Earth Mechanics, Inc.
Geotechnical & Earthquake Engineering

TECHNICAL MEMORANDUM

March 3, 2003
EMI Project No. 02-158

California Department of Transportation, District 4
Office of Design Peninsula, 8th Floor
111 Grand Ave
Oakland, California 94612-0660

Attention: Mr. Skip Sowko, Project Manager

Subject: **Interpretative Geology and Seismicity**
Devil's Slide Tunnels Project
Contract 59A0234, Task Order 1

Dear Mr. Sowko:

Pursuant to your request, this Technical Memorandum was prepared to describe existing geologic and seismic conditions in the Bay Area region as well as in the Devil's Slide Tunnels Project areas. These conditions were interpreted from field data presented in our two Task Order 2A Technical Memoranda and the Task Order 2B Geotechnical Data Report.

We appreciate the opportunity to provide geotechnical and geological engineering services on the subject project. If you have questions or comments regarding this report, please contact our offices.

Sincerely,

EARTH MECHANICS, INC.

MK:JC:DHH:BAS

TECHNICAL MEMORANDUM

INTERPRETIVE GEOLOGY AND SEISMICITY

DEVIL'S SLIDE TUNNELS PROJECT

FINAL

Prepared for
Caltrans
and
HNTB Corporation

March 3, 2003

By:
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1.0 REGIONAL GEOLOGY AND SEISMICITY

1.1 General Features

The Devil's Slide Tunnels (DST) Project is located on the central California coastline west of the central San Francisco Bay. The regional terrain and tectonic setting of the project site is shown in Figure 1-1 and the seismic setting is shown in Figure 1-2a and b. The local seismicity and geology of the project area are also shown on Figure 1-3 and Figure 1-4, respectively.

In terms of its regional terrain and tectonic setting the project site lies along the western margin of the San Andreas fault system on the San Francisco Peninsula near the northern end of the La Honda structural and terrain block, between the San Andreas and San Gregorio branches of the fault system. The Santa Cruz Mountains, including Montara Mountain and its west-northwesterly San Pedro Mountain shoreline termination, form the topographic expression of this structural block at the latitude of the DST project. The La Honda block between the San Gregorio and San Andreas faults is approximately 10 km wide. The project site is about 2.8 km east of the offshore trace of the San Gregorio fault and 7.2 km west of the surface trace of the San Andreas fault (Figure 1-3). The DST project will be constructed in a mountainous, highly deformed terrane of Mesozoic-age crystalline igneous (granitic-like) rock overlain by a series of thrust sheets consisting in part of the same granitic rock and in part of late-Cretaceous- and early-Tertiary-age clastic sedimentary rock (Figure 1-4). The thrust and high-angle faults that cut the project area into plates, blocks, and wedges of varying dimensions do not appear to have originated in response to the stress regime of the modern San Andreas fault system. However, specific evidence as to the timing of this faulting is lacking.

1.2 San Andreas Fault System in the San Francisco Bay Region

The neotectonic regime of the San Francisco Bay region, including the project area, is an expression of predominantly transpressional stress-strain environment of the San Andreas fault system in this region. This regime includes the faults and folds representing direct mechanical deformation of the near-surface crust in response to tectonic stresses and the terrain features that have developed as blocks of the crust were uplifted or depressed, folded, and shifted laterally. The relationship between contemporary tectonic structures and the surficial landscape is evident in the terrain and tectonic setting of the region shown in Figure 1-1. The tectonic evolution of this terrain is described in the Seismic Hazard Study (EMI, 2001a).

1.3 San Andreas and San Gregorio Faults – La Honda Structural Domain

The two major strands of the San Andreas fault system bounding the La Honda block, as noted above, are the San Andreas fault and the San Gregorio fault, or, locally, the San Gregorio–Seal Cove fault. Both faults exhibit distinctive patterns of deformation along their principal traces and in the adjacent crust; these patterns vary along strike.

The northern peninsula segment of the San Andreas fault exhibits transpressional behavior, indicated by the linear rift topography of the main fault trace together with the uplift and shallow active reverse and thrust faults that follow the fault trace. This pattern dies out a few kilometers north of the DST project latitude and is replaced by the transtensional reach referred to as the Merced or Golden Gate Stepover. The transtensional reach is characterized by a local down-dropped block between the right-stepping strands of the San Andreas fault zone and by right normal mechanism earthquakes as shown in Figure 1-2b.

There are two on-land exposures of the San Gregorio fault between Monterey Bay and its intersection with the San Andreas fault north of the Golden Gate near Bolinas Bay. The more extensive of the exposures is the 25 km reach between Año Nuevo Point and San Gregorio, where the fault zone has a rift-like aspect with distinct right lateral deflection of crossing drainages. Closer to the DST project the 4 km Seal Cove reach lies along the landward (east) side of an uplifted slice of late Tertiary Purisima Formation that is probably a horst between the onshore trace and a parallel offshore trace. This is a transpressional feature whereas a down dropped block at Año Nuevo Bay to the south is transtensional. Overall, however, the tectonics of the San Andreas and San Gregorio faults are transpressional, as reflected by the uplift and internal compressional deformation of the La Honda structural domain. The overall uplift of this mountain block has occurred mostly during about the last million years, with several hundred meters of uplift of the coastal side of the block, having occurred in the last several hundred thousand years, indicated by the succession of uplifted wave-cut terraces extending southward from Half Moon Bay. Internal deformation of the La Honda block is indicated by folding and faulting of late Tertiary and early Quaternary-age strata, and by local warping of the wave-cut terrace in the Half Moon Bay area.

1.4 Seismicity of the San Francisco Bay Region

The pattern of seismicity in the San Francisco Bay region during the late Quaternary (including pre-instrumental historic time) corresponds generally to the fault pattern shown in Figure 1-2a. This includes both the major epicenter trends recorded since

about 1950, the traces of surface fault rupture or epicentral areas reported for earlier historic earthquakes, and other fault ruptures that produced pre-historic earthquakes and are known from published paleoseismic studies. Among these, the seismic sources of significant interest for the project are the local reaches of the San Andreas and San Gregorio faults.

1.4.1 Seismicity of San Andreas Fault, Merced - Golden Gate Right Stepover, and San Pedro Point Area

The central San Francisco peninsula and Merced-Golden Gate right stepover reach of the San Andreas fault (Figure 1-2b) have produced major earthquakes at intervals of around 150-250 years according to various paleoseismicity studies. The long-term average slip rate is estimated to be about 1.7 cm/yr. The USGS Working Group on California Earthquake Probabilities has provided an estimate that there is a 21% probability of a strong earthquake (>M6.7) occurring on the peninsula reach of the San Andreas fault within the next 30 years.

The most recent damaging shock to originate on this part of the San Andreas fault system was the M5.3 San Francisco earthquake of 1957. This occurred within the Merced-Golden Gate right stepover structure beneath Daly City and had an extensional focal mechanism (Figure 2.1.3 *in* Zoback et. al., 1999). Zoback et. al. propose that the M7.9 San Francisco earthquake of 1906 may well have nucleated in the stepover structure. This event is considered to approximately correspond to the maximum earthquake possible on the north-central reach of the San Andreas fault.

No significant earthquakes have been observed along the northern San Gregorio fault during historic time and recent instrumentally recorded seismicity has been limited to a diffuse scattering of small earthquakes mostly located south of San Gregorio. Paleoseismic studies along the onshore trace south of Seal Cove have revealed evidence of two large surface-faulting earthquakes (slip > 3 m) during the past 600 to 1,320 years.

Estimates of the slip rate along the northern San Gregorio fault have ranged from 0.05 to 1.6 cm/yr. The maximum earthquake considered possible for this fault is about M7.5.

Relocated epicenters for the period 1969-1995 and estimated areas of nucleation of large historic earthquakes in the southern San Francisco Bay region, as determined by Zoback et. al. (1999), are shown in Figure 1-2b. A larger scale plot of the same data for the northernmost peninsula and offshore Golden Gate platform area, showing focal mechanisms of representative events, is presented on Figure 1-2a. Figure 1-3 shows a still larger scale plot of terrain and epicenters in an area roughly centered at Point San Pedro and includes the adjacent reaches of the San Andreas

and offshore San Gregorio faults. This figure also shows a cross section through the DST project area to 14 km depth. Hypocenters of all earthquakes recorded between 1950 and early December 2001 within a 6 km-wide zone centered along this cross section are plotted on the section.

A later earthquake that occurred on December 24, 2002 is also plotted in Figure 1-3. This M3.6 shock was located beneath Pacifica and was the largest ever instrumentally recorded in the immediate area. Both the map and cross section plots illustrate the spatial separation between the Point San Pedro microseismicity cluster and the microseismicity associated with the San Andreas fault. Zoback et. al. (1999) discuss the Point San Pedro microseismicity as follows:

> "Seismicity in the Point San Pedro area occurs in a NNW trending cluster about 3.5 km long by 2.0 km wide. Fifty-seven $M_a \geq 1.0$ events have occurred here since 1969, the largest event being M_a – 2.5, however most events are in the range M_a = 1.0-2.0. This region exhibits swarm-like activity, with 49 of the 57 recorded events occurring in the 15 months between April 1991 and July 1992 and with 33 of those 49 events occurring in a 2-week period in November 1991. Focal depths of the Point San Pedro events range between 6.0 and 8.0 km. Focal mechanisms for the two largest events indicate dominantly right-lateral strike-slip faulting on NNW trending planes. Hypocentral locations suggest these events are probably not related to the San Gregorio fault. Their locations ~4 km NE of the easternmost mapped strand of the San Gregorio fault zone and at depths of 8 km imply an average dip of about 63° NE for this fault, shallower than the 75°-81° NE dips of the NNW trending nodal planes of events 17 and 18. Alternately, this seismicity could be associated with the Pilarcitos fault: however, the N55°W strike of that fault is significantly more westerly than the N25°-28°W strike of the nodal planes."

The above discussion and analysis is particularly of interest because it shows that the seismicity occurring directly beneath the DST project area, at depths of between 5 and 12 km, appears to occur within a stress field not directly related to the shallow dipping thrust faults that largely define the near-surface structure in the area.

