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Structure and emplacement of Buena Vista Crest Intrusive Suite, California

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STRUCTURE AND EMPLACEMENT OF BUENA VISTA CREST INTRUSIVE SUITE, CALIFORNIA

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by

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ABSTRACT

STRUCTURE AND EMPLACEMENT OF THE BUENA VISTA CREST INRUSIVE SUITE, CALIFORNIA

by Renee McFarlan

The 100 to 95 Ma Buena Vista Crest Intrusive Suite (BVCS) intruded slightly older plutons of the central Sierra Nevada batholith, including the intrusive suite of Yosemite Valley (YVIS). The main results of this study are: 1) Mingling of diorite host rock with the oldest phase of the BVCS and youngest phase of the YVIS implies that the two suites overlap in age. 2) There are two magmatic foliations in the granodiorite of Illilouette Creek of the BVCS; the dominant northwest foliation records regional strain and weaker east-west foliation records internal processes. Regional foliation in 92 Ma rocks to the north is east-west, indicating the regional strain field changed between 99 and 92 Ma. 3) Sharp truncation of host rock markers, irregular contacts between the BVCS and host rocks, and xenoliths in the BVCS indicate stoping was an important material transfer process during emplacement. Roof uplift also likely aided emplacement.

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INTRODUCTION

The mechanics of ascent, assembly, and emplacement of magma that result in the formation of plutons are critical for understanding processes of continental growth, but these mechanisms are controversial and still remain poorly known (e.g., Bateman and Chappell, 1979; Hutton, 1992; Paterson et al., 1996; Coleman et al., 2004). Proposed models for pluton emplacement include those that involve vertical material transfer and others that entail lateral extension (e.g., Hutton, 1992; Paterson et al., 1996).

The significance of magmatic fabrics in plutons is also controversial. Magmatic foliation and lineation have been used by many workers to evaluate ascent and emplacement models, and for understanding processes in magma chambers. These fabrics can also potentially provide insight into the shapes of intrusions, magmatic flow processes, and regional deformation (see review by Paterson et al. [1998]).

The Sierra Nevada batholith is an excellent natural laboratory for exploring the issues of pluton emplacement and the significance of magmatic fabrics. Research is facilitated by vast exposure of plutons and their host rocks, and widespread accessibility by trails and roads. Though parts of the Sierra Nevada batholith have received considerable petrologic and structural study, the structure and emplacement of many individual plutons and intrusive suites of the batholith remain poorly known. The orientations and origins of magmatic fabrics are also poorly known in many of these intrusive suites. For those plutons that have been studied in more detail, the types of emplacement mechanisms and genesis of magmatic fabrics have also been a point of contention, as illustrated by recent studies of the Tuolumne Intrusive Suite of the Sierra Nevada batholith (e.g. compare Paterson and Vernon [1995] and Zak and Paterson [2005] to Coleman et al. [2004] and Glazner et al. [2004]).

One of the least-studied intrusive suites in the central Sierra Nevada batholith is the Buena Vista Crest Suite (BVCS), which was emplaced at ~100 to 95 Ma during the voluminous magmatism of the 100 to 80 Ma Sierra Crest intrusive event (e.g., Saleeby et al., 1990; Coleman and Glazner, 1997). The BVCS is comprised of tonalitic to granitic bodies (Peck, 1980, 2002; Bateman, 1992), and extends 30 km southward from Yosemite Valley to the southeastern boundary of Yosemite National Park (Figs. 1 and 2) (Peck, 2002). It is approximately coeval with the Washburn Lake Intrusive Suite and Merced Peak Intrusive Suite, both located to the east (Fig. 1) (Bateman, 1992). These three suites comprise one of the smaller intrusive units in the central Sierra Nevada. The BVCS is in contact with the coeval Jackass Lakes pluton (98 Ma) of the intrusive suite of Merced Peak to the east, the younger Tuolumne Intrusive Suite (94 to 85 Ma) to the northeast, the intrusive suite of Yosemite Valley (ca. 102 Ma) to the north and west, and the John Muir Intrusive Suite (ca. 90 Ma) to the south (Fig. 1). This study focuses on the northwestern part of the BVCS and its host rocks (Fig. 2). The BVCS consists of six successively younger map units that form a broadly nested pattern, and include, from oldest to youngest: 1) quartz diorite dikes in the El Capitan Granite; 2) granodiorites of Illilouette Creek and Tamarack Creek, tonalite of Crane Creek, and Leaning Tower Granite; 3) granodiorite of Ostrander Lake; 4) granodiorite of Breeze Lake; 5) Bridalveil Granodiorite; and 6) the granite of Chilnuala Lake (Bateman, 1992; Peck, 2002).

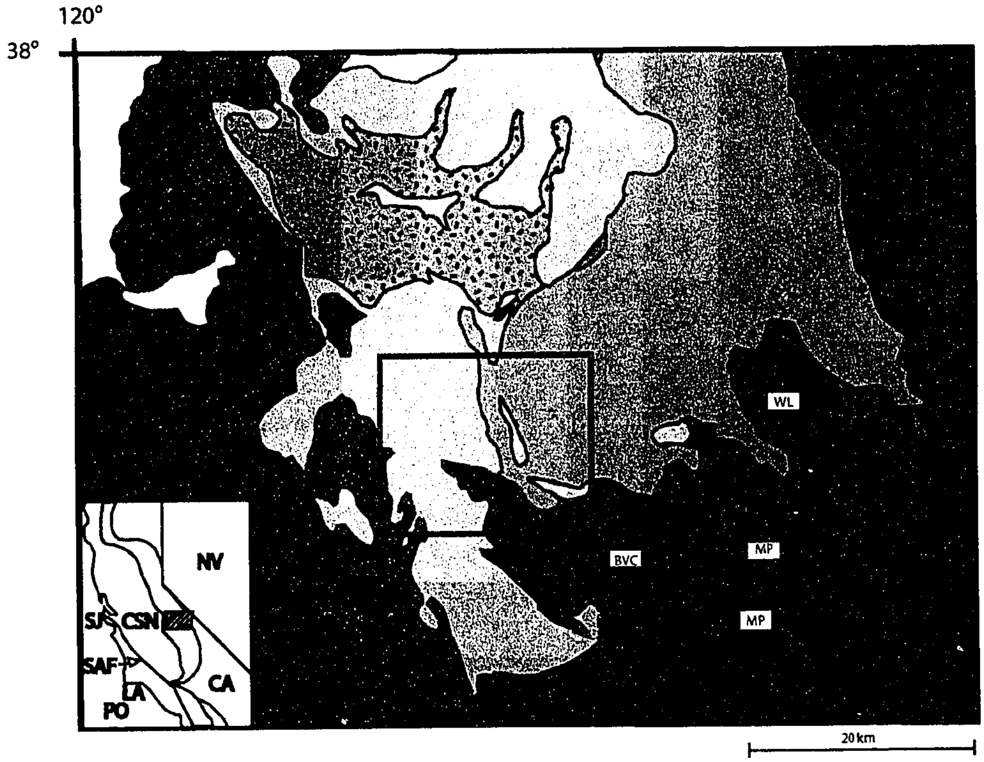


Figure 1. Cretaceous intrusive suites of the central Sierra Nevada batholith. BVC = Buena Vista Crest Suite, MP = Merced Peak Suite, WL = Washburn Lake Suite. Random dashes are Sentinel and Yosemite Creek units of the Tuolumne Suite (after Bateman [1992]). Box shows location of Fig. 2. Insert shows the location of the central Sierra Nevada relative to the Sierra Nevada batholith (in yellow) (from Tobisch et al., 1995). CA = California; CSN = central Sierra Nevada; LA = Los Angeles; NV = Nevada; PO = Pacific Ocean; SAF = San Andreas fault; SJ = San Jose

☐ Unassigned Intrusive Rocks

▨ Tuolumne Intrusive Suite

■ John Muir Intrusive Suite

■ Intrusive Suites of Washburn Lake, Buena Vista Crest, and Merced Peak

▨ Intrusive suite of Yosemite Valley

■ Fine Gold Intrusive Suite

■ Meta-sedimentary and meta-volcanic host rock (undifferentiated)

▨ Meta-sedimentary rocks

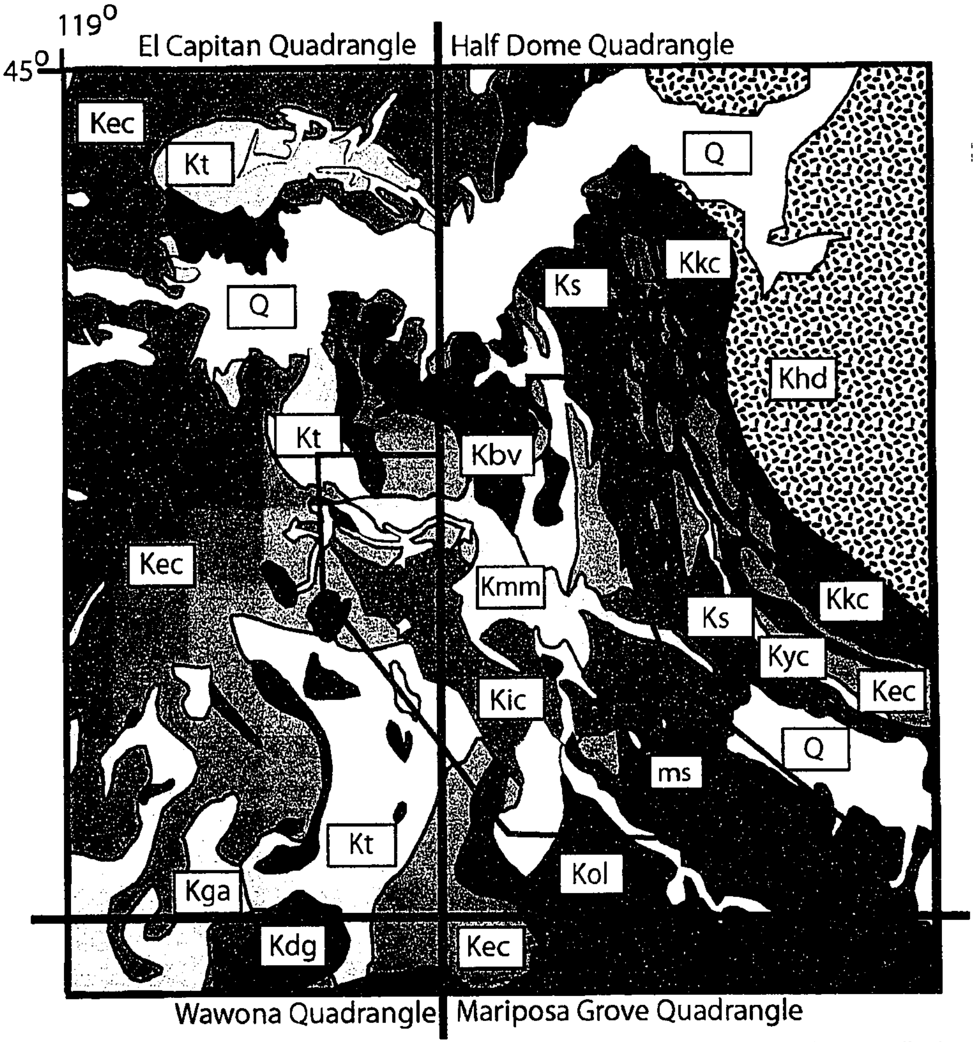


Figure 2. Map showing the location and units of the study area (in box). Modified from Huber et al. (1989). The study area is in the El Capitan and Half Dome Quadrangles. Gdrt. = Granodiorite

5 km

Explanation

Q	Quaternary	■	Illilouette Creek Grdt.
Khd	Half Dome Grdt.	Kmm	McGurk Meadow unit
■	Kuna Crest Grdt.	Kt	Taft Granite
■	Sentinel Grdt.	▨	El Capitan Granite
Kyc	Yosemite Creek Grdt.	Kga	Gateway Tonalite
■	Bridalveil Grdt.	■	diorite and gabbro
■	Ostrander Lake Grdt.	ms	Meta-sedimentary

N

The Illilouette Creek granodiorite forms the northern and southern margins of the main body of the BVCS, and Ostrander Lake granodiorite makes up much of the core of the suite (Peck, 2002).

Only a few radiometric ages have been determined for the BVCS. Tobisch et al. (1995) reported a U-Pb zircon age for the Illilouette Creek granodiorite of 99 ± 1 Ma. The Ostrander Lake granodiorite gave discordant U-Pb ages of 112 and 107 Ma (Stern et al., 1981), which are almost certainly incorrect as the granodiorite intrudes the 99 ± 1 Ma Illilouette Creek granodiorite (Tobisch et al., 1995), and is also younger than the 102 Ma El Capitan Granite of the intrusive suite of Yosemite Valley.

No attempt has been made to quantitatively determine the depth of emplacement of the BVCS. Ague and Brimhall (1988) reported aluminum-in-hornblende geobarometric data for the neighboring 98 Ma Jackass Lakes pluton, which indicates an emplacement depth of 4.2 kbar, or ca. 13-15 km, but McNulty et al. (1996) proposed that it was emplaced at shallower levels (< 3 km) based on field relations.

The most detailed maps of the BVCS and adjacent units in the study area were produced by Peck (1980, 2002) at a scale of 1:62,500. These maps are not sufficiently detailed to show many of the complexities of the map pattern and structures in the intrusive suite. The BVCS is also represented on Bateman's (1992) 1:250,000 map of the central Sierra Nevada and Huber et al.'s (1989) 1:125,000 map of Yosemite National Park. Both Bateman (1992) and Huber et al. (1989) apparently based their maps largely on Peck's mapping.

The structure of the BVCS had not been investigated prior to this study. In particular, the orientations of foliations and lineations were not known in detail for the BVCS, and their potential significance had not been addressed. Processes operating during emplacement were also largely unknown. The BVCS is also an interesting target for study of emplacement mechanisms because its host rocks are plutonic; most emplacement studies have focused more heavily on metasedimentary host rocks. Thus, a structural study was conducted to evaluate foliation and lineation patterns, the origin of the fabrics, and the emplacement mechanism(s) for the BVCS. Another goal of this study was to examine the structure of the host rocks of the suite, particularly that of the intrusive suite of Yosemite Valley.

