Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Geology and Soils Characterization Study
Study Plan Section 4.5

2014-2015 Study Implementation Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

MWH

October 2015

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LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

Abbreviation	Definition
AEA	Alaska Energy Authority
AEC	Alaska Earthquake Information Center
ANCSA	Alaska Native Claims Settlement Act
ARD	Acid Rock Drainage
CFR	Code of Federal Regulations
DEM	Digital Elevation Model
FEA	Finite Element Analysis
FERC	Federal Energy Regulatory Commission
ILP	Integrated Licensing Process
IMASW	Interferometric Multichannel Analysis of Surface Waves
ISR	Initial Study Report
Ka	kiloannus (thousand years)
Km	Kilometer
LiDAR	Light Detection and Ranging
M	Magnitude
Ma	Megaannus (million years)
Mi	mile
OSL	Optically Stimulated Luminescence
PMF	Probably Maximum Flood
PM&E	Protection, Mitigation, and Enhancement
PSHA	Probabilistic Seismic Hazard Assessment
RCC	Roller-Compacted Concrete
RSP	Revised Study Plan
SCR	Study Plan Completion Report
SPD	Study Plan Determination
Work Plan	Geotechnical Exploration Program Work Plan

1. INTRODUCTION

On December 14, 2012, Alaska Energy Authority (AEA) filed with the Federal Energy Regulatory Commission (FERC or Commission) its Revised Study Plan (RSP) for the Susitna-Watana Hydroelectric Project (FERC Project No. 14241), which included 58 individual study plans (AEA 2012). Included within the RSP was the Geology and Soils Characterization Study, Section 4.5. RSP Section 4.5 focuses on the methods for evaluating the geology and soils and defining the existing geological conditions at the dam site, reservoir, and access road and transmission line corridors. This is necessary for developing design criteria to ensure that the proposed Project facilities and structures will be safe and adequate to fulfill their stated functions. RSP 4.5 provided goals, objectives, and proposed methods for data collection regarding this study.

On February 1, 2013, FERC staff issued its study determination (February 1 SPD) for 44 of the 58 studies, approving 31 studies as filed and 13 with modifications. RSP Section 4.5 was one of the 31 study plans approved with no modifications.

Following the first study season, FERC's regulations for the Integrated Licensing Process (ILP) require AEA to "prepare and file with the Commission an initial study report describing its overall progress in implementing the study plan and schedule and the data collected, including an explanation of any variance from the study plan and schedule" (18 CFR 5.15(c)(1)). This Geology and Soils Characterization Study Initial Study Report (ISR) was prepared in accordance with FERC's ILP regulations and details AEA's status in implementing the study, as set forth in the FERC-approved RSP as approved by FERC's February 1 SPD (referred to herein as the "Study Plan").

Since filing the ISR in June 2014, AEA has continued to implement the FERC approved Study Plan for the Geology and Soils Characterization Study. The various tasks undertaken since June 2014 include:

- Drilling in situ testing and instrumentation installation: two borings, cross-holes beneath the Susitna River and two inclined borings on the lower right abutment at the dam site;
- Laboratory testing of rock samples;
- Geotechnical instrumentation monitoring at sites at the dam site;
- Dam site geologic mapping and fault rupture evaluation;
- Seismic Network Monitoring of earthquake activity in the Project area; and
- Crustal Seismic Source Evaluation.

In furtherance of the next round of ISR meetings and FERCs Study Plan Determination (SPD) expected in 2016, this report describes AEA's overall progress in implementing the Geologic and Soils Characterization Study during calendar year 2014 and early 2015. Rather than a comprehensive reporting of all field work, data collection, and data analysis since the beginning of AEA's study program, this report is intended to supplement and update the information presented in Part A of the ISR for the Geologic and Soils Characterization Study through the early 2015. It describes the methods and results of the primarily 2014 effort, and includes a discussion of the results achieved.

2. STUDY OBJECTIVES

The overall goals of this study are to conduct a geology and soils evaluation to define the existing geological conditions and resources at the dam site, reservoir, and access and transmission line corridors; to develop designs and criteria to support the engineering feasibility studies; and to provide baseline spatial data to the geomorphology, paleontological, cultural and botanical resources and the probable maximum flood (PMF) and site-specific seismic hazard studies. The study objectives are established in RSP Section 4.5.1 as follows:

- Identify the existing soil and geology at the proposed construction site, reservoir area, and access road and transmission line corridors.
- Determine the potential effects of Project construction, operation, and maintenance activities on the geology and soil resources (including mineral resources) in the Project area including identification and potential applicability of protection, mitigation, and enhancement (PM&E) measures.
- Identify known mineral resources and mineral potential of the Project area.
- Acquire soils and geologic information for the Project area for use in the preparation of a supporting design report that demonstrates that the proposed structures are safe and adequate to fulfill their stated functions.

The field investigation activities for each season will be coordinated with resource agencies and Alaska Native Claims Settlement Act (ANCSA) Corporation landowners. A Geotechnical Exploration Program Work Plan (Work Plan) will be developed that outlines the field programs and information needed for submitting applications and obtaining land access permits from applicable agencies and ANCSA Corporation landowners (MWH 2011; MWH 2012; MWH 2013c). The Work Plans identify field investigations and studies to be carried out to assess potential impacts to geology and soil resources in the Project area, including the dam, reservoir, and access road and transmission line corridors, and the general arrangement and foundation conditions for the dam and appurtenance structures. FERC regulations require "evaluation of unconsolidated deposits, and mineral resources at the project site" (18 CFR 5.6(d)(3)(ii)(A)). For the Exhibit E, AEA must provide a report on the geological and soil resources in the proposed Project area and other lands that would be directly or indirectly affected by the proposed action and the impacts of the proposed Project on those resources. This study report provides the basis of the information needed for the Exhibit E.

3. STUDY AREA

As established by RSP Section 4.5.3, the study area includes the dam site area, reservoir area, construction material sources, tailwater downstream of the dam, access road and transmission line corridors, airport facilities, and construction camp and permanent village sites.

As described in the ISR Overview (Section 1.4) filed in June 2014 and subsequently the *Proposal to Eliminate the Chulitna Corridor from Further Study* filed with FERC September 17, 2014, AEA explained that it had decided to pursue the study of an additional alternative north/south-oriented corridor alignment for transmission and access from the proposed dam site to the Denali Highway, referred to as the "Denali East Corridor Option," and to eliminate the Chulitna Corridor from further study

4. METHODS AND VARIANCES IN 2014

AEA implemented the methods as described in the approved Study Plan. Study methods implemented along with discussion of the timing and staging of study efforts are described in the following sections organized by the following study components:

- Review of Project Documentation
- Regional Geologic Analysis and Minerals Resources Assessment
- Geologic and Geotechnical Investigation and Testing Program Development
- Field Geologic and Geotechnical Investigations
- Reservoir-Triggered Seismicity
- Reservoir Slope Stability Study
- Geology and Engineering Analysis

4.1. Review of Project Documentation

The review of previous data and development of geo-referenced databases was discussed in the 2014 ISR, Section 4.1.1. In development of geologic and seismic characterization and feasibility level interpretations, the data from previous studies were reviewed and were a factor in completing the 2014-2015 technical memoranda and reports. This task was completed.

4.2. Regional Geologic Analysis and Mineral Resources Assessment

Existing regional geologic mapping depicting both the dam site and the general 5 to 10 mile (3.1 to 6.2 km) vicinity were developed by Csejtey et al. (1978), Acres (1982a, 1982b), and Wilson et al. (2009). The existing published maps were produced at a variety of scales, using various methods, level of detail, or purposes. As a consequence, there are inconsistencies in the completeness and accuracy of geologic mapping leading to areas of general disagreement across the maps. The emphasis of most prior mapping exercises in the region was focused on developing a geologic framework and mineral resource evaluations. At the proposed dam site geologic mapping was highly focused but of limited aerial extent.

4.2.1. Regional Geology

Field investigations and geologic studies included regional crustal seismic source evaluation to further the understanding of seismic conditions in the vicinity of the dam site, to evaluate and collect additional field data to update the previous geologic interpretations of the site developed during the 1980s (Acres, 1982b) and completion of a dam site area fault rupture evaluation of the region surrounding the dam site. Additional details regarding the seismic hazard studies were presented in the ISR Section 16. The 2014 geologic field studies identified and inspected a number of exposures to identify rock type, collect structural (strike and dip) information, and to understand distribution and deformation of rocks in the site area and vicinity. Data was collected along an east-west transect along the Susitna River, from near the confluence with Tsusena Creek downstream to near the confluence with Watana Creek upstream, and a north-south transect along Watana Creek. Also in 2014, AEA acquired additional Light Detection and Ranging (LiDAR) imagery coverage south of Fog Creek and for the upper Watana Creek areas to augment the previous LiDAR coverage.

Regional mapping developed by Acres (1982b) was presented at a small scale of 1 inch equal to 1 mile (1:63,360). Due to the methods employed at that time, there are apparent registration inaccuracies and map artifacts. AEA elected to allow the geologic boundaries and units in the map to remain unadjusted, preserving the original mapping scheme and honoring the original map scale. For example, the sedimentary rocks exposed along the Susitna River are generally accepted as part of the Cretaceous sequence of the Kahiltna formation (i.e., Kalbas et al., 2007). These rocks are shown on Acres (1982b) as map unit Kag: Cretaceous argillite; on Wilson's (2009) map these same rocks are shown as map unit Kjf: Jurassic-Cretaceous flysch. The update based on field observations to the regional geologic map maintains the Acres (1982b) classification scheme for clarity purposes to avoid potential confusion with other abbreviations. However, field traverses along the Susitna River and Watana Creek may offer a somewhat limited structural insight because it captures only a one-dimensional traverse characterization of a three-dimensional landscape.

4.2.2. Dam Site Geology

Geologic mapping of rock outcrops at the dam site was performed on the north and south banks (right and left abutments) of the river beginning about 2,000 feet (610m) upstream of the dam axis, near the previously mapped geologic feature GF1; and extended to about 1,500 feet (457m) downstream of the dam near geologic feature GF7. Measurements and observations of the rock type and structure were collected while traversing the slopes on both banks of the river to assess styles and patterns of structural deformation, and describe level of weathering and alteration. Additional traverses were made along geologic features to assess the style and pattern of structural deformation and to evaluate the possible displacement along existing planes of weakness in bedrock.

Navigating and locating the positions of observations was managed using a Trimble GEO7X GPS equipped with ArcGIS preloaded with maps that included topography, slopes angles, geologic maps, etc., to provide a level of accuracy and to better facilitate navigation and interpretations (MWH 2015b). The locations of outcrops (designated as OC1 to OC118), observation points (designated as BS1 to BS35), and geologic structures were recorded in the Trimble and numbered sequentially.

Mapping efforts in the dam site area, combined with information from the concurrent drilling, in situ testing, and geophysical explorations, identified eight geologic features (GF1 to GF8) that were used to update the interpretation of the geologic conditions at the dam site and present a comprehensive geologic model using both previous and recently acquired data.

4.3. Field Geologic and Geotechnical Investigations

A comprehensive geologic and geotechnical exploration and testing program was developed to provide the data necessary for engineering feasibility and for Exhibit E of the license application (MWH 2013c). Therein the Work Plan detailed the planned phased exploration and testing programs to be undertaken. The scope of the 2014 investigation program was abbreviated from the original Work Plan and was focused on geologic characterization in the dam site and nearby area, continuation of geotechnical instrumentation and seismic station network monitoring, and assessment of structural geologic features and potential fault rupture at the dam site, as well as crustal seismic source characterization. The 2014 investigation and testing program consisted of the following:

- Delineate and characterize geology and soil resources including geologic features, rock structure, and weathering/alternation with emphasis in the dam foundation area.
- Undertake physical laboratory testing, as well as petrographic analysis, to characterize the properties of the geology and soils materials.
- Evaluate lineaments and potential fault rupture hazards relative to delineation of faults, level of activity and significance to site-specific ground motion evaluations and safety for the Project.
- Continue seismic monitoring to catalog earthquakes in the Project area to augment stations in the Alaska Earthquake Information Center network to monitor and detect local earthquakes.