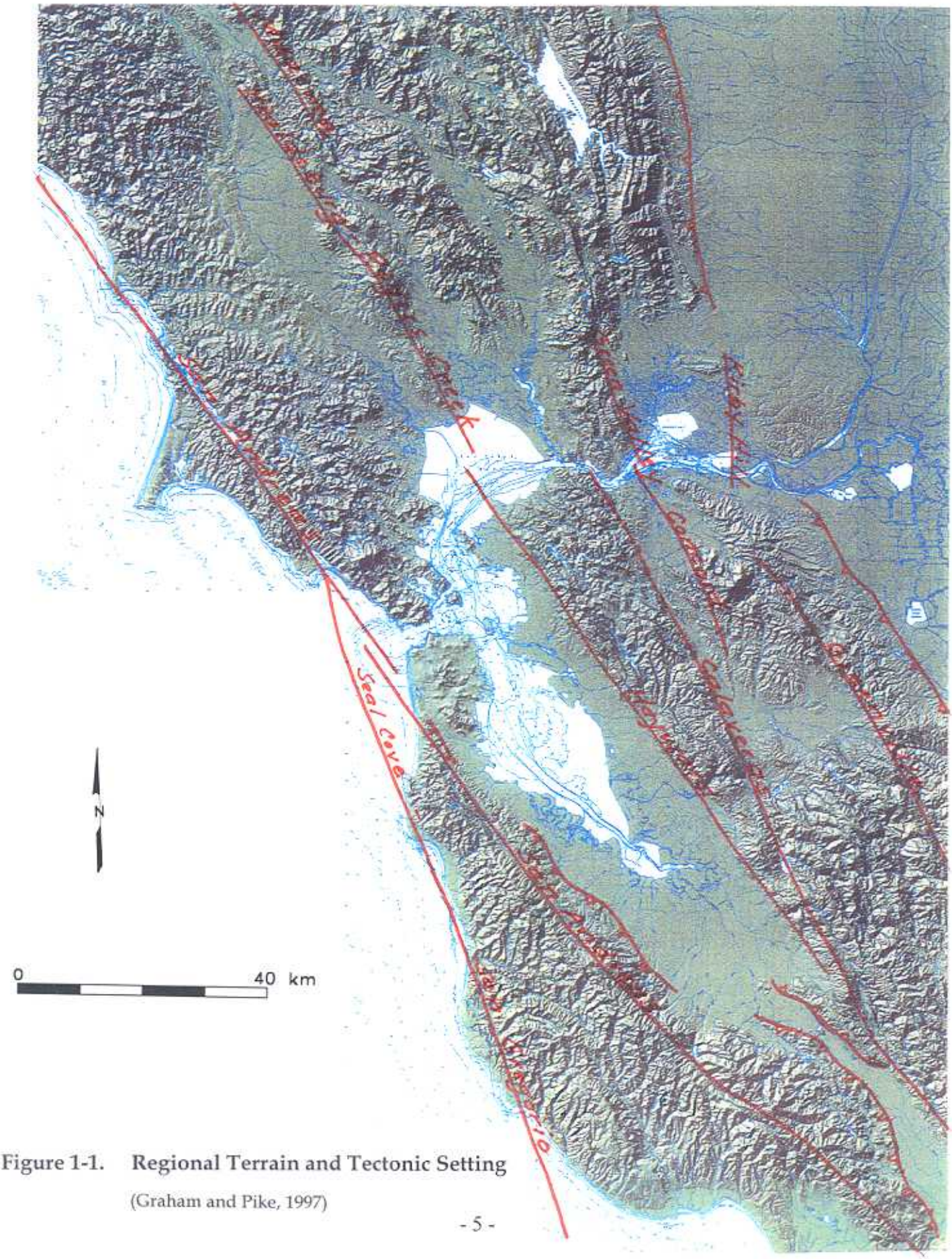
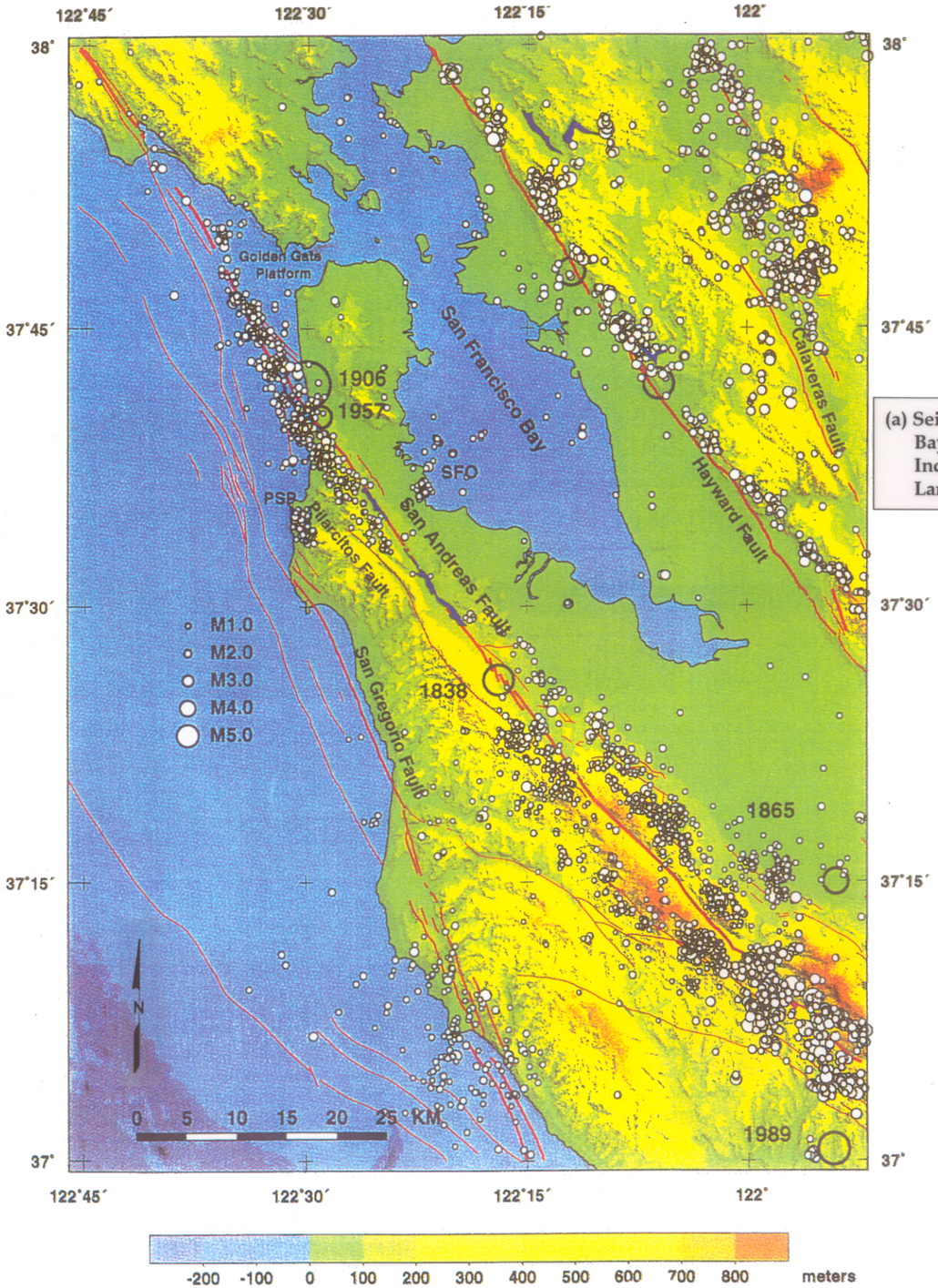


Figure 1-1. Regional Terrain and Tectonic Setting

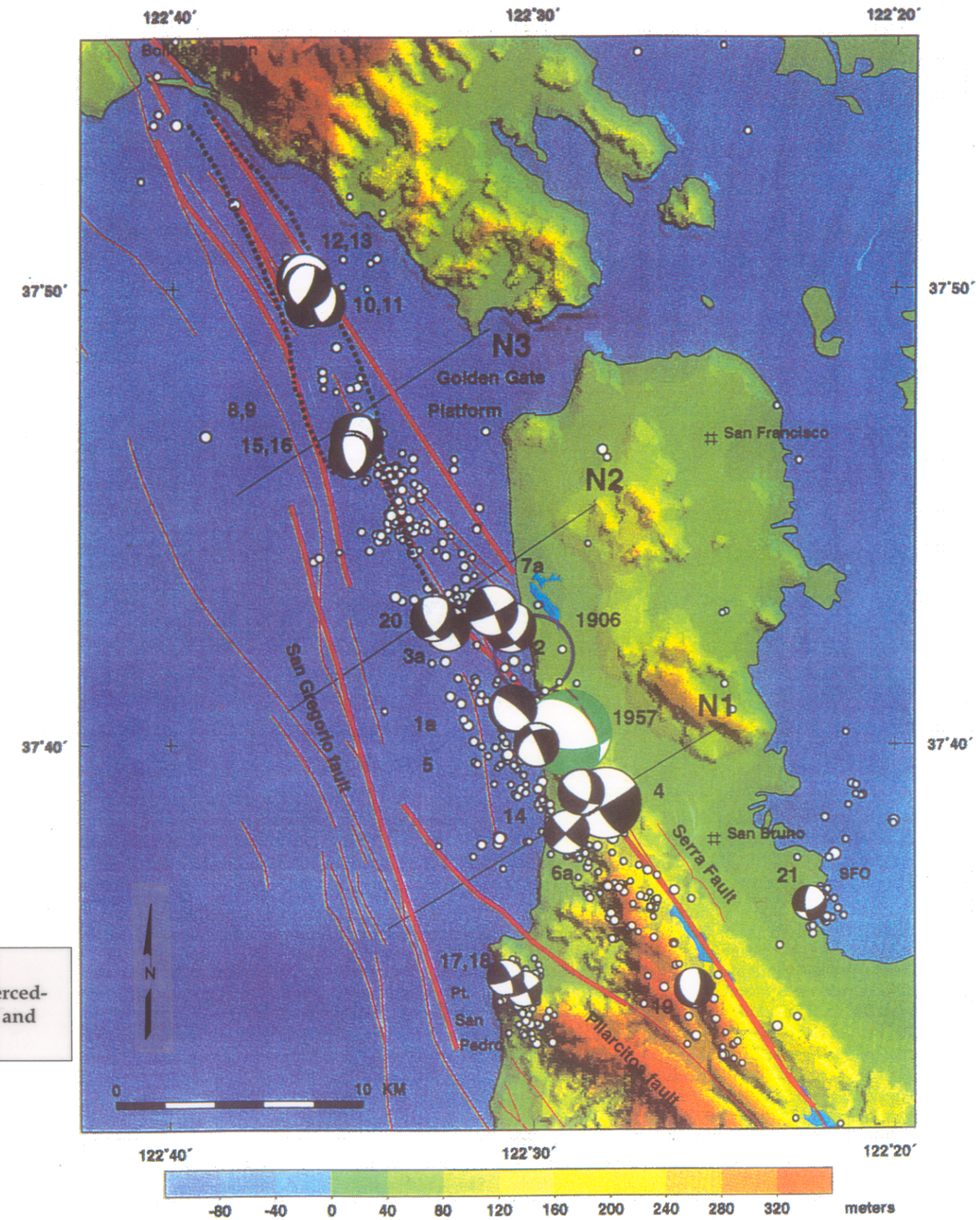
(Graham and Pike, 1997)



Relocated seismicity ($M_d \geq 1.5$) for San Francisco Peninsula together with relocated seismicity ($M_d \geq 1.5$) in the San Francisco bay block [*Olson and Zoback*, 1998], and NCSN locations of $M_d \geq 2.0$ events in the East Bay and Loma Prieta aftershock region. Seismicity is for the time period 1969–1995.

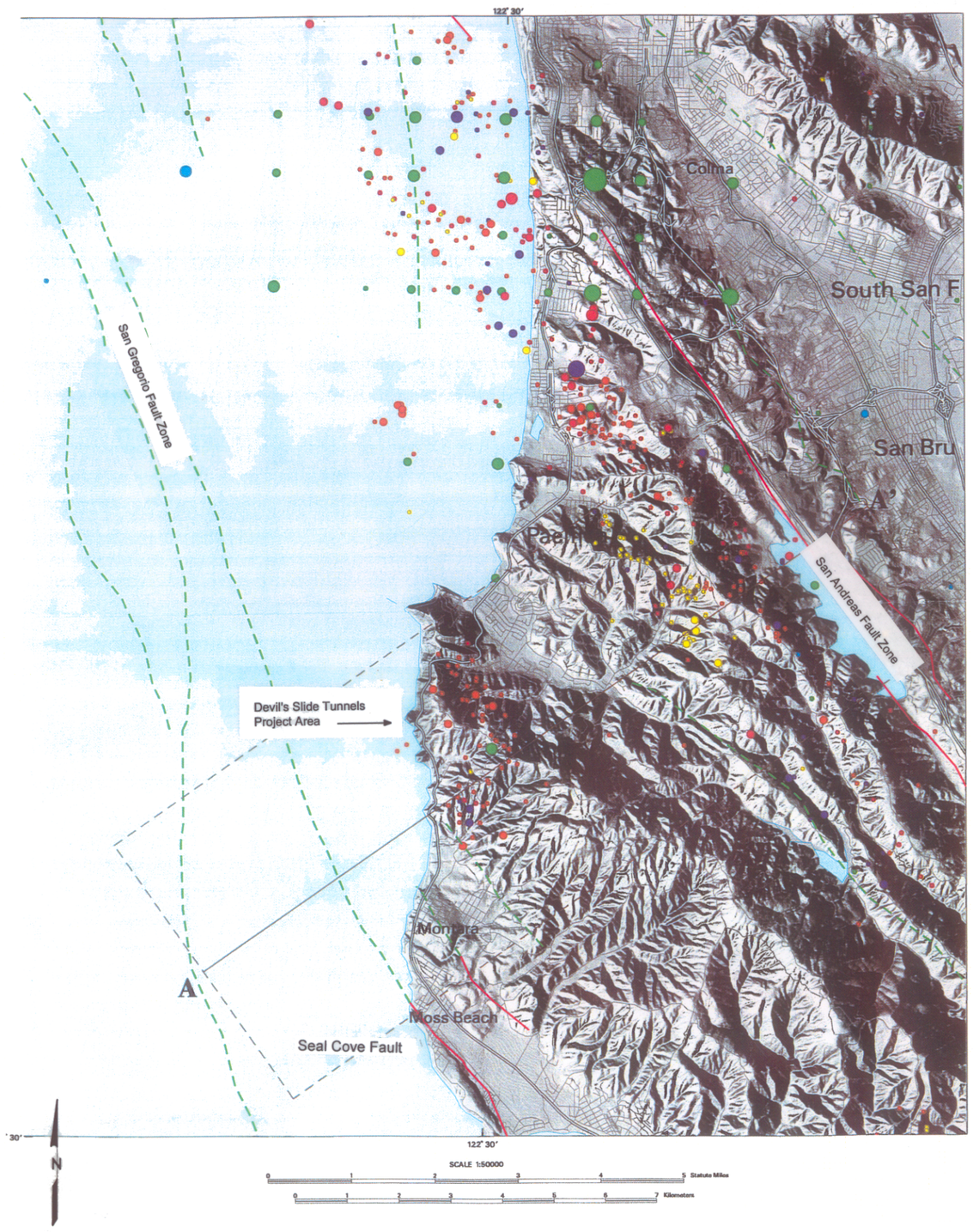
(a) Seismicity of San Francisco Bay and Coastal Region, Including Epicenters of Larger Historic Earthquakes