The focus of the field study was mapping contacts of units within the BVCS and between the suite and its host rocks at a scale of 1:24,000, and identifying and measuring magmatic fabrics and other internal features (e.g., schlieren, enclaves, dikes). This mapping yielded a framework from which structural processes were interpreted and emplacement mechanisms evaluated. Magmatic fabrics (foliation and lineation) were measured to identify patterns and, in conjunction with microstructural analysis, to interpret if they dominantly record internal magmatic processes or regional strain (cf. Paterson et al., 1998). The synthesis of these data allows for the interpretation of processes operating during the assembly, emplacement, and subsequent evolution of the BVCS.

In the following, I describe the host rocks, units of the BVCS, and structure of the suite, and conclude with a discussion of the findings. The major conclusions of this study are the following. 1) A diorite host rock unit to the BVCS is Cretaceous in age and related to the El Capitan and Taft Granites; this diorite was previously mapped as Jurassic. 2) Contact relationships of the diorite and Taft Granite with the granodiorite of Illilouette Creek imply that emplacement of the intrusive suite of Yosemite Valley and BVCS probably overlap temporally. 3) There are two foliations in the granodiorite of Illilouette Creek, and a comparison of the orientations of these foliations with those in the younger Tuolumne Intrusive Suite suggests that the regional strain field changed between 99 and 92 Ma. 4) Narrow magma transfer zones may have facilitated the ascent of BVCS magmas. 5) Stoping was an important material transfer process during emplacement of the BVCS. Roof uplift likely accounts for some of the remaining volume of host rocks that were displaced during BVCS emplacement, but there is no direct field evidence for this mechanism.

HOST ROCKS

The host rocks of the BVCS include metasedimentary xenoliths, the El Capitan Granite and Taft Granite of the intrusive suite of Yosemite Valley, Cretaceous diorite, and the granodiorite of Turner Ridge (Fig. 3; Plate 1).

Metasedimentary Xenoliths

Several small (< 2 m in diameter) metasedimentary xenoliths are found in the granodiorite of Illilouette Creek and granodiorite of Ostrander Lake (Fig. 4). The xenoliths include quartzite, biotite schist, and hornblende-biotite schist. Xenoliths are widely isolated from each other and scattered throughout the plutonic units. Foliation in the xenoliths is strong and typically varies by 40° to 50° from the foliation orientation in the enclosing plutonic rocks. The metasedimentary rocks are similar to those in the May Lake pendant approximately 25 km to the north, which have an inferred late Precambrian to Cambrian protolith age (Lahren and Schweikert, 1989; Glazner et al., 2004). The relationships of the xenoliths to the granodiorite of Illilouette Creek and granodiorite of Ostrander Lake are expanded upon further in the discussion of the BVCS.

The biotite schist xenolith in the granodiorite of Illilouette Creek has alternating layers of recrystallized quartz and quartz with well-formed subgrains, which provides evidence for subgrain rotation recrystallization and deformation by dislocation creep.

Xenoliths in the granodiorite of Ostrander Lake are larger than those in the granodiorite of Illilouette Creek and are concentrated near where Ostrander Lake

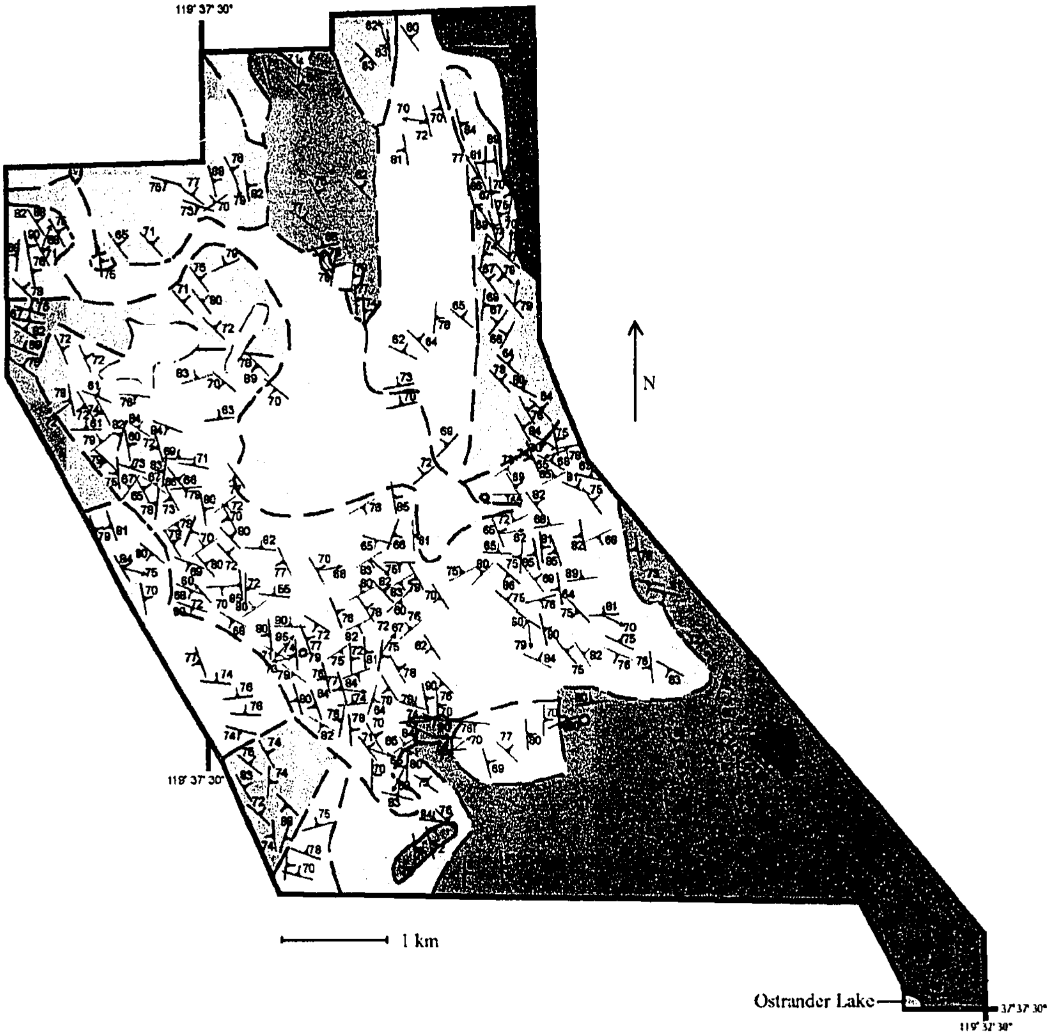


Figure 3. Map of the BVCS and host rocks with foliation pattern. This map is shown in more detail on Plate 1. Grdt. = Granodiorite

Explanation

☐ Quaternary

■ Sentinel Grdrt.

■ Bridalveil Grdrt.

☐ Ostrander Lake Grdrt. with El Capitan Rafts

■ Ostrander Lake Grdrt.

▨ Illilouette Creek Grdrt.

☐ Turner Ridge Grdrt.

▨ McGurk Meadow Tonalite and Quartz Diorite

▨ Taft Granite

▨ El Capitan Granite

▨ Metasedimentary Xenoliths

⊥80 ⊥80 Strike and Dip of Foliation

→80 Trend and Plunge of Lineation

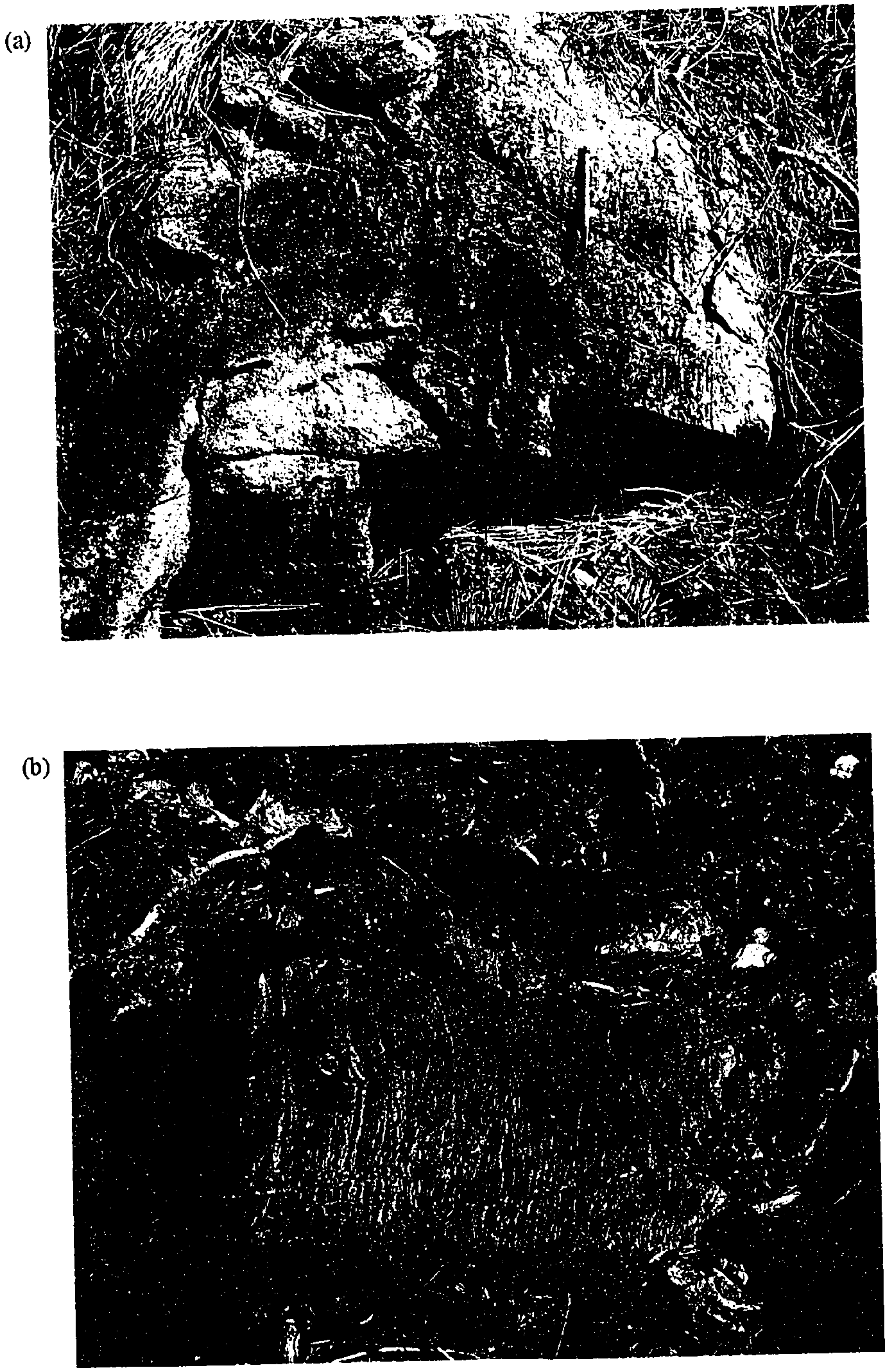


Figure 4. Xenoliths of biotite schist in the granodiorite of Ostrander Lake. Note the steep foliation.

sheets intrude the El Capitan Granite (Fig. 3; Plate 1). A biotite schist in the granodiorite of Ostrander Lake displays tight chevron folds with a wavelength of approximately 4 cm. Hinge lines are oriented roughly 48/334, and axial planes are oriented 333/71 (all data presented in right-hand rule).

El Capitan Granite and Taft Granite of the Intrusive Suite of Yosemite Valley

The ca. 102 Ma El Capitan Granite (Stern et al., 1981; Ratajeski et al., 2001) is intruded by the Taft Granite. These granites are the main components of the intrusive suite of Yosemite Valley. They extend ~75 km from north to south and ~40 km from east to west, and share roughly north-south-trending contacts with the older Fine Gold Intrusive Suite to the west and younger BVCS and Tuolumne Intrusive Suite to the east (Fig.1).

The El Capitan Granite and Taft Granite are located at the northern and western margins of the study area. They display sharp, north-south-trending contacts with each other (Fig. 2). These granites also have sharp contacts with the younger granodiorite of Turner Ridge, and granodiorite of Illilouette Creek, granodiorite of Ostrander Lake, and Bridalveil Granodiorite of the BVCS.

El Capitan Granite

The El Capitan Granite is a coarse-grained biotite granite and contains quartz and potassium feldspar phenocrysts ranging up to 1.5 cm long (Fig. 5). The matrix is composed of fine- to medium-grained plagioclase, biotite, hornblende, and potassium

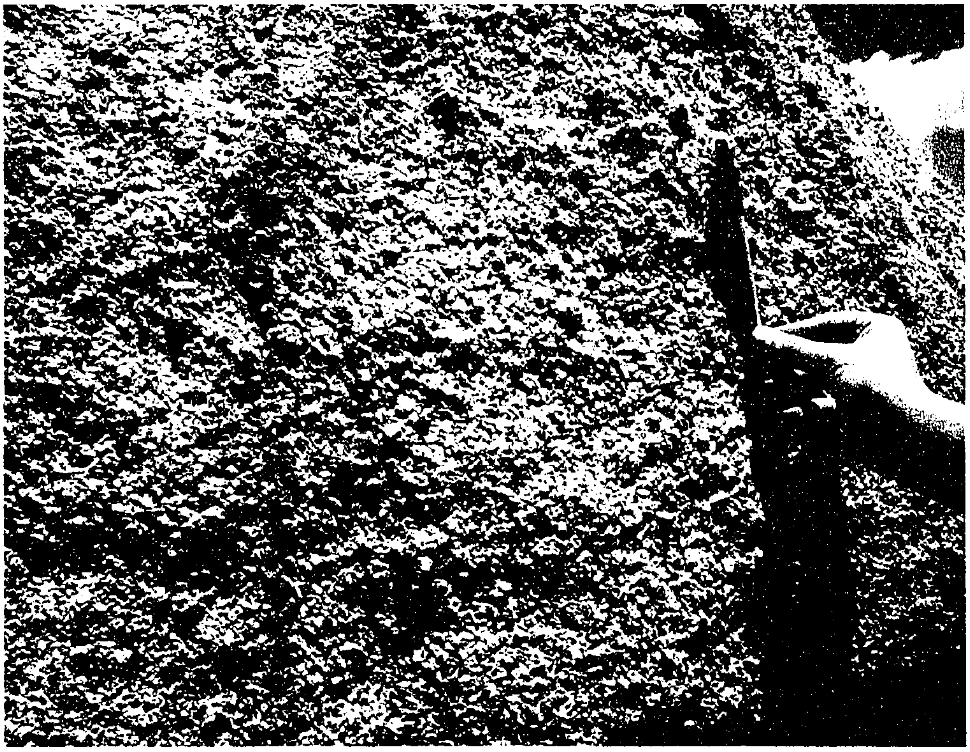


Figure 5. The El Capitan Granite has distinctive medium- and coarse-grained plagioclase and quartz crystals that stand out from the matrix. The marker is aligned parallel to foliation.

feldspar, and fine-grained quartz. Typical modes for El Capitan Granite range from granodiorite to granite, and the unit is composed of anhedral quartz (30-40%), anhedral to subhedral potassium feldspar (5-20%), subhedral to euhedral plagioclase (~30%), subhedral to euhedral biotite (10-15%), and subhedral to euhedral hornblende (0-5%). Fine-grained, anhedral to euhedral sphene (< 2%) is a minor component and alteration minerals include chlorite (< 4%) and epidote (< 2%).