4.3.1. Drilling Program

For the 2014 field exploration program, a limited field program was undertaken and focused on evaluating the previously identified geologic features and shear zones (Acres 1982a, 1982b) that had been postulated to be encountered in the dam, powerhouse and spillway foundations.

Four geotechnical borings were carried out to confirm presence of and characterize properties of geologic features beneath the Susitna River and in the abutments at the dam site (Figure 4.3-1). Two of the borings DH14-9 (683 ft.; 208m) and DH14-10 (692 ft.; 211m) were advanced under the Susitna River in opposing directions in a crossing pattern to investigate the presence of a postulated fault or shear zone beneath the river. Borings DH14-11 (230 ft.; 70m) and DH14-12 (175 ft.; 53m) were targeted to intersect northwest-trending geologic features GF4 and GF5 (Acres 1982b) on the lower to middle sections of the right abutment. Rock core drilling methods were employed and each boring was water pressure tested and surveyed using both optical and acoustic downhole televiewers. Laboratory tests were performed on selected core samples to determine the engineering properties of rock materials. Groundwater and ground temperature monitoring instruments were installed in each boring.

Data obtained from the drilling and in situ testing along with the surface geologic mapping was utilized to interpret the geologic and foundation conditions beneath the proposed dam structure.

4.3.2. Groundwater and Ground Temperature

A geotechnical instrumentation monitoring program was developed to improve the understanding of groundwater and ground temperature conditions at the dam site. This program was initiated during the 2011-2012 field seasons. Field crews assessed and rehabilitated selected instrumentation devices originally installed during the 1970s and 1980's. Down hole geotechnical instrumentation was also installed in new boreholes. Many of these instruments were fitted with data logging equipment such that readings could be taken throughout the year. Due to land access restrictions, the data logging equipment was removed from each of the instrumented borings from November 2013 through May 2014.

Two instrumentation monitoring activities were conducted during the 2014 field season. In June 2014, a field visit was conducted to re-establish the data logging equipment removed in November 2013 (Figure 4.3-2). The second field activity conducted in October 2014 was to download data obtained over the 2014 summer season and to perform maintenance on the instrumentation in preparation of collecting data over the following winter season.

4.4. Seismic Hazard Evaluation

During the 2012 and 2013 field seasons, lineament mapping and evaluation were performed in connection with the crustal seismic source evaluation (Fugro 2013). During the 2014 field season lineament mapping and evaluation continued with a focus on potential crustal seismic source evaluations in or near the dam site that had not been previously evaluated. These efforts also included the completion of a fault rupture evaluation in the vicinity of the proposed dam. Additional details regarding these studies ae available in Section 16 of the ISR.

Lineament groups identified in desk-top studies from LiDAR imagery were evaluated in the field to assess the possible genesis of the features. A set of questions and criteria were developed to guide evaluation of each lineament. This assessment was used to eliminate lineaments that showed strong evidence of being non-tectonic in origin or those that would not appreciably contribute to the seismic hazard at the proposed dam site. The potential tectonic lineaments were then assessed based on geomorphological characteristics and geologic relationships

The approach for evaluating surface rupture hazards at the dam site relies on four principal lines of data analyses:

- Geomorphic evaluation of Quaternary and post-glacial faulting (i.e., lineament mapping and analyses) to assess whether potential seismogenic faults are present,
- Field geologic transects to assess styles and patterns of structural deformation near the site,
- Assessment of results of site-specific investigations of geologic structure in the dam foundation, and
- Assessment of contemporary tectonic framework of the site region as an indication of the potential for reactivation of site geologic features.

These evaluations collectively consider regional tectonic history, sub-regional deformation patterns observed in Mesozoic and Cenozoic rocks, emplacement of intrusions and volcanics at the dam site, crustal stress orientations from earthquake focal mechanisms, known active faulting, plate motions, GPS data, geomorphic landform evaluations, and current understanding of geologic features identified at the dam site.

4.5. Long-Term Earthquake Monitoring System

A long-term seismic monitoring system was established in the Project area to monitor and document earthquake events (see RSP Section 16.6). The system was expanded in 2013 and currently consists of seven instrumented locations (WAT-1 through WAT-7) within about 30 miles (48 km) of the dam site, four 6-component strong motion and broadband seismograph station, and three 3-component broadband seismograph stations. At seismic station WAT-1, located at the dam site, a high resolution GPS station has been co-located to track crustal motion relative to the North American Plate. The monitoring system is linked and integrated into the Alaska Seismographic Network operated by the Alaska Earthquake Information Center (AEC) for real-time data acquisition, processing, and analysis.

During the 2014 field season, maintenance was performed on a number of the monitoring stations. The seismic monitoring network continued to detect and provide event data on the earthquakes in the Project area through June 2015, which is being analyzed by AEC. In June 2015, the number of seismograph stations comprising the monitoring network was reduced and restoration of the sites at WAT2, WAT3, WAT4, and WAT5 (AEC 2015, Attachment 9).

4.6. Geologic and Engineering Analyses

Previous geologic and engineering analysis included provided a preliminary understanding of the geology and soil resources in the Project area. Under this study, LiDAR data was acquired in the proposed dam site and reservoir area that was used to identify suitable construction material sources for dam construction, performed a preliminary assessment of the dam foundation and slope stability relative to optimization of the general arrangement and feasibility development. A preliminary assessment of reservoir rim slope stability and reservoir triggered seismicity was conducted along with an initial mineral resources assessment and seismic hazard evaluation for the Project area. Additionally, the collection of instrumentation data is being used to develop an understanding of potential impacts to groundwater and ground temperature (i.e., presence of permafrost), in particular at the dam site and a catalog of earthquake activity in the Project area to define the background microseismicity and the contemporary stress regime.

Since the development of the ISR (2014), geologic studies have been conducted at the dam site to continue geologic mapping observations, to evaluate the previously mapped geologic features, assess the potential fault rupture hazard and/or the potential for reactivation of features within the current tectonic framework. In addition, development of preliminary foundation and seismic design parameters and foundation designs for the finite element analysis (FEA) were completed for the roller-compacted concrete (RCC) dam in support of engineering feasibility studies.

4.7. Variances from Study Plan

There are no variations from the methods in the study plan, however due to schedule delays because of land access restrictions some tasks anticipated to be competed sooner were not able to be fully completed in 2014. Additionally, as noted above the study area also changed due to the modification to the Project areas to include a new access corridor.

4.8. Review of Project Documentation

The existing geologic, geotechnical, and seismic documentation from the 1970s and 1980s which had been brought into geo-referenced, geotechnical databases along with the newly obtained geologic / geotechnical data were used in developing the geologic interpretation currently depicted in the various reports, figures and drawings. A comprehensive presentation of the data has been formulated and is presented in various technical memorandum and reports (MWH 2014, 2015b; Fugro 2015a).

The additional LiDAR digital elevation model (DEM) data obtained south of Fog Creek and in the upper Watana Creek area were utilized to search for geomorphic features that might represent tectonic in origin in the vicinity of the Talkeetna thrust fault or suture.

4.9. Field Geologic and Geotechnical Investigations

The field investigations performed at the dam site under the study plan have included 15 borings and a total of 4708 feet (1435m) of drilling, primarily in bedrock, over three field seasons. In 2014, four borings (DH14-09b, DH14-10, DH14-11, DH14-12) were drilled totaling 1850 lineal feet (564m) (one boring was abandoned as it did not penetrate rock). Continuous rock core samples were collected and rock core sample were tested to determine physical and mechanical properties. In situ testing and downhole logging was performed in each of the borings. Water pressure testing and downhole televiewer surveys were conducted over the rock length in each hole to evaluate in-situ conditions in the rock mass. Water pressure or Lugeon tests were typically performed over a 20 foot long (6.1m) zone however where high RQDs and apparent low rock mass permeability conditions appeared to be present, the test interval was increased to 30 or 50 feet (9m or 15m) in a few instances. Downhole logging was performed in rock in all four (2014) borings utilizing both optical and acoustical televiewers.

Once these activities were completed, each of the borings, were instrumented with vibrating wire piezometers and temperature acquisition cables to obtain data on groundwater levels and ground temperature in the abutments of the proposed dam site. Currently there are 21 boring locations with geotechnical instrumentation, 15 borings from the 2011-2014 investigations and six borings from the earlier 1970s and 1980s investigations, primarily located in the abutments at the dam site. A majority of the instruments are equipped with data loggers for recording daily measurements that were recovered bi-annually or annually. Data was collected from borings continuously after device installation, primarily over the period from 2012 through 2015 - except for a data gap from November 2013 through May 2014, as noted above.

Over fifty core samples and approximately 500 lbs. (227 kg) of bulk samples were tested for determine the engineering properties of the rock foundation and potential concrete aggregate sources (Quarry A, M). Laboratory testing included strength, density, seismic velocity, moduli, and poisson’s ratio tests and petrographic analysis. For the potential aggregate for concrete and RCC mixes, tests included LA abrasion, soundness, freeze-thaw durability and mortar bar tests. The mortar bar tests were conducted to assess the based on a few cementitious mixes.

The results of the geotechnical investigations and laboratory testing are included in the Geotechnical Data Report (MWH 2015a, Attachment 4).

4.10. Dam Site Geology

Geologic mapping efforts were conducted in and around the dam foundation area to verify and advance the understanding of the geology and soil resources, specifically to define and update the understanding of geologic and foundation materials and conditions; identify, characterize, and assess the significance of discontinuities (e.g., joints, fracture zones and shears), including the previously identified “geologic features” on abutment and foundation stability and foundation design. The mapping was also used to identify potential faults and evaluate the potential for surface fault rupture; and to identify and characterize potential aggregate construction material sources. Geologic mapping transects were performed on the north and south banks (right and left abutments) of the Susitna River beginning about 2,000 feet (610m) upstream of the dam axis near geologic feature GF1 and extended to about 1,500 feet (457m) downstream of the dam near GF7.

Data acquisition consisted of obtaining representative measurements at rock outcrops distributed throughout the site up to about Elevation 2300. At each outcrop, rock type, weathering condition, color, strength, block dimensions, geologic relationships (Figure 5.3-2), and an estimate of the GSI were recorded. Additionally, orientations of prominent joint sets were measured, and characterized following ISRM criteria.

The details of the recent data collected and interpretations of the geology and soil resources and conditions at the dam site were presented in the Dam Site Geology Technical Memorandum (MWH 2015b; Attachment 5).

4.10.1. Geologic Conditions

Overburden on the abutments consists primarily of glacial deposits (e.g. till) and colluvium, and talus. The till is primarily found on the upper slopes with talus and colluvium being dominant below about Elevation 1900. Overburden thickness in the dam site area is generally less than 50 ft. (15m) but may reach 70 ft. (21m) or more [Golder 2013 (Attachment 6); MWH 2015b]. Below about Elevation 1900 ft., overburden has an apparent thickness typically between 15 and 20 ft. (4.6m and 6.1m).

Bedrock at the dam site is primarily underlain by Tertiary volcanic intrusions that range in composition from diorite to granodiorite to quartz diorite. Extrusive volcanics, mostly an andesite porphyry, is also present directly downstream of and at higher elevations above the left abutment (> Elevation 2200). The andesite is similar in chemical composition to the diorite, and both rock types are strong to very strong and competent. Bedrock is typically slightly to moderately weathered at the top of rock and along discontinuities to depths of 50 to 80 ft. (15m to 24m). Locally, bedrock has been hydrothermally altered. Where the diorite has been altered, it is often associated with close fracturing or jointing, fracture zones, or shear zones, penetrating the rock mass on either side of the discontinuities (Table 5-1). Hydrothermal alteration to moderate or severe levels causes chemical breakdown of the feldspars and mafic minerals in the host rock. In such instances, the rock can be weak to extremely weak and contain zones of rock completely altered to clay minerals over several inches thick.

