STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

SUMMARY OF GEOLOGIC DATA FOR TUNNEL ALIGNMENT

CALDECOTT
Improvement Project

On State Route 24,
From SR-13 in Alameda County to
Gateway Boulevard in Contra Costa County
EA No. 294901

PROJECT DEVELOPMENT - EAST
OFFICE OF DESIGN, CONTRA COSTA
DISTRICT 4

December 2007

DRAFT

**Materials are preliminary, subject to revision, and not for construction.*

1.0 MAJOR GEOLOGIC FORMATIONS AND STRUCTURES

The geology of the alignment (see Fig. 1) is characterized by northwest-striking, steeply-dipping, and overturned marine and non-marine sedimentary rocks of the Middle to Late Miocene age. The western end of the alignment traverses marine shale and sandstone of the Sobrante Formation. The "middle" section of the alignment traverses chert, shale, and sandstone of the Claremont Formation. The eastern end of the alignment traverses non-marine claystone, siltstone, sandstone, and conglomerate of the Orinda Formation.

The Middle Miocene Sobrante Formation, which is the oldest formation of the Monterey Group, is composed of marine siltstone and shale, with fine-grained sandstone, that is locally glauconitic (i.e., locally the mineral glauconite is found in relative abundance). The completion report for the BART tunnels reported that rocks that correlate with the Sobrante Formation are complexly faulted and folded with individual beds generally highly contorted and lenticular. The Sobrante Formation includes (from west to east) the First Shale, Portal Sandstone, and Shaley Sandstone and Shale geologic units.

The Middle Miocene Claremont Formation stratigraphically and conformably overlies the Sobrante Formation. The Claremont Formation generally consists of a steeply-dipping, rhythmic alternation of thin (< 10 cm) beds of chert and siliceous shale. Occasionally, the formation contains clay shale, porcelanite, sandstone, and dolomite beds. The Claremont Formation includes (from west to east) the Preliminary Chert, Second Sandstone, and Claremont Chert and Shale geologic units.

The non-marine Middle Miocene Orinda Formation stratigraphically overlies the Claremont Formation along a slight angular unconformity along which some slippage has taken place. The Orinda Formation consists of poorly consolidated mudstone and sandstone, with conglomerate at intervals.

The regional geological structure of the project area (and the East Bay Hills, in general) has been characterized by previous investigators as part of the western, and locally overturned, limb of a broad, northwest-trending syncline (the Siesta Valley Syncline), the axis of which lies east of the project area. The overturned nature of this syncline is locally characterized by the relationship of the Claremont and Orinda Formations, with rocks of the younger Orinda Formation dipping southward and beneath the older, overlying rocks of the Claremont Formation; however, some of the units near the western end of the Caldecott Tunnel (i.e., the Sobrante Formation and basal units of the Claremont Formation) do not appear to have been overturned since the bedding is predominantly dipping to the north.

Four major faults were identified along the tunnel alignment. A brief description of each fault, and geologic units within each formation follows. Terminology used to describe ground conditions are defined in Figure 3.

1.1 Faults

The four faults identified along the alignment (see Fig. 1) are all inactive and define contacts between different geologic units. The faults strike northwesterly, perpendicular to the tunnel alignment. The location, extent and geologic characteristics of the four faults along the alignment are described below.

Fault 1 is located at the First Shale/Portal Sandstone contact near Station 107+78. The fault zone is approximately 20-m (66-ft) (true width) and has a width of 27 m (90 ft) along the tunnel alignment. The fault dips 30 degrees to 45 degrees to the northeast. The geologic material in the fault zone consists of very closely to moderately fractured shale and sandstone.

Fault 2 marks a distinct change in the overall geologic structure of the alignment, as it separates predominantly northeast-dipping strata on the west (the Preliminary Chert and Shale) from predominantly southwest-dipping strata on the east (the Second Sandstone) near Station 109+40. This fault dips nearly vertical. The fault zone is approximately 20-m (66-ft) wide (true width) and has a width of 25 m (82 ft) along the tunnel alignment. The geologic material in the Fault 2 zone consists of very closely to moderately fractured shale, sandstone and chert.