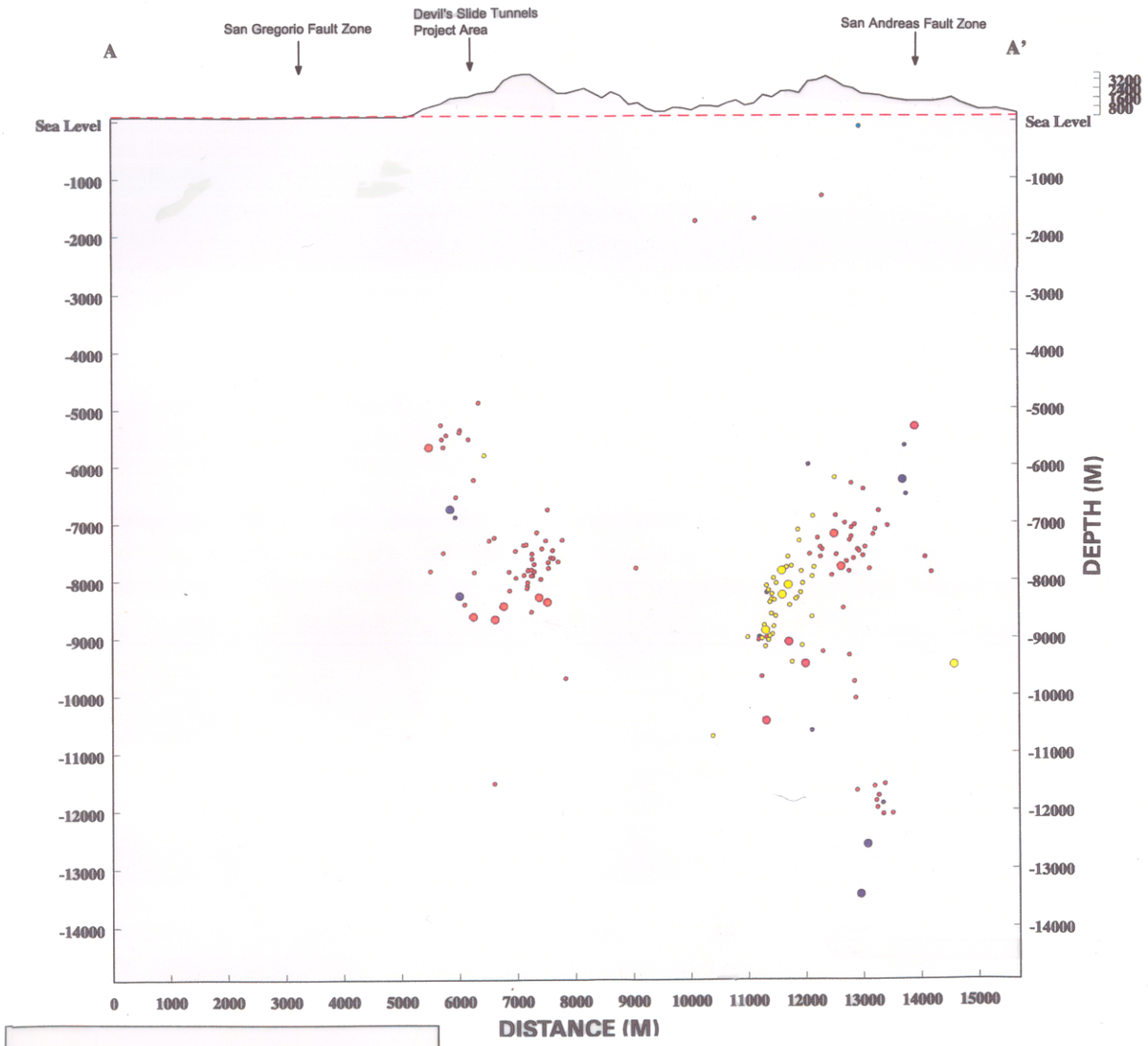
(b) Seismicity and Focal Mechanisms in the Merced-Golden Gate Stepover and San Pedro Point Area



Seismicity and focal mechanisms in northernmost peninsula and Golden Gate platform area. Events are $M_d \geq 3.0$ events except for a few smaller events

Figure 1-2. Regional Seismicity





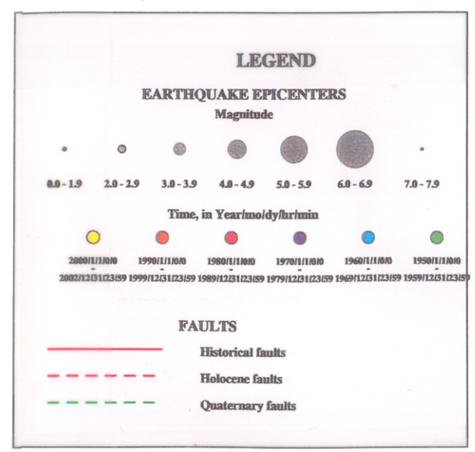
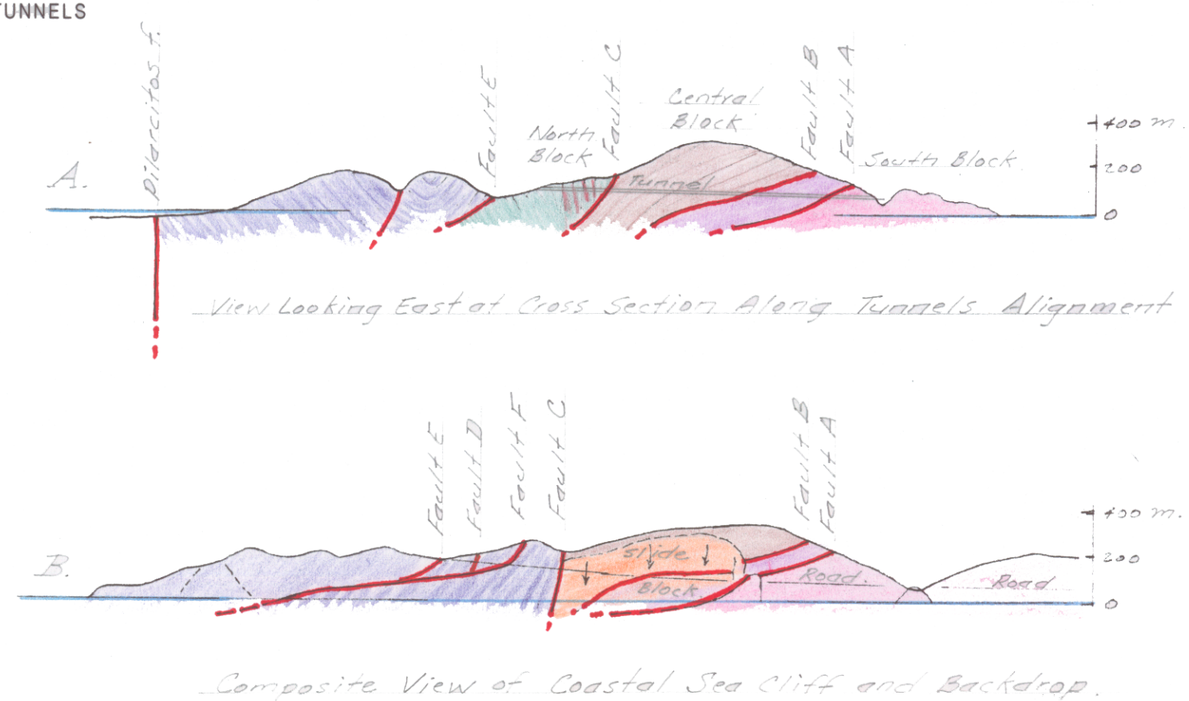
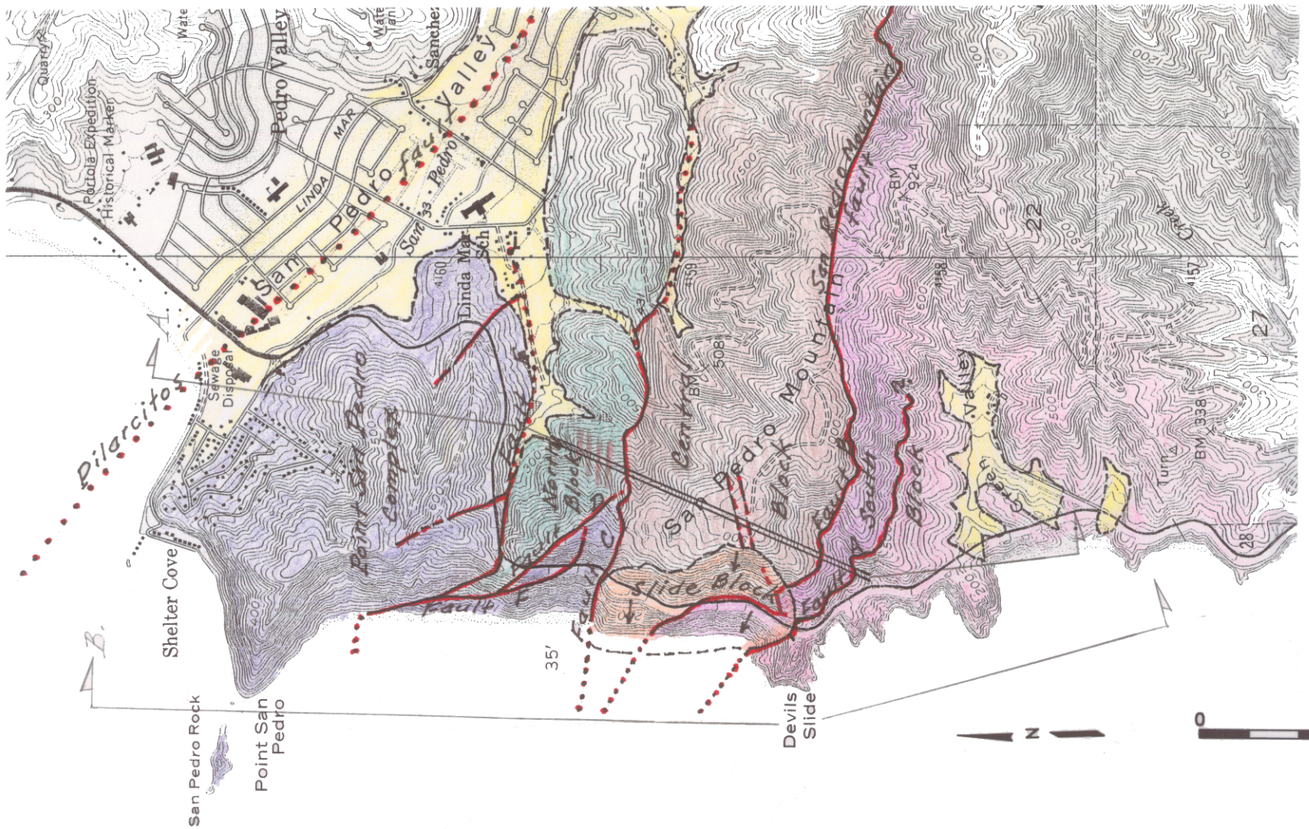


Figure 1-3. Site Seismicity





Stratigraphy

Surficial Units

Surficial deposits undivided, where mapped separately

Devils Slide block landslide and overlying surficial deposits

Point San Pedro stratigraphic complex

Interbedded shale, sandstone and conglomerate, undivided

North Block – unnamed strata of Shamrock Ranch.

Predominantly thin to medium bedded interlayered fine-grained sandstone and clay-siltstone, with one or more beds or lenses of sandy conglomerate low in the section. The North Block section is disturbed by a wide shear zone consisting of many steeply south dipping to near vertical planar zones of fault gouge, some of which enclose blocks of rotated and independently folded strata. The North Block is separated from adjacent structural blocks on the north, west and south by intervening faults E, D, and C, respectively.

Central Block – unnamed strata of San Pedro Mountain.

Predominantly interlayered thick beds of massive sandstone, conglomerate, and clay-siltstone, structurally overlying Granitic Rock of Montara Mountain and truncated on the north by "Fault C". Local areas of specific lithology within the Central Block are color coded on the map, but the strata of San Pedro Mountain are not well enough exposed to be mapped consistently on the surface.

South Block - Granitic rocks of Montara Mountain

Predominantly massive quartz diorite, locally grading to granodiorite; locally with irregular quartz and felsic dikes. "Basement rock" of the San Pedro Mountain region.

Fault A" hanging wall quartz diorite

"Fault A" footwall quartz diorite

Symbols

Geologic contact involving surficial deposits

Fault, dashed where approximately located, dotted where concealed

Figure 1-4. Site Geologic Map, Cross Section, and Stratigraphy

2.0 SITE GEOLOGY

2.1 General Features

The DST project area is located in mountainous terrain immediately inland from the sea cliff and landslide complex that forms the seaward termination of San Pedro Mountain ridge. Resistant beds of massive sandstone and conglomerate of the provisionally named "San Pedro Mountain Sequence" form the crest of this northwest-aligned ridge. The southwest flank of the ridge is eroded into the underlying, mostly deeply weathered, Montara Quartz Diorite. Localized resistant zones within the quartz diorite form promontories reaching 100 m to 200 m elevation along the coastline opposite and south of the south flank of San Pedro Mountain and the south end of the DST project. The north portals of the tunnels will be located in a northeast-aligned spur ridge along the north flank of San Pedro Mountain ridge. This spur ridge extends into the valley of the Shamrock Ranch, which parallels San Pedro Mountain ridge and drains eastward into San Pedro Valley.

The geology, including structure and approximate stratigraphy of the DST project area and vicinity, is shown in Figure 1-4. The geologic map and cross section emphasize the thrust fault-dominated structural framework of the area, consisting of a sequence or "stack" of thrust plates separated by moderately to gently north-dipping thrust faults. High-angle faults are also important components of the structural framework, particularly in the northern part of the project area. It is not known whether the high-angle faults displace the thrusts or vice versa, since there are contradictory indications of their relationship among the available exposures in the area.

The name "Devil's Slide" originally referred to the notably planar 45° north slope of the most prominent promontory along the local reach of coastline. Although this topographic name is still assigned on USGS topographic maps, "Devil's Slide" is now commonly understood to refer to the block landslide complex that exists in the sea cliff extending north from the Devil's Slide promontory. The historic difficulties of maintaining Route 1 in a usable condition across the unstable surface of this landslide complex ultimately led to the DST project as a solution to the problems of keeping this transportation link open.

2.2 Stratigraphy

The stratigraphy of the DST project vicinity consists generally of Mesozoic granitic basement rock, and a structurally overlying complex of Tertiary clastic sedimentary

rocks (Figures 2-1 and 2-2). The sedimentary rocks are present in at least five fault blocks, which results in uncertainly as to the actual stratigraphic succession. Previous stratigraphic work, as summarized by Pampeyan (1994) involved several interpretations as to age, succession and stratigraphic correlations and resulted in assignment of all of the sedimentary rocks on San Pedro Mountain to an upper unit. Strata of the lower unit are mostly present along the north flank of the separate hill located across the valley of Shamrock Ranch from the DST project, facing Shelter Cove and lower San Pedro Valley.