Two major joint sets and two minor joint sets were observed in outcrops and in the downhole surveys conducted in the borings (Table 5-2). The dominant joint set trends northwest-southeast (JS1), with joints dipping steeply to the southwest and northeast. The other major joint set (JS2) trends northeast-southwest and is nearly perpendicular to dominant set. Fracture or shear zones tend to parallel the dominant northwest-southeast (JS1) and to a lesser extent to JS3. The two minor joint sets trends north - south and dips steeply to the west and east and a subhorizontal set that dips less than 30˚.

Previously identified “geologic features” (Acres 1982a, 1982b), shear and/or fracture zones greater than 5 feet in width (e.g. GF4B, GF5), were investigated during these studies, several of which cross beneath the proposed dam foundation (Figure 5.3-1). Topographic constraints, along with the findings from geologic mapping and drilling, allowed refinements to be made to the locations, widths and continuity of these fracture zones and shear zones are described as follows:

- GF4B, located on the north abutment, consists of multiple fracture zones, a northwest-southeast zone (parallel to JS1) that intersects a north-northwest trending fracture zone. The individual fracture zones are less than about 10 feet wide (3m) and contain some minor shear zones that are typically less than 12 inches wide (300mm).
- GF5 is comprised of multiple fracture zones with minor shear zones oriented parallel to JS1. The individual fracture zones are 5 to about 10 feet wide (1.5 to 3.0m). Some of the fracture zones contain minor shear zones that are typically less than 12 inches wide.

Although not directly observed at the surface, it appears that the gullies on the right abutment correlated with geologic features GF4B and GF5, likely formed initially by the preferential erosion of weak and relatively narrow fracture zones that have been widened and enhanced to their present dimensions by erosion due to stress relief and freeze thaw processes.

In the immediate vicinity of the dam site, an evaluation was undertaken to assess the potential for fault rupture to occur along seismogenic faults or re-activation of geologic features. Based on this study there is a lack of evidence to support the likelihood of surface fault rupture or re-activation, therefore; the potential for this to occur is considered extremely low given the following:

- The apparent lack of continuity and small scale of structural geologic features at the site (shear zones) upon which surface fault rupture could conceivably take place;
- The dominant northwest-southeast trend is unfavorably oriented with respect to the contemporary tectonic stress regime, as the primary mode of tectonic deformation appear to involve right-lateral strike slip structures with east-northeast strikes;
- The absence of any nearby crustal scale fault structures and any neotectonic or paleoseismic evidence of Quaternary faulting; and,
- The absence of Quaternary faults mapped within about 15 miles of the dam site.

4.10.2. Abutment Stability

Overall the slopes at the dam site are stable. Minor shallow debris flows are evident in the landscape, particularly on the moderately dipping north facing slopes on the upper left abutment where thawing of frozen glacial till overlying bedrock has occurred. Based on the geologic mapping and drilling data obtained to date, overall the slopes at the dam site are stable. Preliminary sliding stability analyses were performed to provide a general assessment of abutment stability. The results of the 2D preliminary geologic analyses indicate that the abutments have acceptable sliding stability under the reservoir loads (MWH 2014).

4.10.3. Groundwater

The groundwater table at the dam site typically follows the shape of the surface topography. Groundwater movement in the subsurface is largely a function of movement through fractures and joints in the rock mass or in some instances along the top of bedrock (MWH 2014). The groundwater conditions are complicated by the presence of frozen ground particularly on the left (south) abutment and in the lower right abutment (see subsection 5.3.4). On the right abutment, the groundwater level is quite variable but is generally found within bedrock except for local areas where artesian conditions were encountered in borings (e.g., DH84-8) (MWH 2015a; Golder 2015). In the lower elevations, below about elevation 1800, table generally is 30 to 160 feet (9m to ≈50m) below the ground surface but may be deeper in places (Figure 5.3-2). On the left abutment, where groundwater levels are influenced by permafrost, groundwater is deep within the abutment, at a depth of about 170 to more than 200 feet (53m to >60m) except for the "perched" water due to thawing of the active layer and the impermeable nature of the frozen ground. Locally, isolated artesian conditions were observed at boring BH-12. Boring DH12-8 which is located just above the river level and was drilled south into the left abutment, the groundwater level approximates the water level in the river. Groundwater levels general indicate seasonal variations of about 10 to 20 feet (3 to 6.1m).

On the upper abutments and the upland plateau above the dam site, groundwater levels appear to be much shallower, ranging from near ground surface to depths as much as 20 feet (6.1m). Where overburden reaches considerable depths and multiple glacial and fluvial stratigraphic units are present, the groundwater regime may be characterized by multiple aquifers (Harza-Ebasco 1983).

The details of the recent data collected and interpretations of the groundwater conditions at the dam site are presented in the in the Dam Site Geology Technical Memorandum (MWH 2015b).

4.10.4. Permafrost

Permafrost distribution in the Project area specifically in the vicinity of the dam site has been characterized as "discontinuous" (50–90 percent) and is considered a warm permafrost, with the lowest ground temperatures recorded being 30°F (-1.5˚C). In the 1980s assessment, and the recent site investigations at the proposed dam site, ground temperature monitoring was performed to characterize the thermal conditions and to determine the extent of perennial frozen ground. The ground temperature instrumentation data obtained at the dam site from borings indicate that temperatures range from 30˚ to 38˚F in the upper 250 feet (76m) below the ground surface and that ground temperature is heavily influenced by slope aspect (i.e., sun angle) and slope angle, as well as geologic material (MWH 2015b). In general, permafrost in the Project area is associated with fine grained soil deposits but can also penetrate bedrock to appreciable depths.

In the abutments of the proposed dam site, perennially frozen ground has been detected beneath north-facing slopes, below Elevation 2100, and locally beneath the lower south-facing slopes, adjacent to the Susitna River. Frozen ground is typically encountered within 10 ft. (3m) of the surface and can extend to depths of approximately 240 ft. (73m), on the south (left) abutment (Figure 5.3-3)(MWH 2015b). On the north (right) abutment, lower in the canyon which is shielded from the sun's radiation by the left abutment, frozen ground may extend to depths as much as 50 ft. (15m) locally.

To the northeast of the proposed dam site, near the upland plateau above the river valley, previous subsurface investigations and ground temperature monitoring of the thick sequence of glacial and fluvial deposits was undertaken of a potential construction material source (Borrow Area D). Numerous borings were completed and visible ice was observed in soil samples collected to depths of up to 110 ft. (34m) in several borings. Periodic ground temperature monitoring in borings revealed that frozen ground may be present locally to 70 ft. and the temperature is very close to 32˚F such that there is not enough latent heat capacity to refreeze after disturbance (Harza-Ebasco 1983).

4.11. Reservoir Area Geology

Data was collected to further define and characterize the geology and soil resources in the reservoir area over that which was reported in the ISR (2014). These studies had included development of a landform based interpretation of the landscape, terrain units, as similar geologic processes tend to result in landforms with similar environmental and geotechnical properties; partial completion of an assessment of the mineral resources; and evaluated mass wasting and erosion potential particularly post-impoundment along the proposed reservoir shoreline (ISR 2014). Through the continuation of field studies, a clearer picture began to develop of igneous and volcanic emplacement and late Quaternary chronology (Fugro 2015b).

4.11.1. Igneous and Volcanic Emplacement

The rocks that make up the dam site were formed by regional magmatism, plutonic intrusions and volcanisms (Figures 5.4-1 and 5.4-2). Multiple ages of early Cenozoic (i.e., Tertiary) volcanics intruded the Kahiltna formation as well as the Wrangellia terrain rocks and the Talkeetna suture zone (Wilson et al, 2009). These volcanic rocks have a complex history as the andesite and diorite vary in texture and composition, have gradational contacts, inclusions of diorite have been observed within the andesite, and felsic dikes cut the diorite but not the andesite, suggesting that the andesite is younger. Field observations and relationships confirm multiple ages of volcanism, intrusion, or flows which intrusions likely occurred between 50 to 60 Ma. With igneous emplacement, there is a possibility that the geologic features and fractures observed at the dam site may be derived from or during the emplacement process and may not necessarily be associated with plate tectonics and thus of tectonic origin (Fugro 2015b).

4.11.2. Late Quaternary Geology and Chronology

Understanding the Quaternary geologic history in the middle and upper Susitna River basin is important to understanding the resultant surficial geologic deposits, geomorphic processes, and the stratigraphic and chronological relationships. During the Quaternary, the entire Project area was covered by glacial ice or glacial lakes as late as about 17 ka, with ice receding and glacial lakes decreasing in size through 12 ka to 11ka. Potential ice fee areas during the later stages of the late Wisconsin advance lies to the east of Watana Creek on both sides of the Susitna River and along the southeastern margin of the Talkeetna Mountains above the limits of Lake Ahtna.

Reconstruction of possible ice profiles suggest that the late glacial maximum ice thickness near the dam site was at least several hundreds of feet as ice caps from both the North and South Talkeetna Mountains coalesced with southwest flowing ice from the Alaska Range, as evidenced by the strongly grooved landscape evident within the middle Susitna basin. As the ice began to recede, contributions from the Alaska Range diminished and the Northern Talkeetna Mountains ice sources became dominant flowing northeast towards Butte and Deadman Lakes. As deglaciation proceeded, ice in the middle Susitna basin at the dam site thinned which is recorded by the large ice-disintegration deposits between Tsusena and Deadman Creeks, north of the Susitna River. Soil samples of this late stage deglaciation were collected in 2014 and from an exposure on the banks of Deadman Creek, 2.5 miles (4 km) northeast of the dam site. Optically Stimulated Luminescence (OSL) dating of this last stage of deglaciation suggests that the Deadman Creek ice lobe must be older than 14 ka to 15 ka. Therefore it is likely that Quaternary surfaces and deposits were formed during the post-late Wisconsin period of the latest Pleistocene precede 15 ka (Fugro 2015b).

4.11.3. Groundwater

Groundwater conditions in the reservoir area are inferred based a general understanding of the characteristics of terrain units found in the area as well as extrapolation of data obtained from the dam site area. Typically, groundwater is located at a shallow depth, less than 20 feet (6.1m) in the more impermeable deposits such as lacustrine, and alluvial fan deposits and very shallow, less than 3 feet (1m) in organic and floodplain deposits. Perched groundwater is often associated with areas where mass wasting processes, solifluction, debris flows and landslides are prevalent.

In fine grained glacial deposits, principally outwash and ablation and basal till, the groundwater table can be shallow to deep (greater than 50 feet; >15m). Coarse grained deposits such as eskers, kames, colluvium and bedrock the groundwater table is often deep.

Bedrock is exposed along much of the lower river valley slopes with colluvium and glacial till and lacustrine deposits predominate in the uplands. Therefore it is assumed that in the lower river valley slopes groundwater is considered to be deep while on the uplands groundwater is shallow (3 to 20 feet; 1 to 6m) to moderately deep (20 to 50 feet; 6 to 15m). With filling of the reservoir, the groundwater conditions will change, raising the groundwater table based on the elevation of the reservoir.

4.11.4. Permafrost

Permafrost distribution in the greater Susitna-Watana proposed reservoir region has been characterized as "discontinuous" (50–90 percent) and is considered warm permafrost, with ground temperatures generally above 30˚F. Permafrost is evidenced by ground ice, patterned ground – stone nets, and shallow debris flows and landslides. Typically frozen ground is associated with basal till, lacustrine and organic deposits and is influenced by slope aspect and angle. The north-facing slopes and in some places, the lower south-facing steep slopes along the Susitna River where fine-grained soil deposits are present appear to be underlain by perennially frozen ground. In the Watana Creek area, which appears to be the most active area in terms of slope stability, the instability of slopes underlain by lacustrine and basal till deposits is believed to be associated with thawing of ice-rich surficial deposits. Thus gentle to moderate south-facing slopes and upland areas on the north side of the river which are generally thought to be unfrozen, are also underlain by discontinuous permafrost locally.

Based on the subsurface investigations at the proposed dam site, permafrost is associated with fine grained soil deposits and can penetrate bedrock to appreciable depths. Frozen ground is typically encountered within 10 ft. (3m) of the surface and can extend to depths of approximately 240 ft. (73m) on the south abutment. Elsewhere, away from the Susitna River channel, on the upland area, previous subsurface investigations in a thick sequence of glacial and fluvial deposits (Borrow Area D) encountered visible ice in soil samples collected to depths of up to 110 ft. (34m) (Harza-Ebasco 1983).