Fault 3 marks the contact between the Second Sandstone and the Claremont Chert and Shale near Station 110+57. Fault 3 is expected to be approximately 70-m (230-ft) wide (true width) and also has a width of 70 m (230 ft) along the tunnel alignment. The fault dips about 85 degrees to the southwest across bedding planes. The geologic material adjacent to Fault 3 consists of very closely to moderately fractured sandstone, chert and shale.

Fault 4, near Station 114+00, marks the contact between marine cherts and shales of the Claremont Formation to the west with the non-marine sediments of the Orinda Formation to the east. Fault 4 dips about 80 degrees to the southwest and is approximately sub-parallel to bedding. It is approximately 20-m (66-ft) wide (true width) and has a width of 26 m (85 ft) along the tunnel alignment. The geologic material adjacent to Fault 4 consists of very closely to moderately fractured sandstone, conglomerate, siltstone, claystone, and shale.

1.2 Geologic Units

1.2.1 Sobrante Formation Geologic Units

First Shale
The First Shale is a gray to brown to black, silty to clayey shale with occurrences of sandstone, siltstone, claystone, argillite, and igneous dike and sills. These rocks are closely to very closely fractured and crushed into a relatively interlocked arrangement of small angular fragments that are typically 2 to 3 cm (0.8 to 1.2 in) across. The crushed angular fragments are bound by a low plasticity, clayey-silt (ML) matrix. Along the tunnel alignment, these crushed zones with high clayey-silt content range in thickness from 0.5 cm to 2.5 m (0.25 in to 8 ft). These rocks are severely to moderately weathered, and have weak strength and low to moderate hardness.

Portal Sandstone
The Portal Sandstone consists of gray fine- to medium-grained sandstone and silty fine sandstone. Locally, the Portal Sandstone is well-cemented with carbonate, which results in relatively

stronger and harder rocks. The Portal Sandstone becomes increasingly silty and shaley to the east. Bedding is generally massive or indistinct. These rocks are closely to moderately fractured and locally crushed, slightly weathered to fresh, with weak to moderate strength and low to moderate hardness. Fractures in the unit generally are tight (< 1 mm wide), and many are coated with oxides or carbonate. As in the First Shale, some of the crushed zones in the silty-sandstone have a clayey-silt matrix. The majority of the Portal Sandstone is very blocky with crushed zones that occur in thicknesses ranging from 0.15 to 2.1 m (0.5 to 7 ft).

Shaley Sandstone and Shale
The Shaley Sandstone and Shale consists of silty fine sandstone and shale that varies in color from gray to brown. It is interbedded locally with the light blue sandstone that is common within the Portal Sandstone. There is no distinct contact between the Portal Sandstone and the Shaley Sandstone and Shale; and the two units grade into each other. The silty-sandstone is also locally interbedded with shale. A shale bed approximately 4-m (13-ft) thick occurs near the contact with the Preliminary Chert and Shale. These rocks are closely to very closely fractured and crushed, slightly weathered to fresh, with weak to low strength and low to moderate hardness. Randomly-oriented, closely-spaced fractures are pervasive throughout the Shaley Sandstone and Shale. These fractures are typically healed with calcite. The shale beds and the silty-sandstone are very blocky to disintegrated. Some disintegrated zones exhibit a clayey matrix and are up to 2-m (6.5-ft) wide, but generally they are less than 0.6-m (2-ft) wide.

1.2.2 Claremont Formation Geologic Units

Preliminary Chert and Shale
The Preliminary Chert and Shale consists of shale, siliceous (cherty) shale, and chert that vary in color from gray to brown. This geologic unit also contains a few minor beds or dikes of sandstone. Bedding thickness ranges from a few millimeters to several centimeters and is fissile in the shale and chert. These rocks are closely to very closely fractured and crushed, slightly weathered to fresh, with weak strength and low to moderate hardness. Random irregular fractures occur throughout the unit and there are many disintegrated crushed zones, typically ranging from 0.15 to 0.91-m (0.5 to 3.0-ft) wide.