The two-unit stratigraphic grouping adopted by Pampeyan is appropriate for regional-scale mapping, but it does not adequately differentiate the several stratigraphic groups that characterize the geology of the DST project. These stratigraphic groups are contained, as noted above, in at least five fault blocks, each of which is distinct from the others. For the purposes of reference and description, we have adopted a system of three block units for the sedimentary rocks and the granitic basement unit. The blocks in the immediate tunnels area are keyed to their relative position along the tunnels alignment, as South (granitic rock), Central, and North Block units. All strata present across faults located north and west of these structural blocks are referred to as the "Point San Pedro stratigraphic complex."

The rocks present in the South, Central and North blocks of the DST project area have been explored by 23 EMI and 14 WCC core holes, by trenches in three areas, and by mapping and sampling available outcrops. All core recovered from these borings was logged geologically and eight of the EMI borings were logged by down-hole video and acoustic imaging. Petrographic thin-section analyses were performed on 31 samples from both cores and outcrops during the EMI and WCC investigations. This work has provided the principal database for characterizing the stratigraphy of the three structural blocks of the DST project.

2.2.1 South Block

This block consists entirely of crystalline igneous rock of the "Granitic Rock of Montara Mountain" (Pampeyan, 1994). Pampeyan notes that rock of this general unit varies in composition locally and has been assigned petrologic names ranging from tonalite to quartz diorite by different researchers. Petrographic analyses of samples from the DST project area show the unit locally ranges in composition from granodiorite to quartz diorite. In this discussion, it is referred to only as quartz diorite, crystalline igneous, or granitic rock.

Although the quartz diorite forming the South Block of the DST project area probably originated as a massive, fairly uniform body of plutonic igneous rock, it has been variably affected by hydrothermal alteration, secondary calcite mineralization, mylonitization and mechanical degradation by pervasive fracturing

and local faulting and intense shearing, all followed by weathering ranging from slight alteration along deep fractures to complete in-place alteration to clay, quartz grains, and oxide minerals. In addition to the protolith quartz diorite, the unit contains late magmatic stage irregular dikes of quartz and felsite. Because of the nearly pervasive alteration and tectonic deformation of the quartz diorite, relatively little of it now has much mechanical strength. This is shown in the field by the rarity of outcrops in the hills and by the propensity of the rock to break down mostly to gravel and sand in the surf zone at the base of sea cliffs. This observed low-strength character is confirmed in the results of laboratory testing of unconfined compressive strength, which are generally low.

In the South Block of the DST project area, the quartz diorite can be subdivided into several categories of condition and engineering properties. The primary subdivision is based on position relative to Fault A, the two categories being the hanging wall rock above the fault and the footwall rock below the fault. The footwall rock is further divided into three subunits:

(1) Mylonitized rock present in a zone directly underlying Fault A;

(2) Intact, moderately strong, pervasively jointed rock forming the south portal rock slope and east-facing rock slope; and

(3) Massive rock characterized by granular disintegration and intense weathering alteration underlying the South Rock Cut and Spoil Disposal areas.

The distribution of the hanging wall unit and three footwall subunits is reflected in the form of the coastline opposite the DST project area. There, the generally pervasively fractured hanging wall unit is present only within the down-dropped slide block, but has remained mostly intact within the block. This unit shows no greater resistance to sea cliff erosion than the thinly interbedded shale and sandstone that forms the sea cliff north of Fault C, with resulting development of a grossly linear cliff line above a beach largely devoid of intact blocks of quartz diorite.

The coastline changes dramatically at Fault A (Figure 1-4). The exposed surface of Fault A forms the planar, 45°, north slope of Devil's Slide Promontory. This promontory juts out sharply from the coastline and rises to an elevation of 130 m, with its south side forming an essentially vertical cliff. It consists of highly resistant recrystallized and recemented mylonitized quartz diorite. The shear fabric of this rock mass approximately parallels the attitude of the Fault A surface, and is prominently visible in the southern cliff wall of the promontory.

South of the Devil's Slide Promontory, the coastline features alternating smaller joint-bounded promontories and coves, which clearly delineate the distribution of footwall quartz diorite subunits b (jointed moderately hard rock) and c (with more intensely weathered, relict joints and fractures).

Thirteen core borings have been drilled in the quartz diorite within the DST project area. The rock encountered in these borings relative to the project features and quartz diorite subunits is as follows, listed from south to north:

Boring	***Quartz Diorite Subunit***
South Rock Cut	
02-15	Footwall subunit c
02-13	
02-14	
P-3-96	
South Portal	
P-2-96	Footwall subunit b
P-1-96	
02-2 / 2A / 2B	
Tunnel NB Sta. 118+50 to 120+10	
02-21 (below approx. El. +100 m)	Footwall subunits a and b
Tunnel, NB Sta. 120+10 to 124+00	
02-21 (below approx. El. +186 m)	Hanging wall unit
P-14-96	
P-9-96	
02-5	

Representative views of outcrops of the various South Block quartz diorite subunits are shown on Photos P-1 to P-4. Petrographic descriptions and photomicrographs of petrographic thin sections of outcrop and core samples are presented in Appendix C-4 of the Geotechnical Data Report (EMI, 2003).

2.2.2 Central Block

The "Central Block" of the DST project corresponds to the central upper mass of the San Pedro Mountain ridge overlying the quartz diorite of the South Block across the gently north-dipping tectonic contact formed by Fault B (San Pedro Mountain fault). The Central Block stratigraphy consists entirely of a sequence of sandstone, conglomerate and claystone-siltstone beds. The aggregate thickness of this sequence along the DST alignment is about 290 m. This thickness, however, is a minimum for the original section since the lower part is faulted out along Fault B and the upper part is partly faulted out and partly removed by erosion.

The 290 m aggregate thickness comprises of about 108 m of sandstone in six main beds, 82 m of conglomerate in three main beds, and 102 m of claystone–siltstone in five main beds. The maximum thickness of claystone–siltstone and sandstone intervals is about 60 m each. The maximum conglomerate interval is about 35 m. Very little of this rock is exposed in outcrop because the Central Block narrows as it approaches the coast line sea cliff at Devils Slide and nearly all of the Central Block section along the coastline is displaced and mostly obscured by the slide complex. Consequently, the Central Block stratigraphy is known mainly from the eleven exploratory borings that have been drilled into it along and near the alignment. These are, from south to north, borings P-9-96, 02-5, P-5-96, P-8-96, 02-6, 02-6A, P-12-96, P-13-96, 02-7, 02-7A and 02-8B. Several additional borings previously drilled by Caltrans to explore the landslide complex and the proposed deep cut across San Pedro Mountain ridge that would have been required for the Martini Creek Bypass, also penetrated parts of the Central Block stratigraphic section, revealing clastic sedimentary rocks similar to those present along the DST alignment.

The predominant Central Block rock type, sandstone, ranges in texture from very fine to very coarse grained, the latter grading to pebbly or conglomeratic sandstone, or sandy conglomerate in some intervals. The sandstone is heterolithic, mostly consisting of quartz and feldspar sand grains, and lithic fragments in a silty, calcite-cemented matrix. Views of outcrops of Central block massive pebbly to coarse-grained sandstone are shown on Photo P-5. Views of claystone-siltstone interbeds are shown on Photo P-6.

2.2.3 North Block

The northern reach of the proposed tunnels is within a northeasterly trending ridge on the north flank of San Pedro Mountain. This part of the tunnels alignment is referred to as the North Block.

Exploration of the North Block area was accomplished in stages, beginning with the reconnaissance surface mapping and drilling of borings P-96-6 and P-96-7 during the 1996 Feasibility Investigation. This was followed by more detailed mapping of accessible outcrops and the cut bank along the ranch road crossing the North Block area in 2001 and early 2002, and finally by the Phase 2B exploration consisting first of excavation, logging, and backfilling of trench T-3, followed by drilling, low angle borings 02-11, 02-11A, and 02-16 at and near tunnel grade, and drilling slant borings 02-8A, B, and C, 02-12, and 02-18A and B downward toward the tunnel bores from the crest of the North Block ridge. The relatively greater density of exploration of the North Block area compared to the Central and South Block areas resulted from concern about the evidence of extensive shearing and artesian groundwater in boring P-96-7, which had been drilled downward into the slope beneath the

southbound bore, and also about possible landsliding along the slope where the North Portal excavations were to be made.

Trench T-3 provided a continuous exposure of the entire North Block rock section extending from boring P-96-7 along the ranch road to the nose of the ridge 170 m to the north. Of this, approximately the southerly 100 m extended across the area of the portal excavations and northernmost tunnel bores. This actually crossed about 80 m of the 200m of stratigraphic section that will be penetrated by the tunnels in the North Block. The 80 m of trench exposure, however, provided a cross section at approximate tunnel grade, of the entire width of the planned North Portal excavations.

In general, two types of geologic conditions were exposed along the 170 m extent of trench 02-T3. (Note: the stationing in the following three paragraphs refers to the 02-T3 stationing of Appendix D-1 of the 2003 EMI Geotechnical Data Report, not the tunnel alignment stationing). Between Sta. 20+00 and the north end of the trench at the nose of the North Portal ridge, at Sta. 170+00, the trench revealed a mostly intact section consisting of thin to thick-bedded, moderately to steeply south to locally west dipping sandstone, with one approximately 28 m thick sandy conglomerate interbed. The sandy conglomerate was present between Sta. 92+00 and 132+00.

Structural discontinuities were identified at four locations within the entire length of trench (Sta. 20+00 to 170+00). These consisted of

(1) A fault marked by a 10-cm thick zone of tight fault gouge with shear fabric parallel to the N85^{o}W, vertical orientation of the fault;

(2) A fault oriented east-west and dipping 55° south, also marked by a 10-cm thick gouge zone, at Sta. 52+50;

(3) A small fault oriented N40^{o}E, dipping 30°SE at Sta. 70+00; and

(4) A complex of faults, shears, and local folding between Sta. 148+00 and 153+00.

More deformation was evident in the Sta. 2+00 to 20+00 interval of trench 02-T3. There a partly overturned fold with axis striking approximately N30^{o}W is present in a structural block isolated between two pronounced fault zones. The northerly zone, present between Sta. 16+00 and 19+00, is oriented between E-W and N70^{o}E, dips about 70°SE and consists of a 1.5-m thick shear-gouge zone. The southerly zone at Sta. 4+00 is oriented about parallel to the former one but only contains 5 to 10 cm of gouge. The bedding at the extreme south end of the trench is oriented similarly to that north of the rotated structure between the faults at Sta. 4+00 and 20+00, striking N80^{o}E and dipping 50°SE

Rocks at the north portal consist primarily of fine-grained sandstone and siltstone with a few interbeds of claystone. Claystone and siltstone comprise only minor interbeds at the location of the north-bound portal, but within a short distance to the south claystone and siltstone ("shale") beds increase in abundance to form a major component of the rock mass. The fine-grained rocks were referred to as shale in the previous reports (WCC, 1996) but fissility is very rare so the bulk of the rock is claystone, siltstone, or mudstone. No more than 5-10 % of the rock is true shale. The geotechnical properties of the rocks are summarized in the Geotechnical Data Report (EMI, 2002). Conglomerate also occurs in the north block but is present north of the proposed tunnel (Figure 2-4) and therefore will not be a factor in tunneling.

The rocks are commonly decomposed to intensely weathered to depths (measured normal to the slope face) of 5 to 10 m and moderately weathered to more than 15 m, except at boring 02-16, which encountered slightly weathered to fresh rock at a depth of only about 6 m.

The shallow occurrence of fresh rock in 02-16 could be explained by the idea that it was drilled in a landslide back scar. That is, a slump occurred within surficial weathered material and moved the weathered rock downslope into the adjacent ravine exposing fresh rock in the scar. Apparently, the slide debris has largely been removed by subsequent erosion within the ravine.

The rocks are intensely weathered in approximately the upper 5 m to moderately weathered in the upper 10 to 15 m (measured normal to the surface slope). Below about 15 m, the rocks are unweathered except in two zones at 52-54 m and 63-82 m in boring 02-11 and at 62-67 m and 75-84 m in boring 02-11A.

The rocks in the North Block area generally strike in an east-west to northwest direction, ranging from about N45^{o}W to N70^{o}E. Most commonly, the strike is within about 20° of east-west. These rocks generally dip at moderate angles (45° to 60°) southwest to south-southeast at the surface, and gradually steepen within the mountain (i.e. southerly) to about 70-80 degrees. Abundant graded bedding indicates the entire sequence is overturned, that is, the stratigraphic top of the bedding is to the north. The rocks are generally well bedded with bed thicknesses ranging from laminations to a few centimeters (<10cm). Bedding plane separations commonly range from laminations up to about 30 cm thick.

The North Block is mostly intensely to very-intensely fractured with RQD generally zero. Joints generally have small apertures and are clean or have clay fill and oxidation. Joint roughness ranges from smooth to stepped surfaces, but most joints are rough to moderately rough. The high degree of fracturing combined with the thin bedding results in a highly fragmented rock mass that rarely produces any fragments as large as boulder-size, and even cobble-size fragments are few.

There are several faulted and sheared zones in the North Block, which are collectively referred to as the "North Block Shear Zone". The individual shear zones contain sand-sized fragments in a clayey matrix with abundant polished and slickensided rock surfaces. Slickensides appear randomly oriented. Similar sheared rock, but without deformation of adjacent beds, also occurs at various locations in the fined grained rocks of the North Block area. These shear zones consist of intensely fractured and contorted claystone beds between rigid tabular unbroken sandstone beds.