4.12. Seismic Hazard Study

Seismic hazard studies conducted since the 2014 ISR were associated with completing the crustal seismic sources assessment, conducting a fault rupture evaluation in the dam site proximity (Fugro 2015b: Attachment 7, Section 5), and continuation of the seismic monitoring network (Fugro 2015a, Attachment 8; AEC 2015, Attachment 9). The results of these work tasks are described in detail in the 16.6 Site Specific Seismic Hazard Study Plan Completion Report (SCR) (AEA 2015). The following is a summary of the results of the Seismic Hazard Study pertinent to this study:

- The crustal seismic source evaluation indicate:
    - A lack of evidence of major crustal Quaternary faults near the dam site.

  - Detailed evaluations have not identified any evidence of potential Quaternary faulting within at least 25 mi (40 km) of the Watana dam site.
  - Within the current stress regime of the Talkeetna block, which includes the dam site, the primary modes of tectonic deformation appear to involve right-lateral strike slip structures with east-northeast strikes and dip slip or compressional shortening along structures with northeast strikes or elongations (Figure 5.5-1).
  - The Watana dam site area is subject to northwest-southeast oriented sub-horizontal compressive stress associated with the on-going subduction of the Pacific Plate. Crustal deformation related to the plate interactions have been accommodated primarily by the Denali fault. Geologic evidence suggests that the Talkeetna Block is relatively stable.
  - Relative to the fault rupture evaluation at the dam site, the previously identified “geologic features”, appear to be relatively minor structures and are least favorable to reactivation in the contemporary stress regime.

- In 2014, a total of 1,387 earthquakes were recorded within the Project area of which 643 events were located in the crust at depths of less than 18.6 mi (30 km), and 744 events were located deeper, within the subducting North American Plate (intraslab seismicity). The crustal events ranged in magnitude from -0.5 to 3.0; the intraslab events from magnitude 0.1 to 4.6 (Fugro 2015a, Attachment 8). Details of the maximum earthquakes recorded are:
  - The largest intraslab event, M4.6, occurred on November 29, 2014 at a depth of 37.9 mi (62.1 km), with an epicenter 24.5 mi (40 km) southeast of the proposed dam site.
  - The largest crustal event, M3.0, occurred on September 27, 2014 at a depth of 3.9 mi (6.2km), with an epicenter of 36.7 mi (59.2 km) northeast of the proposed dam site.
- In the first six months of 2015, the largest intraslab earthquakes recorded were M4.5, which occurred on March 5 and May 11 and occurred on at a depth of 40.9 mi (65.8 km) and located 31.9 mi (51.4 km) southwest, and at a depth of 41.9 mi (67.4 km) located 20.3 mi (32.6 km) northeast of the dam site. The largest crustal earthquake, M2.9, occurred on April 29 at a depth of 9.2 mi (14.9 km) located 19.4 mi (31.3 km) also northeast of the proposed dam site (AEC 2015, Attachment 9).

For additional details on the results of the seismic hazard studies, see 16.6 Site Specific Seismic Hazard Study Plan Completion Report and the various attachments (AEA 2015).

5. RESULTS

In 2014, in support of the geology and soil resources study plan, several additional technical memoranda and reports were prepared. The Project documents that provide the details of the subtasks include:

- Geology and Soils - Interim Mineral Resource Assessment Report (Golder 2014; Attachment 1); this report describes the mineral resources in the Project area including registered mineral claims, areas of significant acid rock drainage (ARD), and wildlife mineral licks.
- Exploration and Testing Program Work Plan 2014-15 (MWH 2013c; Attachment 2); this report describes the development of a phased geotechnical exploration and laboratory testing program work plan for engineering feasibility and licensing.
- Preliminary Reservoir Slope Stability Technical Memorandum (MWH 2013b; Attachment 3); this desk top study report presents a preliminary geomorphic assessment of future reservoir rim erosion and stability.
- Geotechnical Data Report (MWH 2015a; Attachment 4); this report includes the data acquired from the geotechnical field investigations performed at the proposed dam site and laboratory testing programs from 2011 to 2014.
- Dam Site Geology Technical Memorandum (MWH 2015b; Attachment 5); this is a feasibility level interim report that provides a characterization of the geologic conditions at the proposed dam site; including the 2015 Watana Geotechnical Instrumentation Data.
- Regional Geologic Analysis Technical Memorandum (Golder 2013; Attachment 6); this memorandum includes terrain unit analysis provides a databank upon which interpretations concerning geomorphologic development of the landscape for the dam site and reservoir area.
- Crustal Seismic Source Evaluation (Fugro 2015b; Attachment 7); the report includes the identification and assessment of potential seismic sources in the Project area.
- Seismic Network 2014 Annual Seismicity Report (Fugro 2015a; Attachment 8); the report summarizes seismic activity in the Susitna-Watana Project area and includes analysis of the seismic data.
- Susitna-Watana Seismic Monitoring Project: January –June 2015 Quarterly Report (AEC 2015; Attachment 9); the report summarizes seismic activity in the Susitna-Watana area.
- Engineering Feasibility Report; the report summarizes the geologic and seismic conditions at the proposed dam site, identifies construction material sources, provides geologic, geotechnical and seismic design criteria used in engineering design, etc. (MWH 2014).

Based on the studies performed, the following conclusions can be drawn with respect to the geology and soils resource characterization for the Project:

Bedrock in the immediate vicinity of proposed dam, powerhouse, spillway and appurtenance structures consist of fresh to slightly weathered, blocky, strong to very strong diorite that is locally altered and fractured and includes minor shears and shear zones. Fracture zones, shear zones, and alteration zones tend to trend in a northwest-southeast direction (parallel to major joint set JS1) and to a lesser extent tend to trend in a north south orientation (JS3). Previously identified "geologic features", shear and/or fracture zones greater than 5 feet (1.5m) in width (e.g. GF4B, GF5) were interpreted to be over-represented in the geologic characterization conducted in previous studies. Gullies associated with these geologic features, particularly those on the right abutment (GF4B and GF5) appear to have be formed initially by the preferential erosion of weak and relatively narrow fracture zones that have been widened and enhanced to their present dimensions by erosion due to stress relief and freeze thaw processes. Individual fracture zones are less than about 10 feet wide (3m) and contain some minor shear zones that are typically less than 12 inches wide (300mm).

Based on the data from regional geology and seismology, geologic mapping, and drilling, major faults capable of surface rupture associated with major earthquakes in the contemporary tectonic environment are absent from the Watana dam site area. The fracture and shear zones observed at the site are likely associated with mid-early Tertiary intrusive processes as evidenced by several narrow northwest trending shear zones that appear to have been cross-cut by a felsic dike (Figure 6-1). Moreover, the potential for any reactivation of the geologic features which might transect the dam footprint must be considered extremely low given the apparent lack of continuity and small scale characteristics of these features, the dominant northwest strike of these features which is unfavorably oriented with respect to the contemporary tectonic stress regime, the absence of any nearby crustal scale fault structure, and the absence of Quaternary faults mapped with about 15 miles (~25 km) of the dam site (see 16.6 Site Specific Seismic Hazard Study for details; AEA 2015).

6. DISCUSSION

Significant progress has been made on characterizing the geology and soils resources in accordance with study plan objectives and engineering design development at the proposed dam site. Additional investigations are planned to complete the tasks outlined.

Some of the key Project-related conclusions that can be drawn from the data collected for geology and soil resources characterization to date include:

<u>Dam Site</u>

- The proposed dam site lies within a relatively coherent structural block of folded Kahiltna Basin rocks (Cretaceous age) that have been intruded by mid to early Cenozoic igneous plutons. More recently the landscape was repeatedly covered by glacial ice and / or lakes.
- The dam site is underlain by a fresh to slightly weathered, hard, strong dioritic rock. The rock mass is locally fractured, sheared and altered and is characterized as blocky to very blocky.
- Fracture zones, shear zones, and alteration zones generally trend in a northwest-southeast direction and to a lesser extent in a north –south direction. The fracture and shear zones are generally less than 2 feet wide but in a few locations the width can be up to 10 feet or more (recognized as "geologic features").

- Previously recognized "geologic features", shear and/or fracture zones greater than 5 feet in width, particularly those that would be encountered in the dam and spillway foundations (e.g., GF5), have been over-represented in the previous characterization of the dam site geologic conditions.
- Potential for surface fault rupture is considered extremely low because of the following conditions:
  - Apparent lack of continuity and small scale of structural geologic features upon which surface fault rupture could occur.
  - Identified shears within this area appear to be primarily associated with the mid-early Tertiary intrusive rocks.
  - The river at the dam site is not controlled by a major structural feature (e.g., fault or wide shear or fracture zone).
  - Field investigations have not identified any evidence of potential Quaternary faulting within at least 15.5 miles (25 km) of the dam site.
  - Potential sources of primary or secondary surface fault rupture at the dam site are absent.
  - The dominant northwest strike of the discontinuities and geologic features is unfavorably oriented with respect to the contemporary tectonic stress regime.
- Groundwater levels at the dam site are generally moderate to deep in the right (north) abutment where the ground is unfrozen. In the left abutment (south), groundwater levels are complicated by the presence of frozen ground but are generally at about 170 feet depth except for perched water.
- Perennially frozen ground, permafrost, is present at considerable depth in the left abutment and at moderate depths in the lower right abutment. Ice-filled discontinuities in bedrock will affect rock mass properties, strength and permeability, and will likely impact foundation treatment during construction.
- Stripping of overburden materials and the excavation of bedrock will impact the geology and soils resources, however, this would not likely result in loss of important geology and soil resources. A significant portion of these resources would be used in Project-related construction activities.

Reservoir Area

- Surficial deposits (glacial and fluvial materials) mask much of the bedrock in the area, especially the lower portion of the proposed reservoir area.
- The reservoir area geology contains variable thicknesses of glacial till, lacustrine deposits, colluvium, outwash and alluvium overlying igneous and metamorphic bedrock. Till and lacustrine deposits dominate in the upland plateau areas while bedrock is exposed along the lower river channel.

- Perennially frozen ground (permafrost), is evidenced by periglacial features, patterned ground, exposures of frozen ground in debris flows, and thawing ice-rich deposits.
- Most active landslides and debris flows are associated with the thawing of frozen ground.
- Based on a preliminary study, eleven mining claims and three gold placer prospects have been identified within the proposed reservoir.
- Geology and soil resources in the reservoir area would likely be affected by:
  - Submergence of potential aggregate (sand and gravel) sources in the river channel, mining claims and gold placer prospects by the impoundment of the reservoir.
  - Frozen ground beneath and adjacent to the reservoir, is anticipated to thaw as a result of reservoir impoundment.
  - Groundwater levels adjacent to the reservoir will rise to higher levels as a function of reservoir impoundment.
  - Due to thawing permafrost and changes in the groundwater levels, mass wasting as a function of slope instability is likely to occur along the reservoir rim.

Access and Transmission Corridors

- This study has not been initiated and is incomplete.

7. CONCLUSION

While significant progress in completing study components is outlined above, the following tasks remain to be completed

- Mineral Resources – an assessment of the mineral resources within the Project area was initiated and an interim report prepared (Golder 2014, Attachment 1). The catalog of claims and prospects will need to be updated.
- Geotechnical Exploration – field investigations and testing will be conducted in the future to characterize the geology and soil resources, determine construction impacts, and mitigate the impacts in the dam site area, reservoir area, construction material sources, and access road and transmission line corridors.
  - Reservoir area – studies will be completed to evaluate geology and soils resources with respect to reservoir slope stability in the Watana Creek area where thawing and degradation of the bluffs that will come in contact with the reservoir is occurring.
  - Access Road and Transmission Line Corridors - studies to evaluate the geology and soils resources relative to develop and characterize the geologic conditions and uncertainties, identify suitable construction material sources, and to identify

mitigation measures due to construction and operation on the geology and soils resources.

