-16
Geologic Section
Seismic Line-34
Pebble East Area

Notes
1. For section locations, see Figures 6-11 and 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major depositional units encountered in the drillholes. The gradation of the units is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between units may vary.
6. Seismic data provided by Frontier Geosciences, Inc.
7. Drillhole intervals with no color were drilled and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

Legend
- Gravel
- Sand
- Clay
- Organic Deposit
- Alluvium
- Glacial Till Deposit
- Glacial Drift Deposit
- Biotite
- Graphite
- Pumice

Gravel Depressions
- Quaternary Sediments and Volcanics: Typically consist of Mutunite/Siltstone, Volcaniclastic Breccia, Sandstone, Conglomerate, andesite, Basalt, Dacite, Latite, Rhyodacite, and Basalt
- Cretaceous Sediments and Volcanics: Typically consist of Mutunite/Siltstone, Conglomerate, Sandstone, and Basalt
- Cretaceous Intrusion: Typically consist of Granodiorite, Monzogranite, Monzodiorite, Porphyry, Monzo-diorite, Granite, and Gabbro
- Fault Zone
- Termination of Hole
- Piezometers: completion zone, measured groundwater level (GW) and date of measurement
- Hydraulic conductivity from packer tests in centimeters per second (cmsg)
- Ground surface
- Interpreted groundwater level from seismic data
- Interpreted bedrock surface from seismic and drillhole data
- Depth to end of drillhole

Scale: 1:8,900
Date: September 17, 2009
Version: 2009a-1
Author: Knight Pacer, Ltd.
Figure 6-17
Geologic Section
Seismic Line-38
Pebble East Area

Notes
1. For section locations, see Figures 6-11 and 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types and boundaries encountered in the drillholes. The gradation of the units is approximate, the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were identified and have minimal to no data available from cuttings or standard penetration tests samples, therefore, the deposit type is unknown.
8. Sedimentology defined by Pebble Partnership geologists.

FILE: 817.png
Date: September 17, 2010
Version: 2006-1
Author: Knight Piésold Ltd.
Figure 6-19
Geologic Section
Seismic Line-13
Area E / Area A

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit type and particle size encountered in the drillholes. The gradation of the soils is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Sediment data provided by Frontier Geosciences Inc.
7. Drilled intervals with no color were interpreted and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

File: H1126sp
Date: September 17, 2010
Version: 2006-1
Author: Knight Piesold Ltd.
Figure 6-21
Geologic Section
Seismic Line-15
Area E

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are
   from ground surface, unless otherwise indicated.
3. The names indicated represent the major deposit types and
   thicknesses encountered in the drillholes. The position of the lines
   is approximate, and the boundary between deposit types
   may vary.
4. The stratigraphy shown in the drillholes may vary.
   are found in RP-2004b, 2005, 2006a, 2006b and 2009.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were logged and have
   minimal to no data available from cuttings or standard
   penetration tests; therefore, the deposit type is
   unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

SECTION 9/FIGURE 6-21
SECTION ALONG SEISMIC LINE-15
Horizontal Scale 4, Vertical Scale 3

Legend
- Gravel
- Sand
- Clay
- Glacial Till
- Tertiary Sediments and Volcanics
- Cretaceous Sediments and Volcanics
- Basement Complex
- Fault Zone
- Tectonic Displacement
- Geological Unit
- Hydrogeologic Unit

Drilled Depth
- Terrestrial Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Volcaniclastic: Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Basalt, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Conglomerate, Sandstone, and Basalt
- Cretaceous Intrusive: Typically consist of Granite, Granite, Monzonite, Porphyritic diorite, Diorite, and Gabbro
- Fault Zone

Groundwater level (GW) and date of measurement
Hydraulic conductivity from packer tests in
Centimeters per second (cm/s)
Interpreted groundwater level from seismic data
Interpreted bedrock surface from seismic and
Drillhole data
Depth to end of drillhole
Figure 6-22
Geologic Section
Seismic Line-27 Area E

Notes
1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit type observed in the drillholes. The gradation of the scale is approximate; in some cases, the transition may be gradual.
4. The stratigraphy may vary between drillholes.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillholes terminated with no color were infilled, and therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-23
Geologic Section
Seismic Line-28 Area E

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types encountered in the drillholes. The elevation of the scale is approximate and may vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were infilled and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

Legend:
- Tertiary Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Volcaniclastic Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Lava, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Conglomerate, Sandstone, and Basalt
- Cretaceous Intraclasts: Typically consist of Granodiorite, Monzonite, Monzodiorite, Porphyritic Monzodiorite, Diorite, and Galena
- Fault Zone
- Glacial Drift
- Glacial Outwash
- Frontier Drift
- Organic Deposit
- Alluvium
- Tuff
- Volcanic Ash

Symbols:
- **Shows location of section on map**
- **Shows location of section on map**
- PWI: 75' Water Level
- Background: Groundwater level (GWL) and date of measurement
- Hydrostatic line: Water level
- Interpreted groundwater level from seismic data
- Interpreted bedrock surface from seismic and drillhole data
- Depth to bed of glacial deposits
Figure 6-24
Geologic Section
Seismic Line-29 Area E

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit hypersaline siltstrata encountered in the drillholes. The estimates of the scale is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were inferred and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
SECTION 13/FIGURE 6-12
SECTION ALONG SEISMIC LINE-30
Horizontal Scale A, Vertical Scale B

Legend:
- Gravel
- Sand
- Clay
- Organic Deposit
- Albite
- Blackbird Deposit
- Blackbirdite Deposit
- Feldspar
- Cukotka

- Tertiary Sediments and Volcanics; Typically consist of Mudstone/Shale, Volcaniclastic, Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Lava, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics; Typically consist of Mudstone/Shale, Conglomerate, Sandstone, and Basalt
- Cretaceous Intrusive; Typically consist of Granodiorite, Monzonite, Monzodiorite, Porphyritic Monzonite, Diorite, and Gabbro
- Fault Zone

Notes:
1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strings indicated represent the major deposit hypsometric lines encountered in the drillholes. The resolution of the scale is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were ignored and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-26
Geologic Section
Seismic Line-31 Area E

Notes
1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit hydroparticle sizes encountered in the drill sites. The gradation of the scale is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drill sites may vary.
6. Sediment data plotted by Frontier Geosciences Inc.
7. Drilling intervals with no color were thinner and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Sedimentology defined by Pebble Partnership geologists.

Legend
- Gravel
- Sand
- Silt
- Clay
- Organic Deposit
- Alluvium
- Beach Sand Deposit
- Black Sand Deposit
- Glacial Gravels Deposit
- Ternite
- Columbite
- Tertiary Sediments and Volcanics; Typically consist of Mudstone/Shale, Volcaniclastic Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Laiite, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics; Typically consist of Mudstone/Shale, Conglomerate, Sandstone, and Basalt
- Cretaceous Intraslope; Typically consist of Granodiorite, Monzonite, Monzocline, Porphyritic Monocline, Dacite, and Galbra
- Fault Zone

GEW @ 75 ft
Pneumometer completion zone, measured groundwater level (GW) and date of measurement
INTERP @ 2004
Hydraulic conductivity from packer test in centimeters per second (cm/s)
WHITE LINE
Ground surface
INTERP @ 2004
Interpreted groundwater level from seismic data
INTERP @ 2004
Interpreted bedrock surface from seismic and drill hole data
EODH
Depth to end of bedrock

Scale: 1/2 in = 100 ft

File: S26spg
Date: September 20, 2010
Version: 2008-1
Author: Knight Findlay Ltd.
Figure 6-27
Geologic Section
Seismic Line-32 Area E

Notes
1. For section locations, see Figures 6-11 and 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The shales indicated represent the major deposit. Hypersaline shales are present in the wash holes. The elevation of the shaft is estimated to be varying. The contact between deposits is approximately linear, and the transition may be gradual.
4. The stratigraphy between the wash holes may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Wash holes with no data were informed and have minimal to no data available from cuttings or standard penetration tests; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
SECTION 6/FIGURE 6-12
SECTION ALONG SEISMIC LINE-33
Horizontal Scale A, Vertical Scale B

Legend
- Gravel
- Sand
- Clay
- Organic Deposit
- Alluvium
- Glaciotectonite Deposit
- Glacial Drift Deposit
- Tertiary Sediments and Volcanics; Typically consist of Mudstone/Shale, Volcaniclastic
  Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Lava, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics; Typically consist of Mudstone/Shale, Conglomerate, Sandstone, and Basalt
- Cretaceous Infill; Typically consist of Granodiorite, Monzodiorite, Microgabbro, Monzonite, Diorite, and Gabbro
- Fault Zone
- GW 2.75
- Talcinite
- Piezometer completion zone, measured groundwater level (GW) and date of measurement
- Hydraulic conductivity from packer tests in centimeters per second (cm/s)
- Ground surface
- Interpreted groundwater level from seismic data
- Interpreted bedrock surface from seismic and drone data
- Depth to end of drillhole