Second Sandstone
The Second Sandstone consists of fine to medium grained sandstone with local interbeds of shale and siliceous shale that varies in color from gray to brown to orange. Angular, elongate shale inclusions up to about 10 cm (3.9 in) across are found in the unit, as are sandstone dikes and sills. The appearance of the Second Sandstone is similar to that of the Portal Sandstone, but its average strength is lower. These rocks are closely to widely fractured and locally crushed, slightly weathered to fresh, with weak to moderate strength and low to moderate hardness. The sandstone beds are generally massive to very blocky away from the fault contacts that bound the Second Sandstone. Several crushed or sheared shale and chert interbeds up to 2.4-m (8-ft) thick were observed in Boring N4 within 82 m (270 ft) of the Preliminary Chert and Shale contact at Fault 2. These crushed and sheared zones result in a blocky/disturbed and seamy rock mass structure. Some of these crushed zones of shale are clayey. Near the contact with the Claremont Chert and Shale (i.e. near Fault 3), the Second Sandstone is very blocky to blocky/disturbed/seamy.

Claremont Chert and Shale
Chert, siliceous (cherty) shale, shale, and siltstone that vary in color from dusky red to gray and brown are the predominant rock types in the Claremont Chert and Shale. The unit includes

sandstone beds and probable sandstone dikes/sills, thin dolomitic beds, and diabase dikes and sills which may be altered and softened. These rocks are closely to very closely fractured and crushed, slightly weathered to fresh, with weak to moderate strength and soft to moderate hardness. Locally, the chert and siliceous shale are strong and hard. The lithology proportions vary along the alignment within this unit. Except for the eastern 50 m (165 ft) of the Claremont Chert and Shale near Fault 4, the unit is composed of thin, sharply defined layers of cherty material alternating with less siliceous shale. The thickness of the cherty beds ranges from less than 25 mm to 15 cm (1 to 6 in), but on average is 25 to 50-mm (1 to 2-in) thick. The interbeds of less siliceous shale tend to be thinner than the cherty beds and are estimated to average about 12-mm (0.5-in) thick. By contrast, the rocks within the eastern 50 m (165 ft) of the unit are predominantly dark brown, dark gray, and black shale/claystone and siltstone and are thinly bedded with local interbeds of cherty shale and sandstone. Reports from past construction indicate that this unit includes lenticular beds and "stubby lenses" of dolomite up to about 30-cm (12-in) thick, with carbonate filled fractures.

The chert and cherty shale tends to separate along bedding and break into gravel-sized blocks due to cross-fracturing perpendicular to bedding. The unit is fractured throughout and crushed extensively in a 183-m (600-ft) wide zone including Fault 3, and other locations such as within Fault 4. Also, convoluted bedding is present in this unit, as in the Preliminary Chert and Shale. The occurrence of dikes, joints, crushed zones, minor systematic faults, and locally convoluted bedding contribute to complex rock mass structures which range from very blocky to disintegrated.

1.2.3 Orinda Formation Geologic Units

The Orinda Formation consists of interbedded bluish gray and greenish gray conglomerate, sandstone, and siltstone, and grayish red claystone. Claystones/siltstones are estimated to make up 55 percent of the Orinda Formation along the alignment of the 4th bore. The percentages of conglomerate and sandstone are approximately 25 percent and 20 percent, respectively. A volcanic dike and sill were observed in outcrop in the cut slopes on the north side of Portal 2 (east portal); however, no volcanic rocks were encountered in the exploratory borings drilled in this unit. It has been reported that asphalt, hydrocarbons, lignite (coal), and diabase dikes were encountered locally in the formation in the first and second bores. It has also been noted that "bituminous material" occurred near the contact with the Claremont Formation in the third bore. These rocks generally are slightly weathered to fresh, moderately to very widely fractured, and have weak to moderate strength and low to moderate hardness. The claystone and siltstone is generally fresh to severely weathered and moderately to very widely fractured (closely to very closely fractured locally) with weak to moderate strength and low hardness.