- Relict Channel – studies to characterize and assess the potential for reservoir leakage and/or piping as well as treatment alternatives in the buried valley area on the right abutment, upstream of the dam will be deferred until detailed design.

Several preliminary studies related to geology and soils were completed as far as the study extent outlined in the RSP.

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9. TABLES

Table 5-1. Discontinuity Classes

Discontinuity Type	Distinguishing Characteristics	Persistence	Example
Joint	Generally planar breaks and fractures; some with minor infilling and mineralization. Healed joints are also present.	Individual joints are typically continuous from several feet to more than 50 feet. Joints generally occur as coplanar joint sets with varied spacing	Joint Sets 1 and 2
Fracture Zone	Areas of very closely to closely spaced (from less than 1 inch and up to 8 inches) jointed rock where no apparent relative movement has occurred	Tens to thousands of feet	GF-1, GF-4, GF-5
Shear Zone	Zone of rock along which there has been visible evidence of or measurable displacement. These zones are characterized by breccia, gouge, and/or slickensides indicating relative movement.	Tens to thousands of feet	

Table 5-2. Summary of Joint Set Orientations from Outcrops

Joint Set	Strike (Azimuth)	Strike Average (Azimuth)	Dip
JS1	270° to 330°	300°	80° SW to 70° NE
JS2	025° to 060°	040°	80° SE to 70° NW
JS3	340° to 020°	350°	70° E to 80° W
JS4	Variable	Variable	Less than 35°

10. FIGURES

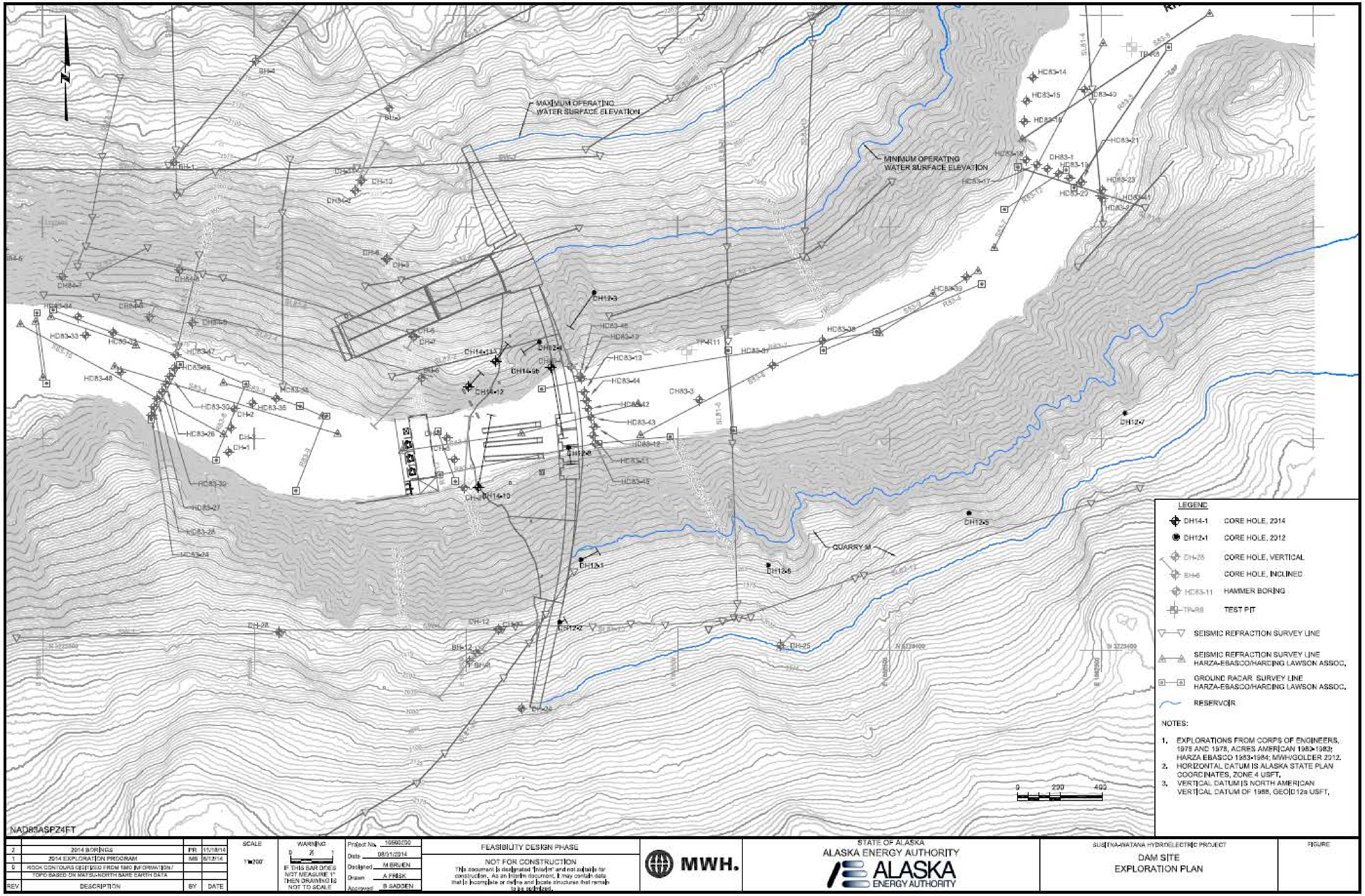


Figure 4.3-1. Dam Site Exploration Plan – 2014

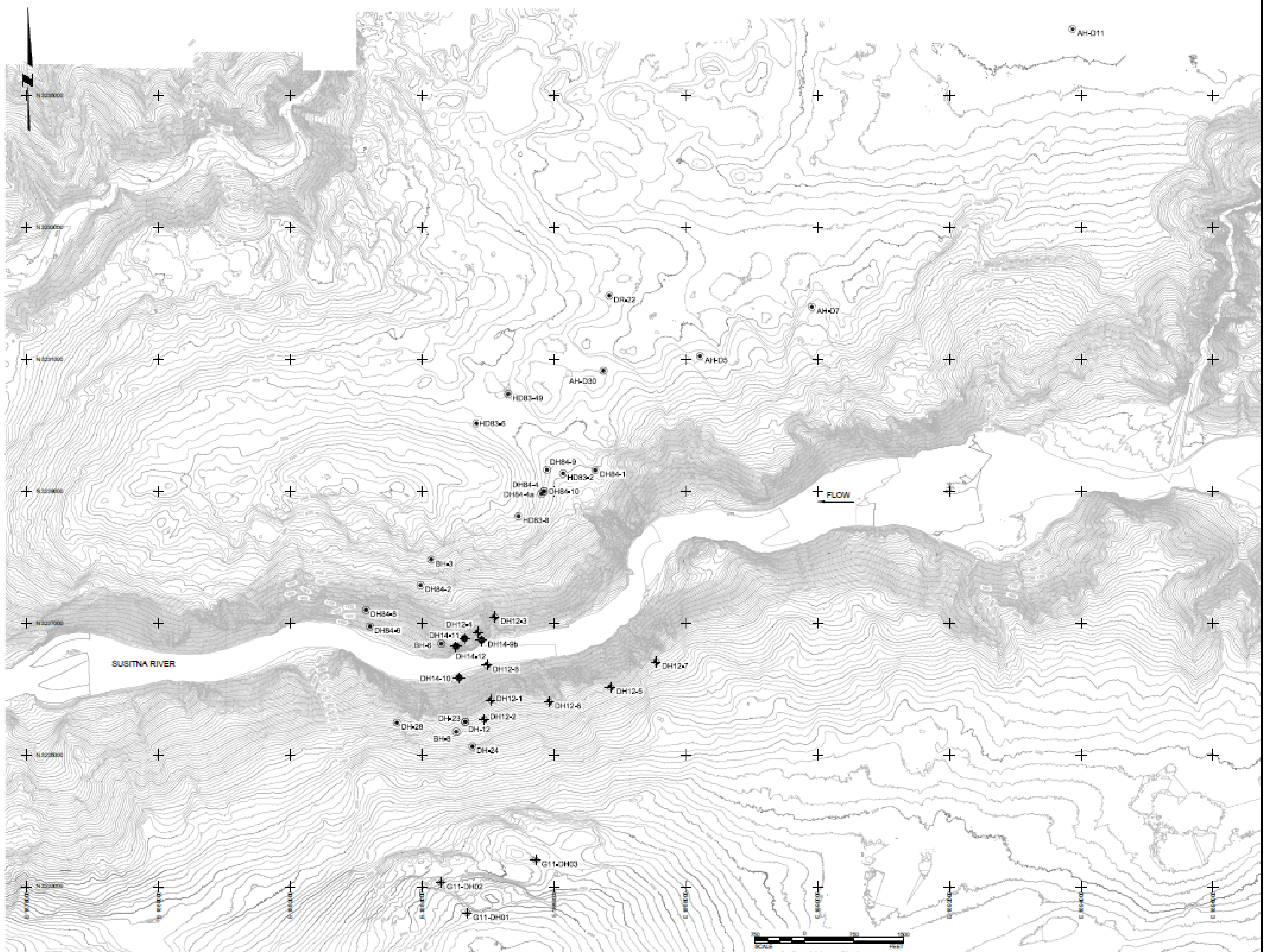
GEOTECHNICAL EXPLORATION SUMMARY			
DH NO.	NORTHING (FT)	EASTING (FT)	ELEVATION (FT)
AH-D5	3231048	1888216	2225.3
AH-D7	3231795	1889914	2215.4
AH-D11	3236010	1893868	2362.3
AH-D30	3230825	1886751	2229.2
BH-3	3227960	1884138	2156.5
BH-6	3226685	1884291	1616.9
BH-8	3225349	1884517	1984.0
DH-12	3225501	1884655	1952.6
DH-23	3225497	1884653	1953.8
DH-24	3225125	1884762	2061.6
DH-28	3225486	1883616	1975.7
DH12-1	3225828	1885044	1877.6
DH12-2	3225533	1884943	1961.3
DH12-3	3227091	1885107	1712.3
DH12-4	3226857	1884848	1630.4
DH12-5	3226024	1886881	2000.8
DH12-6	3225803	1885929	1935.5
DH12-7	3226407	1887554	2025.1
DH12-8	3226359	1884985	1461.8
DH14-9b	3226738	1884902	1500.0
DH14-10	3226171	1884559	1480.3
DH14-11	3226766	1884641	1671.8
DH14-12	3226646	1884513	1638.1
DH84-1	3229319	1886629	2149.9
DH84-2	3227572	1883978	2029.1
DH84-4	3228998	1885849	2167.8
DH84-4a	3228956	1885809	2174.6
DH84-6	3226947	1883209	1530.3
DH84-8	3227197	1883148	1685.4
DH84-9	3229324	1885896	2167.6
DH84-10	3228996	1885848	2167.9
DR-22	3231965	1886840	2233.1
G11-DH01	3222597	1884686	2565.0
G11-DH02	3223063	1884284	2487.2
G11-DH03	3223402	1885723	2480.0
HD83-2	3229270	1886140	2152.3
HD83-6	3230029	1884824	2215.5
HD83-8	3228617	1885464	2224.3
HD83-49	3230472	1885307	2210.0

DRILL HOLE LEGEND

- DH14-9b — 2014 DRILL HOLE
- DH12-6 — 2012 DRILL HOLE
- G11-DH03 — 2011 DRILL HOLE
- HD83-6 — 1978 - 1984 DRILL HOLE

NOTES:

1. BASE TOPOGRAPHIC CONTOURS FROM 2011 MSB LIDAR IMAGERY. CONTOUR INTERVAL IS 10 FEET.
2. COORDINATES IN ALASKA STATE PLANE, ZONE 4, FEET, NAD 83.
3. ELEVATIONS ON NAVD88 VERTICAL DATUM
4. GEOTECHNICAL INSTRUMENTATION INSTALLED IN DRILL HOLES INCLUDES PIEZOMETERS (VIBRATING WIRE, PNEUMATIC AND OPEN STANDPIPE), AND MULTI-POINT THERMISTOR STRINGS OR THERMAL PROBES. SEE USACE (1979); ACRES (1982A, 1982B); HARZA-EBASCO (1983, 1984); GOLDER (2012, 2013).