Notes
1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The shales indicated represent the major deposits across the Oil Shale. The elevation of the profile is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillholes intersected with no color were diamond and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-29
Geologic Section
Northwest Area E

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The lines in the geologic section indicate major depositional units.
4. The stratigraphy between drillholes may vary.
6. Sedimentology data provided by Frontier Geosciences Inc.
7. Drillholes terminated with no color were ungraded and have minimal to no data available from cuttings or standard penetration tests.
8. Bedrock geology defined by Pebble Partnership geologists.
Geologic Section Seismic Line-23 Area G

Legend:
- Gravel
- Sand
- Silt
- Clay
- Organic Deposit
- Alluvium
- Glaciolacustrine Deposit
- Glacial Drift Deposit
- Tertiary Sediments and Volcanics: Typically consist of Mudstone/Shale, Volcaniclastic Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Diabase, Lava, Rhyolite, and Basalt
- Cretaceous Sediments: Monochronous and Basalt
- Cretaceous Intrusive: Typically consist of Granite, Monzonite, Monchonite, Porphyritic Granite, Diorite, and Galena
- Fault Zone
- Tectonic deformation
- Hydrocarbon source rock
- Fault
- Hydrocarbon accumulation
- Groundwater level (GW) and date of measurement
- Isopach lines: thickness in meters
- Isoline: equal concentration
- Contour: equal property value
- Isotach: equal transport velocity
- Isodyne: equal thermal gradient
- Surface geology

Notes:
1. For section locations, see Figures 6-11 and 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The shales indicated represent the major deposit hyperpartial sites encountered in the drillholes. The gradation of the shale is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
7. Drillhole intervals with no color were ignored and have minimal to no data available from cutting or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-31
Geologic Section
Upstream of Seismic Line-23
Area G

Notes
1. For section locations, see Figures 6-11 and 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit sequences encountered in the drillholes. The gradation of the soils is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Sediment data provided by Frontier Geosciences Inc.
7. Drillhole lithology with no color were ignored and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-32
Geologic Section
Northwest Ridge Area G

Notes
1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The stippled indicated represent the major deposit Sequence.
4. The stratigraphy between drillholes may vary.
6. Seismic data provided by Petrel Geoscience Inc.
7. Drillhole intervals with no color were logged and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-33
Geologic Section
Southwest Ridge
Area G

Notes
1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are
   from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit strata
   encountered in the drillholes. The completion of the scale
   is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
   are found in WP, 2009 B, 2007, 2006, 2005 and 2009
   respectively.
6. Sediment data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were interpreted as
   minimal to no data available from cuttings or standard
   penetration test samples; therefore, the deposit type is
   unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-36
Geologic Section
North Area L

Notes:
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major depositional units encountered in the drillholes. The gradation of the units is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Sediment data provided by Frontier Geosciences Inc.
7. LithologyInterpretations with no color were inferred and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-37a
Geologic Section
Area L Sheet 1 of 2

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types and rock units encountered in the drillholes. The contact between deposit types is gradational, and the transition may be gradual.
5. Seismic data acquired by Frontier Geosciences Inc.
6. Drift/rock interface identified in all rock types and are minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
7. Bedrock geology defined by Pebbly Partnership geologists.

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Date: September 30, 2010
Version: 2006-1
Author: Knight Pliskin Ltd.
Figure 6-37b
Geologic Section
Area L Sheet 2 of 2

Northeast Slope
Northwest Slope

Legend
- Gravel
- Sand
- Clay
- Organic Deposit
- Alluvium
- Glaciofluvial Deposit
- Glaciolacustrine Deposit
- Glacial Drift Deposit
- Fortymile
- Quaternary
- Tertiary Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Volcaniclastics, Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Lava, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Conglomerate, Sandstone, and Basalt
- Cretaceous Intrusive: Typically consist ofGranodiorite, Monzonite, Monzodiorite, Porphyry, Monzonite, Diorite, and Gabbro
- Fault Zone
- Picnic complex completion zone, measured groundwater level (GW) and date of measurement
- Hydraulic conductivity from packer tests in centimeters per second (cm/s)
- Ground surface
- Interpreted groundwater level from seismic data
- Interpreted bedrock surface from seismic and drillhole data

Notes
1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit type(s): volcanic rocks, breccia, sandstone, conglomerate, andesite, monzonite, dacite, lava, rhyolite, and basalt.
4. The contact between deposit types is approximate; the transition may be gradual.
6. Seismic data plotted by Frontier Geosciences Inc.
7. Drillhole information with no color were interpreted and have minimal to no data available from cutoffs or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

File: 11.dwg
Date: September 20, 2010
Version: 2008-1
Author: Knight Piesold Ltd.
Figure 6-38a
Geologic Section
Seismic Line-6
South Fork Koktuli River Area
Sheet 1 of 2

SECTION 26/FIGURE 6-11
SECTION ALONG SEISMIC LINE-6
Horizontal Scale 4, Vertical Scale 8

Legend
- Gravel
- Sand
- Silt
- Clay
- Organic Deposit
- Glacial Bedrock
- Glacial Till Deposit
- Felsic/Late
- Clastic

- Tertiary Sediments and Volcanics; Typically consist of Mudstone/Shale, Volcanics: Breccia, Sandstone, Conglomerate, Andesite, Montana, Debris, Limestone, and Basalt
- Cretaceous Sediments and Volcanics; Typically consist of Mudstone/Shale, Conglomerate, Sandstone, and Basalt
- Cretaceous Involcanics: Typically consist of Granodiorite, Monzonite, Monocidrite, Porphyrictic Monocidrite, Diorite, and Gabbro
- Fault Zone

Notes:
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit hypsometric and are not drilled. The gradation of the scale is approximate; the transition may be gradual.
4. The stratigraphy between strata may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drilling intervals with no data were included and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-38b
Geologic Section
Seismic Line-6
South Fork Koktuli River Area
Sheet 2 of 2

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types encountered in the drillholes. The gradation of the scale is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Seismic data plotted by Frontier Geosciences Inc.
7. Drillholes intersected with no color were infilled and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

Legend
- Tertiary Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Volcaniclastic: Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Latite, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Conglomerate, Sandstone, and Basalt
- Cretaceous Intraunits: Typically consist of Granodiorite, Monzonite, Monzodiorite, Porphyritic Monzodiorite, Diorite, and Galena
- Fault Zone
- Trench
- Gravel
- Sand
- Silt
- Clay
- Organic Deposit
- Alluvium
- Bedrock/EndDeposit
- Glacial Drift Deposit
- Ferromanganese
- Gilaxian Lava

GW: 75' Trench
Piezometer completion zone, measured groundwater level (GW) and date of measurement

<hydro conductivity from packer tests in centimeters per second (cm/s)
Ground surface
Interpreted groundwater level from seismic data
Depth to bedrock surface from seismic and driller data
EDH

Map Location

File: 8423d.png
Date: September 20, 2010
Version: 2009-1
Author: Knight Pendalton Limited
Figure 6-39
Geologic Section
Seismic Line-7
South Fork Koktuli River Area

Notes:
1. For section locations, see Figures 6-11 and 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The lines indicated represent major deposit boundaries created in the drillholes. The projection of the scale is appropriate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color were not logged and have minimal information available from cutting or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-40
Geologic Section
Seismic Line-8
South Fork Koktuli River Area

Notes
1. For section locations, see Figures 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types and are approximate. The transition may be gradual.
4. The stratigraphy between different units may vary.
6. Seismic data provided by Frontier Geosciences Inc.
7. Stratigraphic data with no color were interpreted and have minimal to no data available from cuttings or standard penetration tests, therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

SECTION 28/FIGURE 6-11
SECTION ALONG SEISMIC LINE-8
Horizontal Scale A, Vertical Scale B

Legend
- Gravel
- Sand
- Clay
- Organic Deposit
- Alluvium
- Bouldery Deposit
- Glacial Drift Deposit
- Peat
- Ternement
- Glacial