Horizontal boreholes 02-11 and 02-11A revealed two major shear zones and several minor shear zones. As discussed under section 2.4 below these shear zones were probably encountered in boreholes 02-8A and C and 18A and B as well as P-96-7. The major shear zones occurred at about 55 to 70 m and 100 to 115 m in from the borehole collar. Due to the abundance of random shearing, a precise width and orientation for these major shear zones is difficult to determine. The first major shear zone at 55-70 m is associated with a fold zone and faulting that resembles the shear/fold zone exposed near the western end of Trench 02-T3.

Discontinuity orientations are difficult to summarize because the rocks are so intensely jointed, faulted, sheared, and thinly bedded. The dominant joint set appears be the bedding-plane joints which are oriented similar to bedding in a general east-west to west-northwest trend with moderate (45 ^{o}) to steep (70-90°) southerly dips (see Figure 2-2)..

Secondary discontinuity orientations are predominantly joints oriented approximately orthogonal to bedding joints; that is, strikes are north to north-northwest and dip steeply (80-90°) eastward, or westerly at low angles (0-40°). However, random jointing is also common in the rocks of the North Block.

2.3 Hypogene Alteration, Cataclasis, Secondary Mineralization and Weathering

The entire rock section in the DST project area has been affected by hypogene hydrothermal alteration and low-grade metamorphism, followed by cataclasis and then by pervasive secondary calcite mineralization. Additionally, all near-surface rock is affected by oxidation and dissolution, as well as mechanical disintegration resulting from weathering. Most of the weathering occurs within the vadose zone, above the level of saturation or "water table", but some fractures exhibit oxidation and clay alteration at depths well into the zone of permanent saturation.

The hypogene alteration has affected both the basement quartz diorite and the structurally overlying sedimentary rocks and is therefore of Tertiary age rather than

of earlier Mesozoic late-stage magmatic origin. Since both the hydrothermal alteration and the subsequent cataclasis deformation occurred under conditions of elevated temperature and high confining pressure, both processes may have occurred during the time of elevated temperature and tectonic deformation associated with the northward migration of the Mendocino triple junction more than 10 million years (e.g. McLaughlin et. al., 1996).

2.4 Structure

The principal features of geologic structure in the DST project area and vicinity are shown in plan and cross section on Figure 1-4. Traces of faults and bedding attitudes in the immediate DST project area are shown in more detail in Figure 2-1. Geologic cross sections along and transverse to the northbound tunnel alignment are shown in Figure 2-2a and b. Traces of extensive faults and joints, and joint attitudes in the South Portals, Approach, and Rock Cut area are shown in Figure 2-3.

The overall geologic structure of the Point San Pedro–Devil's Slide area can be represented as a sequence or "stack" of at least three gently north-dipping thrust plates. The rocks in the sedimentary section contained in the upper two plates are further deformed by block tilting, and rotation, folding, and displacement by high-angle faults. These rocks are separated from the lowest plate by the San Pedro Mountain fault (designated "Fault B" in this report). Fault A, the basal thrust, is developed within the quartz diorite basement rock where exposed in the coastal DST project area. This fault has not been mapped in the granitic terrain east of the coastal area and the westward extension of its trace is offshore. Therefore, it is not possible to determine whether Fault A underlies all of the fault and fold structures present north of Devil's Slide promontory or whether it is displaced by the high-angle Fault C.

The near-vertical Fault C, where exposed in the coastal sea cliff, separates unlike sedimentary rock sections, with resistant massive Central Block sandstone, conglomerate and underlying clay-siltstone on the south and thinly interbedded sandstone and claystone–siltstone on the north. A generally similar relationship exists where this fault intersects the DST alignment, although the stratigraphy on the north side of the fault there appears somewhat different from the section present along the coast. The coastal and tunnel alignment area sections also dip in opposite directions and are separated by the high-angle NW-SE striking Fault D.

The rocks and structure of the project area are structurally separated from the rocks exposed along the coast north of Fault C and north of the valley of Shamrock Ranch by Faults D, E and F. Fault E is the uppermost of the thrust faults recognized in the area and Fault F is a reverse fault that branches upward from it and extends down

the valley of Shamrock Ranch to the east.

The six principal faults intersecting the DST alignment are discussed in more detail in the following Sections 2.4.1 to 2.4.4.

2.4.1 Fault A

Fault A is the southernmost and structurally lowest of the faults that cross the tunnels alignment. Fault A was intersected at a slant depth of about 120 m in boring 02-21. The structure was referred to as the "thrust fault" in previous reports by Caltrans geologists, and might properly be called the Devil's Slide fault because the planar north-facing slope of the Devils Slide Promontory is the feature identified by that name on USGS topographic maps (see Figure 2-1). Fault A can be traced along a strike length of at least 1,000 m and it probably continues farther to the northwest, offshore, and to the southeast along the south flank of San Pedro Mountain. In addition to its spectacular surface expression as the north slope of Devils Slide promontory, Fault A is cross-cut and well exposed in the walls of the adjacent Route 1 "saddle cut" (see Photo P- 7). The fault is also exposed in an eroded cut about 160 m south of the saddle cut, and it can be located at points offshore to the northwest and along the upper slopes of the east rock slope to the southeast by the pattern of prominent outcrops formed by the generally resistant altered quartz diorite in its footwall side. The exposed surface of Fault A on the Devil's Slide Promontory strikes N49^{o}W and dips about 44° NE over the upper surface of the exposure but the dip shallows to less than 25° at sea level. We consider it likely that the dip of Fault A shallows to only a few degrees further down dip, and that the clayey shear zone encountered between sea level and El. -10 m in Caltrans boring P-1-88 probably represents Fault A, as plotted on the cross section of Figure 2-2b, as well as the sole of the main Devil's Slide slump block. The likely existence of a sub-horizontal fault plane in this location would appear to offer an explanation of how the rotational block slump of the main landslide mass could have a basal failure surface within quartz diorite bedrock.

A cross section of Fault A is well exposed in the Route 1 "saddle cut" through the Devil's Slide promontory. There it appears as a narrow planar surface of dislocation and shearing separating weathered, highly fractured rock in the hanging wall from relatively fresh, less-fractured, and much-stronger and more-resistant rock in the footwall. This appears to be characteristic of conditions along Fault A throughout its known extent.

2.4.2 Fault B

Fault B, called the "oblique fault" in previous Caltrans geology reports (e.g. Beeston and Gamble, 1980) and formally named the San Pedro Mountain fault in Pampeyan

(1994), forms the tectonic contact between quartz diorite basement rock and the overlying Tertiary-age clastic sedimentary rock section, in the DST project area. This fault has been mapped by the USGS over a distance of about 8 km from its shoreline exposure eastward to the vicinity of Pilarcitos Reservoir where it is probably cut off by the Pilarcitos fault. Fault B may be displaced down dip by the underlying Fault A.

Fault B was intercepted at depths of 123 m in boring P-9-96 and 198 m in boring 02-5. Preserved within the Devils Slide slump block, the fault is exposed along the lower seaward slope of San Pedro Mountain. In its sea cliff shoreline exposure, the entire width of Fault B is perfectly displayed. There, the slump block has moved as a unit, including Fault B, so the fault structure and contacts are preserved, though out of place, by the amount the block has rotated out of the mountain-front slope. In this exposure, the hanging wall of Fault B is black shale (claystone/siltstone), which grades downward into pervasively sheared and plastically deformed fault gouge. The shear zone is notable for the boudins of hard sandstone within the shear-deformed shale (claystone/siltstone). The sheared shale (claystone/siltstone) is actually fairly resistant and may have been hardened by hydrothermal alteration. The footwall rock is crushed and sheared, but altered and recemented, cataclasite derived from the underlying quartz diorite.

It is noteworthy that the sea cliff morphology does not significantly reflect the presence of Fault B, in contrast to the prominent expressions of Fault A to the south and Fault C to the north. Rock conditions along and below Fault B that were encountered in borings P-9-96 and 02-5 are unlike and significantly worse than in the sea cliff shoreline exposure. In the P-9-96 intercept, the hanging wall rock was massive but highly fractured conglomerate and the footwall quartz diorite was completely sheared and altered to clay in an approximately 2 m-thick interval. Although the reason for this difference in conditions is not known, it may be related to the absence of shale directly in the fault hanging wall. Possibly the massive conglomerate caused more crushing and shearing within the footwall altered quartz diorite in the vicinity of P-9-96 while the shale formed a low strength interface in the sea cliff shoreline exposure.

2.4.2.1 02-5 Fault Zone

A high angle zone of faulting shearing, rotation of bedding dip within fault slices, and sand injection was encountered in the depth interval of 65 to 115 m in boring 02-5. This zone is interpreted as the probable eastward extension of the high angle dislocation within the adjacent slide complex that drops the Central Block sedimentary section down to the north relative to the quartz diorite on the south. This dislocation also displaces Fault B within the slide complex and so is represented as similarly displacing it beneath the tunnels alignment on Figure 2-2 cross section,

even though there is no direct drill hole evidence to confirm this interpretation. Except for the dislocation within the slide complex, fault zone 02-5 was not recognized at the surface in the project area.

2.4.2.2 Fault C

As exposed in the sea cliff west face of San Pedro Mountain, Fault C forms an approximately vertical contact between the massive sandstone and conglomerate with shale interbeds of the project area central block and the much less resistant thinly interbedded shale and sandstone of the Point San Pedro stratigraphic sequence on the north. The tectonic fault contact apparently served as the locus of gravity failure along the north side of the Devils Slide block slump, so conditions along the sea cliff exposure may not be directly representative of those inland beyond the area of slide disturbance. In the sea cliff shoreline area north of the main fault/slide contact, a few exposures in gulches eroded through the colluvial cover show vertically dragged and highly sheared sandstone and shale (claystone/siltstone). This deformation is interpreted to be tectonic shearing associated with the tectonic movement of Fault C rather than being related to the younger movement of the block slump. If this is the case, the zone of Fault C-related deformation at the shoreline might be 10 to 20 m or more wide.

Inland from its prominent exposure at the sea cliff termination of San Pedro Mountain ridge Fault C is notable for its obscurity. Trench 02-T2A, excavated across the topographic saddle that aligns with the fault in the sea cliff, exposed only massive to poorly bedded claystone with no significant faulting or shearing evident. Trench 02-T2B was excavated about 75 m north of 02-T2A, extending northward to an interval of essentially continuous rock exposure along the access road cut-bank. This trench did expose a north-dipping zone of shearing within massive claystone in about the expected location for Fault C, but without showing discernable stratigraphic separation across the shear zone. About 250 m east of 02-T2B, the apparent south limit of a 150 m wide zone of faulting and shearing crossing the North Block of the DST project, was approximately defined by drilling along the tunnels alignment. The boundary between the North and Central Blocks was interpreted as being located within an interval of sheared claystone–siltstone at a slant depth of about 60 m in boring 02-8B. As in the case of Trench 02-T2B, the shearing interpreted as corresponding to Fault C was relatively unremarkable and was not itself a contact between recognizably contrasting lithologies. Because of the uncertain relationship of the sheared zone at the apparent boundary between the Central and North Blocks along the DST alignment, the wide zone of shearing and structural dislocations in the North Block is referred to as the North Block shear zone in this report.

2.4.3 North Block Shear Zone

This zone of generally east-west aligned, steeply dipping to vertical, shears largely defines the structural fabric of the south half of the DST project area North Block. The zone consists of approximately eleven distinguishable individual shears consisting of variably fragmented, crushed, and sheared claystone–siltstone and fine-grained sandstone, recognized in borings and in Trench 02-T3 at tunnel grade. The North Block shear zone can apparently be correlated with similar zones intersected by borings above and below tunnel grade. These zones separate more or less intact, steeply inclined to vertical tabular bodies of claystone–siltstone and fine-grained sandstone. The overall zone is approximately 150 m wide.

The existence of shearing in the North Block part of the DST project area was initially indicated by intervals of sheared claystone found in boring P-7-96, which was a slant hole drilled below tunnel grade from the ranch road opposite NB Sta. 130+60. The orientation of this shearing was unknown however, since the core was not oriented. Because of the importance of defining the structure in the North Portals and North Block part of the project, several slant borings were drilled from sites along the overlying ridge crest together with the near horizontal borings 02-11 and 02-11A drilled along the pillar between tunnels, and boring 02-16 drilled from the side of the ridge obliquely toward the tunnel alignment.

The first information demonstrating the general orientation of the North Block shear zone came from Trench 02-T3, which was excavated before the 2002 drilling program began. This trench was started from a point located 2 m north of the collar of boring P-7-96, and extended for a distance of 170 m to the point where the road along which it was excavated wrapped around the nose of the "North Portal ridge". Four shears, each steeply dipping and striking roughly east-west, were encountered cutting across the south to southwest-dipping thin to medium bedded sandstone of the trenched interval. These proved to be the northernmost of the series of shears that extended a further 120 m to the south as defined by the 2002 drilling program.

The approximately 150-m wide North Block shear zone defines the secondary geologic structure, rock conditions, and to a large extent ground-water conditions in the northerly 170 m of the NB tunnel and the northerly 130 m of the SB tunnel and the SB North Portal. There are no natural exposures of this shear zone other than the few local exposures of shearing in the rock north of Fault C along the shoreline base of the sea cliff, and the relationship of these shears to the North Block shear zone is uncertain. In the absence of outcrop data, the North Block shear zone is known only from borehole data and from its partial exposure in Trench 02-T3. Parts of the shear zone were intersected in borings P-7-96, 02-8A/B/C, 02-11/11A, 02-12, 02-16, 02-18A/B. Difficult drilling conditions associated with the shear zone, including around-water inflow into borings 02-11 and 02-11A, resulted in termination of

drilling of borings 02-8A, 02-8C, 02-11, 02-11A and 02-16 before reaching their target depths.