SCALE 1"=750' ANSI D FULL SIZE	WARNING 0 ½ 1 IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE	Project No. 103-05560.01 Date 12/10/2014 Designed — Drawn A. GARRIGUS Approved M. BRUEN	CONCEPTUAL DESIGN PHASE NOT FOR CONSTRUCTION This document is designated "interim" and not suitable for construction. As an interim document, it may contain data that is incomplete or define and locate structures that remain to be optimized.	MWH.
STATE OF ALASKA ALASKA ENERGY AUTHORITY ALASKA ENERGY AUTHORITY	SUSITNA-WATANA HYDROELECTRIC PROJECT WATANA DAM SITE GEOTECHNICAL INSTRUMENTATION	FIGURE SHEET 1 OF 1		

REV	DESCRIPTION	BY	DATE

Figure 4.3-2. Watana Dam Site Geotechnical Instrumentation

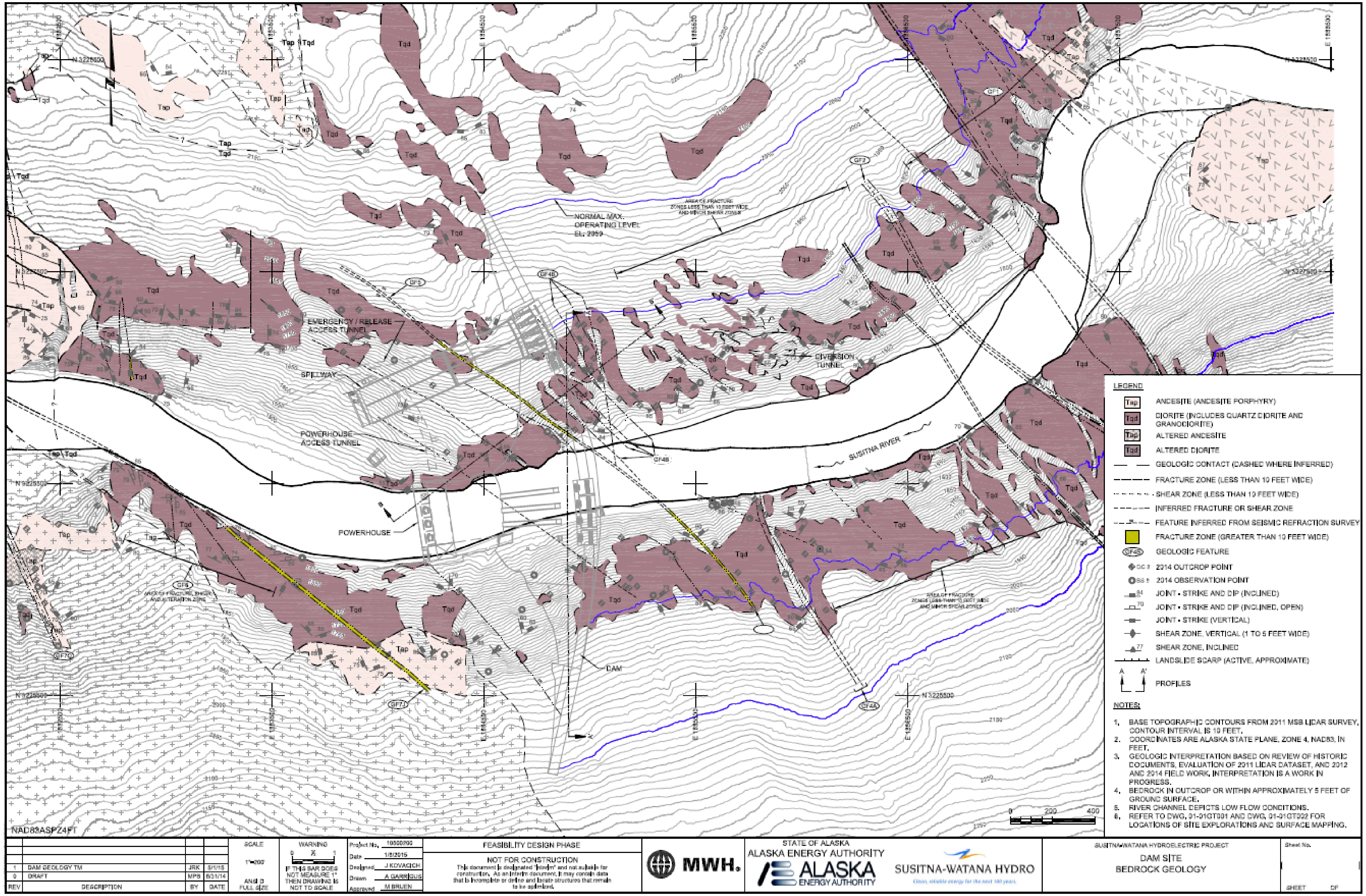
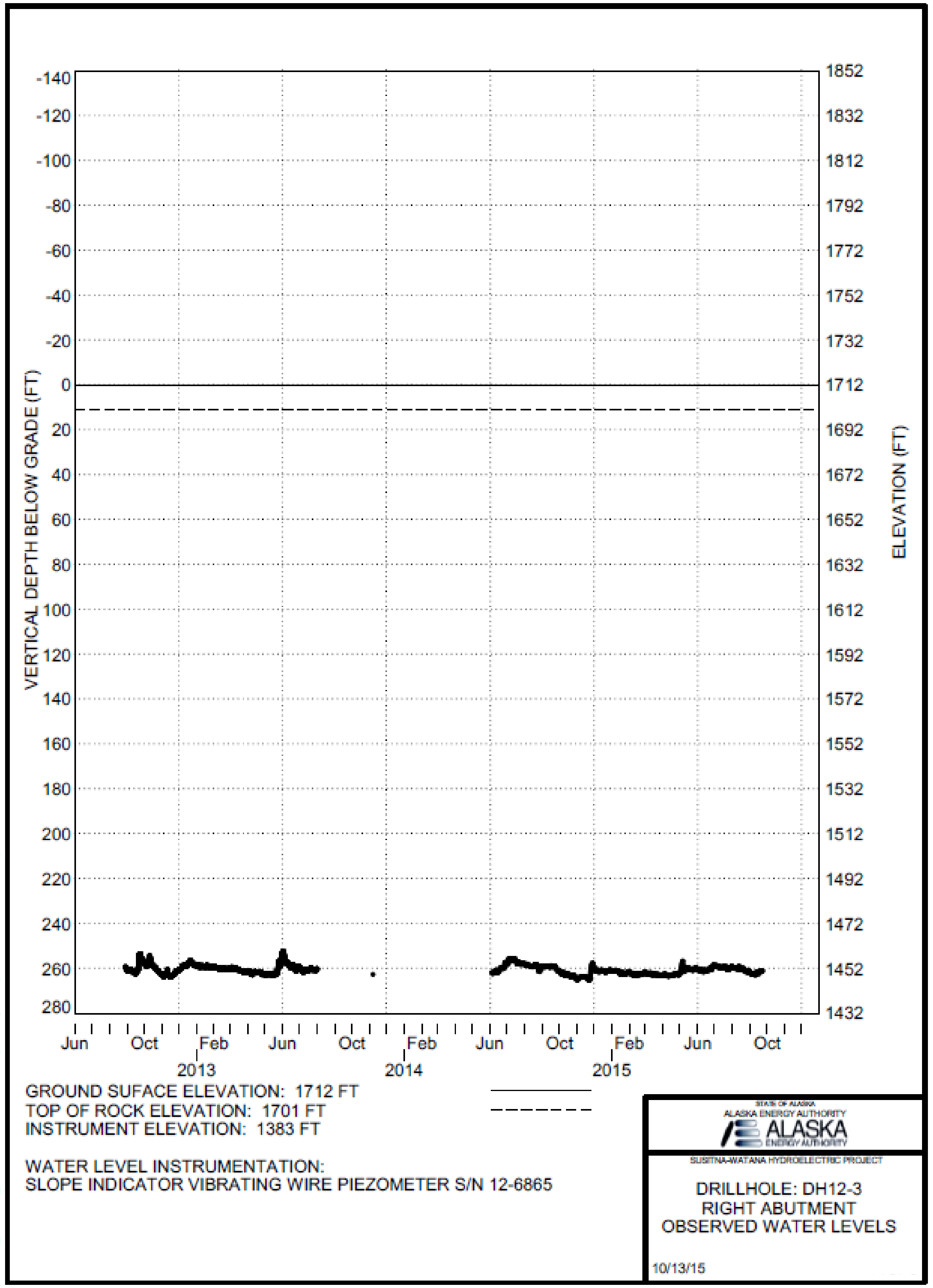