- Tertiary Sediments and Volcanics: Typically consist of Mudstone/Shale, Tuffs and Tuffites, Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Diabase, Rhyolite, and Basalt
- Eocene Sediments and Volcanics: Typically consist of Mudstone/Shale, Conglomerate, Sandstone, and Basalt
- Cretaceous Intraclasts: Typically consist of Granodiorite, Monzonite, Rhyolite, Porphyry, Monzodiorite, Ortho, and Gabbro
- Fault Zone
- Pliocene completion zone, measured groundwater level (GW) and date of measurement
- Ground surface
- Interpreted groundwater level from seismic data
- Interpreted bedrock surface from seismic and drill-hole data
- Depth to end of drill hole
Figure 6-41
Geologic Section
Seismic Line-19
South Fork Koktuli River Area

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types and package sizes encountered in the drillholes. The gradation of the scale is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Sediment data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color are licenced and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-42
Geologic Section
Area J

Legend
- Gravel
- Sand
- Silt
- Clay
- Organic Deposit
- Alluvium
- Glacial Drift Deposit
- Glacial Lake Drift Deposit
- Glacial Till Deposit
- Scree
- Boulders
- Fault Zone
- Tertiary Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Volcaniclastic Breccia, Sandsand, Conglomerate, Andesite, Morrocoyte, Dacite, Latite, Rhyolite, and Basalt
- Cretaceous Sediments and Volcanics: Typically consist of Mudstone/Siltstone, Conglomerate, Sandstone, and Basalt
- Cretaceous Intrusive: Typically consist of Granodiorite, Monzodiorite, Monzonite, Porphyry Monzonite, Diabase, and Gabbro

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types and their transition may be gradual.
4. The transition between deposit types is anticipated to vary. The contact between deposit types may be gradual.
6. Sediment data provided by Frontier Geosciences Inc.
8. Sediment data provided by Frontier Geosciences Inc.
10. Sediment data provided by Frontier Geosciences Inc.
12. Sediment data provided by Frontier Geosciences Inc.
Figure 6-44
Geologic Section
North Valley Bottom Area A

Section 32/Figure 6-12
NORTH VALLEY BOTTOM GEOLOGIC SECTION
Horizontal Scale A  Vertical Scale B

Legend
- Gravel
- Sand
- Clay
- Organic Deposit
- Albite
- Felsic Granite Deposit
- Plutonic Granite Deposit
- Glacial Drift Deposit
- Felsite
- Mt. Mckee

- Tertiary Sediments and Volcanics: Typically consist of Mudstone/Shale, Volcanics/ breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Lavas, Rhyolite, and Basalt.
- Cretaceous Sediments and Volcanics: Typically consist of Mudstone/Shale, Conglomerate, Sandstone, and Basalt.
- Cretaceous Intrusive: Typically consist of Granite, Monzonite, Porphyry/Granodiorite, Diorite, and Galena.
- Fault Zone

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strikes indicated represent the major deposit boundaries and are not always straight. The transverse strike is anticipated to vary. The transition between deposit types is approximate; the transition may be gradual.
4. The composition between bedrock may vary.
6. Sediment data provided by [provider].
7. Drillhole intervals with no color were not included and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

Map:
- NIP4 Location

Scale: [Scale]

File: BGF-002
Version: 2006-1
Date: September 20, 2010
Author: Knight Pierson Ltd.
Figure 6-45
Geologic Section
Seismic Line-3
Southern Upland Area
Area A

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types/size encountered in the drillholes. The gradation of the soils is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Sediment data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color users marked and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.

Legend
- Glacial Drift
- Ice Sheet
- Organic Deposit
- Alluvium
- Bedrock Drift
- Glacial Till
- Tertiary Sediments and Volcanics; Typically consist of Mudstone/Shale, Volcaniclastic: Breccia, Sandstone, Conglomerate, Andesite, Monzonite, Dacite, Lava, and Basalt
- Cretaceous Sediments and Volcanics; Typically consist of Mudstone/Shale, Conglomerate, Sandstone, and Basalt
- Cretaceous Intraclast; Typically consist of Granodiorite, Monzonite, Monzodiorite, Porphyritic Monzodiorite, Diorite, and Gabbro
- Fault Zone

SECTION 33/FIGURE 6.11
SECTION ALONG SEISMIC LINE-3
Inch scale: B, Vertical scale: C

LEGEND
- Peckometer completion zone, measured groundwater level (GWL) and date of measurement
- Interpreted groundwater level from sediment and drillhole data
- Depth to end of bedrock

File: 947.bep
Date: September 20, 2010
Version: 1.00
Author: Knight Piérdid, Ltd.,
Figure 6-47
Geologic Section
Seismic Line-5
Southern Upland Area
Area A

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally; measurements are from ground surface, unless otherwise indicated.
3. The data indicated represent the major deposit type/particle sizes encountered in the drillholes. The gradation of the sands is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
7. Drillhole intervals with no color were lenticular and have minimal to no data available from core samples or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-48
Geologic Section
Southwest Transverse
Southern Upland Area
Area A

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The strata indicated represent the major deposit types or particle sizes encountered in the drillholes. The gradation of the soils is anticipated to vary. The contact between deposit types is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Sediment data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color are stained and have minimal to no data available from cavings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-49
Geologic Section
Seismic Line-20
Lower/Mid Side Slopes
Area A

Notes
1. For section locations, see Figure 6-11 and Figure 6-12.
2. Groundwater levels may vary seasonally. Measurements are from ground surface, unless otherwise indicated.
3. The shales indicated represent the major deposit layer(s) encountered in the drillholes. The gradient of the sides is approximate; the transition may be gradual.
4. The stratigraphy between drillholes may vary.
6. Total alkalinity data provided by Frontier Geosciences Inc.
7. Drillhole intervals with no color are thin and have minimal to no data available from cuttings or standard penetration test samples; therefore, the deposit type is unknown.
8. Bedrock geology defined by Pebble Partnership geologists.
Figure 6-51
Seismicity of Southern Alaska Showing Distribution of Earthquakes by Depth

Legend
- Active and potentially active faults
- Zone of recorded earthquakes included on SECTION A-A

EARTHQUAKE FOCAL DEPTH
- Depth ≤ 25 miles
- Depth > 25 miles

EARTHQUAKE MAGNITUDE
- 4.0 - 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9
- 8.0 +

Large magnitude earthquakes recorded between 1899 & 1904

Location and direction of view for Geological Sections

Notes
Figure 6.53
Mapped Location of Lake Clark Fault and Direction of Glacial Advance

Legend

- Potentially active fault
- Mine Study Area

Figure shows satellite image of Lake Clark-Iliamna Lake area. Large yellow arrows show principal routes followed by glaciers issuing from Lake Clark through and flowing westward from Cook Inlet into Iliamna Lake basin.
Source: Surficial Geologic Map of the Pebble Limited Partnership's Pebble Project.