2.0 Anticipated Tunnel Ground Conditions

2.1 Ground Classification

The various geologic materials along the alignment have been grouped into four ground classes that require a unique combination of excavation sequence and initial support elements, collectively referred to as a Support Category.

Figure 2 shows the estimated extent of ground classes along the alignment for information only. The limits of the ground classes along the tunnel are expected to vary and the actual determination of the limits of ground classes along the alignment is to be determined during construction. Ground Class Descriptions.

2.1.1 Ground Class 1

Ground Class 1 is further subdivided into two sub-classes depending on the occurrence of local shears: (1) Ground Class 1a where local shears are absent, and (2) Ground Class 1b where local shears occur. Local shears are characterized by slickensided or clayey joints, or intensely fractured and crushed rock. Ground Class 1b will occur within reaches of Ground Class 1a.

Ground Class 1a rock mass characteristics are as follows:

- Blocky to massive structure and poor to good discontinuity surface conditions in terms of the GSI classification.
- Lithologies consist of sandstone with local interbeds of shale and siliceous shale (Second Sandstone); and interbedded conglomerate, sandstone, siltstone, and claystone (Orinda Formation).
- Fracture spacing is moderate to very wide, but will be very close occasionally.
- Weak to moderate strength and low to moderate hardness.
- Weathering is generally slight to fresh.
- Discontinuities will be slightly weathered, planar to undulating, slightly rough to rough, with some joints infilled by carbonate, calcite, or clay. Some bedding planes in the Orinda Formation will be slickensided.

Ground Class 1b rock mass characteristics are as follows:

- Blocky/disturbed/seamy to disintegrated structure and poor to fair discontinuity surface conditions in terms of the GSI classification.
- Consists of shear zones with widths that vary 0.3 to 5 m (1 to 16.5 ft).
- Lithologies consist of sandstone with local interbeds of shale and siliceous shale (Second Sandstone); and interbedded conglomerate, sandstone, siltstone, and claystone (Orinda Formation).
- Fracture spacing is close to very close.
- Weak to moderate strength and low to moderate hardness.
- Weathering is variable from severe to fresh.
- Discontinuities will be slightly to severely weathered, planar to undulating, polished to rough, with some joints infilled by carbonate, calcite, or clay. Some bedding planes in Orinda Formation will be slickensided.

2.1.2 Ground Class 2

Ground Class 2 is divided into two sub-types. Ground Class 2a is comprised of Orinda Formation only, while Ground Class 2b is comprised of: Portal Sandstone; Shaley Sandstone and Shale; Preliminary Chert and Shale ; Second Sandstone; Claremont Chert and Shale and Orinda Formation. Locally, shears will occur within Ground Class 2a with widths that vary from 0.3 m (1 ft) to 5 m (16.5 ft).

Ground Class 2a rock mass characteristics are as follows:

- Very blocky structure and poor to fair discontinuity surface conditions in terms of the GSI classification.
- The lithology consists of interbedded conglomerate, sandstone, siltstone, and claystone (Orinda Formation).
- Fracture spacing is moderate to very wide.
- Weak to moderate strength and low to moderate hardness.
- Weathering is slight to fresh.
- Discontinuities will be slightly weathered, planar to undulating, smooth to moderately rough, with some joints infilled by calcite or clay.
- The local shear characteristics are as follows:
- Blocky/disturbed/seamy to disintegrated structure and poor to fair discontinuity surface conditions in terms of the GSI classification.
- Fracture spacing is close to very close.
- Weak to moderate strength and low to moderate hardness.
- Weathering is variable from severe to fresh.
- Discontinuities will be slightly to severely weathered, planar to undulating, polished to rough, with some joints infilled by calcite or clay.