As noted above, the series of shears and dislocations forming the North Block shear zone appear to cut the ground in the overall zone into steeply dipping tabular blocks or slices. It was observed in Trench 02-T3 and in several of the borings that the bedding structure within some of these blocks is rotated and independently folded relative to that in adjacent blocks, indicating that considerable differential movement with associated drag has occurred along individual shears within the zone.

2.4.4 Faults, Joints, and Fractures in the Greater South Portal Area

The ''greater South Portal Area'' addressed in this section comprises the South Portal slopes and approach, the South Rock Cut area, and adjacent sea cliff promontories and coves.

A general plot showing individual joint and fracture attitudes and traces of relatively extensive discontinuity surfaces in the footwall quartz diorite of the DST project area South Block is presented in Figure 2-3. The plot is intended to illustrate the pattern of larger scale discontinuities in the massive footwall quartz diorite, but not their density or spacing in any uniform way. This is because the only parts of the area that are readily accessible for direct measurements are the road cuts along Route 1 and the trail crossing of the "east rock slope" outcrops across the waterfall ravine from the south portal rock slope. Discontinuities exposed on the latter slope were measured using rock-climbing equipment for access, but this did not provide complete or uniform coverage. Large-scale patterns of jointing present in the sea cliff promontories and coves exposed over a vertical range of about 70 m below the level of Route 1 are readily visible on aerial photographs and can be accurately plotted as to strike. The three dimensional pattern of discontinuities present in the cliff faces can be observed and sketched from points of view on adjacent promontories and, with lower resolution and less detail, on oblique aerial photos.

Although the excellent sea cliff exposures are useful for observing characteristic patterns of jointing in the massive footwall quartz diorite (especially the pattern of joint intersections forming downward-converging wedges) and for defining some laterally extensive joint sets that project into the South Portal and South Rock Cut areas, these exposures are otherwise not reliable as indicators of rock discontinuity conditions at the location and elevation of the project features for two reasons:

(1) Structurally important jointing patterns and cross cutting fractures vary from place to place, such that potentially significant fractures exist in both the South Portal rock slope and the South Rock Cut that are not evident in

projections to these areas either from distant sea cliff exposure or even from areas of higher elevation on the same slope; and

(2) Surface stress relief ("exfoliation") discontinuities that are very important to the surface stability of rock masses on the higher elevation, along the exposed east side rock slope, and possibly also on the upper South Portal rock slope, do not exist or are not evident on the steep, lower elevation actively retreating cliff faces.

Given these limitations we have favored a combination of direct measurements of accessible discontinuities and preparation of overlays to distant oblique photographs of rock outcrops on slopes where project development will occur. Some general observations regarding discontinuities in the footwall quartz diorite of the DST project area South Block are the following:

(1) A wide zone of laterally extensive, steeply dipping fractures extends from the sea cliff in line with the tunnels alignment into the South Portal rock slope and the adjacent west side of the "waterfall ravine". The strike of this fracture set is in the range of N20^{o}E to N30^{o}E, approximately paralleling the N25^{o}E tunnels alignment orientation.

(2) Another wide zone of laterally extensive, steeply dipping fractures with a more easterly strike, typically around N55^{o}E, governs the outline of the several narrow, finger-like promontories that form the coastline directly west of the South Portal rock slope and extends into the rock mass of this slope. Fractures of this set dip steeply toward, and form acute angle intersections with, those of the N20^{o}-30°E set.

(3) Prominent cross fractures or joints present in the lower South Portal rock slope, the upper east side rock-slope, and the erosional alcove of the South Rock Cut area, each appear to be local features that do not extend to other parts of the area.

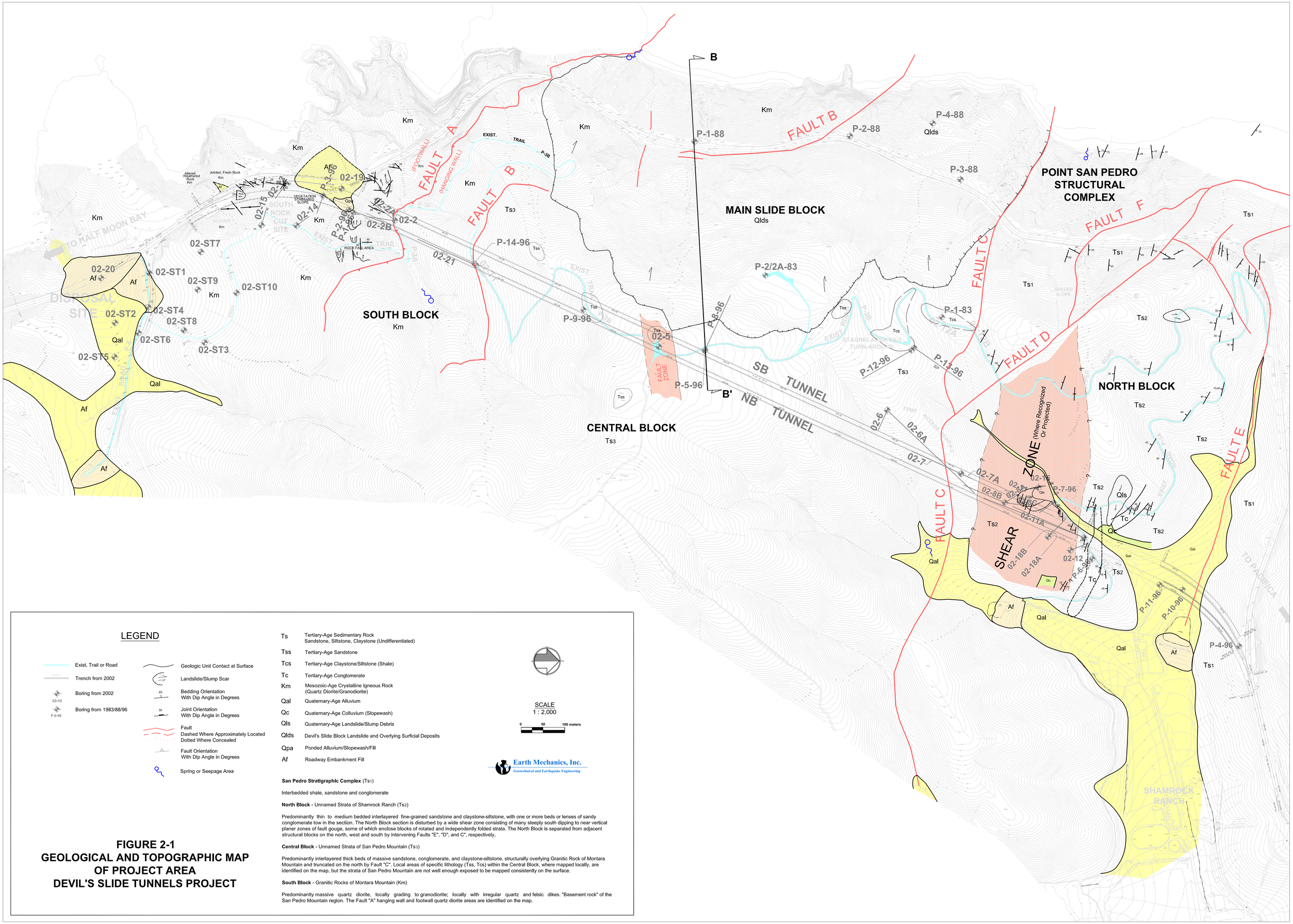
(4) The South Portal rock slope cross fracture strikes NE and dips about 55° NW, into the slope. It cuts obliquely across the portal area of the South Portal equipment chamber.

(5) The upper east side rock slope cross fractures strike about N80^{o}-85°E and are approximately vertical. They cut the exfoliation slabs of this area into large rectangular blocks. The cross fracture in the South Rock Cut alcove strikes about N5^{o}W and is vertical. It extends upward across the eroded slope of the alcove from a family of closely spaced joints at road level to an eroded slot in the upper part of the slope.

(6) The dome-like morphology of the upper east-side rock slope is governed by failures of sections of exfoliation slabs. The exfoliation joint surfaces dip progressively more steeply going down slope, and future failures of cross joint-bounded sections of exfoliation slabs would endanger the northbound lane entering the tunnel.

(7) The form of the south and southwest-facing part of the South Portal rock slope is also suggestive of a partial exfoliation dome, with the slope-parallel outer faces of outcrops and in-place blocks possibly being exfoliation joints. The east margin of this slope, however, is controlled by the N20^{o}-30°E vertical joint set and the upper part of the slope, at the elevation where the east side dome is best developed, is underlain by the shattered rock of the Fault A hanging wall plate.

(8) The South Rock Cut area is underlain by the quartz diorite Fault A footwall subunit (c) facies, described as "massive rock characterized by granular disintegration and intense weathering decomposition." This rock mass contains the same pattern of intersecting joints as the harder rock that forms the South Portal and promontory sea cliff rock slopes. Because the weathered facies (c) rock mass is cohesive but not brittle, the relict joints and fractures seem mainly to guide erosion rather than serve as wedge or block failure surfaces.



LEGEND

- Exist. Trail or Road
- Trench from 2002
- 02-10 Boring from 2002
- P-6-96 Boring from 1983/88/96
- Geologic Unit Contact at Surface
- Landslide/Slump Scar
- 45 Bedding Orientation With Dip Angle in Degrees
- 30 Joint Orientation With Dip Angle in Degrees
- Fault Dashed Where Approximately Located Dotted Where Concealed
- Fault Orientation With Dip Angle in Degrees
- Spring or Seepage Area

Ts	Tertiary-Age Sedimentary Rock Sandstone, Siltstone, Claystone (Undifferentiated)
Tss	Tertiary-Age Sandstone
Tcs	Tertiary-Age Claystone/Siltstone (Shale)
Tc	Tertiary-Age Conglomerate
Km	Mesozoic-Age Crystalline Igneous Rock (Quartz Diorite/Granodiorite)
Qal	Quaternary-Age Alluvium
Qc	Quaternary-Age Colluvium (Slopewash)
Qls	Quaternary-Age Landslide/Slump Debris
Qlds	Devil's Slide Block Landslide and Overlying Surficial Deposits
Qpa	Ponded Alluvium/Slopewash/Fill
Af	Roadway Embankment Fill

SCALE
1 : 2,000

0 50 100 meters

Earth Mechanics, Inc.
Geotechnical and Earthquake Engineering

San Pedro Stratigraphic Complex (Ts_1)

Interbedded shale, sandstone and conglomerate

North Block - Unnamed Strata of Shamrock Ranch (Ts_2)

Predominantly thin to medium bedded interlayered fine-grained sandstone and claystone-siltstone, with one or more beds or lenses of sandy conglomerate low in the section. The North Block section is disturbed by a wide shear zone consisting of many steeply south dipping to near vertical planer zones of fault gouge, some of which enclose blocks of rotated and independently folded strata. The North Block is separated from adjacent structural blocks on the north, west and south by intervening Faults "E", "D", and C", respectively.

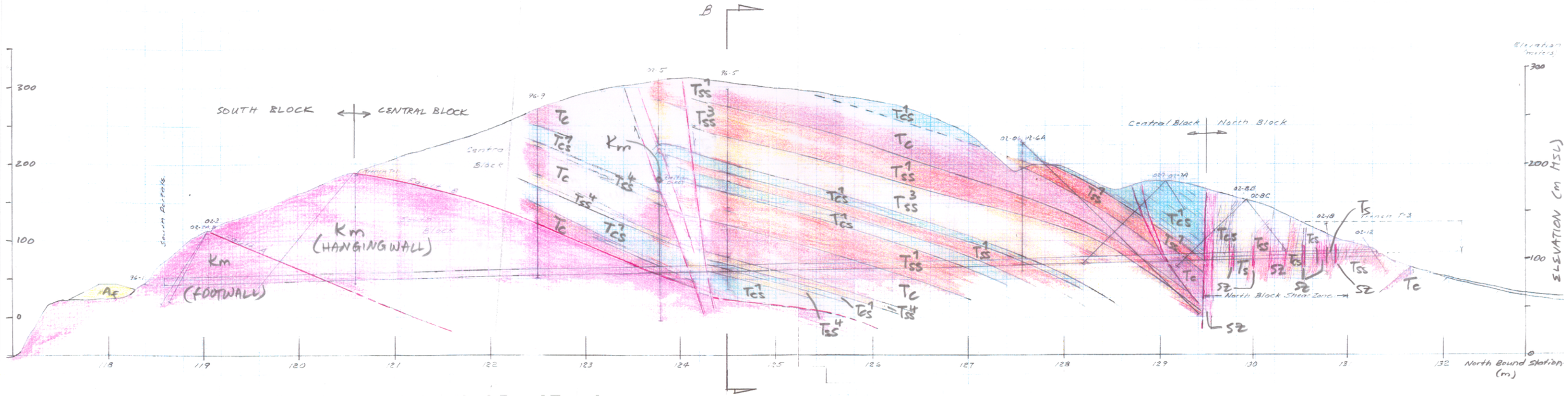
Central Block - Unnamed Strata of San Pedro Mountain (Ts_3)

Predominantly interlayered thick beds of massive sandstone, conglomerate, and claystone-siltstone, structurally overlying Granitic Rock of Montara Mountain and truncated on the north by Fault "C". Local areas of specific lithology (Tss, Tcs) within the Central Block, where mapped locally, are identified on the map, but the strata of San Pedro Mountain are not well enough exposed to be mapped consistently on the surface.