Notes
APPENDICES
APPENDIX 6A

Test Pit Investigations Summary, 2004 through 2008
<table>
<thead>
<tr>
<th>Test Pit #</th>
<th>Northing (ft)</th>
<th>Elevation (ft)</th>
<th>Location of Test Pit</th>
<th>Total Depth (ft)</th>
<th>From (ft)</th>
<th>To (ft)</th>
<th>Material</th>
<th>Geomorphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP04-01</td>
<td>2,119,517</td>
<td>1,366,560</td>
<td>South Fork Koktuli River Area</td>
<td>7.9</td>
<td>0.7</td>
<td>7.9</td>
<td>SILT - some sand, some gravel, frequent cobbles.</td>
<td>Colluvium/Till</td>
</tr>
<tr>
<td></td>
<td>1,366,880</td>
<td>824</td>
<td></td>
<td>10.8</td>
<td>0.2</td>
<td>1.1</td>
<td>SAND and GRAVEL - trace silt occasional cobbles.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>1,368,389</td>
<td>212</td>
<td></td>
<td>0.3</td>
<td>0.3</td>
<td>0.8</td>
<td>sandy GRAVEL - trace silt, frequent cobbles.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td></td>
<td>945</td>
<td>61</td>
<td></td>
<td>2.2</td>
<td>0.3</td>
<td>2.5</td>
<td>clayey SILT - some sand, some gravel, occasional cobbles.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>945</td>
<td>61</td>
<td></td>
<td>2.2</td>
<td>0.3</td>
<td>2.5</td>
<td>clayey, gravelly SAND - trace silt, occasional cobbles.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td></td>
<td>974</td>
<td>61</td>
<td></td>
<td>2.5</td>
<td>0.3</td>
<td>2.8</td>
<td>PEAT - some silt, some sand, trace clay.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>840</td>
<td>61</td>
<td></td>
<td>2.8</td>
<td>0.2</td>
<td>3.0</td>
<td>silty SAND - some gravel, frequent cobbles.</td>
<td>Glaciofluvial</td>
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<tr>
<td></td>
<td>2,119,805</td>
<td>1,366,349</td>
<td>South Fork Koktuli River Area</td>
<td>8.2</td>
<td>0.2</td>
<td>8.4</td>
<td>PEAT - some silt, some sand, some gravel.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>945</td>
<td>61</td>
<td></td>
<td>2.8</td>
<td>0.3</td>
<td>3.1</td>
<td>SAND and GRAVEL - some silt, occasional cobbles.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td></td>
<td>1,369,204</td>
<td>753</td>
<td>South Fork Koktuli River Area</td>
<td>10.5</td>
<td>1.2</td>
<td>11.6</td>
<td>8.9 - some sand, some gravel, trace clay.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>1,381,960</td>
<td>896</td>
<td>South Fork Koktuli River Area</td>
<td>11.6</td>
<td>1.2</td>
<td>12.8</td>
<td>6.5 - some sand, trace gravel.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>1,383,670</td>
<td>833</td>
<td>South Fork Koktuli River Area</td>
<td>12.8</td>
<td>2.0</td>
<td>14.8</td>
<td>SAND and GRAVEL - occasional cobbles.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>906</td>
<td>61</td>
<td>South Fork Koktuli River Area</td>
<td>14.8</td>
<td>3.0</td>
<td>17.8</td>
<td>9.5 - some clay, trace gravel.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>2,124,325</td>
<td>1,383,320</td>
<td>South Fork Koktuli River Area</td>
<td>17.8</td>
<td>3.0</td>
<td>20.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>945</td>
<td>61</td>
<td>South Fork Koktuli River Area</td>
<td>20.8</td>
<td>3.0</td>
<td>23.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>2,122,382</td>
<td>1,383,930</td>
<td>South Fork Koktuli River Area</td>
<td>23.8</td>
<td>3.0</td>
<td>26.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>906</td>
<td>61</td>
<td>South Fork Koktuli River Area</td>
<td>26.8</td>
<td>3.0</td>
<td>29.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
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<tr>
<td></td>
<td>2,122,133</td>
<td>1,390,523</td>
<td>South Fork Koktuli River Area</td>
<td>29.8</td>
<td>3.0</td>
<td>32.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>945</td>
<td>61</td>
<td>South Fork Koktuli River Area</td>
<td>32.8</td>
<td>3.0</td>
<td>35.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>2,123,882</td>
<td>1,390,930</td>
<td>South Fork Koktuli River Area</td>
<td>35.8</td>
<td>3.0</td>
<td>38.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>906</td>
<td>61</td>
<td>South Fork Koktuli River Area</td>
<td>38.8</td>
<td>3.0</td>
<td>41.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>2,122,133</td>
<td>1,390,523</td>
<td>South Fork Koktuli River Area</td>
<td>41.8</td>
<td>3.0</td>
<td>44.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
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<td>945</td>
<td>61</td>
<td>South Fork Koktuli River Area</td>
<td>44.8</td>
<td>3.0</td>
<td>47.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>2,123,882</td>
<td>1,390,930</td>
<td>South Fork Koktuli River Area</td>
<td>47.8</td>
<td>3.0</td>
<td>50.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>906</td>
<td>61</td>
<td>South Fork Koktuli River Area</td>
<td>50.8</td>
<td>3.0</td>
<td>53.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
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<td>2,122,133</td>
<td>1,390,523</td>
<td>South Fork Koktuli River Area</td>
<td>53.8</td>
<td>3.0</td>
<td>56.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td></td>
<td>945</td>
<td>61</td>
<td>South Fork Koktuli River Area</td>
<td>56.8</td>
<td>3.0</td>
<td>59.8</td>
<td>9.5 - some clay, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
</tbody>
</table>

**Geotechnical and Seismic Study - Bristol Bay Drainages**
<table>
<thead>
<tr>
<th>Test Pit #</th>
<th>Northing (ft)</th>
<th>Easting (ft)</th>
<th>Elevation (ft)</th>
<th>Location of Test Pit</th>
<th>Total Depth (ft)</th>
<th>From (ft)</th>
<th>To (ft)</th>
<th>Material</th>
<th>Geomorphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP04-29</td>
<td>2,137,590</td>
<td>1,388,330</td>
<td>1.132</td>
<td>Area A, Southern Upland Area</td>
<td>7.9</td>
<td>1.1</td>
<td>7.9</td>
<td>GRAVEL - some sand, trace silt, well graded, angular particles.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-30</td>
<td>2,133,658</td>
<td>1,403,932</td>
<td>1.096</td>
<td>Area A, Southern Upland Area</td>
<td>8.2</td>
<td>2.0</td>
<td>4.9</td>
<td>SILT and SAND - trace gravel, trace clay.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td>TP04-31</td>
<td>2,134,661</td>
<td>1,399,782</td>
<td>0.988</td>
<td>Area J</td>
<td>8.9</td>
<td>0.7</td>
<td>8.9</td>
<td>SANDY GRAVEL - some silt, occasional cobbles, well graded.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td>TP04-32</td>
<td>2,135,064</td>
<td>1,388,905</td>
<td>1.106</td>
<td>Area J</td>
<td>9.2</td>
<td>2.0</td>
<td>7.2</td>
<td>SILT and SAND - trace gravel, poorly graded.</td>
<td>Colluvium</td>
</tr>
<tr>
<td>TP04-33</td>
<td>2,130,059</td>
<td>1,400,958</td>
<td>1.070</td>
<td>South Fork Koktuli River Area</td>
<td>9.8</td>
<td>1.3</td>
<td>9.8</td>
<td>SAND - trace silt, trace gravel, well graded.</td>
<td>Outwash/Glaciofluvial</td>
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<td>TP04-34</td>
<td>2,134,276</td>
<td>1,405,091</td>
<td>0.959</td>
<td>Area A, Southern Upland Area</td>
<td>8.2</td>
<td>0.2</td>
<td>8.2</td>
<td>SAND and GRAVEL - some silt, angular particles.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-35</td>
<td>2,135,319</td>
<td>1,374,771</td>
<td>1.032</td>
<td>Area L</td>
<td>8.2</td>
<td>1.6</td>
<td>9.8</td>
<td>GRAVEL - some clay, some silt, occasional cobbles.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td>TP04-36</td>
<td>2,135,349</td>
<td>1,379,264</td>
<td>1.066</td>
<td>Area L</td>
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<td>2.3</td>
<td>8.5</td>
<td>SAND - some gravel, some silt, trace clay.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td>TP04-37</td>
<td>2,168,502</td>
<td>1,402,576</td>
<td>1.358</td>
<td>Upper Talarik Creek Area</td>
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<td>1.6</td>
<td>9.8</td>
<td>GRAVEL and SAND - some silt, well graded.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td>TP04-38</td>
<td>2,172,154</td>
<td>1,407,266</td>
<td>1.184</td>
<td>Upper Talarik Creek Area</td>
<td>8.9</td>
<td>4.3</td>
<td>9.2</td>
<td>SAND - some gravel, trace clay.</td>
<td>Outwash</td>
</tr>
<tr>
<td>TP04-39</td>
<td>2,172,841</td>
<td>1,409,447</td>
<td>1.198</td>
<td>Upper Talarik Creek Area</td>
<td>7.2</td>
<td>0.3</td>
<td>7.2</td>
<td>SAND and GRAVEL - some clay, trace silt, well graded.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td>TP04-40</td>
<td>2,169,863</td>
<td>1,404,682</td>
<td>1.102</td>
<td>Upper Talarik Creek Area</td>
<td>8.5</td>
<td>1.6</td>
<td>8.5</td>
<td>GRAVEL, trace silt, occasional cobbles.</td>
<td>Outwash</td>
</tr>
<tr>
<td>TP04-41</td>
<td>2,170,256</td>
<td>1,399,503</td>
<td>1.463</td>
<td>Upper Talarik Creek Area</td>
<td>9.2</td>
<td>1.3</td>
<td>9.2</td>
<td>SAND and GRAVEL - some silt, trace clay, occasional cobbles.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-42</td>
<td>2,168,374</td>
<td>1,395,920</td>
<td>1.319</td>
<td>Area E</td>
<td>9.2</td>
<td>1.3</td>
<td>9.2</td>
<td>SAND - some silt, trace gravel, well graded.</td>
<td>Glaciofluvial/Drift</td>
</tr>
<tr>
<td>TP04-43</td>
<td>2,165,906</td>
<td>1,385,899</td>
<td>1.463</td>
<td>Area E</td>
<td>9.2</td>
<td>1.6</td>
<td>9.2</td>
<td>SAND and GRAVEL - some silt, coarsening with depth.</td>
<td>Outwash</td>
</tr>
<tr>
<td>TP04-44</td>
<td>2,170,881</td>
<td>1,395,573</td>
<td>1.188</td>
<td>North Fork Koktuli River Area</td>
<td>8.5</td>
<td>0.2</td>
<td>3.0</td>
<td>SAND - trace silt, trace gravel, well graded.</td>
<td>Glaciofluvial/Lacustrine</td>
</tr>
<tr>
<td>TP04-45</td>
<td>2,172,585</td>
<td>1,384,620</td>
<td>1.145</td>
<td>North Fork Koktuli River Area</td>
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<td>0.3</td>
<td>7.9</td>
<td>SAND - some silt, trace gravel, poorly graded.</td>
<td>Outwash</td>
</tr>
<tr>
<td>TP04-46</td>
<td>2,163,989</td>
<td>1,387,095</td>
<td>1.319</td>
<td>Area E</td>
<td>7.9</td>
<td>1.6</td>
<td>7.9</td>
<td>SAND - medium grained, some gravel, poorly graded.</td>
<td>Outwash</td>
</tr>
<tr>
<td>TP04-47</td>
<td>2,169,371</td>
<td>1,388,419</td>
<td>1.119</td>
<td>North Fork Koktuli River Area</td>
<td>7.9</td>
<td>0.3</td>
<td>0.6</td>
<td>SAND and GRAVEL - well graded</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-48</td>
<td>2,173,502</td>
<td>1,407,455</td>
<td>1.227</td>
<td>Area A, Southern Upland Area</td>
<td>7.9</td>
<td>0.3</td>
<td>7.2</td>
<td>SANDY GRAVEL - trace clay, well graded.</td>
<td>Glacial Drift/Till</td>
</tr>
<tr>
<td>TP04-49</td>
<td>2,121,260</td>
<td>1,397,864</td>
<td>0.925</td>
<td>South Fork Koktuli River Area</td>
<td>8.2</td>
<td>0.6</td>
<td>0.3</td>
<td>SANDY SAND and GRAVEL - some cobbles.</td>
<td>Outwash/Glacial Drift</td>
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<tr>
<td>TP04-50</td>
<td>2,126,340</td>
<td>1,401,778</td>
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<td>GRAVEL - poorly graded.</td>
<td>Glacial Drift/Till</td>
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<td>TP04-51</td>
<td>2,128,786</td>
<td>1,401,004</td>
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<td>SAND - some gravel, trace silt.</td>
<td>Glacial Drift</td>
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<td>TP04-52</td>
<td>2,131,634</td>
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<td>7.9</td>
<td>SAND and GRAVEL - some silt, trace clay.</td>
<td>Glaciofluvial</td>
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<tr>
<td>TP04-53</td>
<td>2,132,802</td>
<td>1,408,336</td>
<td>0.919</td>
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<td>7.9</td>
<td>0.3</td>
<td>1.6</td>
<td>SAND - fine grained, some silt, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-54</td>
<td>2,175,384</td>
<td>1,385,610</td>
<td>1.312</td>
<td>North Fork Koktuli River Area</td>
<td>7.9</td>
<td>0.3</td>
<td>0.6</td>
<td>SAND - fine grained, some gravel, some silt, poorly graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-55</td>
<td>2,178,455</td>
<td>1,386,460</td>
<td>1.342</td>
<td>North Fork Koktuli River Area</td>
<td>3.0</td>
<td>0.6</td>
<td>0.6</td>
<td>GRAVEL - trace fines, gravel content decreases with depth.</td>
<td>Abandoned location - water</td>
</tr>
</tbody>
</table>