Ground Class 2b rock mass characteristics are as follows:

- Very blocky to a disintegrated structure and fair to poor discontinuity conditions in terms of the GSI classification.
- The lithology consists of sandstone and silty sandstone (Portal Sandstone); silty sandstone and shale (Shaley Sandstone and Shale); shale, siliceous (cherty) shale and chert (Preliminary Chert); sandstone with local interbeds of shale and siliceous shale (Second Sandstone); chert, siliceous (cherty) shale, siltstone, sandstone, dolomite, sandstone and volcanic dikes or sills (Claremont Chert and Shale); and interbedded conglomerate, sandstone, siltstone, and claystone (Orinda Formation).
- Fracture spacing is very close to very wide and locally crushed.
- Weak to moderate strength and low to moderate hardness.
- Weathering is generally slight to fresh, but will be variable within local shears. Local shears that occur in this ground class will be consistent with the disintegrated rock mass structure condition that will occur in Ground Class 2b.
- Discontinuities will be slightly weathered, smooth to planar, polished to moderately rough, with some joints infilled by oxides, carbonate, calcite, or clay.

2.1.3 Ground Class 3

The geologic units comprising Ground Class 3 include Shaley Sandstone and Shale; Preliminary Chert and Shale; Second Sandstone; Claremont Chert and Shale; and the Orinda Formation. Ground Class 3 also includes the occurrence of moderately to severely weathered volcanic dikes that occur in any geologic unit along the alignment, and Faults 2, 3 and 4. This ground class is divided into two sub-types based on the extent of disintegrated rock with thick local clayey shears or dikes. The first sub-type (Ground Class 3a) includes zones of disintegrated rock with thick local clayey shears or dikes with extents of less than 7.6 m (25 ft), as well as all other Ground

Class 3 geologic units. The second sub-type (Ground Class 3b) corresponds to a more extensive (i.e. greater than 7.6 m or 25 ft) occurrence of the disintegrated rock with thick local clayey shears or dikes.

Ground Class 3a rock mass characteristics are as follows:

- Very blocky to disintegrated structure and fair to very poor discontinuity surface conditions in terms of the GSI classification.
- The lithologies consist of silty sandstone, shale (Shaley Sandstone and Shale); sandstone with local interbeds of shale and siliceous shale (Second Sandstone); chert, siliceous (cherty) shale, siltstone, sandstone, dolomite, sandstone and volcanic dikes or sills (Claremont Chert and Shale); and interbedded conglomerate, sandstone, siltstone, and claystone (Orinda Formation).
- Fracture spacing is very close to moderate.
- Weak to moderate strength and low to moderate hardness.
- Weathering is severe within very closely fractured zones or altered dikes, and is slight to fresh elsewhere.
- Discontinuities will be moderately to severely weathered within very closely fractured zones and slightly weathered, planar and polished to moderately rough elsewhere.

Ground Class 3b rock mass characteristics are as follows:

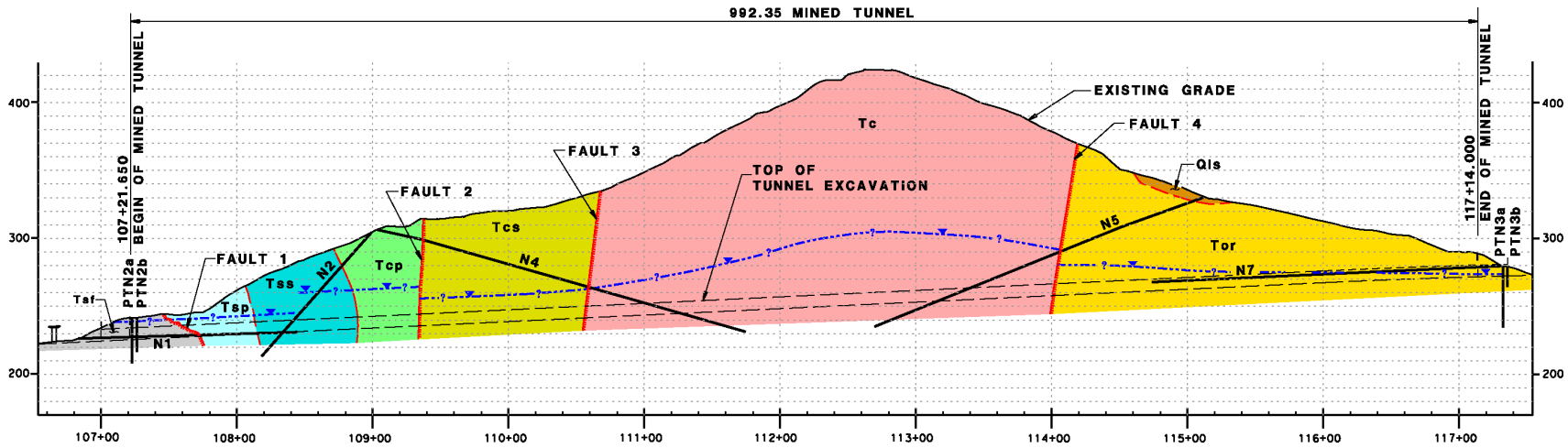
- Blocky/disturbed/seamy to disintegrated structure and fair to very poor discontinuity surface conditions in terms of the GSI classification.
- The lithologies consist of shale, siliceous (cherty) shale, chert, siltstone, sandstone, dolomite, sandstone and volcanic dikes or sills (Claremont Chert and Shale)
- Fracture spacing is moderate to very close.
- Weak to moderate strength and low to moderate hardness.
- Weathering is moderate to severe.
- Discontinuities will also be moderately to severely weathered.