The El Capitan Granite is characterized by a weak magmatic foliation defined by biotite, and to a lesser extent by quartz and plagioclase. Foliation intensity is approximately the same throughout the unit. The foliation has a mean principal orientation of 323/79 (Fig. 6). There is some scatter in strikes, but dips are invariably steep. The few lineations measured are steep (Fig. 7). Subgrains are characteristic of quartz in thin section, but recrystallization is only minor reflecting weak subsolidus strain.

Sheets of a wide range of composition and grain size intrude the El Capitan Granite and strike north to northwest, concordant to the foliation. Abundant fine-grained granitic dikes of roughly the same composition as the El Capitan Granite range from 1 cm to 30 cm in width. These dikes are composed of subhedral to euhedral plagioclase (35%), anhedral quartz (30%), subhedral to euhedral biotite (15%), and anhedral potassium feldspar (20%). Pegmatitic dikes range from 2 cm to 24 cm in width. Aplite dikes were found in a few locations and are 5 cm to 15 cm wide. Local hornblende-biotite tonalite to quartz diorite dikes are 6 cm to 10 cm wide.

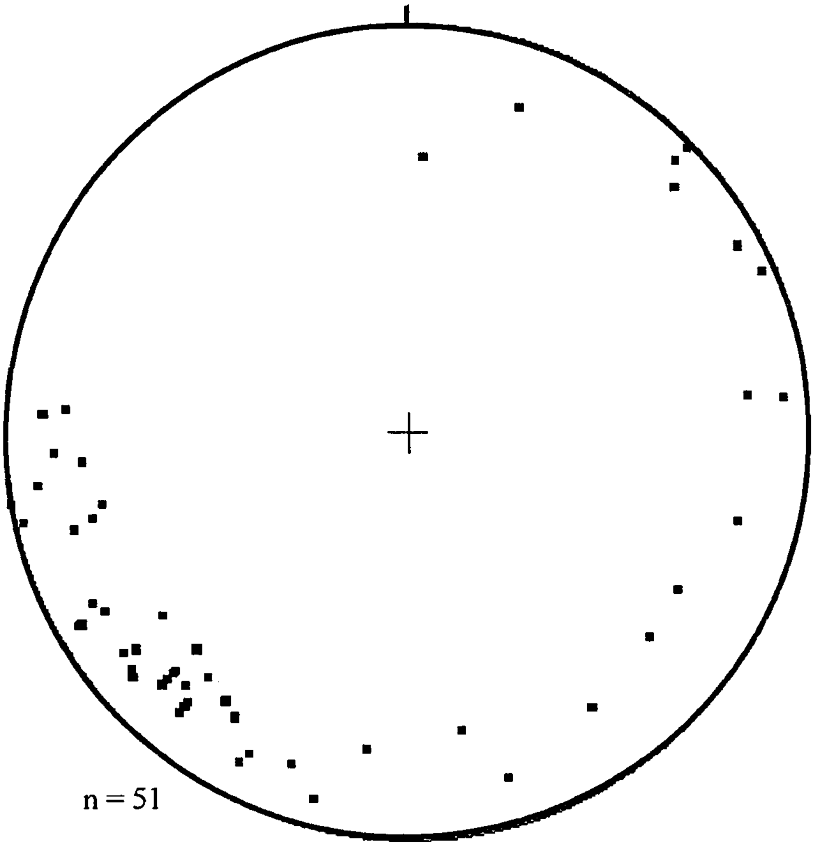


Figure 6. Stereonet projection of poles to foliation planes in the El Capitan Granite. The mean principal orientation is 323/79. All stereonet plots in this thesis are lower hemisphere projections.

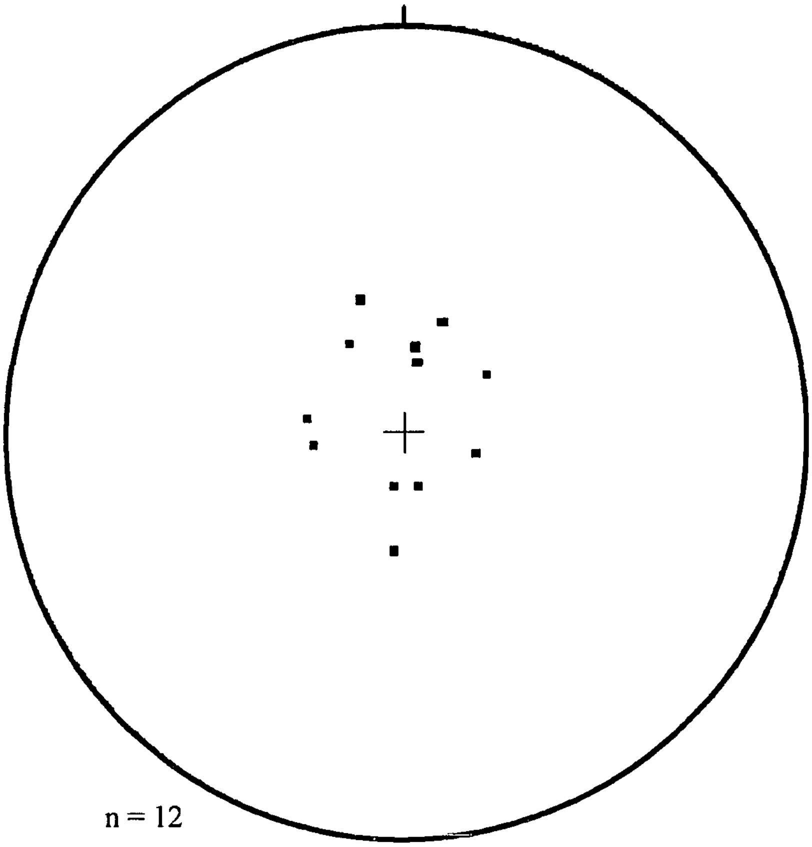


Figure 7. Stereonet projection of host rock lineation, including the El Capitan Granite and the Taft Granite. Lineation is steep and the mean principal direction is 85/345.

Enclaves are widespread in the El Capitan Granite, and are ~2 cm to 50 cm in length (Fig. 8). The orientation of the long axes of enclaves changes from one outcrop to another, and within individual outcrops, from random to parallel to the north- to northwest-striking foliation. Plagioclase phenocrysts, ranging up to 2 cm in length, are common in the typically fine-grained diorite enclaves. The enclaves consist of subhedral to euhedral hornblende (35%), anhedral to subhedral biotite (30%), subhedral to euhedral plagioclase (15%), chlorite that has replaced biotite (15%), and anhedral quartz (< 5%).

Quartz diorite bodies, typically ca. 3 m wide by 20 m long and circular to oblong in map pattern, are widespread in the El Capitan Granite. The long axes of these bodies are not consistently oriented. The bodies typically consist of hornblende and plagioclase phenocrysts, ranging up to 1 cm long, set in a fine-grained matrix. Potassium feldspar phenocrysts, also ranging up to 1 cm long, are concentrated in the outermost 10 cm to 50 cm of the bodies. These phenocrysts are interpreted to record mechanical mixing between the quartz diorite and enclosing granite, as the phenocrysts are the same size and shape as those in the granite. The quartz diorites were thus probably injected while the El Capitan Granite was still partially molten for the mixing to occur. These observations are consistent with those made by Ratajeski et al. (2001), in their study of the "diorite of the Rockslides" in the El Capitan Granite on the northern side of Yosemite Valley, that hornblende gabbros and diorites are associated with the El Capitan Granite and Taft Granites in the form of enclave swarms, small pods, and synplutonic dikes.

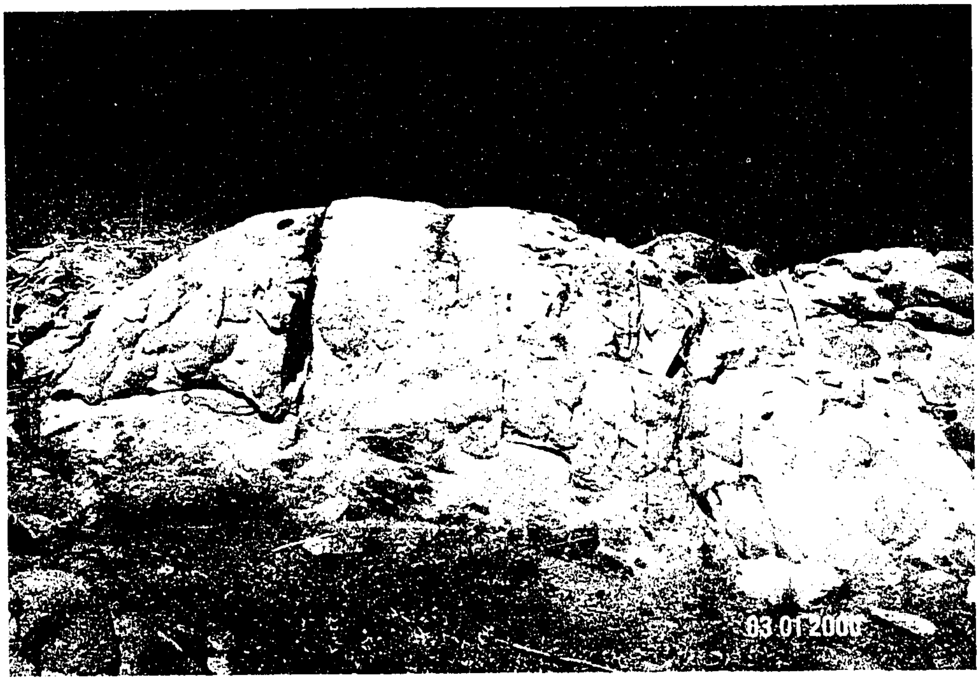


Figure 8. Outcrop of a large (> 500 m^2) enclave swarm in the El Capitan Granite. Note the semi-spherical shapes and random orientation of the enclaves. The swarm strikes northwest.

Taft Granite

The Taft Granite is a fine- to coarse-grained, biotite leucogranite to granite that grades locally into granodiorite and tonalite at its margins. Large felsic minerals are typical of the coarse-grained variety of the Taft Granite, and plagioclase phenocrysts are locally up to 1 cm long. The Taft Granite consists of anhedral quartz (20-50%), subhedral to euhedral plagioclase (10-50%), anhedral potassium feldspar (5-30%), and subhedral biotite (5-15%); subhedral hornblende (5%) is present in one of the samples examined in thin section. Fine-grained, anhedral to euhedral sphene (1%), secondary muscovite (1-5%) and chlorite that has replaced biotite (1-5%), are also present. Potassium feldspar crystals rimmed by myrmekite are typical of the granite.

The Taft Granite is distinguished from the El Capitan Granite by its lower color index and abundant myrmekite. Grain size is also more variable in the Taft Granite and increases towards the center of individual bodies.

Foliation in the Taft Granite is typically weak to medium in intensity, but is not discernible in some places. Its intensity does not change systematically across the unit. The foliation has a mean principal orientation of 328/83 (Fig. 9). It is defined by biotite and to a lesser extent by plagioclase, potassium feldspar, and quartz. Subgrains are typical of quartz, but recrystallization is minor, reflecting weak subsolidus strain. The few lineations measured are steep (Fig. 7).