**Notes:**
- **Colluvium**
- **Outwash/Glacial Drift**
- **Glacial Drift/Till**
- **Glaciofluvial**
- **Bedrock**
<table>
<thead>
<tr>
<th>Test Pit #</th>
<th>Coordinates</th>
<th>Location of Test Pit</th>
<th>Total Depth</th>
<th>From</th>
<th>To</th>
<th>Material</th>
<th>Geomorphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP04-56</td>
<td>21,178,234</td>
<td>1,385,158, 1,339</td>
<td>North Fork Koktuli River Area</td>
<td>7.9</td>
<td>0.3</td>
<td>SAND - medium grained, some gravel, some silt, poorly graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-57</td>
<td>21,181,170</td>
<td>1,387,406, 1,368</td>
<td>North Fork Koktuli River Area</td>
<td>6.9</td>
<td>0.3</td>
<td>SAND - medium grained, some gravel, poorly graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-58</td>
<td>21,163,561</td>
<td>1,363,328, 1,312</td>
<td>Area G</td>
<td>7.9</td>
<td>0.3</td>
<td>SAND - medium grained, some silt, poorly graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-59</td>
<td>21,162,206</td>
<td>1,385,592, 1,430</td>
<td>Area G</td>
<td>7.9</td>
<td>0.5</td>
<td>SAND and GRAVEL - fine grained, poorly graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-60</td>
<td>21,164,853</td>
<td>1,360,814, 1,378</td>
<td>Area G</td>
<td>7.9</td>
<td>0.3</td>
<td>GRAVEL - some silt, some sand, well graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-61</td>
<td>21,151,177</td>
<td>1,371,202, 1,700</td>
<td>Area G</td>
<td>5.2</td>
<td>1.3</td>
<td>sandy GRAVEL - trace silt, well graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-62</td>
<td>21,150,814</td>
<td>1,373,019, 1,549</td>
<td>Area G</td>
<td>7.2</td>
<td>0.5</td>
<td>SAND and GRAVEL - some silt, frequent cobbles, well graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-63</td>
<td>21,164,043</td>
<td>1,370,247, 1,826</td>
<td>Area G</td>
<td>5.9</td>
<td>1.3</td>
<td>SAND - medium grained, some gravel, poorly graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-64</td>
<td>21,150,389</td>
<td>1,375,132, 1,585</td>
<td>Area G</td>
<td>8.9</td>
<td>2.3</td>
<td>SAND - some silt, well graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-65</td>
<td>21,160,860</td>
<td>1,385,876, 1,795</td>
<td>Area G</td>
<td>5.6</td>
<td>0.3</td>
<td>SAND - some gravel, well graded becoming poorly graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-66</td>
<td>21,147,858</td>
<td>1,369,837, 1,795</td>
<td>Area L</td>
<td>7.9</td>
<td>0.5</td>
<td>SAND - some gravel, trace silt.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-67</td>
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<td>1,385,705, 1,581</td>
<td>Area E</td>
<td>7.5</td>
<td>1.8</td>
<td>SAND - some gravel, some silt, trace silt, well graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-68</td>
<td>21,161,138</td>
<td>1,357,577, 1,421</td>
<td>Area E</td>
<td>8.2</td>
<td>0.6</td>
<td>SAND - medium to fine grained, some angular gravel.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-69</td>
<td>21,160,521</td>
<td>1,397,157, 1,430</td>
<td>Area E</td>
<td>7.9</td>
<td>0.3</td>
<td>GRAVEL - clean, poorly graded, rounded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-70</td>
<td>21,159,565</td>
<td>1,396,393, 1,485</td>
<td>Area E</td>
<td>7.9</td>
<td>0.3</td>
<td>SAND and GRAVEL - trace silt, well graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-71</td>
<td>21,158,549</td>
<td>1,395,077, 1,578</td>
<td>Area E</td>
<td>7.9</td>
<td>0.3</td>
<td>GRAVEL - clean, poorly graded, angular to subrounded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-72</td>
<td>21,160,911</td>
<td>1,395,593, 1,509</td>
<td>Area E</td>
<td>7.9</td>
<td>0.3</td>
<td>CLAYEY SAND - fine grained, some silt, trace gravel, poorly graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-73</td>
<td>21,155,573</td>
<td>1,395,219, 1,496</td>
<td>Area E</td>
<td>7.9</td>
<td>0.3</td>
<td>SAND - some silt, trace clay.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-74</td>
<td>21,154,872</td>
<td>1,395,080, 1,493</td>
<td>Area E</td>
<td>8.4</td>
<td>0.3</td>
<td>GRAVEL - clean, poorly graded, rounded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-75</td>
<td>21,154,177</td>
<td>1,394,900, 1,424</td>
<td>Area E</td>
<td>8.2</td>
<td>0.3</td>
<td>SAND and GRAVEL - some silt, poorly graded.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-76</td>
<td>21,156,402</td>
<td>1,403,631, 1,014</td>
<td>Mineral Deposit Area</td>
<td>9.5</td>
<td>0.5</td>
<td>sand GRAVEL - some gravel, some silt.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-77</td>
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<td>Mineral Deposit Area</td>
<td>9.2</td>
<td>0.5</td>
<td>sand GRAVEL - trace silt, frequent cobbles.</td>
<td>Glacial Drift</td>
</tr>
<tr>
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<td>9.2</td>
<td>0.5</td>
<td>sand GRAVEL - trace silt, occasional cobbles.</td>
<td>Glacial Drift</td>
</tr>
<tr>
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<td>1,407,006, 1,009</td>
<td>Mineral Deposit Area</td>
<td>6.2</td>
<td>0.3</td>
<td>SAND and GRAVEL - some silt, trace clay, well graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-80</td>
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<td>1,405,084, 1,001</td>
<td>Mineral Deposit Area</td>
<td>9.2</td>
<td>0.2</td>
<td>SAND and GRAVEL - occasional cobbles, well graded.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-81</td>
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<td>Area A, Lower/Mid Side Slopes</td>
<td>7.5</td>
<td>0.3</td>
<td>GRAVEL and SAND - some silt, trace clay, occasional cobbles.</td>
<td>Glaciofluvial</td>
</tr>
<tr>
<td>TP04-82</td>
<td>21,152,347</td>
<td>1,401,081, 1,065</td>
<td>Area A, Lower/Mid Side Slopes</td>
<td>7.9</td>
<td>0.3</td>
<td>GRAVEL and SAND - some silt, isolated cobbles.</td>
<td>Glacial Drift</td>
</tr>
<tr>
<td>TP04-83</td>
<td>21,150,449</td>
<td>1,398,809, 1,188</td>
<td>Area A, Lower/Mid Side Slopes</td>
<td>7.5</td>
<td>0.6</td>
<td>SAND - some gravel, some silt.</td>
<td>Glacial Drift</td>
</tr>
</tbody>
</table>