2.1.4 Ground Class 4

Ground Class 4 occurs in the First Shale at the Portal 1 (west portal) area, and within Fault 1. Ground Class 4 includes the Portal Sandstone within the fault zone at Fault 1.

Ground Class 4 rock mass characteristics are as follows:

- Blocky/disturbed/seamy to disintegrated structure and fair to very poor discontinuity surface conditions in terms of the GSI classification.
- The lithologies consist of silty to clayey shale with occurrences of sandstone, siltstone, claystone, argillite, and igneous dikes and sills (First Shale); and sandstone, silty sandstone (Portal Sandstone).
- Fracture spacing is very close to close.
- Weak to moderate strength and low to moderate hardness.
- Weathering is slightly weathered to severe in these rocks.
- Discontinuities will be slightly to severely weathered, moderately rough to polished, with some joints infilled by thin clay film, clay, oxides, or carbonate.



GEOLOGIC UNITS

QUATENARY

- Qls — LANDSLIDE

MIDDLE TO LATE MIOCENE

MORAGA FORMATION (VOLCANIC ROCKS)

- Tor — ORINDA FORMATION: INTERBEDDED SANDSTONE SILTSTONE, MUDSTONE AND CONGLOMERATE (UNDIFFERENTIATED)

CLAREMONT FORMATION

- Tc — CHERT AND SHALE
- Tcs — SANDSTONE (PAGE'S [1950] "SECOND SANDSTONE")
- Tcp — SHALE AND CHERT (PAGE'S [1950] "PRELIMINARY CHERT")

SOBRANTE FORMATION

- Tss — SANDSTONE AND SHALE (PAGE'S [1950] "SHALY SANDSTONE")
- Tsp — SANDSTONE (PAGE'S [1950] "PORTAL SANDSTONE")
- Tsf — SHALE (PAGE'S [1950] "FIRST SHALE")

SYMBOLS

- GEOLOGIC CONTACT — SOLID WHERE ABRUPT, DASHED WHERE APPROXIMATE OR GRADATIONAL
- FAULT CONTACT
- BORINGS
- GROUNDWATER TABLE