Figure 5.3-1. Dam Site Bedrock Geology



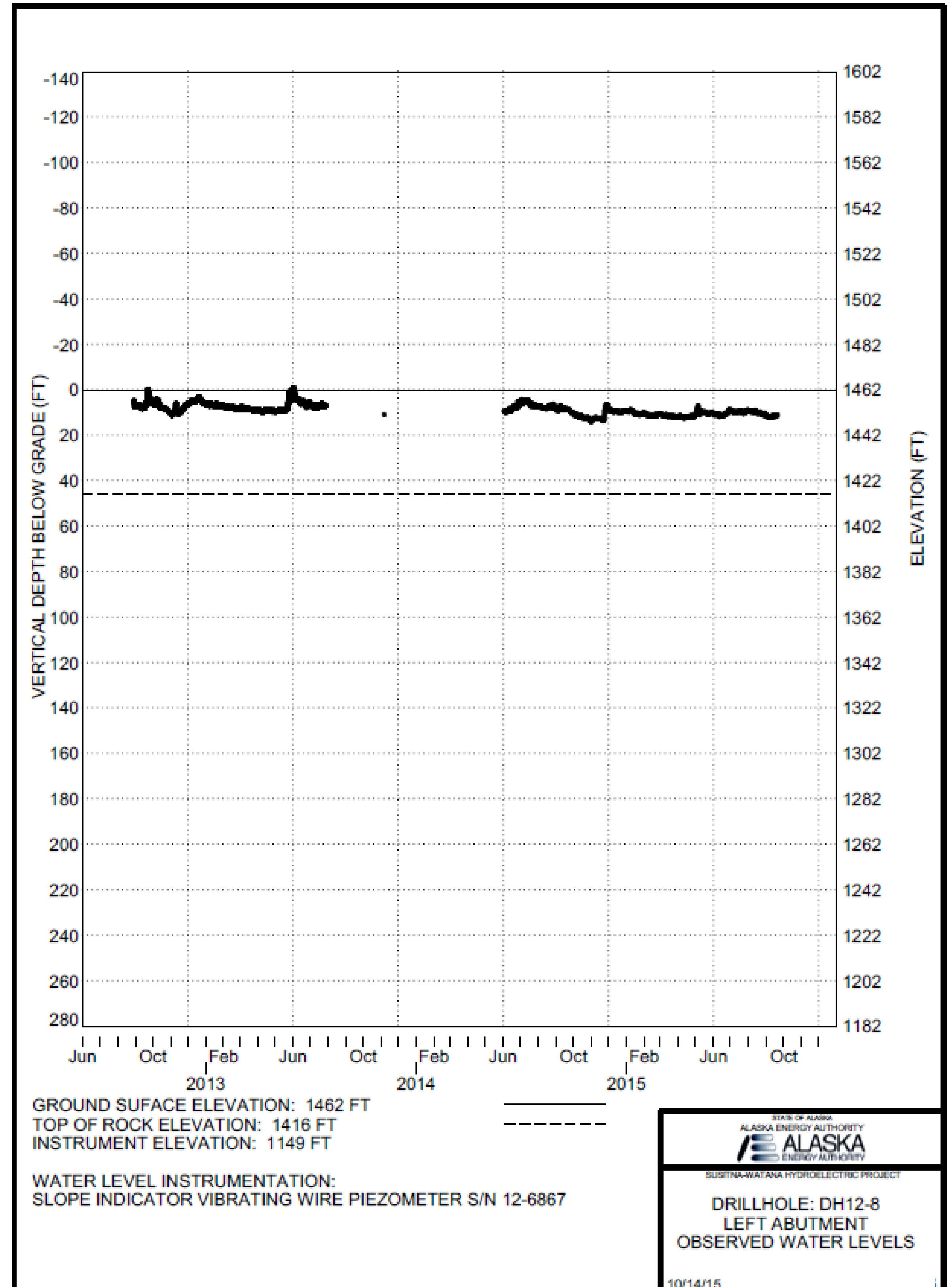
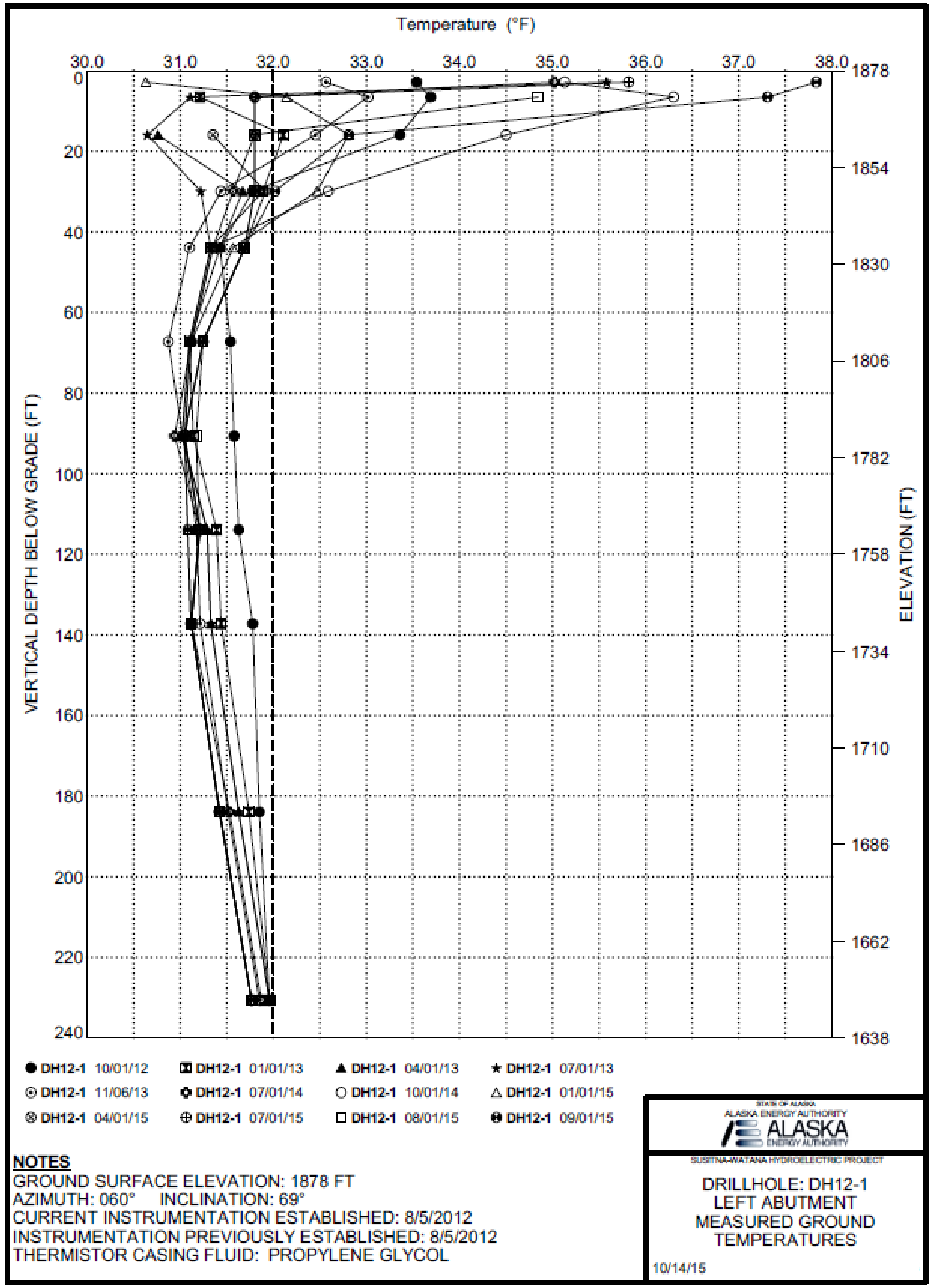


Figure 5.3-2. Groundwater Levels and Dam Site (DH12-3, DH12-8)



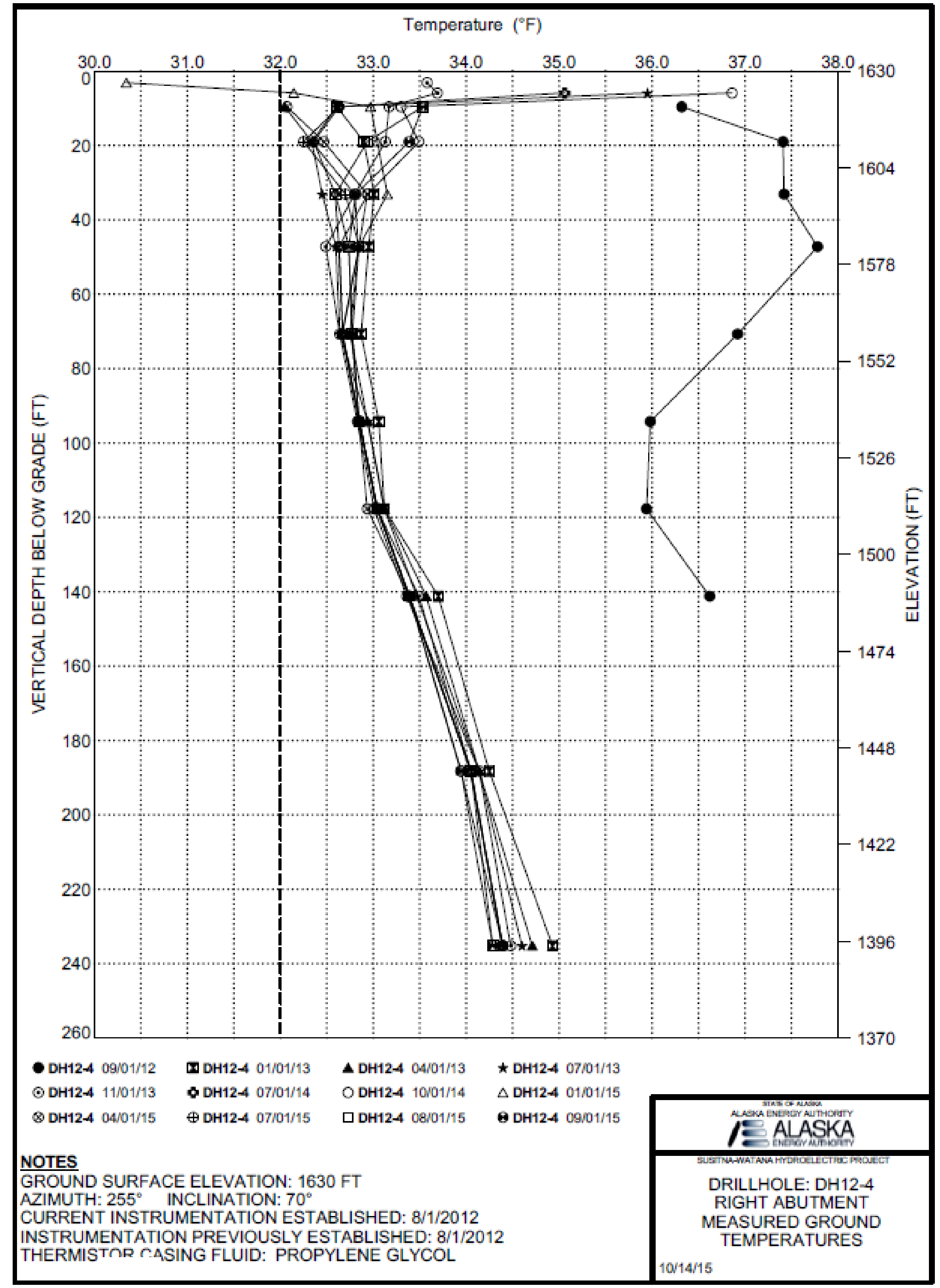


Figure 5.3-3. Ground Temperature at Depth (DH12-1, DH12-4)

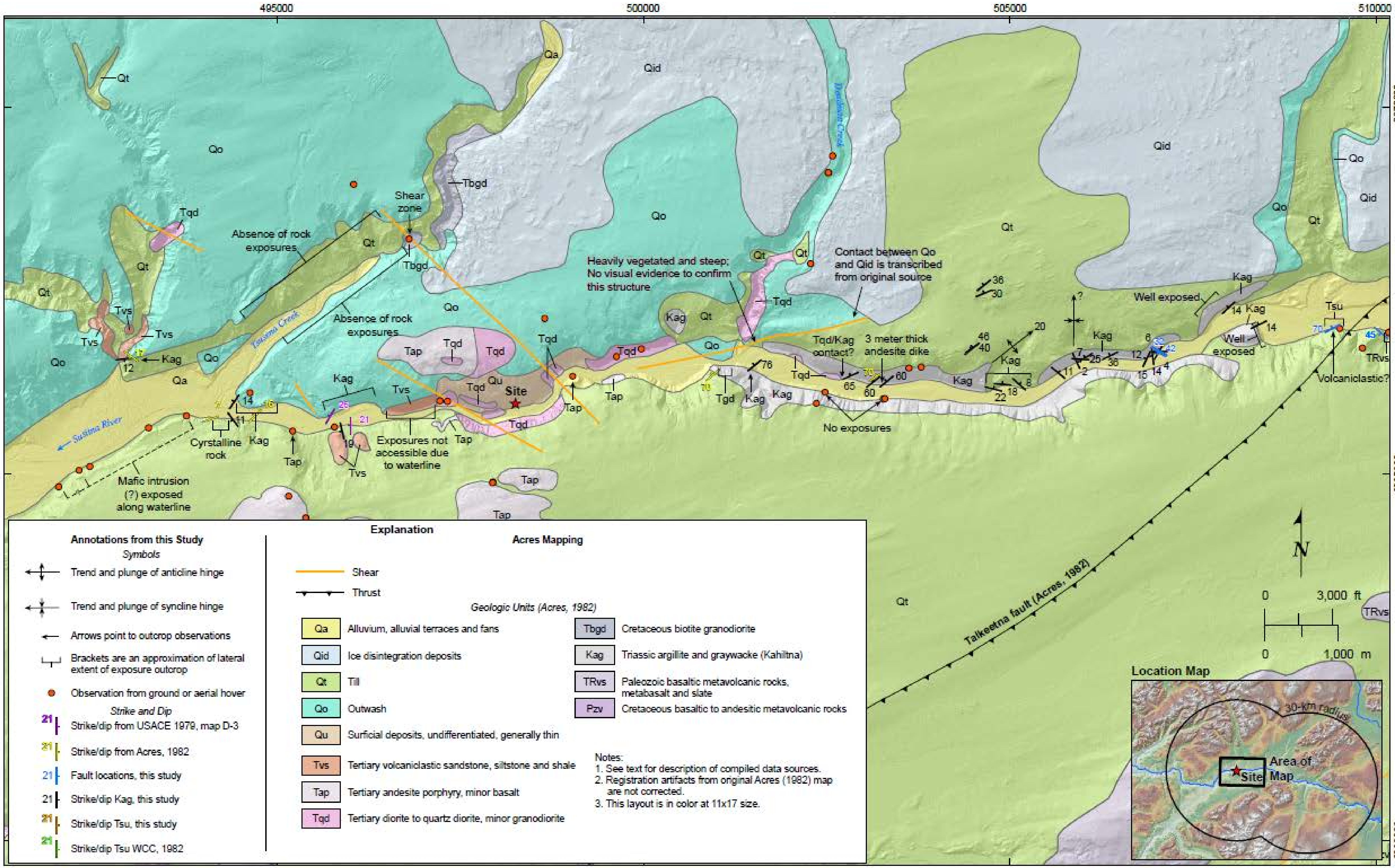


Figure 5.4-1. Regional Geology; 1 of 2 (Fugro 2015b)