**Notes:**
- SAND = sand, GRAVEL = gravel, silt = silt.
- Some values may be rounded or truncated for readability.
- Geomorphology includes Glacial Drift, Glaciofluvial, and Glacial alluvial.
<table>
<thead>
<tr>
<th>Test Pit</th>
<th>Northing (ft)</th>
<th>Easting (ft)</th>
<th>Elevation (ft)</th>
<th>Location of Test Pit</th>
<th>Total Depth From (ft)</th>
<th>From (ft) to (ft)</th>
<th>Geomorphology</th>
<th>Material</th>
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<tbody>
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<td>0.3 to 8.5</td>
<td>Recessional/lateral moraine - till</td>
<td>silty, gravelly SAND - some clay, well graded.</td>
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<tr>
<td>TP04-85</td>
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<td>0.3 to 8.5</td>
<td>Colluvial</td>
<td>gravelly SAND - some silt, trace clay, well graded.</td>
</tr>
<tr>
<td>TP04-86</td>
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<td>1,402,040</td>
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<td>6.9</td>
<td>0.4 to 6.5</td>
<td>Alluvial</td>
<td>clayey SILT - trace sand, trace gravel with depth, poorly graded.</td>
</tr>
<tr>
<td>TP04-87</td>
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<td>1,405,487</td>
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<td>1.5 to 8.5</td>
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<td>silty, sandy, silty GRAVEL - trace clay, well graded.</td>
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<tr>
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<td>1.1 to 8.5</td>
<td>Glacial alluvial</td>
<td>silty SAND and GRAVEL - some clay.</td>
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<tr>
<td>TP04-89</td>
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<td>1,403,029</td>
<td>0.966</td>
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<td>2.7 to 8.5</td>
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<tr>
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<td>1,405,077</td>
<td>1.124</td>
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<td>0.6 to 8.8</td>
<td>Glaciolacustrine</td>
<td>silty SAND - some gravel, well graded.</td>
</tr>
<tr>
<td>TP04-91</td>
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<td>1,380,137</td>
<td>0.973</td>
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<td>9.2</td>
<td>2.0 to 8.5</td>
<td>Alluvial till/lateral moraine</td>
<td>silty, gravelly SAND - trace clay, occasional cobble.</td>
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<tr>
<td>TP04-92</td>
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<td>2.6 to 8.8</td>
<td>Glaciolacustrine</td>
<td>gravelly SAND - some silt, trace clay.</td>
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<tr>
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<td>1,382,874</td>
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<td>1.6 to 8.5</td>
<td>Recessional/lateral moraine - till</td>
<td>gravelly, silty SAND - trace clay, occasional cobbles.</td>
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<td>2.0 to 8.5</td>
<td>Glaciolacustrine</td>
<td>gravelly SAND - some silt, trace clay.</td>
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<td>0.2 to 8.5</td>
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<tr>
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<td>0.983</td>
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<td>1.3 to 8.5</td>
<td>Ablation till</td>
<td>silty SAND - fine grained, trace clay, trace gravel.</td>
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<td>0.8 to 7.5</td>
<td>Glacial alluvial</td>
<td>gravelly SAND and SAND - trace silt, occasional cobble.</td>
</tr>
<tr>
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<td>8.8</td>
<td>0.8 to 7.5</td>
<td>Glacial alluvial</td>
<td>GRAVEL and SAND - some silt, fine grained, trace gravel.</td>
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<td>1,374,203</td>
<td>1.118</td>
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<td>0.6 to 7.5</td>
<td>Glacial alluvial</td>
<td>gravelly SAND - some silt, isolated cobble.</td>
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<tr>
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<td>1,377,507</td>
<td>1.380</td>
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<td>9.2</td>
<td>3.6 to 8.5</td>
<td>Glaciolacustrine</td>
<td>silty SAND - some gravel, trace clay, well graded.</td>
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<td>Glacial alluvial</td>
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<td>0.6 to 8.5</td>
<td>Alluvial fan/outwash</td>
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<tr>
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<td>1.5 to 8.5</td>
<td>Ablation till</td>
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<td>1.155</td>
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<td>0.3 to 6.5</td>
<td>Glacial alluvial</td>
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<td>0.8 to 8.5</td>
<td>Ablation till/moraine</td>
<td>silty SAND - some gravel, some silt, occasional cobbles.</td>
</tr>
<tr>
<td>TP05-109</td>
<td>2,132,551</td>
<td>1,387,586</td>
<td>0.948</td>
<td>Area J</td>
<td>5.0</td>
<td>0.0 to 5.0</td>
<td>Glaciofluvial</td>
<td>silty SAND - some silt, trace gravel.</td>
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<td>1,399,795</td>
<td>0.907</td>
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<td>0.0 to 4.5</td>
<td>Ketield Moraine</td>
<td>silty SAND - some gravel, occasional cobbles, well graded.</td>
</tr>
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<td>1,389,669</td>
<td>1.088</td>
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<td>5.0</td>
<td>0.0 to 5.0</td>
<td>Ketield Moraine</td>
<td>silty SAND and SAND - some gravel, occasional cobbles, trace clay, well graded, subrounded to rounded.</td>
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<td>2,133,807</td>
<td>1,404,678</td>
<td>0.953</td>
<td>Area A, Southern Upland Area</td>
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<td>0.5 to 8.5</td>
<td>Outwash Sands and gravels</td>
<td>Silt and SAND - some gravel, occasional cobbles, well graded, subrounded to rounded.</td>
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<td>1,404,700</td>
<td>1.065</td>
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<td>0.0 to 5.0</td>
<td>Moraine</td>
<td>silty SAND - some gravel and cobbles, subrounded to rounded.</td>
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<td>TP05-114</td>
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<td>1,410,972</td>
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<td>Area A, Upper Side Slopes</td>
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<td>Blockfield</td>
<td>gravelly SAND, occasional cobbles, subangular to rounded.</td>
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<td>0.5 to 8.5</td>
<td>Moraine</td>
<td>SAND and GRAVEL - occasional cobbles &amp; boulders, well graded, subrounded to subrounded.</td>
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APPENDIX 6B

Vertical Overburden/Bedrock Drillhole Investigations Summary, 2004 through 2008
### Overburden/Bedrock Geotechnical Drillhole Investigations Summary, 2004 through 2008