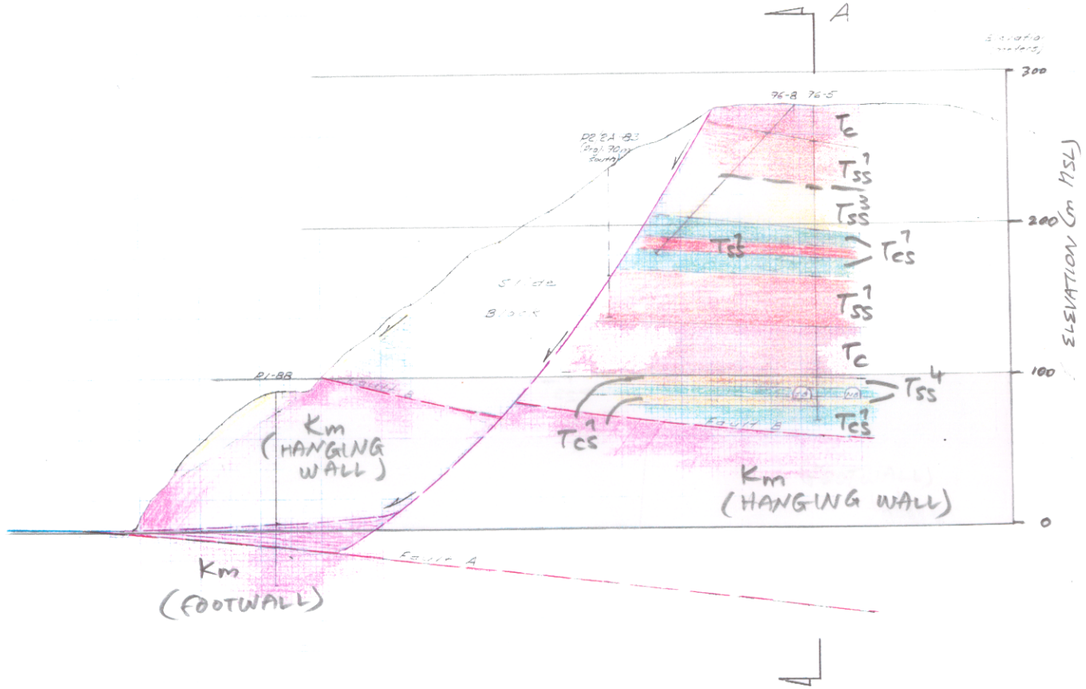
South Block - Granitic Rocks of Montara Mountain (Km)

Predominantly massive quartz diorite, locally grading to granodiorite; locally with irregular quartz and felsic dikes. "Basement rock" of the San Pedro Mountain region. The Fault "A" hanging wall and footwall quartz diorite areas are identified on the map.

FIGURE 2-1
GEOLOGICAL AND TOPOGRAPHIC MAP OF PROJECT AREA
DEVIL'S SLIDE TUNNELS PROJECT



(a) **Cross Section A-A' Along North Bound Tunnel**



(b) **Transverse Cross Section B-B'**

Lithogy

North Block

T_{ss}		Sandstone, thin to medium beds, very fine to fine grained, hard, comonly with thin dark silt laminae
T_{cs}		Siltstone, grading to claystone, with [illegible] to well developed bedding and [illegible]
T_s		Sandstone, siltsone, and claystone, as above closely interlayered

Central Block

T_{cs}^1		Siltstone-claystone, dark grey, when fresh, massive to indistinctly bedded
T_{cs}^2		Siltstone-claystone, dark grey, with fine grained sandstone interlayers
T_{ss}^1		Sandstone, massive to thick bedded, fine grained, hard.
T_{ss}^2		Sandstone and siltstone, fine to medium-grained sandstone and dark grey siltstone, interbedded
T_{ss}^3		Sandstone, massive, medium to coarse-grained
T_{ss}^4		Sandstone, massive pebbly sandstone grading to microconglomerate
T_c		Conglomerate, well rounded to moderately angular clasts in a medium to coarse grained sandstone matrix
K_m		Boulder, granitic rock, up to about 1 m. size

South Block

K_m		Quartz diorite, grading to granodiorite, massive fine to coarse grained, locally with shear fabric, includes some quartz and felsic dikes
A_f		Roadway fill