Figure 1: Geologic Profile

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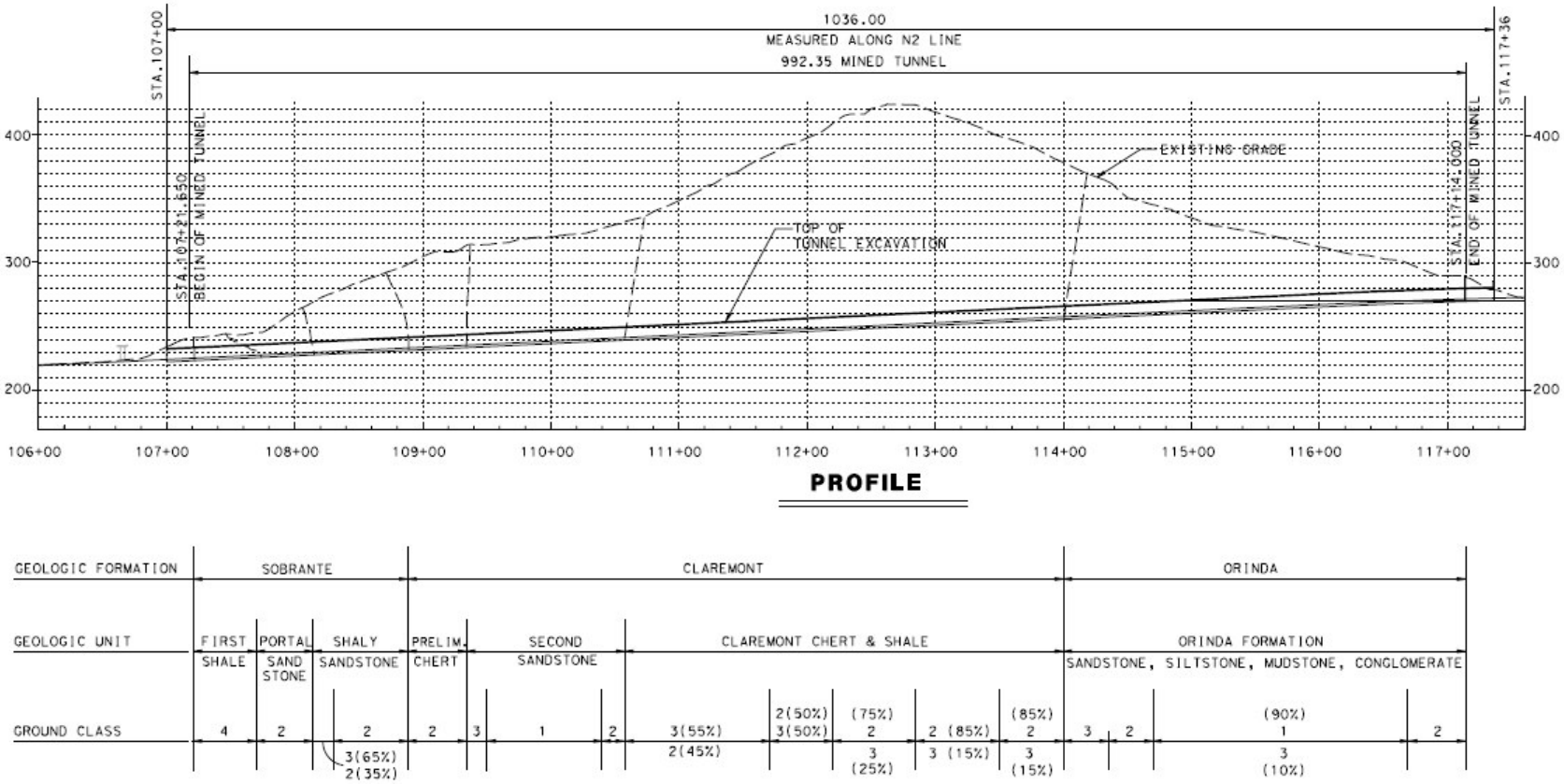

Figure 2: Estimated Distribution of Ground Classification

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KEY TO TERMS USED TO DESCRIBE THE PHYSICAL CONDITION OF ROCK CORE[1]

FRACTURE SPACING	SPACING/CORE RECOVERY LENGTHS	FRACTURE DENSITY[2]
(VC) Very closely spaced (crushed)	Less than 30 mm (<0.1 ft)	Very intensely
(Cl) Closely spaced	30 to 100 mm (0.1 ft to 0.3 ft)	Intensely
(Mo) Moderately spaced	100 to 300 mm (0.3 ft to 1.0 ft)	Moderately
(Wi) Widely spaced	300 mm to 1 m (1.0 ft to 3.0 ft)	Slightly
(VW) Very widely spaced	1 to 3 m (3.0 ft to 10.0 ft)	Very Slightly
(Ex) Extremely wide	Greater than 3 m (>10 ft)	Unfractured