#### Alaska State Plane Coordinates

<table>
<thead>
<tr>
<th>Drillhole</th>
<th>Location of Drillhole</th>
<th>Northing</th>
<th>Easting</th>
<th>Elevation</th>
<th>Depth to Bedrock</th>
<th>Depth to Water</th>
<th>Date Measured</th>
<th>Lithocode</th>
<th>Bedrock Type</th>
<th>Average Est. UGF (Mpa)</th>
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<td>1,382,100</td>
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<td>150.0</td>
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<td>Tertiary Andesite</td>
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<td>Depth to Bedrock (ft)</td>
<td>Bedrock Depth (ft) to Water (rising/falling head)</td>
<td>Hydrologic Conductivity (μS/cm)</td>
<td>Stipple (μS/cm)</td>
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3 of 13
### Geological and Seismic Study-Bristol Bay Drainages

#### Piezometer Information

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**Note:** Details include drillhole numbers, locations, depths, and geologic information for various areas in the study region, including piezometer information and water quality data.
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**Notes:**
- **No Packer Tests Performed** indicates no tests were conducted at these locations.
- **Dry Well** indicates the well was dry without production.
- **Flowing** indicates the well was flowing with a specified rate.
- **No Take** indicates the test was inconclusive or had low hydraulic conductivity.
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### Hydraulic Conductivity

- **Total Depth (ft)**
- **Depth to Bedrock (ft)**
- **Hydraulic Conductivity (Lugeon)**

### Parameter Information

- **Field Test Results**
- **Drillhole Type**
- **Average RQD**
- **Average Est. UCS**
- **Average Estimated RMUS**

### Bedrock Type

- **Granodiorite**
- **Tertiary Basalt**
- **Tertiary Volcaniclastic Breccia**
- **Teriary Volcaniclastic Breccia**
- **Granodiorite**

<p>| GH08-166 | Area G | 2,159,524 | 1,385,441 | 1,877 | 205 | 196 | 1.53E-06 | GH08-166 | 3.92E-04 | 3.00E-03 |
| GH08-168 | Area G | 2,158,856 | 1,372,567 | 1,848 | 305 | 282 | GH2 to 323 | GH08-168 | 3.92E-04 | 3.00E-03 |
| GH08-150 | Area G | 2,132,584 | 1,309,359 | 1,940 | 460.5 | 224 | GH2 to 488 | GH08-150 | 3.92E-04 | 3.00E-03 |
| GH08-111 | Area L | 2,147,561 | 1,371,064 | 1,945 | 500 | 418 | GH2 to 88 | GH08-111 | 3.92E-04 | 3.00E-03 |
| GH08-111 | Area L | 2,147,241 | 1,370,411 | 1,889 | 100 | 84 | GH2 to 120 | GH08-111 | 3.92E-04 | 3.00E-03 |
| GH08-111 | Area L | 2,147,561 | 1,371,064 | 1,945 | 205 | 185 | GH2 to 150 | GH08-111 | 3.92E-04 | 3.00E-03 |
| GH08-117 | Area L | 2,145,101 | 1,372,058 | 1,984 | 110 | 110 | GH2 to 170 | GH08-117 | 3.92E-04 | 3.00E-03 |
| GH08-115 | Area L | 2,147,147 | 1,373,749 | 1,887 | 145 | 135 | GH2 to 145 | GH08-115 | 3.92E-04 | 3.00E-03 |
| GH08-117 | Area L | 2,146,261 | 1,371,843 | 1,876 | 165 | 154 | GH2 to 110 | GH08-117 | 3.92E-04 | 3.00E-03 |
| GH08-117 | Area L | 2,142,782 | 1,392,383 | 1,946 | 260 | 101 | GH2 to 260 | GH08-117 | 3.92E-04 | 3.00E-03 |</p>
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<th>Elevation (ft)</th>
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<th>Depth to Bedstr (ft)</th>
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<th>Packer Zone To (ft)</th>
<th>Packer Test (Lugos)</th>
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<td>Area J</td>
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<td>40</td>
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<td>Area E</td>
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<td>Elevation</td>
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<td>Depth to Bedrock (ft)</td>
<td>Total Packers</td>
<td>Packer Zone</td>
<td>Location of Hydraulic Conductivity (ft)</td>
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<td>Size</td>
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<td>Area L</td>
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<td>1,373,795</td>
<td>1,387</td>
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<td>54</td>
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<td>1,411,337</td>
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<td>32</td>
<td>54</td>
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<td>1,394,003</td>
<td>1,073</td>
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<td>135</td>
<td>35</td>
<td>54</td>
<td>35</td>
<td>No Packer Tests Performed</td>
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<td>GH08-203B</td>
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<td>PQ3 to 10' H23 to 140' N23 to 230'</td>
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<td>32</td>
<td>54</td>
<td>35</td>
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<td>PQ3 to 20' H23 to 230' 75'</td>
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<tr>
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<td>15</td>
<td>109</td>
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<td>1,392,479</td>
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<td>30</td>
<td>179</td>
<td>205</td>
<td>3.4E-06</td>
<td>2.53</td>
<td>1</td>
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<td>Area A, Upper Side</td>
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<td>1,419,508</td>
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<td>Area A</td>
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<td>1,392,582</td>
<td>1,515</td>
<td>PQ3 to 20' H23 to 300'</td>
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<td>78</td>
<td>80</td>
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<td>1,429,263</td>
<td>1,256</td>
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<td>63</td>
<td>94</td>
<td>97</td>
<td>3.8E-04</td>
<td>3.18</td>
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### GEOTECHNICAL AND SEISMIC STUDY—BRISTOL BAY DRAINAGES

#### Alaska State Plane Coordinates**A,B**

<table>
<thead>
<tr>
<th>Drillhole #</th>
<th>Location of Drillhole</th>
<th>Northing (ft)</th>
<th>Easting (ft)</th>
<th>Elevation (ft)</th>
<th>Nominal Hole Size</th>
<th>Total Depth (ft)</th>
<th>Depth to Bedrock (ft)</th>
<th>Packer Zone From (ft) to (ft)</th>
<th>Packer Zone To (ft)</th>
<th>Stickup (in)</th>
<th>Size (cm/s)</th>
<th>Completion Zone From (ft) to (ft)</th>
<th>Packer Test (Lugon)F</th>
<th>Date Measured</th>
<th>UCS (Mpa)</th>
<th>RMR89D,J</th>
<th>UCS and RMR is for all of the bedrock per drillhole, the values have not been separated out for different rock types.</th>
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<tr>
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<td>Area A, Lower Side Slopes</td>
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<td>1,096</td>
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<td>116</td>
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<td>110</td>
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<td>1.30E-04</td>
<td>12-Oct-08</td>
<td>1.30E-04</td>
<td>12-Oct-08</td>
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<td>102</td>
<td>1.30E-04</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Notes:**

B. Coordinates surveyed by PLP personnel.
C. Lithocodes were determined by PLP.
D. RMR89 = Rock Mass Rating Classification System (Bromsweig, 1989).
E. Unsaturated compressive strength (UCS) values were estimated in the field.
F. Packer hydraulic conductivity tests (Lugon Method) were conducted in the bedrock and Rising/Falling Head Tests (Hydromet Method) were conducted in either the bedrock or overburden depending on the location of the completion zone of the piezometer.
G. Static water levels can vary dramatically seasonally.
H. All depth measurements are with respect to ground surface level, including water level measurements.

1. Artesian flow is defined as sustained water flow >150 gpm. A gpm is 1 gpm = 0.151 liters/sec.
2. Average UCS, UCS and RMR is for all of the bedrock per drillhole, the values have not been separated out for different rock types.
APPENDIX 6C

Oriented Geotechnical Drillhole Investigation Summary, 2004 through 2008
### Pebble Deposit Area Oriented Geotechnical Drillhole Investigation Summary, 2004 through 2008

<table>
<thead>
<tr>
<th>Year Drilled</th>
<th>KP/SRK Nomenclature</th>
<th>Northing (ft)</th>
<th>Easting (ft)</th>
<th>Collar Elevation (ft)</th>
<th>Azimuth (°)</th>
<th>Inclination (°)</th>
<th>Total Depth (ft)</th>
<th>Lithocode</th>
<th>Bedrock Types Encountered</th>
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<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Coordinates

- **Year Drilled**: The year the drillhole was drilled.
- **KP/SRK Nomenclature**: The identifier for the drillhole.
- **Drillhole No. (NDM/PLP Nomenclature)**: The drillhole number within the NDM/PLP system.
- **Northing (ft)**: The northing coordinate in feet.
- **Easting (ft)**: The easting coordinate in feet.
- **Collar Elevation (ft)**: The elevation of the collar in feet.
- **Azimuth (°)**: The azimuth angle of the drillhole.
- **Inclination (°)**: The inclination angle of the drillhole.
- **Total Depth (ft)**: The total depth of the drillhole.
- **Lithocode**: The code representing the lithology encountered.
- **Bedrock Types Encountered**: The types of bedrock encountered.