Figure 2-2. Transverse and Longitudinal Geologic Cross Sections

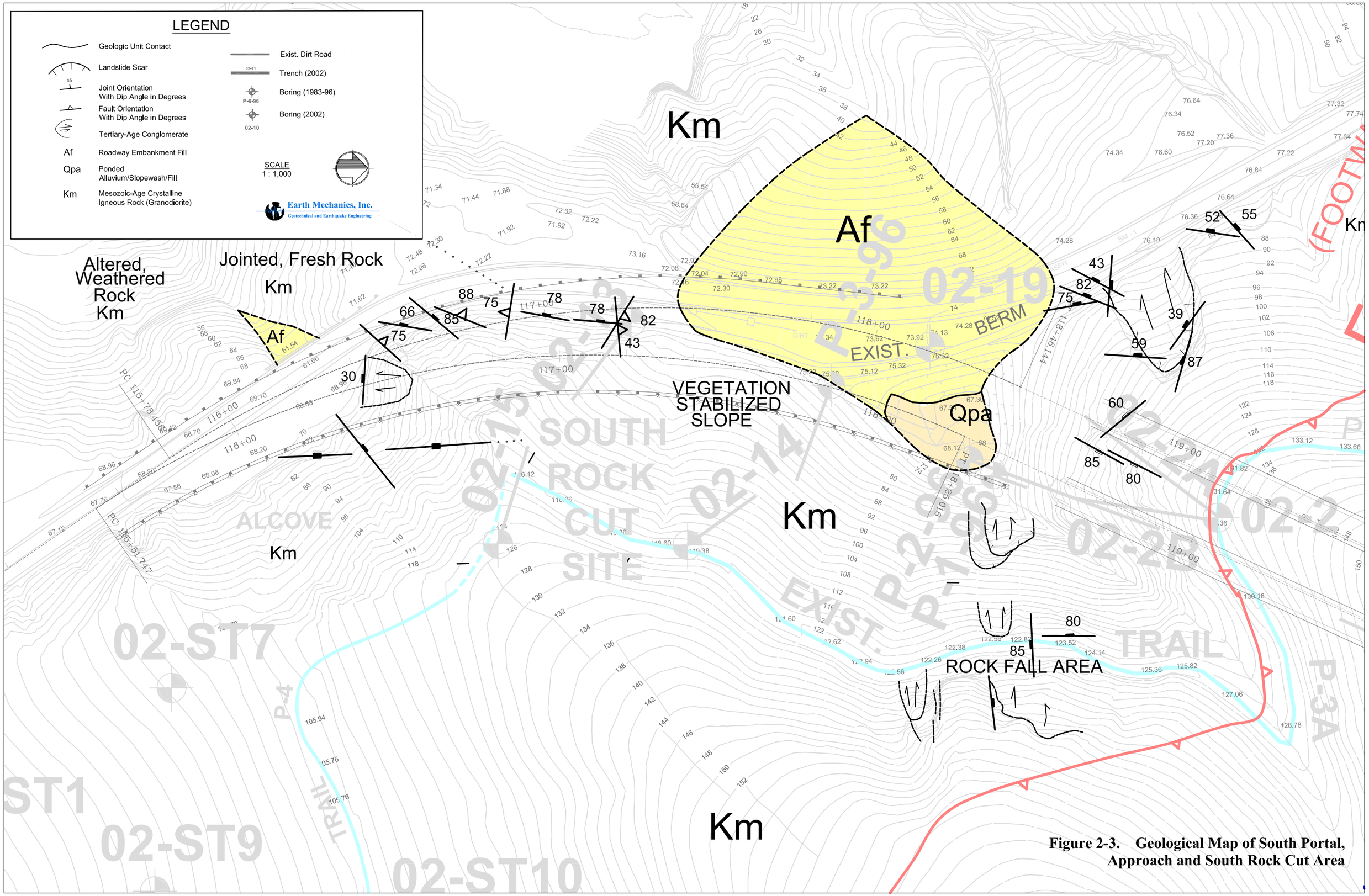


Figure 2-3. Geological Map of South Portal, Approach and South Rock Cut Area

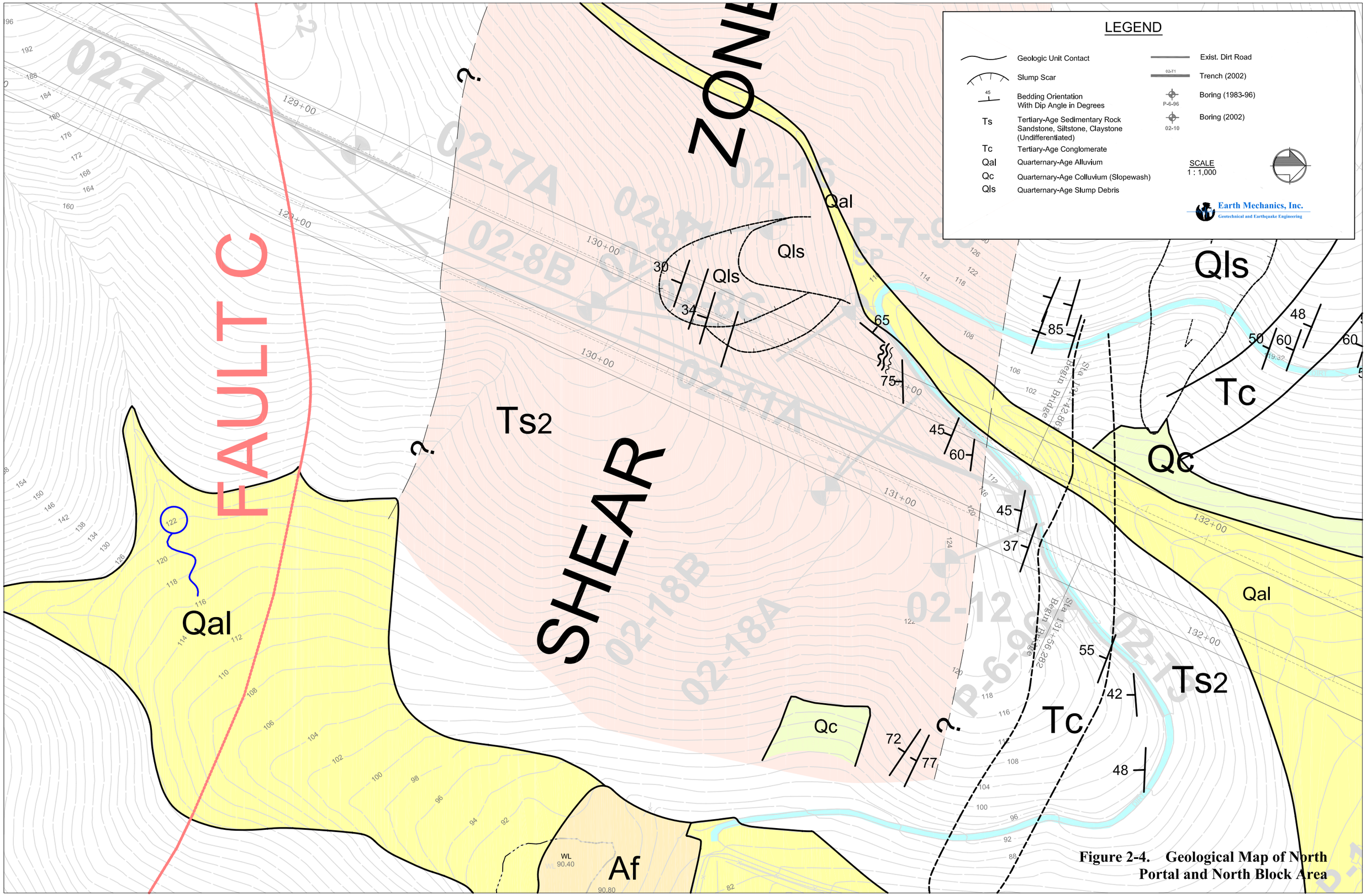


Figure 2-4. Geological Map of North Portal and North Block Area

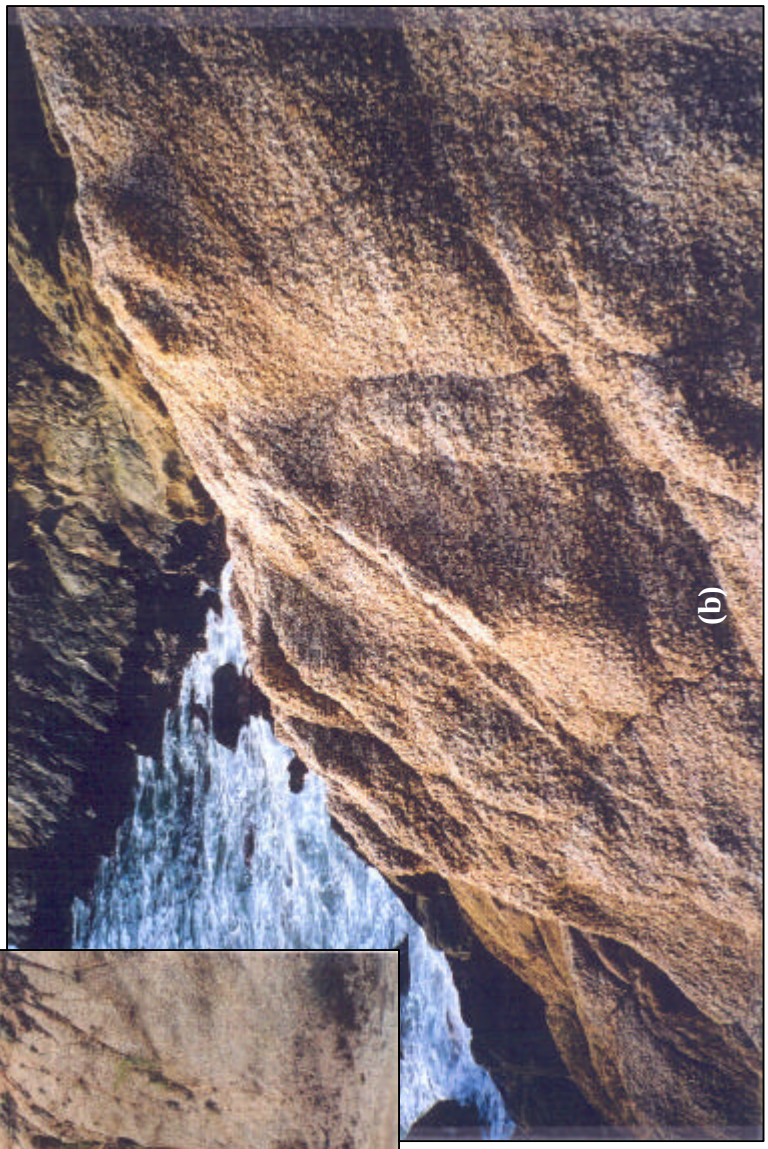


Photo P-1. South Block Quartz Diorite

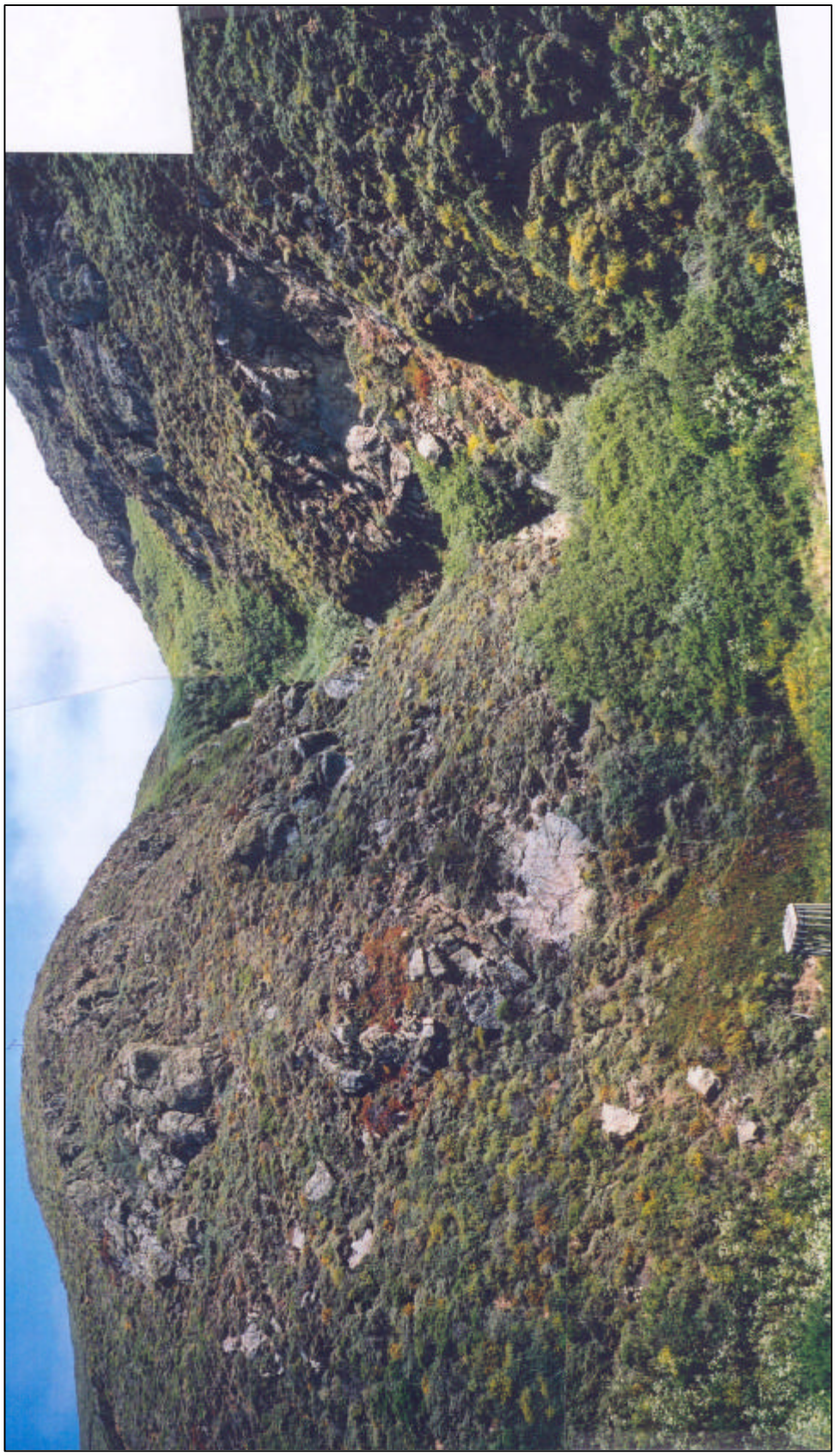


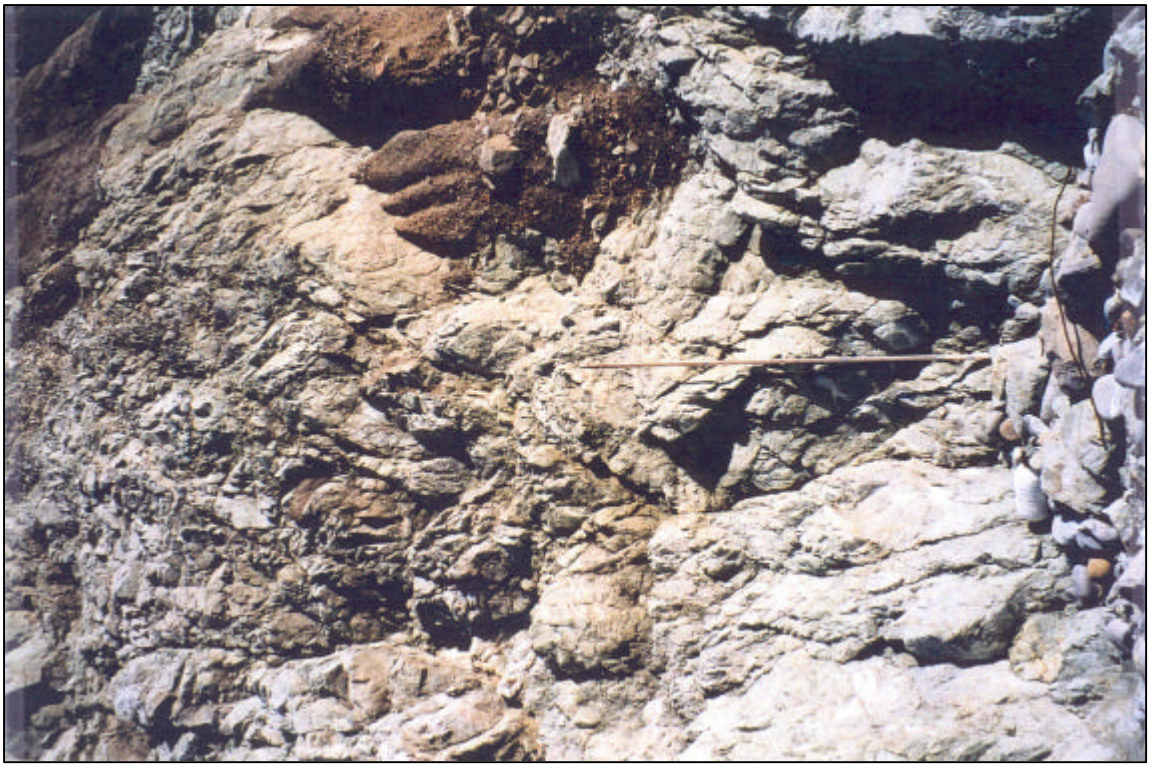
Photo P-2. South Block Quartz Diorite

(b)

(a)

Photo P-3. South Block Quartz Diorite

(a)



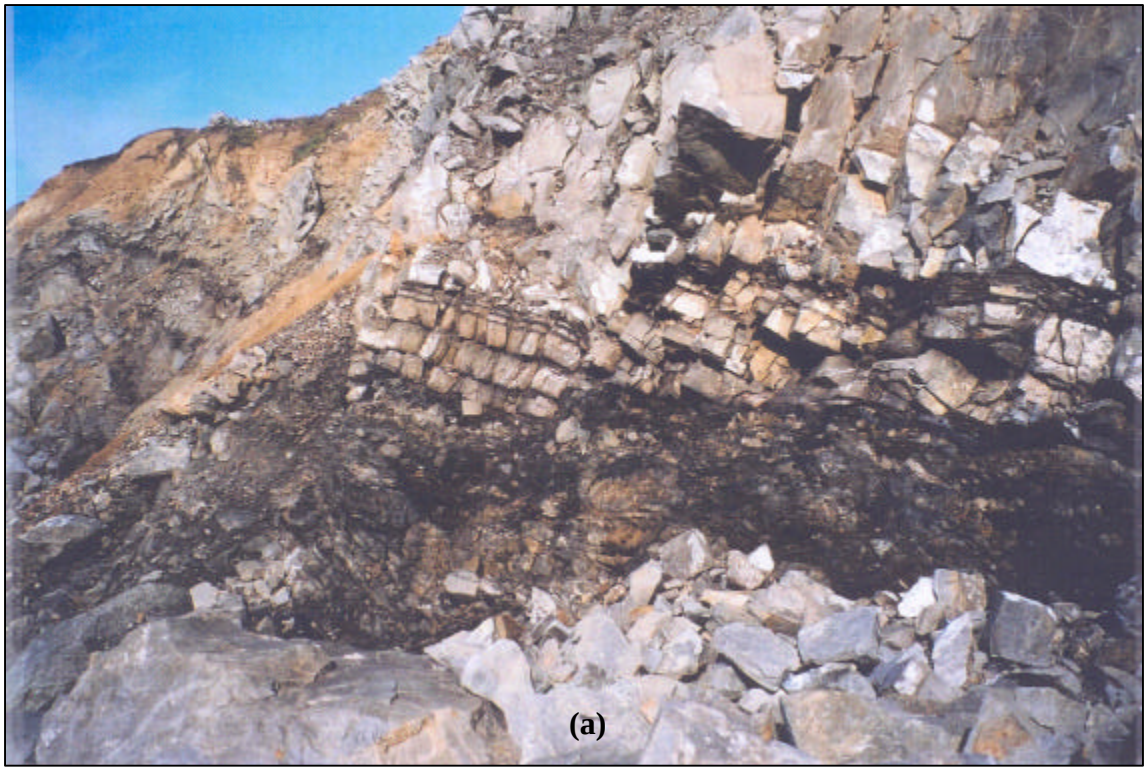
(b)

Photo P-4. South Block Quartz Diorite

(b)

(a)

Photo P-5. Central Block Sandstone



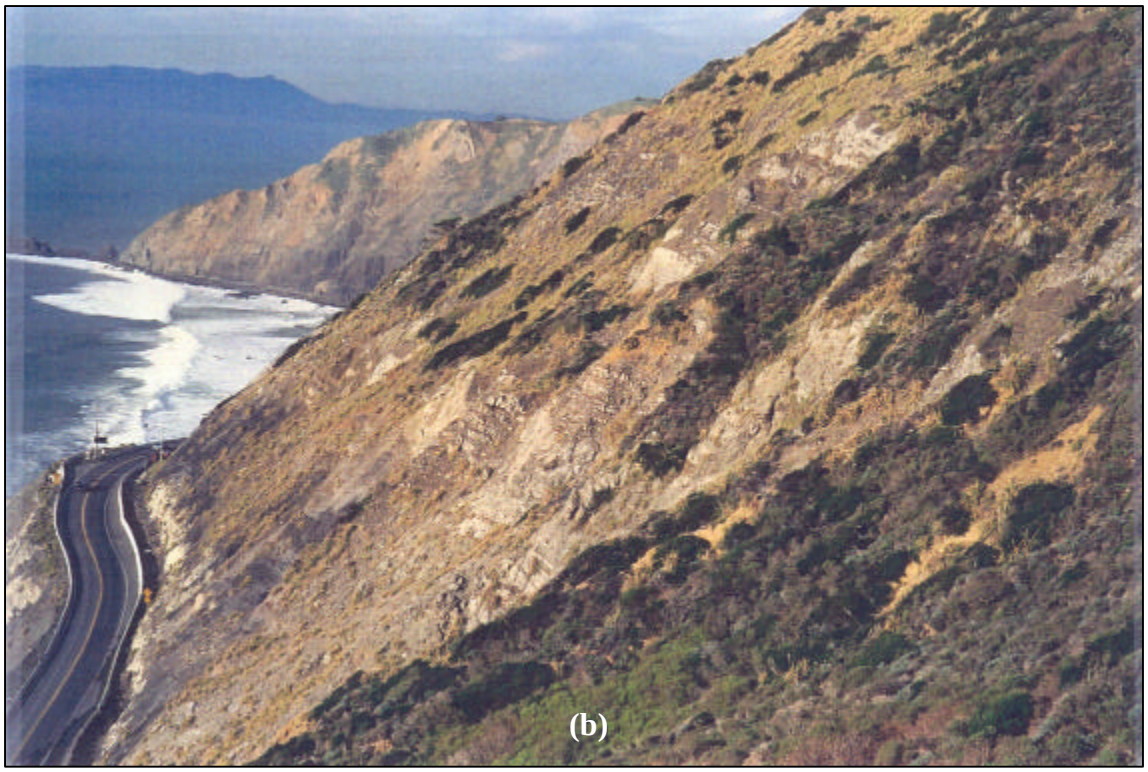


Photo P-6. Central Block Claystone-Siltstone

Photo P-7. Fault A

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