BEDDING OR FLOW TEXTURE	THICKNESS/SPACING
(La) Laminated	Less than 10 mm (<0.03 ft (3/8 in))
(VTn) Very thinly bedded	10 to 30 mm (0.03 (3/8 in) to 0.1 ft)
(Tn) Thinly bedded	30 to 100 mm (0.1 to 0.3 ft)
(Mo) Moderately bedded	100 to 300 mm (0.3 to 1 ft)
(Tk) Thickly bedded	300 mm to 1 m (1.0 to 3.0 ft)
(VTk) Very thickly bedded	1 to 3 m (3.0 to 10.0 ft)
(Ma) Massive	Greater than 3 m (>10 ft)

ROCK HARDNESS	
(So) Soft	can be grooved or gouged easily with a knife, can be scratched with fingernail
(Lo) Low Hardness	can be grooved 1/16 inch (2 mm) deep with a knife with moderate or heavy pressure
(Mo) Moderately Hard	can be scratched with a knife with light or moderate pressure
(Ha) Hard	can be scratched with a knife with difficulty
(VH) Very Hard	cannot be scratched with a knife

ROCK STRENGTH	
(Fr) Friable	breaks with light to moderate manual pressure
(We) Weak	core or fragment breaks with light hammer blow or heavy manual pressure
(Mo) Moderately Strong	core or fragment breaks with moderate hammer blow
(St) Strong	heavy hammer blow required to break specimen
(VS) Very Strong	core or fragment breaks only with repeated heavy hammer blows
(Ex) Extremely Strong	core or fragment can only be chipped with repeated heavy hammer blows

RELATIVE WEATHERING			
	DECOMPOSITION	DISCOLORATION	FRACTURES
(Fr) Fresh	Unaltered; cleavage surfaces glistening	No discoloration	No stains or coatings
(Sl) Slight	No megascopic alteration of minerals; no grain separations	Slight and localized	Few stains on fracture surfaces
(Mo) Moderate	Slight alternation of minerals; cleavage surfaces lusterless/stained; partial separation of grains visible	Moderate discoloration, usually throughout	Thin coatings or stains
(Se) Severe	Moderate to complete alteration of minerals; feldspars to clay, etc.; rock is friable	Discolored throughout	Extensively coated with oxides, carbonates, or clay

KEY TO TERMS USED TO DESCRIBE DISCONTINUITES[1]

DISCONTINUITY TYPE (and dip inclination)
(Be) Bedding plane
(Fo) Foliation
(Me) Mechanical break (dip angle not recorded)
(Jo) Joint
(Sh) Shear or Fault
(Ve) Vein

SURFACE SHAPE
(Ir) Irregular
(Pl) Planar
(Wa) Wavy or undulating

APERTURE	
(Ti) Tight	No visible separation
(Op) Open	Amount of separation, staining or coatings on fracture surfaces, and fracture surface moisture conditions may be noted
(He) Healed	Degree of healing, (i.e., partial or complete), thickness and mineralogy/hardness may be noted
(Fi) Filled	Degree of filling, (i.e., partial or complete), thickness and type of filling may be noted

ROUGHNESS (note presence of slickensides or striations)	
(St) Stepped	Near normal steps and ridges occur on fracture surface
(Ro) Rough	Large, angular asperities can be seen
(Mo) Moderately rough	Asperities are clearly visible and fracture surface feels abrasive
(Sl) Slightly rough	Small asperities on the fracture surface visible and can be felt
(Sm) Smooth	No asperities, smooth to touch
(Po) Polished	Extremely smooth and shiny

Notes:

1. Based on US Bureau of Reclamation, 1998, Engineering Geology Field Manual, Second Edition, Vol.1.
2. Fracture density refers to the range of core recovery lengths for a given run and excludes mechanical breaks.

Figure 3: Rock Mass Description System

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