### Examples of Bedrock Types Encountered

- **Tertiary Sediments**
- **Tertiary Basalt**
- **Granodiorite**
- **Diorite**
- **Quartz Monzodiorite**
- **Fault Breccia**

### Notes

- The coordinates provided are in feet.
- The azimuth and inclination are measured in degrees.
- The total depth is measured in feet.
- The lithocode is used to identify the specific lithological units encountered.

---

**APPENDIX 6C**

GEOTECHNICAL AND SEISMIC STUDY-BRISTOL BAY DRAINAGES

---

1 of 2
<table>
<thead>
<tr>
<th>Year Drilled</th>
<th>KP/SRK Nomenclature</th>
<th>Drillhole No. (NDM/PLP Nomenclature)</th>
<th>Coordinates</th>
<th>Azimuth (°)</th>
<th>Inclination (°)</th>
<th>Total Depth (ft)</th>
<th>Lithocode</th>
<th>Bedrock Types Encountered</th>
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<td>848</td>
<td>240</td>
<td>5,091</td>
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<td>321</td>
<td>75</td>
<td>4,489</td>
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Notes:  
1. NAD 83, Alaska State Planes, Zone 5.  
2. All depth measurements are downhole.  
3. Lithocodes were determined by NDM/Pebble Partnership.  
APPENDIX 6D

Rock Mass Rating Classification System
## Rock Mass Rating Classification System

### Intact Rock Strength

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<th>UCS (MPa)</th>
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<td>4</td>
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<tr>
<td>8</td>
<td>200</td>
<td>many blows by hammer to break</td>
<td>14</td>
<td>4</td>
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<td>6.5</td>
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<td>single blow</td>
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### RQD

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### Joint Spacing (Js)

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### Joint Condition

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<tr>
<td>&gt; 20</td>
<td>1</td>
<td>1</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Aperture (millimeters)</th>
<th>VALUE</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>&lt; 0.1</td>
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<tr>
<td>0.1-1.0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1-5</td>
<td>3</td>
<td>3</td>
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<tr>
<td>5-10</td>
<td>2</td>
<td>3</td>
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<table>
<thead>
<tr>
<th>Roughness</th>
<th>VALUE</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>V Rough</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Rough</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>SL Rough</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Smooth</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Slicks</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infilling (millimeters)</th>
<th>VALUE</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Hard Infilling</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Soft Infilling</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weathering</th>
<th>VALUE</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRESH</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>SW</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>MW</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>HW</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CW</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Groundwater Condition

<table>
<thead>
<tr>
<th>Inflow (l/min/10m)</th>
<th>General</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Wet</td>
<td>10-25</td>
<td>7</td>
</tr>
<tr>
<td>Dripping</td>
<td>25-125</td>
<td>4</td>
</tr>
<tr>
<td>Flowing</td>
<td>&gt; 125</td>
<td>0</td>
</tr>
</tbody>
</table>

### DIP OF ADVERSE JOINT SET

<table>
<thead>
<tr>
<th>Strike Perpendicular to Tunnel Axis Drive with Dip</th>
<th>Unfavorable</th>
<th>Favorable</th>
<th>Very Favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>-10</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>-10</td>
<td>-10</td>
<td>-5</td>
<td>-12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strike Perpendicular to Tunnel Axis Drive against Dip</th>
<th>Unfavorable</th>
<th>Favorable</th>
<th>Very Favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfavorable</td>
<td>-10</td>
<td>-5</td>
<td>-12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strike Parallel to Tunnel</th>
<th>Unfavorable</th>
<th>Favorable</th>
<th>Very Favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfavorable</td>
<td>-10</td>
<td>-5</td>
<td>-12</td>
</tr>
</tbody>
</table>

### Notes:
- **ROCK MASS RATING**
  - 80 - 100: GOOD
  - 60 - 80: FAIR
  - 40 - 60: POOR
  - 20 - 40: VERY POOR
- **RMR CLASS**
  - I = Intact Rock
  - II = Jointed Rock
  - III = Fractured Rock
  - IV = Discontinuous Rock
  - V = Totally Disconnected Rock
- **DESCRIPTION**
  - VERY GOOD
  - GOOD
  - FAIR
  - POOR
  - VERY POOR
- **Inflow (l/min/10m)**
  - 0-20
  - 20-45
  - 45-90
- **Adjustment for Joint Orientation**
  - Strike Perpendicular to Tunnel Axis Drive with Dip
  - Strike Perpendicular to Tunnel Axis Drive against Dip
  - Strike Parallel to Tunnel
- **Notes:**
  - UCS = unconfined compressive strength
  - PLST = point load strength test
  - RQD = rock quality designation
### Rock Mass Rating Classification System

#### Intact Rock Strength

<table>
<thead>
<tr>
<th>PLST (MPa)</th>
<th>10</th>
<th>8</th>
<th>6.5</th>
<th>5.5</th>
<th>5</th>
<th>4.5</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>&lt; 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCS (MPa)</td>
<td>250</td>
<td>200</td>
<td>160</td>
<td>140</td>
<td>125</td>
<td>110</td>
<td>75</td>
<td>50</td>
<td>25</td>
<td>&lt; 25</td>
</tr>
</tbody>
</table>

**Field Est.**
- chipped by hammer
- many blows by hammer to break
- single blow
- pocket knife

**RATING**
- 15
- 14
- 13
- 12
- 11
- 10
- 8
- 6
- 4
- 3
- < 3

#### Joint Spacing (Js)

<table>
<thead>
<tr>
<th>Js (centimeters)</th>
<th>&gt; 200</th>
<th>160</th>
<th>130</th>
<th>90</th>
<th>60</th>
<th>40</th>
<th>20</th>
<th>15</th>
<th>10</th>
<th>&lt; 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>RATING</td>
<td>20</td>
<td>18</td>
<td>16</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

#### Joint Condition

<table>
<thead>
<tr>
<th>Persistence (meters)</th>
<th>&lt; 1</th>
<th>1-3</th>
<th>3-10</th>
<th>10-20</th>
<th>&gt; 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>RATING</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aperture (millimeters)</th>
<th>None</th>
<th>&lt;0.1</th>
<th>0.1-1.0</th>
<th>1-5</th>
<th>5-10</th>
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<tbody>
<tr>
<td>RATING</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Roughness</th>
<th>V Rough</th>
<th>Rough</th>
<th>SL Rough</th>
<th>Smooth</th>
<th>Slicks</th>
</tr>
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<tbody>
<tr>
<td>RATING</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infilling (millimeters)</th>
<th>None</th>
<th>Hard Infilling</th>
<th>Soft Infilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>RATING</td>
<td>6</td>
<td>&lt; 5</td>
<td>&gt; 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weathering</th>
<th>Fresh</th>
<th>SW</th>
<th>MW</th>
<th>HW</th>
<th>CW</th>
</tr>
</thead>
<tbody>
<tr>
<td>RATING</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Groundwater Condition

<table>
<thead>
<tr>
<th>Inflow (l/min/10m)</th>
<th>None</th>
<th>&lt; 10</th>
<th>10-25</th>
<th>25-125</th>
<th>&gt; 125</th>
</tr>
</thead>
<tbody>
<tr>
<td>General RATING</td>
<td>15</td>
<td>10</td>
<td>7</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

#### DIP OF ADVERSE JOINT SET

<table>
<thead>
<tr>
<th>Joint Condition</th>
<th>Unfavorable</th>
<th>Favorable</th>
<th>Very Favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>Favorable</td>
<td>Very Favorable</td>
<td></td>
</tr>
<tr>
<td>20-45</td>
<td>-10</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>45-90</td>
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<td>-5</td>
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#### Notes:
- **ROCK MASS RATING**
  - 80 - 100: VERY GOOD
  - 60 - 80: GOOD
  - 40 - 60: FAIR
  - 20 - 40: POOR
  - 0 - 20: VERY POOR
- **RMR CLASS**
  - I: Completely weathered
  - II: Moderately weathered
  - III: Moderately weathered
  - IV: Moderately weathered
  - V: Highly weathered
- **PLST** = point load strength test
- **UCS** = unconfined compressive strength
- **RQD** = rock quality designation
- **Notes:**
  - 0-20: Dripping
  - 20-45: Flowing
  - 45-90: Very Favorable