Magmatic structures are less common in the Taft Granite than in the El Capitan Granite. Two biotite- and hornblende-bearing tonalitic to dioritic dikes are 50 cm and 2 m in width, respectively. Two other fine- to medium-grained dikes are composed of

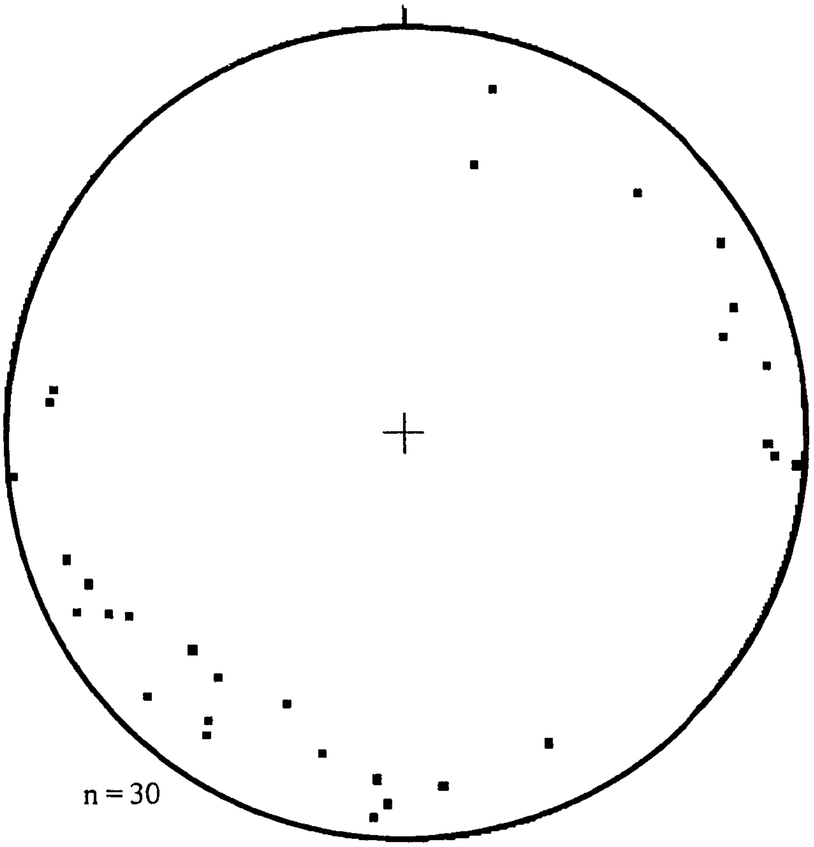


Figure 9. Stereonet projection (lower hemisphere) of poles to foliation planes in the Taft Granite. The mean principal orientation is 328/83. Note the steep dips and scatter of strikes.

anhedral quartz (45%), euhedral plagioclase (20%), subhedral to euhedral biotite (< 5%), and oxides (< 1%), and are 20 cm and 60 cm wide, respectively. Pegmatitic dikes are 7 cm to 15 cm wide. Dikes have variable strikes and dip steeply (> 60°).

Compositional layering occurs in two zones. Layers strike northwest, dip steeply (> 60°), and are approximately parallel to the contact between the Taft Granite and a body of Cretaceous diorite. The better-exposed layered zone is 4 m by > 6 m and is defined by alternating layers of granitic and intermediate rock type; individual layers range from 2 cm to 15 cm in width and typically have sharp boundaries. The layering is interpreted to have formed by the intrusion of sheets related to the McGurk Meadow tonalite and quartz diorite into the Taft Granite.

Fine-grained enclaves were observed at only five locations. Most contain hornblende phenocrysts ranging up to 5 mm long. The enclaves are 2 cm to 50 cm in length, and most long axes are elongate parallel to foliation in the host granite.

Heterogeneous Zone Within the Taft Granite is a heterogeneous zone of different rock types, enclaves, dikes, complex layering, and strong magmatic deformation. This zone is ~500 m from the contact between the Taft Granite and El Capitan Granite, and it covers an area that is, at a minimum, 370 m long and 25 m wide. It strikes 344° and dips steeply to the east. The rock types in the heterogeneous zone are the Taft Granite, the El Capitan Granite, and a tonalite. The tonalite in the zone is interpreted to be associated with the mafic injections that are commonly found within the El Capitan and Taft Granites (see above) (Ratajeski et al., 2001).

Enclaves in the zone are 2 cm to 15 cm long and elongate parallel to foliation. They are dioritic and contain much hornblende. In one large outcrop, the sigmoidal shape of the enclaves on a vertical face indicates west-side-up, non-coaxial shear in the zone (Fig. 10). The lack of evidence for solid-state strain indicate that the non-coaxial shear is magmatic.

Dikes within the zone are tonalitic and 3 cm to 12 cm wide. Potassium feldspar phenocrysts ranging up to 1 cm long are common in the dikes. Many dikes have stepped contacts, indicating that the host rock was relatively rigid at the time of intrusion. One 6-cm-thick dike has been obliquely opened during injection of a younger 3-cm-thick dike (Fig. 11). The opening direction indicates a left-lateral sense of displacement on a horizontal surface during dike injection. Thin, irregularly shaped, diffuse veinlets of granite, presumably formed when partially crystallized melt was fractured and filled by granitic material, are also common in the zone.

Compositional layering is common in the heterogeneous zone, and is characterized by alternating 1 cm to 10 cm wide layers of fine-grained tonalite and fine- to medium-grained granite. The layering is generally sharp and planar, although there is some diffuse layering with wavy contacts between layers. Two layered samples are described below; one sample is well-layered and the other is weakly layered. Tonalitic layers in these samples are composed of subhedral to euhedral plagioclase (30-35%), anhedral quartz (20-25%), anhedral to euhedral biotite (20%), anhedral to subhedral

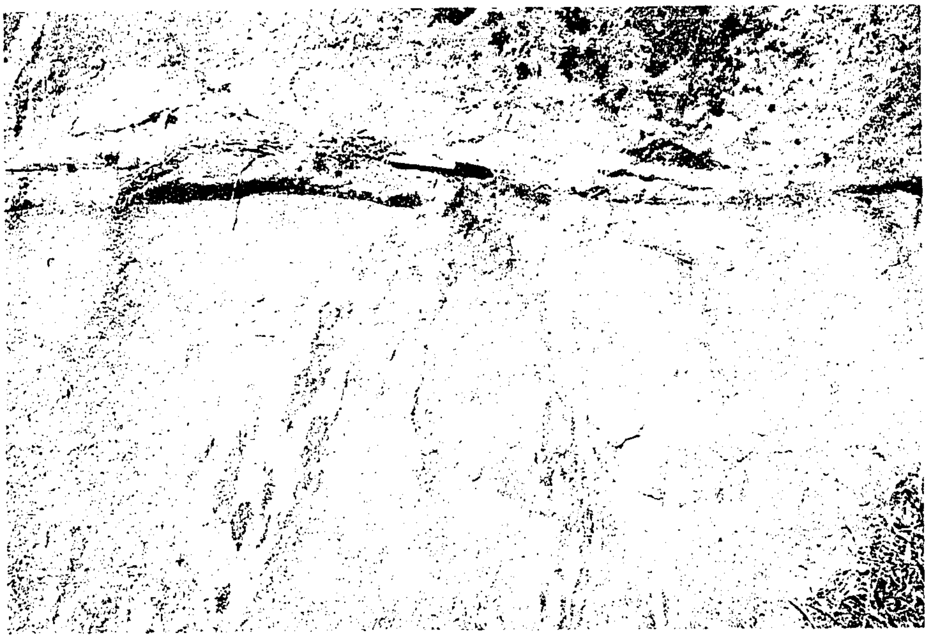


Figure 10. Enclaves (on a vertical face) in the heterogeneous zone in the Taft Granite. Note the sigmoidal shape of the enclaves. View is to the north-northwest.

Figure 11. Oblique opening in a dike, on a horizontal face, in the heterogeneous zone. Note the sinistral kinematics for both of the dikes.

hornblende (15-20%), anhedral sphene (1%), allanite (1%), and secondary epidote (5%). The granitic layers are composed of subhedral to euhedral plagioclase (25-35%), anhedral quartz (25%), anhedral potassium feldspar (20-25%), anhedral to subhedral biotite (10-15%), anhedral to subhedral hornblende (5-15%), anhedral sphene (1%), and secondary epidote (1%). Both types of layers display prominent plagioclase alignment (trachyitic texture). The layers are interpreted to have formed during injection and subsequent mingling of the tonalite and Taft Granite in the zone.

The tonalite is fine- to medium-grained and composed of subhedral to euhedral plagioclase (30%), anhedral to euhedral hornblende (25%), anhedral to euhedral biotite (20%), anhedral quartz (15%), anhedral to euhedral sphene (5%), secondary epidote (5%), and oxides (1%). Plagioclase is aligned and tabular. Hornblende and biotite form aggregates and also occur as inclusions in plagioclase crystals. The tonalite has a weak foliation defined by plagioclase and quartz. Weakly developed subgrains in quartz reflect minor subsolidus strain.

Small rafts of El Capitan Granite are enclosed by Taft Granite and tonalite in the heterogeneous zone. These rafts are typically < 3 m wide and 5 m long. Contacts range from sharp to gradational. Along gradational contacts with the tonalite, potassium feldspar phenocrysts are common in the outermost 20 cm of the host tonalite, and the phenocrysts resemble those in the El Capitan Granite. The phenocrysts are interpreted to record mechanical mixing between the two units. The foliation in the host tonalite is deflected around the El Capitan rafts. A sample of an El Capitan Granite raft in the heterogeneous zone is fine- to coarse-grained and composed of subhedral to euhedral plagioclase (30%), anhedral quartz (30%), anhedral to euhedral potassium feldspar (25%), subhedral biotite (10%), anhedral to euhedral sphene (< 5%), and secondary epidote (< 5%). The plagioclase is characterized by a graphic intergrowth with potassium feldspar. Poorly developed subgrains in quartz indicated minor subsolidus strain.

Magmatic flow in the heterogeneous zone was heterogeneous and complex. This is evident from different directions of flow recorded by the asymmetric enclaves compared to the sense of displacement of the oblique dike opening, the flow of the tonalite around El Capitan Granite rafts, and the mingling between different magmas.

McGurk Meadow Tonalite and Quartz Diorite

This unit has been previously mapped as a Jurassic-Cretaceous diorite (Peck, 1980, 2002) in conjunction with many other similar small bodies throughout the central Sierra Nevada batholith (Peck, 1980, 2002; Huber et al., 1989; Bateman, 1992). Samples of the "diorite" examined in thin section have a composition ranging from tonalite to quartz diorite. Thus, the unit is referred to herein as the McGurk Meadow tonalite and quartz diorite, named for its exposure in the McGurk Meadow area. In the study area, the largest body of the unit is approximately 2 km across and 3 km long (Fig. 3; Plate 1). These rocks are typically fine- to medium-grained and composed of subhedral to euhedral plagioclase (25-40%), anhedral to euhedral hornblende (30-40%), anhedral to euhedral biotite (25%), anhedral quartz (10%), anhedral clinopyroxene (5%), anhedral to euhedral sphene (5%), and secondary muscovite. Oscillatory zoning and seritization are typical of plagioclase. Clinopyroxene cores are preserved in larger hornblende crystals. Quartz is mostly interstitial and recrystallized.

The unit shares a laterally extensive, gradational contact with the Taft Granite where there is evidence of magma mingling in a 70-m-wide zone extending for 500 m of the contact. At one location along the contact, a northwest-striking, 4 m by ≥ 6 m contact parallel zone of 2 cm to 15 cm wide compositional layers of Taft Granite and McGurk Meadow tonalite and quartz diorite was observed. Fine-grained enclaves of intermediate composition are also common in swarms along the McGurk-Taft contact, and one large swarm is ~40 m^2. The swarms are elongate parallel to the McGurk-Taft contact.

The McGurk Meadow unit is also mingled with the 99 ± 1 Ma granodiorite of Illilouette Creek of the BVCS in two areas where enclaves and compositional layering are common; one area is ~500 m long and 140 m wide and the other is ~500 m long and 120 m wide. Compositional layers are oriented 138/70 and are defined by alternating units of Illilouette Creek and McGurk Meadow rocks. Individual layers range up to 50 cm thick. The layers of the McGurk Meadow unit are typically fine-grained and contain hornblende up to 7 mm long. Fine-grained enclaves in the granodiorite of Illilouette Creek are more widespread than compositional layering (Fig. 12). The enclaves are interpreted to be derived from the McGurk Meadow unit. The enclaves are 5 cm to 50 cm long, and many have diffuse and cuspate-lobate boundaries. They generally contain plagioclase up to 5 mm long and hornblende up to 3 mm long. The long axes of the enclaves trend 065, which is at a high angle to compositional layering. There is some

Figure 12. Mingling zone between McGurk Meadow tonalite and quartz diorite and granodiorite of Illilouette Creek.

back-veining of the granodiorite of Illilouette Creek into the McGurk Meadow unit and the enclave swarms.

The McGurk Meadow unit was originally mapped as Jurassic-Cretaceous diorite (Peck, 2002), but field relationships described above suggest that the McGurk Meadow unit is co-magmatic with the Taft Granite, and thus Cretaceous. The mingling of the McGurk Meadow unit with both the Taft Granite and granodiorite of Illilouette Creek implies that the emplacement of the intrusive suite of Yosemite Valley and the earliest part of BVCS overlap temporally.

Granodiorite of Turner Ridge

The granodiorite of Turner Ridge consists of granodiorite and tonalite that form a small pluton and dikes that extend from near Bridalveil Campground to the South Fork of the Merced River (Peck, 2002). The small pluton is located in the southwest corner of the map area and intrudes the El Capitan Granite and Taft Granite along sharp contacts (Fig. 3; Plate 1). These medium-grained rocks have equant quartz and plagioclase crystals up to 1 cm long set in a fine-grained groundmass of quartz, plagioclase, potassium feldspar, biotite, and hornblende.

The granodiorite of Turner Ridge is characterized by a steeply dipping magmatic foliation that strikes west-northwest (Fig. 3; Plate 1). Foliation intensity is constant throughout the unit. Lineation plunges steeply.

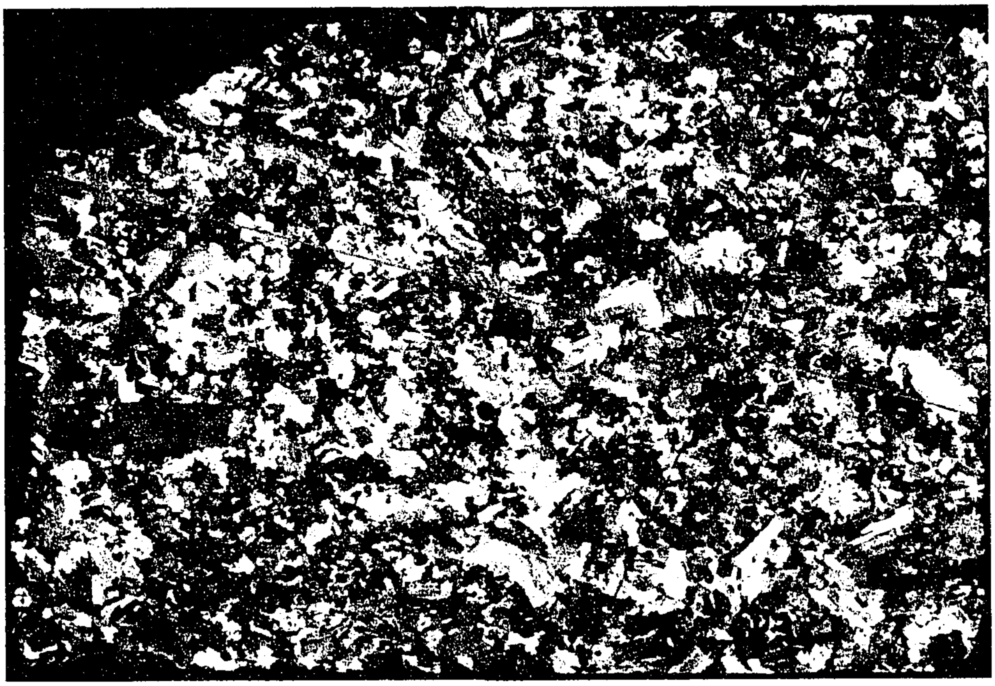
Enclaves are found locally and range from 1 cm to 30 cm in length and contain plagioclase phenocrysts up to 5 mm in length. The enclaves are generally elongate parallel to foliation.