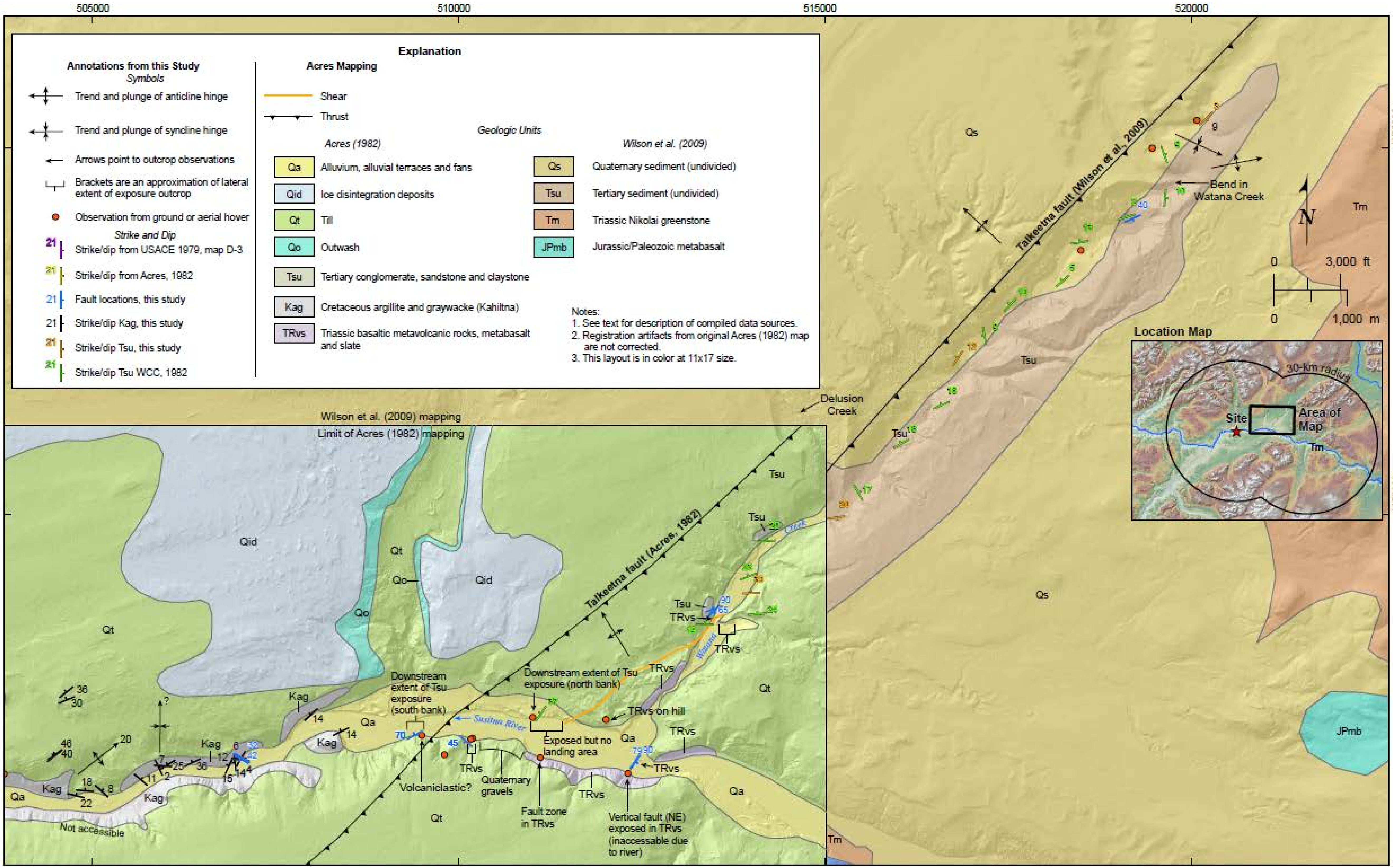


Figure 5.4-2. Regional Geology; 2 of 2 (Fugro 2015b)

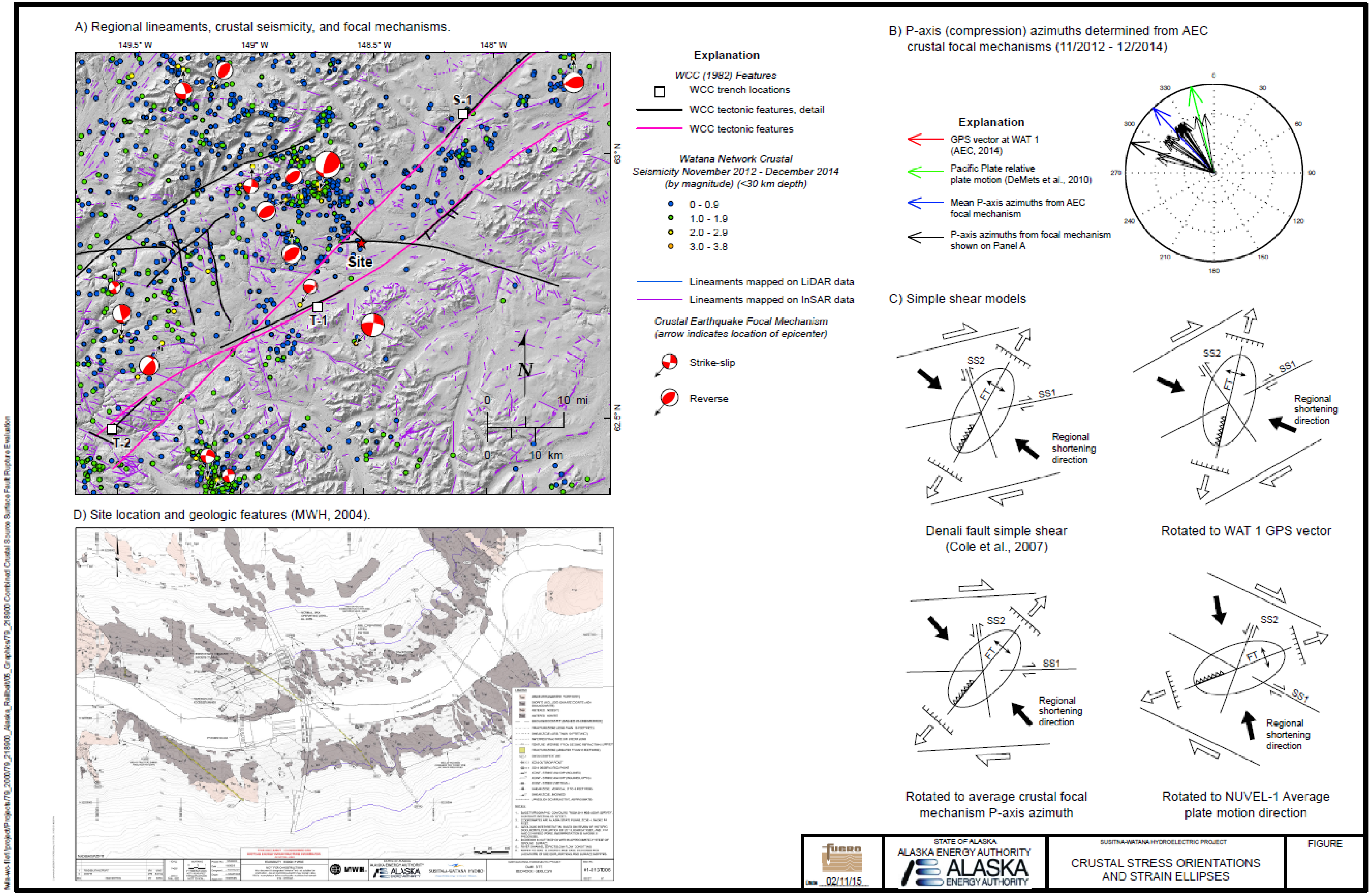


Figure 5.5-1. Crustal Stress Orientations and Strain Ellipses (Fugro 2015b)

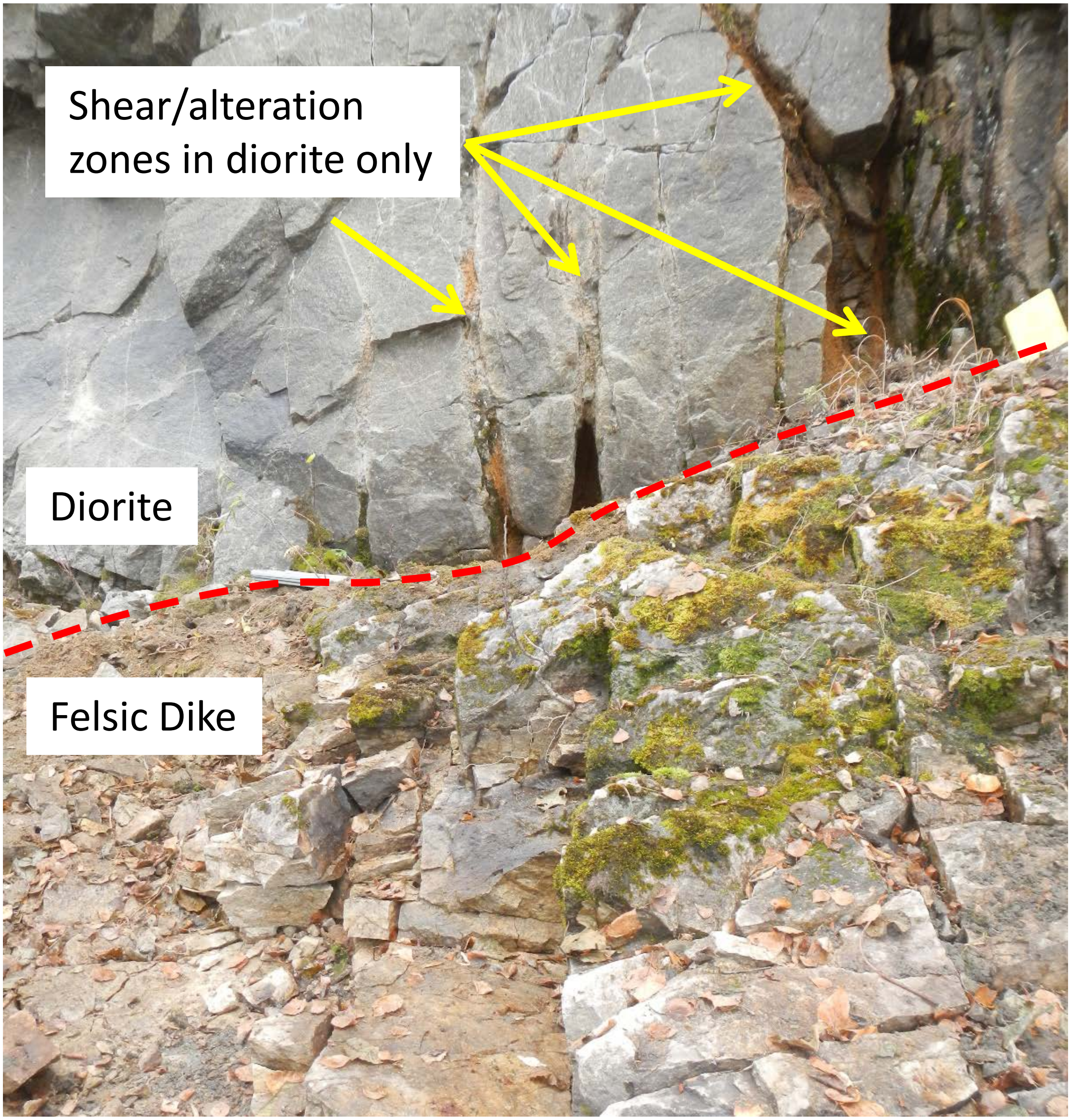


Figure 6-1. Shear/Alteration Zone at BS-27