ROCK TYPES OF BUENA VISTA CREST INTRUSIVE SUITE

The Buena Vista Crest Suite consists of six map units, as discussed above, which form a broadly nested pattern (Fig. 2). The units present in the map area, which encompasses the northern part of the BVCS, are, in younging order, the granodiorite of Illilouette Creek, the granodiorite of Ostrander Lake, and the Bridalveil Granodiorite (Fig. 3; Plate 1).

Granodiorite of Illilouette Creek

The granodiorite of Illilouette Creek is the marginal unit of the BVCS (Fig. 2). It is fine- to coarse-grained, hornblende-biotite granodiorite composed of subhedral to euhedral plagioclase (25-30%), anhedral to euhedral biotite (25%), anhedral to euhedral hornblende (10-20%), anhedral quartz (15-20%), potassium feldspar (5-15%), anhedral clinopyroxene (0-5%), anhedral to euhedral sphene (< 5%), oxides (<2%), and allanite (1%) (Fig. 13). Secondary epidote (2%) is also present. Hornblende displays reaction textures with other igneous phases; it is partially replaced by biotite and has clinopyroxene cores. This texture is attributed to early crystallized clinopyroxene reacting with melt to form hornblende, and hornblende then reacting with the remaining melt to form biotite. The patchy biotite formed from hornblende contrasts with subhedral to euhedral grains of biotite that, in some cases, protrude into the patchy biotite, and thus likely formed later in the crystallization of the granodiorite. Another distinctive feature of the unit is irregularly shaped sphene that rims oxides. Quartz is interstitial and



——————- Trace of the dominant foliation

—.— — —- Trace of the weak foliation

Figure 13. Typical granodiorite of Illilouette Creek displaying two magmatic foliations under cross-polarized light. The foliations are defined by hornblende, biotite, plagioclase, and quartz. The base of the picture is 7.5 cm.

displays chessboard subgrains, indicative of high-temperature subsolidus deformation (Kruhl and Huntemann, 1991; Masberg et al., 1992; Kruhl, 1996), and some grain boundary migration recrystallization.

Sheeting is observed in the granodiorite of Illilouette Creek in an ~100 m^2 area along Bridalveil Creek Trail just south of Bridalveil Creek Campground. These < 2-m-wide sheets are roughly the same composition as the host granodiorite, but are finer-grained. The sheets generally trend north-northwest and dip > 40° to the east. One of the fine- to medium-grained sheets is composed of subhedral to euhedral plagioclase (30%), anhedral quartz (25%), subhedral to euhedral biotite (20%), anhedral to euhedral hornblende (10%), anhedral potassium feldspar (10%), subhedral sphene (< 2%), chlorite (< 2%), and epidote (< 2%).

Northwest-striking compositional layers and schlieren were found in the unit at three localities: at the contact of the granodiorite and the El Capitan Granite; at the contact of the granodiorite and a metasedimentary xenolith; and near the sheeted zone. Layering is defined by variations in the amount of biotite and hornblende. At the Illilouette Creek-El Capitan contact, schlieren dip steeply (> 60°) to the northeast and southwest. This layered domain is 5 m by $\leq$ 7 m, and individual schlieren are 2 cm to 25 cm in width. The zone of compositional layering developed near the sheeted zone is < 1 m wide.

The granodiorite of Illilouette Creek is characterized by two medium to strong magmatic foliations, both of which are defined by biotite, hornblende, plagioclase, and quartz (Figs. 13 and 14). The dominant foliation generally strikes northwest. The orientation of the weaker of the two foliations is more variable, and ranges from west-southwest to north-northwest. Dips are steep and to both the north and south. Lineation plunges steeply in both of the foliations.

Enclaves and small mafic "clots" are widespread in the granodiorite of Illilouette Creek. Fine-grained enclaves of intermediate composition range from 1 cm to 40 cm in length. Some enclaves are elongate parallel to the dominant foliation, whereas the long axes of others are at moderate to high angles to this foliation. Some of the latter enclaves are elongate parallel to the weak foliation. Hornblende grains ranging up to 1 mm long and plagioclase grains ranging up to 5 mm long are common in the enclaves. Mafic "clots" are typically observed near enclaves. As used in this context, a "clot" is an aggregate of mafic minerals, typically 3 cm to 10 cm in width. The minerals in the clots occur in trains or as more weakly elliptical concentrations of minerals. The fine-grained clots may have been enclaves that were disaggregated during magmatic flow. The clots possibly encountered obstacles such as larger grains or enclaves, which created a "log jam," and the clots were prevented from further flow.

Numerous dikes intrude the granodiorite of Illilouette Creek. Fine- to medium-grained granitic dikes are the most abundant and range in width from 5 mm to 20 cm and extend laterally for up to ~50 m. Pegmatite dikes range from 1 cm to 10 cm in thickness. A 25-cm-wide aplite dike was found in one location and a 1-m-wide dioritic dike that coarsens inward was found at another locality.

———————— Trace of foliation

Figure 14. Two foliations in the granodiorite of Illilouette Creek. The enclaves are aligned in the stronger foliation.

Granodiorite of Ostrander Lake

The granodiorite of Ostrander Lake consists of biotite granodiorite in its interior and grades to hornblende-biotite granodiorite and/or tonalite outward near its contact with the granodiorite of Illilouette Creek. Biotite granodiorite is the most voluminous rock type, and is located in the southern part of the field area (Fig. 3; Plate1). It is characterized by poorly formed biotite and has potassium feldspar phenocrysts up to 5 mm long. The modal trends in the Ostrander Lake granodiorite are compatible with the outward increase in color index required for it to be classified as a normally zoned pluton.

The unit is fine- to medium-grained and composed of subhedral to euhedral plagioclase (25-40%), anhedral to subhedral biotite (10-15%), anhedral quartz (25-35%), anhedral potassium feldspar (15-35%), subhedral to euhedral hornblende (5%), and sphene (5%). Fine-grained alteration minerals include epidote (3%) and muscovite (2%). The quartz displays subgrains and minor recrystallization. Plagioclase commonly displays oscillatory zoning and is altered to sericite. Potassium feldspar is perthitic.

The granodiorite of Ostrander Lake is characterized by a weak- to medium-intensity magmatic foliation and lineation that are defined by biotite, plagioclase, quartz, and hornblende. Foliation generally strikes from north-northwest to northeast and dips steeply to the east. Near Ostrander Lake some of the foliations strike east-northeast to approximately east-west (Fig. 3; Plate 1).

Felsic dikes are abundant in the granodiorite of Ostrander Lake. Aplite dikes are 1 cm to 10 cm wide and extend from 50 m to 100 m. Granitic and pegmatitic dikes that have widths of 5 cm to 30 cm and 1 cm to 7 cm, respectively, commonly intrude the granodiorite.

Sparse enclaves in the granodiorite are typically 1 cm to 30 cm long. Some are elongate parallel to foliation in the host granodiorite, whereas others have long axes at moderate to high angles to foliation. Enclaves are intermediate in composition, typically fine-grained, and contain plagioclase and hornblende grains up to 5 mm long. An enclave swarm that is 25 m long and 10 m wide contains enclaves that range in length from 2 cm to 30 cm. The larger enclaves in the swarm are elongate parallel to foliation, whereas the smaller ones are elongate at moderate to high angles to foliation and typically have lower aspect ratios.

Rafts of El Capitan Granite and a few xenoliths of schist and quartzite are enclosed in the granodiorite of Ostrander Lake near the northern contact of the granodiorite (Fig. 3; Plate 1). The rafts occur over an area of 600 m^2. The short axes of individual rafts are up to 10 m wide, but the lengths of rafts are unknown due to insufficient exposure. The long axes trend northwest to north-northwest and are generally parallel to the northwest-striking foliation in both the rafts and granodiorite of Ostrander Lake. Similarly, dips of foliation in the rafts and granodiorite are steep (> 60°). The long axes and foliation, however, are nearly orthogonal to the contact between the raft-rich zone and the granodiorite of Illilouette Creek. The composition of the granodiorite of Ostrander Lake in the raft area becomes more hornblende-rich towards the east, but there are no significant compositional changes in the granodiorite on either side of individual rafts. El Capitan rafts end near a zone of mingling between hornblende-rich granodiorite of Ostrander Lake and a diorite. The sharp contacts between the granodiorite of Ostrander Lake and El Capitan Granite indicate that the latter unit had solidified before intrusion of the granodiorite..

Bridalveil Granodiorite

The Bridalveil Granodiorite mostly forms gently dipping, <1.5-km-wide sheets that crop out on the southern wall of Yosemite Valley, and larger bodies farther to the south (Peck, 2002) (Fig. 2). In contrast, the two bodies of Bridalveil Granodiorite in the study area dip steeply. One body, located in the northern part of the study area, is ~1-km-wide (Fig. 3; Plate 1). The other ~500 m^2 body is located in the central part of the study area and is irregularly shaped (Fig. 3; Plate 1).

The Bridalveil Granodiorite is a fine- to medium-grained biotite granodiorite and granite composed of subhedral to euhedral plagioclase (20-35%), anhedral to euhedral potassium feldspar (30-35%), anhedral quartz (25-30%), anhedral to subhedral biotite (5-15%), and anhedral sphene. Accessory and secondary minerals include allanite (1%) and muscovite (< 5%). Most of the plagioclase shows oscillatory zoning. Quartz displays subgrains and minor grain boundary migration recrystallization.

The unit is characterized by a weak to moderately strong magmatic foliation and lineation defined primarily by biotite and quartz, and to a lesser extent by potassium feldspar. The foliation generally strikes north to northwest and dips steeply to the east. Lineation plunges steeply.

The Bridalveil Granodiorite is a homogenous unit that lacks the internal structures, such as dikes and compositional layering, which are common to the other units of the BVCS. However, enclaves up to 50 cm long are observed in the granodiorite in one location next to the contact with the granodiorite of Illilouette Creek.

SENTINEL GRANODIORITE

The ~94.5 Ma Sentinel Granodiorite (Calkins, 1930; Coleman and Glazner, 1997) consists of equigranular granodiorite and less abundant tonalite. It is located in the northeast corner of the study area and in a small northwest-striking body that intrudes the granodiorite of Ostrander Lake on the east side of Horizon Ridge (southeast part of map area) (Fig. 3; Plate 1). The Sentinel Granodiorite intrudes the intrusive suite of Yosemite Valley and granodiorite of Ostrander Lake of the BVCS, and may be an older unit of the Tuolumne Intrusive Suite (e.g., Bateman, 1992; Petsche, 2006).

The unit is fine- to medium-grained and composed of subhedral to euhedral plagioclase (25-40%), anhedral quartz (20-25%), anhedral to euhedral biotite (15-20%), anhedral to euhedral hornblende (10-20%), anhedral potassium feldspar (10-25%), anhedral to euhedral sphene (< 5%) and allanite (< 1%). Secondary minerals include chlorite (< 5%), epidote (< 5%), and oxides (< 1%). Quartz is characterized by subgrains and minor recrystallization, and plagioclase displays oscillatory zoning. Hornblende and biotite occur as aggregates and are generally replaced by chlorite and epidote. Magmatic foliation and lineation in the unit are defined by hornblende, biotite, plagioclase, and quartz, and the hornblende-biotite aggregates are typically elongate in the foliation.

The main mass of the Sentinel Granodiorite in the northeastern part of the field area (Fig. 3; Plate 1) contains abundant enclaves and is cut by 3 cm to 10 cm wide pegmatite dikes. The enclaves are of intermediate composition, range up to 10 cm long, and are typically oriented parallel to magmatic foliation. The foliation is steep and varies in strike from east-west in the northernmost part of the field area to north-south near the contacts with the El Capitan and Taft Granites (Fig. 3; Plate 1). Lineation plunges steeply.

The body of Sentinel Granodiorite on the east side of Horizon Ridge is more heterogeneous. The granodiorite here is mingled with disrupted bodies of diorite that are 3 m to 4 m in diameter and have crenulated margins. In one location, a diorite body is also mingled with granodiorite of Ostrander Lake along the contact between the Sentinel Granodiorite and Ostrander Lake unit. In addition to the larger diorite bodies, abundant enclaves of diorite range up to 15 cm long and have long axes parallel to the north-northwest-striking foliation in the Sentinel Granodiorite. Schlieren in the granodiorite on Horizon Ridge occur in a 1-m-wide-zone, are 2 cm to 5 cm wide, and are defined by concentrations of hornblende and biotite. They strike northeast and dip steeply next to the northeast-striking southern contact between the Sentinel Granodiorite and granodiorite of Ostrander Lake (Fig. 3; Plate 1). Pegmatite dikes, 1 cm to 10 cm wide, and aplite dikes, 6 cm to 8 cm wide, are common. The dikes typically strike north-northeast and extend for up to 100 m.

The foliation of the Sentinel Granodiorite on Horizon Ridge is parallel to the general northwest trend of the contacts of the granodiorite and has a moderate to strong intensity (Fig 3). The foliation is discordant to the northwestern and southeastern ends of the body.

The main mass of the Sentinel Granodiorite, in the northeastern part of the study area, has sharp contacts with the El Capitan and Taft Granites. The contact of the northwest-striking body on Horizon Ridge with the granodiorite of Ostrander Lake is more variable. The western Sentinel-Ostrander Lake contact is sharp, whereas the eastern contact is gradational over several meters and is defined by the disrupted body of diorite mingled with both the granodiorites, as described above. At the eastern contact, hornblende-rich diorite dikes intrude into the granodiorite of Ostrander Lake and have cuspate-lobate margins. This relationship is inferred to indicate that crystallization of the dikes partially melted and remobilized the granodiorite of Ostrander Lake along the Sentinel-Ostrander Lake contact to produce the mingling structures.

STRUCTURE OF BUENA VISTA CREST INTRUSIVE SUITE

The main structures in the study area are magmatic, and include foliation, lineation, schlieren and other compositional layering, enclaves, and dikes. No major faults or shear zones have been recognized in the study area. The contacts between host rock units and the BVCS generally trend north-south, slightly oblique to the northwest trend of host rock contacts in the Sierra Nevada batholith as a whole. In the following, I discuss: 1) fabric patterns in the units of the BVCS and their relation to contacts, schlieren and other compositional layering, enclaves, and dikes; and 2) contact relationships between the BVCS and host rocks, and between the units of the BVCS.

Fabric Patterns and their Relationships to other Structures in the BVCS

Granodiorite of Illilouette Creek

The earliest outcrop-scale magmatic structures in the granodiorite of Illilouette Creek are rare schlieren and other compositional layers. They generally strike northwest, concordant to the dominant foliation, and dip steeply (> 60°) to the northeast.

The granodiorite of Illilouette Creek is characterized by two magmatic foliations, a dominant northwest-striking fabric and weaker east-west striking fabric (Fig. 15) (Plate 1). The strike of the dominant foliation has little variability; this foliation dips steeply (> 60°) and preferentially to the northeast (Figs. 15 and 16). The weaker foliation has a more variable strike, which varies mainly from southwest to west-northwest, but also

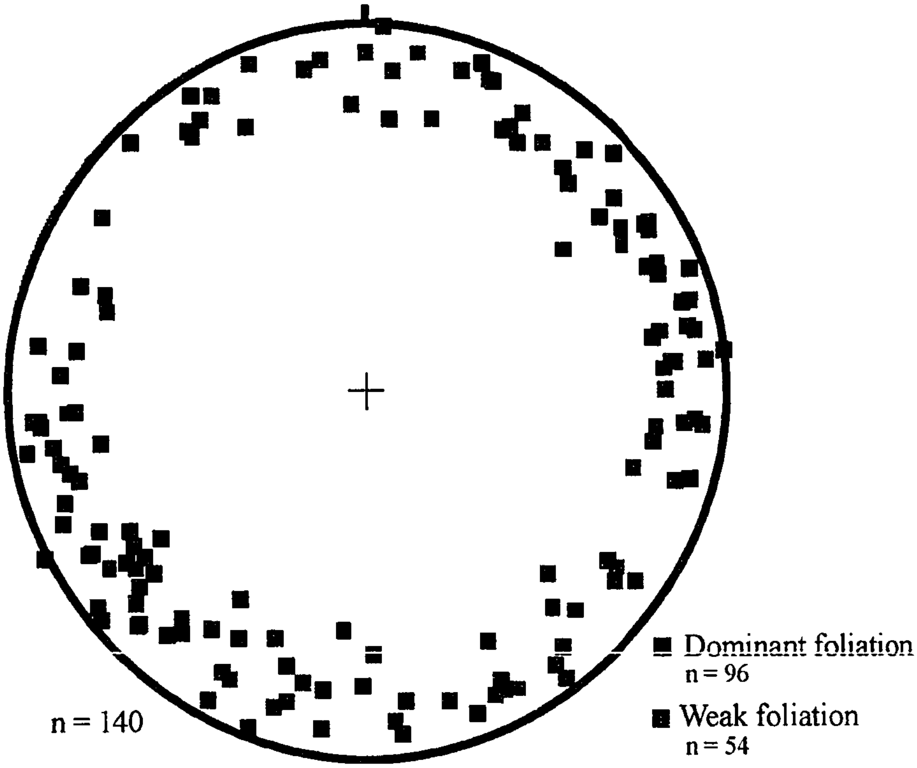


Figure 15. Stereonet projection of the poles of foliations in the granodiorite of Illilouette Creek. Note the steep dips.

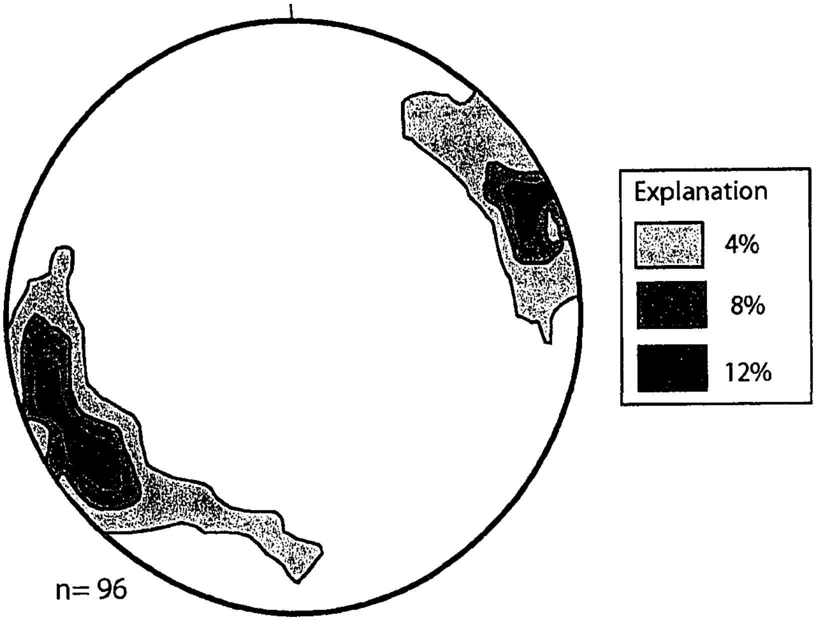


Figure 16. Contoured stereonet projection of poles to foliation in the Illilouette Creek Granodiorite. The dominant foliation strikes northwest and has a mean principal orientation of 328/84.

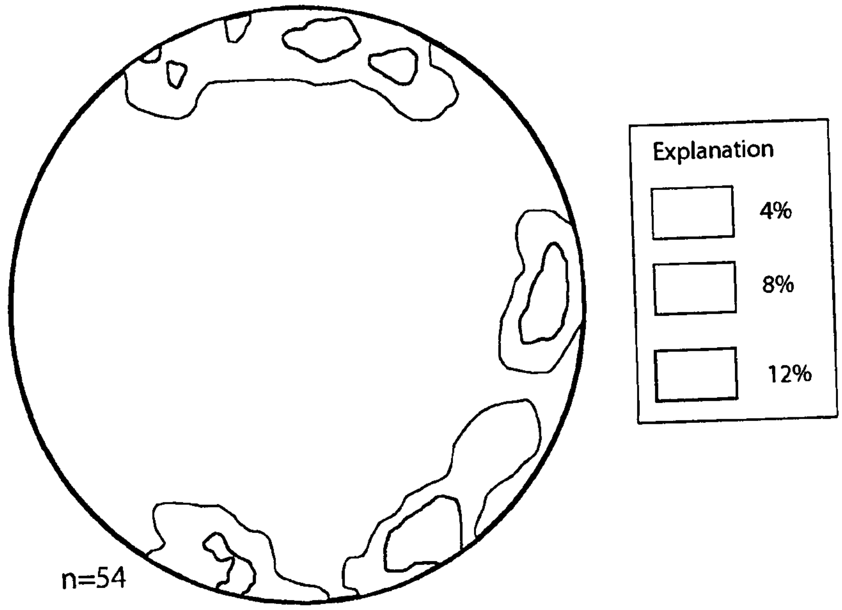


Figure 17. Contoured stereonet projection of poles to the weak foliation in the Illilouette Creek Granodiorite. The foliation strikes dominantly east-west and has a mean principal orientationof 258/90.The north-south concentration of foliation is attributed to deflection around north-south-trending contacts with host rocks.

includes north-south orientations (Figs. 15 and 17). It dips steeply (> 60°). Both of the foliations are invariably present at the outcrop scale, but may not be measurable due to outcrop exposure. Foliation intensity is consistent throughout the unit, but is typically stronger in a narrow zone near contacts with host rocks. The lineation plunges steeply (> 60°) (Fig. 18), subparallel to the intersection of the two foliations. Both the dominant and weak foliations in the granodiorite are stronger than the lineation, and thus a flattening-type fabric ellipsoid is indicated. The long axes of some of the enclaves in the granodiorite are parallel to the dominant foliation, whereas the long axes of others are parallel to the weak foliation.

Minor dikes in the granodiorite of Illilouette Creek vary in orientation, but typically strike approximately east-west to northwest and dip steeply (> 60°), preferentially to the north and northeast. The dikes are generally aligned 5° to > 15°, respectively, from either the dominant or weak foliation depending on location; thus, dike emplacement was probably not controlled by foliation anisotropy. The dikes apparently record north-south to northeast-southwest stretching.

No direct evidence was recognized in the study area for the relative timing of the two foliations in the granodiorite of Illilouette Creek. For example, no simple cross-cutting relations, such as the rotation of one foliation into another, were seen. Enclaves are elongate in both the dominant and weak foliation, and the same minerals occur in both of the foliations.

Indirect evidence for the relative timing of foliations comes from the map pattern. The dominant northwest-striking foliation is highly discordant to the east-west trending

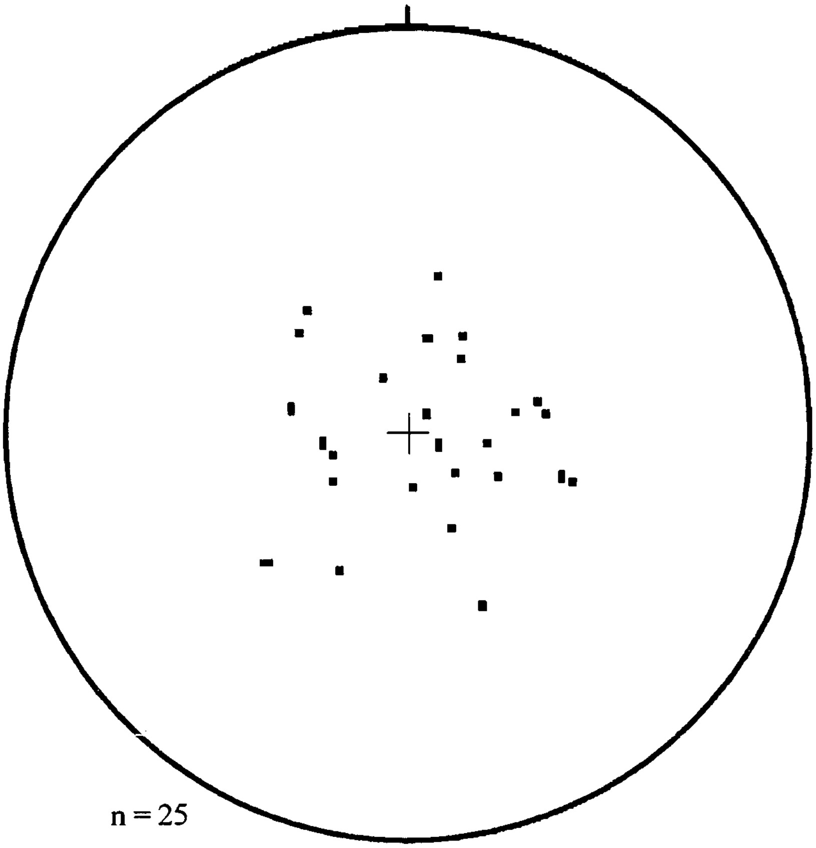


Figure 18. Stereonet projection of lineation for all of the units of the BVCS. The lineation is steeply plunging and the mean principal direction is 87/102.

contacts between Illilouette Creek granodiorite and its host rocks (Fig 3; Plate 1), but is approximately parallel to the foliation in the host rocks. These relationships imply that the dominant foliation reflects regional strain rather than internal magmatic processes, such as flow along walls of a magma chamber (Paterson et al., 1998).

The east-west-striking foliation is broadly concordant to host rock contacts and is typically at a high angle to the foliation in the host rocks. It is probably related to the emplacement and/or internal magmatic processes of the granodiorite of Illilouette Creek.

Granodiorite of Ostrander Lake

The granodiorite of Ostrander Lake has magmatic foliation and lineation that are variable in orientation (Fig. 19). The foliation ranges from northeast-striking in the south to north-south-striking in the north-central part of the body, to east-west striking near the contact with Illilouette Creek granodiorite (Fig. 3; Plate 1). Dips are steep (> 60°). Foliation is discordant to contacts with the Taft Granite. In contrast, it is mostly concordant to east-west and north-south striking contacts with the granodiorite of Illilouette Creek, and foliation intensity increases near these contacts. Lineation is steeply plunging (> 60°) (Fig. 18). A flattening-type fabric ellipsoid is indicated by the stronger intensity of foliation than lineation.

The orientation of enclaves is variable throughout the unit. Long axes may be aligned parallel to the foliation or at a high angle to it. The large enclave swarm near Ostrander Lake, as described above, trends north-northwest, at a high angle to the

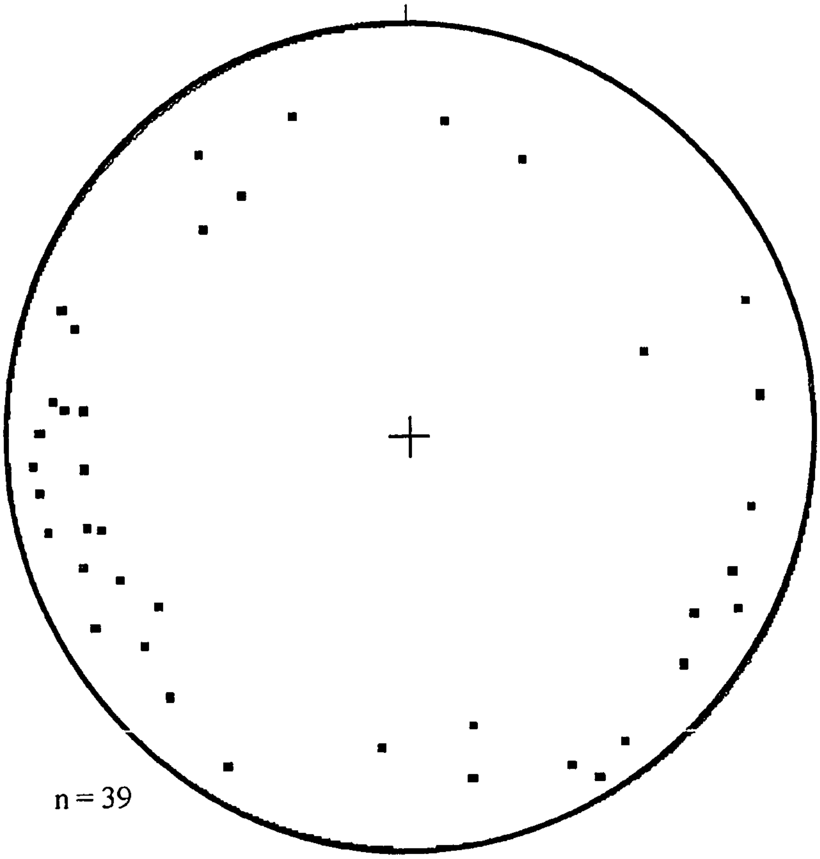


Figure 19. Stereonet projection (lower hemisphere) of poles to foliation planes in the granodiorite of Ostrander Lake. The mean principal orientation is 004/83, but there is clearly much scatter.

northeast-striking foliation in the host granodiorite. Schlieren near the enclave swarm also strike north-northwest.

Dikes in the granodiorite of Ostrander Lake strike north-northeast, northwest, and east-west in the south near Ostrander Lake. Dips are to the east-southeast, northeast, and north, respectively. Strikes are generally north-northwest and north-south in the north-central part of the granodiorite. These dikes dip to the northeast and east. The dikes show no simple relationship to nearby foliation, contacts, or other structural features, and do not yield any consistent extension direction.

Bridalveil Granodiorite

The Bridalveil Granodiorite is characterized by a magmatic foliation with a general northwest strike (Fig. 20). This strike is discordant to north-south-striking contacts with the host rocks (Fig. 3; Plate 1). Dips are steep (> 60°) and generally to the northeast. Foliation intensity is consistent throughout the unit. Lineation is steeply plunging (> 60°). Foliation is stronger than the lineation, and thus a flattening-type fabric ellipsoid is indicated. The enclave swarm in the granodiorite trends northwest, concordant to the strike of foliation.

Fabric Analysis

The presence of two magmatic foliations in individual outcrops has only been reported for a few plutons (e.g., the Half Dome Granodiorite of the Tuolumne Intrusive

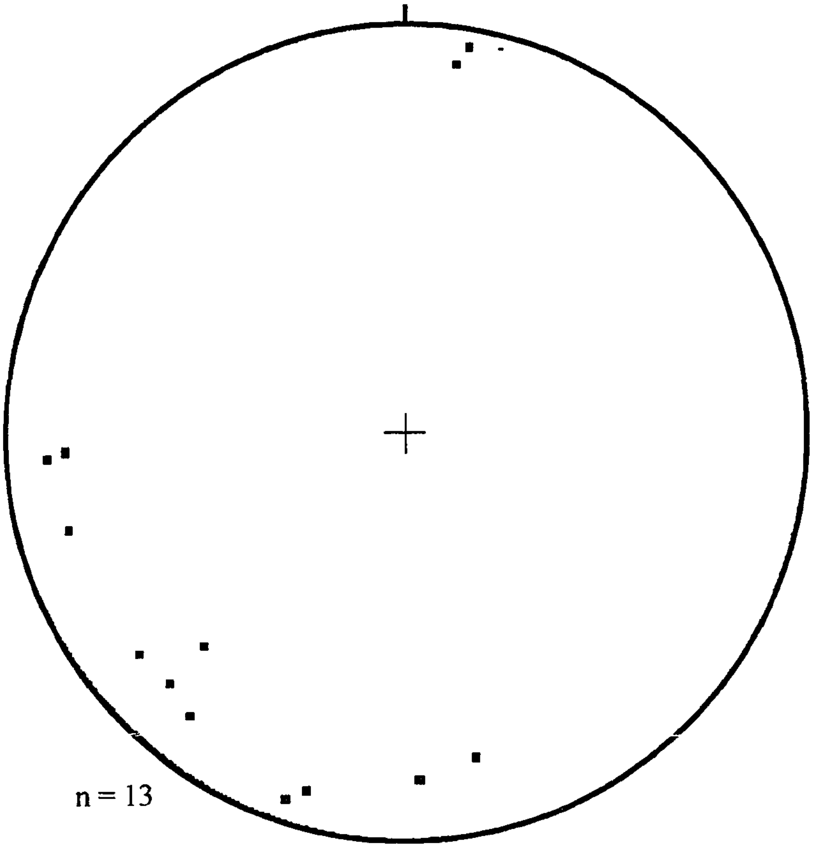


Figure 20. Stereonet projection (lower hemisphere) of poles to foliation planes in the Bridalveil Granodiorite. The mean principal orientation is 303/76.

Suite) (Bateman, 1992; Paterson and Vernon, 1995; Teruya and Miller, 2000; Paterson et al., 2003; Zak et al., 2007). Thus, given the potential significance of multiple foliations in the granodiorite of Illilouette Creek, the fabrics were further evaluated using shape preferred orientation (SPO) analysis on three samples.

To prepare for the SPO analysis, digital scans were made from 5 X 7.5 cm thin sections that were cut perpendicular to foliation, two samples for the dominant foliation and one for the weak foliation, and the scans were imported into the drafting program, Adobe Illustrator. The images were modified by filling in individual minerals with color. The colorized images were then in the proper form to be analyzed by the software program, INTERCEPT, which was created by Launeau and Robin (1996). Each whole rock sample was analyzed by the INTERCEPT program (i.e., the different mineral phases were not broken out for analyses). The program scans the image at angular intervals of 9° in order to analyze the mineral boundaries. The program calculates a series of lines based on where the scan enters and leaves an object over the course of a 360° scan. Several summary diagrams are constructed by the program, and the rose of mean intercept lengths is the most relevant for this study (Launeau and Robin, 1996; Teruya, 2005). For more details on the fabric analysis process, see Launeau and Robin (1996).

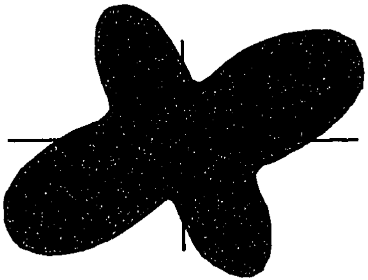
The intensity of the fabric is described by the rose of mean intercept length. A single fabric will produce an ellipse whose long axis represents the greatest alignment of a mineral phase. If two fabrics are present, the ellipse will be distorted. Two fabrics of equal strength will be represented as a square or diamond shape (Launeau and Robin, 1996; Teruya, 2005). Where there are two fabrics of unequal strength, the strong fabric is represented by the long axis of the ellipse, and the weak fabric is recorded by a bulge that distorts the ellipse.

Figures 21 through 23 display the roses of mean intercept lengths for three samples of the granodiorite of Illilouette Creek. The x-y, x-z, and y-z planes on the figures refer to the axes of the fabric ellipsoid. For samples 361 (Fig. 21) and 381 (Fig. 22), a distorted ellipse clearly indicates that one foliation is stronger than the other. For sample 362 (Fig. 23), the square shape indicates that the foliations are of sub-equal intensity. Field and thin section observations indicate that the same minerals define each foliation. The two orientations can be correlated to the two magmatic foliations in the granodiorite of Illilouette Creek: thus, the fabric analysis confirms field and thin section observations.

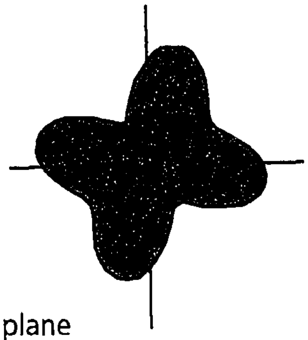
Contact Relationships

The following paragraphs describe the contact relationships between the BVCS and its host rocks, as well as internal contacts between units of the BVCS. Contacts are described in order of decreasing age, beginning with those of the granodiorite of Illilouette Creek.

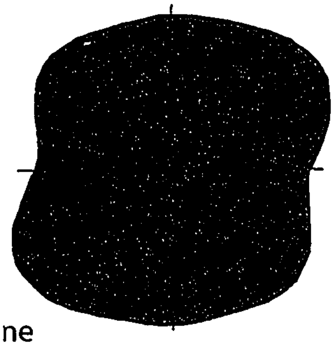
Contacts between the granodiorite of Illilouette Creek and host rocks are sharp and steep (> 60°). The granodiorite truncates generally north-south to northeast-southwest-trending contacts and northwest-striking foliations in the units of the intrusive suite of Yosemite Valley (Fig. 3; Plate 1). The dominant foliation of the Illilouette Creek granodiorite is discordant to host rock contacts, whereas the weak foliation is generally



x-y plane

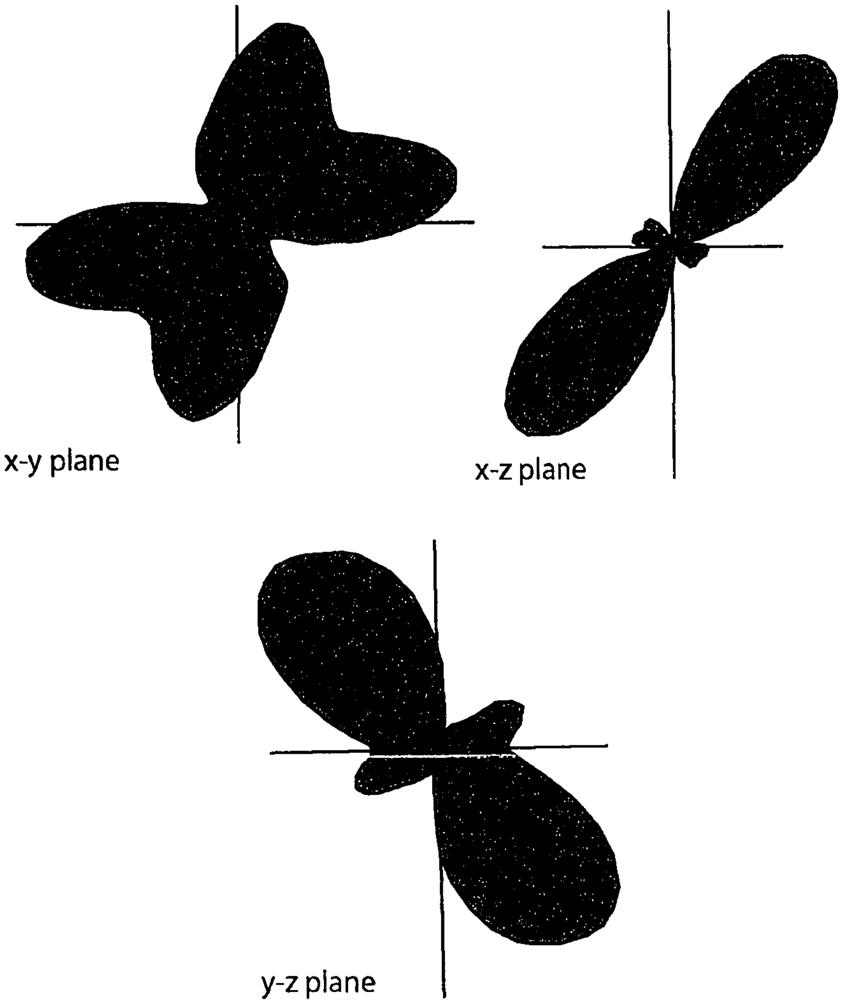


x-z plane



y-z plane

Figure 21. Roses of mean intercept lengths for sample 361.
x-y plane = parallel to the dominant foliation; x-z plane = perpendicular to the dominant foliation, parallel to the lineation; y-z plane = perpendicular to both the dominant foliation and lineation

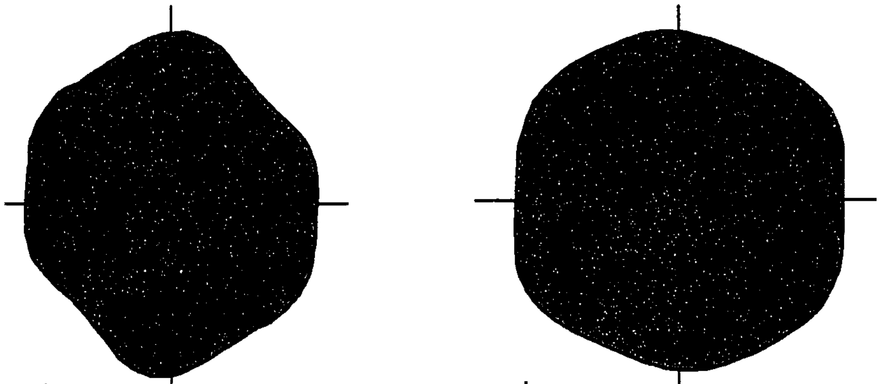


x-y plane

x-z plane

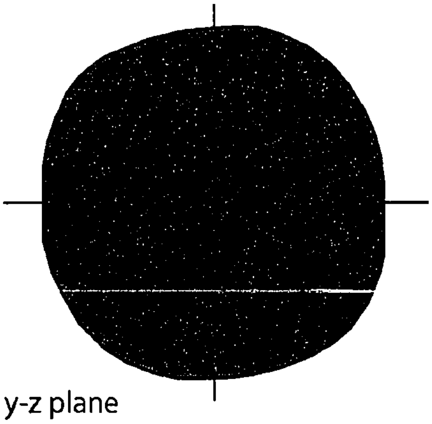
y-z plane

Figure 22. Roses of mean intercept lengths for sample 381. x-y plane = parallel to the dominant foliation; x-z plane = perpendicular to the dominant foliation, parallel to the lineation; y-z plane = perpendicular to both the dominant foliation and lineation



x-y plane

x-z plane



y-z plane

Figure 23. Roses of mean intercept lengths for sample 362. x-y plane = parallel to the weak foliation; x-z plane = perpendicular to the weak foliation, parallel to the lineation; y-z plane = perpendicular to both the weak foliation and lineation

concordant to these contacts. The only gradational contacts in the study area are found where the granodiorite of Illilouette Creek and Taft Granite are in contact with the McGurk Meadow tonalite and quartz diorite.

Metasedimentary xenoliths in the granodiorite of Illilouette Creek are < 2 m in diameter. One of the xenoliths is elongate parallel to foliation in the granodiorite and the other is square-shaped in two dimensions. Foliation in the xenoliths varies from northwest-striking, parallel to the dominant of the two magmatic foliations in the granodiorite, to northeast-striking, at a high angle to both of the foliations in the granodiorite.

The granodiorite of Ostrander Lake has a sharp, irregularly shaped contact with the Taft Granite, and foliation in the Ostrander Lake unit is generally discordant to the contact with the granite. Metasedimentary xenoliths in the granodiorite are < 2 m in diameter, are generally square- and rectangular shaped in two dimensions, and are located within a few meters of each other. The long axis of one of the rectangular xenoliths is oriented northeast-southwest. Foliation in the xenoliths has strikes that range from northwest- to north-northeast, at high angles to the east-west-striking foliation in the enclosing granodiorite. The El Capitan Granite rafts in the granodiorite of Ostrander Lake are elongate north to northwest, parallel to the strike of foliation of the host granodiorite in that area.

The granodiorite of Illilouette Creek and granodiorite of Ostrander Lake have a long east-west-trending contact, which locally steps to the north (Figs. 2 and 3). In the study area, the contact is sharp and steep (> 60°) (Fig. 3; Plate 1). The intensity of magmatic foliation in the granodiorite of Ostrander Lake is stronger in a zone extending ~100 m inward from the contact, whereas foliation intensity in the granodiorite of Illilouette Creek does not change nearer the contact.

The main body of Bridalveil Granodiorite has sharp, steep (> 60°), generally north-south-trending, planar contacts with the El Capitan Granite, Taft Granite, and the McGurk Meadow tonalite and quartz diorite unit. Foliation in the Bridalveil Granodiorite is discordant to these contacts. The contact between the small, southern body of the granodiorite and the Illilouette Creek and Ostrander Lake units is also sharp, but is irregular in map view.

DISCUSSION

Emplacement

The structure of the BVCS had received minimal study, and processes operating during emplacement were unknown prior to this investigation. The BVCS is an interesting target for evaluation of emplacement mechanisms because, contrary to many classical studies that have focused on plutons hosted by metasedimentary rocks, the host rocks of the BVCS are plutonic. An emplacement model for the BVCS must account for several key observations, including contact relationships between the suite and host rocks, foliation and lineation orientations and intensities in the suite and host rocks, faults and shear zones in the region, internal contacts of units in the suite, and the presence of metasedimentary xenoliths in the intrusive suite.

Contacts between host rock units generally trend north-south to northeast-southwest and are cut discordantly by the BVCS at angles ranging from approximately 50° to 80°. Similarly, northwest-striking magmatic foliations in the host rock are typically not deflected near, and are truncated by, the margin of the BVCS (Fig. 3; Plate 1). In addition, solid-state deformation is weak everywhere in host rocks, and no solid-state deformation in host rocks can be attributed to emplacement of the BVCS. This discordance of host rock contacts and foliation, and lack of solid-state deformation indicate that no structural aureole is present. Thus, emplacement models involving significant ductile flow of host rocks, such as downward flow, horizontal expansion, and probably floor sinking are not supported by field relations.

Fault-related material transfer processes have been suggested for other plutons in the central Sierra Nevada batholith (e.g., Tikoff and Teyssier, 1992; Titus et al., 2005). Major faults and shear zones are not present in the study area, but approximately 10 km to the southeast of the area is a regional structure, the Quartz Mountain shear zone (Fig. 24). It is one of a family of northwest-striking, southwest-dipping, contractional shear zones of the central Sierra Nevada that includes the Bench Canyon shear zone, Rosy Finch shear zone, Kaiser Peak shear zone, and Courtright-Wishon shear zone (Tobisch et al., 1995). The other major structures are ~25 to 75 km from the Quartz Mountain shear zone and eastern margin of the BVCS, so it is unlikely that they played a role in the emplacement of the suite.

The 1- to 2-km-wide Quartz Mountain shear zone is approximately 10 km long (Fig. 24). It deforms the granodiorite of Illilouette Creek and granodiorite of Ostrander Lake in the southeastern part of the BVCS. The shear zone terminates by splaying out in the granodiorite of Ostrander Lake and is cut off to the southeast by the ca. 90 Ma Mt. Givens pluton (Tobisch et al., 1995).

The Quartz Mountain shear zone probably initiated at ca. 98 Ma during cooling of 102 to 99 Ma plutons (Tobisch et at., 1995), and thus may have been active during emplacement of the ca. 99 ± 1 Ma Illilouette Creek. There is no extension of the shear zone in the host rocks north of the plutons in the study area, however, arguing against regional faulting as a significant material transfer process. In addition, the motion of the shear zone is not compatible with emplacement in a dilational step-over of a strike- slip

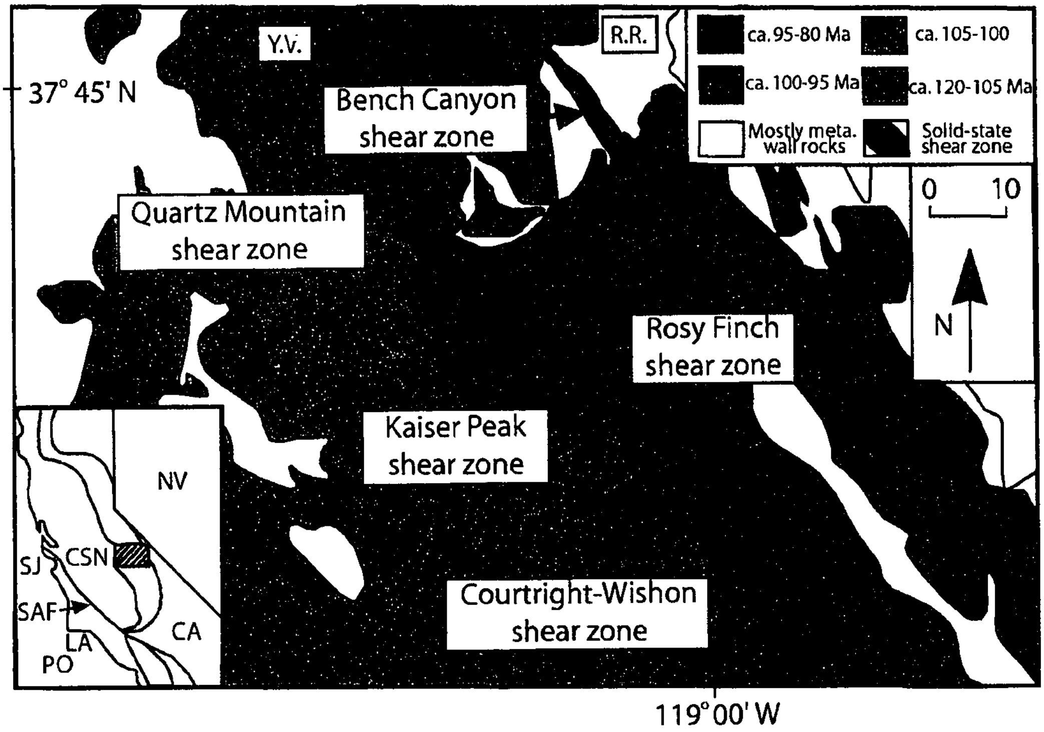


Figure 24. Major shear zones of the central Sierra Nevada batholith (modified from Tobisch et al. [1995]). Note that the Quartz Mountain shear zone terminates in the 100 to 95 Ma BVCS. R.R. = Ritter Range; Y.V. = Yosemite Valley. Inset shows the location of the central Sierra Nevada (box): CA = California; CSN = central Sierra Nevada; LA = Los Angeles; meta. = metasedimentary; NV = Nevada; PO = Pacific Ocean; SAF = San Andreas fault; SJ = San Jose.

or normal fault system. The termination of another shear zone of the system, the Bench Canyon shear zone, is inferred to have controlled the emplacement of the youngest phase of the Tuolumne Intrusive Suite (Titus et al., 2005). The Ostrander Lake granodiorite, however, continues for > 20 km northwest from the termination of the Quartz Mountain shear zone, and there is minimal solid-state deformation of the granodiorite in the study area. The shear zone also does not deform the younger Bridalveil Granodiorite. Thus, although it is conceivable that at depth the Quartz Mountain shear zone acted as a pre-existing anisotropy that helped guide the BVCS magmas, it is highly unlikely that motion on the shear zone acted as a material transfer process during emplacement of the suite.

Roof uplift is a potentially significant emplacement process at shallow crustal levels (e.g., Corry, 1988; Clemens and Mawer, 1992; Cruden 1998), and estimates of magmatic overpressure required to dome roof rocks largely restricts this mechanism to within 3 km to 5 km of the surface (Corry, 1988; Petford, 1996). The BVCS is a potential candidate for roof uplift because the suite was likely emplaced at shallow levels based on the emplacement depth (< 3 m) of the neighboring and roughly coeval Jackass Lake pluton (McNulty et al., 1996). Unfortunately, roof uplift is a difficult emplacement mechanism to evaluate for the BVCS because a roof has not been recognized in the study area, or elsewhere (Peck, 2002), and foliations in the BVCS units and host rocks are steep. If host rock markers were steep when the BVCS was emplaced, as is probable, then there would be little deflection of markers during any roof uplift.

As noted by Cruden (1998) the piston method of roof uplift creates brittle faults along the walls of the pluton. Such faults are not present along the wall rocks of the

BVCS, and thus roof uplift by a piston-type method did not likely occur. Similarly, ductile shear zones may form along pluton walls during roof uplift (Corry, 1988; Cruden 1998), but have not been observed next to the BVCS. Alternatively, during roof uplift, host rocks may be draped over the sides of the intruding pluton. This draping is difficult to evaluate if the host rock foliations are steep prior to roof uplift, as was likely the case for the BVCS. However, it cannot be ruled out that late stoping along pluton margins may have removed earlier faults, narrow ductile shear zones, and narrow structural aureoles (see discussion of stoping below). Roof uplift is, thus, an attractive, but unproven, hypothesis for the BVCS based on the shallow emplacement depth.

Stoping is another emplacement process that is considered to be a common process in the upper crust by most workers (e.g., Daly, 1903; Paterson et al., 1996), and xenoliths preserved in the Illilouette Creek and Ostrander Lake granodiorites are interpreted to record stoping. These xenoliths are < 2 m in diameter, and widely isolated from each other (Fig. 4). There are two xenoliths in the Illilouette Creek unit. One has a foliation oriented parallel to the dominant foliation in the unit and the regional northwest-southeast structural grain. The other xenolith has a foliation that strikes northeast, at an angle to both of the foliations in the enclosing granodiorite. Xenoliths in the granodiorite of Ostrander Lake have a foliation that is rotated relative to foliation in the surrounding granodiorite.

Within the BVCS, stoping is suggested by irregularly shaped contacts and sharply truncated pre-existing host rock markers such as contacts and foliation (e.g., Paterson et al., 1996). This sharp truncation and the small, rotated xenoliths in the BVCS suggest that stoping was a significant process during emplacement of the suite. The volume of xenoliths, however, is low. This is a common problem in many plutons for which stoping is inferred (e.g., Fowler and Paterson, 1997; Glazner and Bartley, 2006). Xenoliths may be removed from the level of emplacement by sinking or disaggregating into xenocrysts, which would be difficult to recognize in the field (e.g., Marsh, 1982; Paterson et al., 1996).

In summary, field relationships lead to the following conclusions about emplacement of the BVCS. 1) The contacts of the BVCS are discordant to generally north-south and northeast-southwest-trending contacts between host rock units, and the northwest-striking foliation in the host rock is not deflected by the BVCS. These relationships and the lack of solid-state deformation of host rocks suggest that models involving major ductile flow of host rocks are not applicable to the BVCS. 2) Major faults and shear zones are not present in the study area, and the nearby Quartz Mountain shear zone is unlikely to have aided emplacement. 3) Roof uplift may have facilitated emplacement of the BVCS, but there is little concrete field evidence to evaluate its significance as a material transfer process. 4) The xenoliths, sharp truncation of host rock markers, and irregularly shaped contacts between the BVCS and its host rocks indicate that stoping was a significant material transfer process during emplacement.

Stoping is the only emplacement mechanism for which there is direct field evidence; however, geochemical and thermal modeling suggest that stoping is unlikely to transfer much more than 30% of the host rocks needed to account for the volume of intruding magma (Fowler and Paterson, 1997; Zak and Paterson, 2006). Stoping may remove structural features such as faults along pluton walls and/or narrow ductile aureoles. In view of the shallow level of emplacement, I infer that roof uplift accounts for at least some of the remaining volume of displaced host rock. Thus, as with many plutons, it is difficult to account for all of the necessary material transfer during emplacement of the BVCS.

Construction of the Buena Vista Crest Intrusive Suite

The mechanics of magma ascent and the construction of plutons is a point of contention (e.g., Clemens and Mawer, 1992; Petford, 1996; Miller and Paterson, 1999; Glazner et al., 2004). In the next paragraphs, I discuss the relevance to the BVCS of the following ascent and construction mechanisms: 1) the incremental assembly of dikes with no steady-state magma chamber; 2) the intrusion of dikes to create a steady-state magma chamber; and 3) the ascent of multiple visco-elastic diapirs, which may also form relatively large steady-state magma chambers.

It has been recently hypothesized that plutons are constructed via many small dike-like increments over millions of years during progressive dilation of host rocks, and that during this construction, no steady-state magma chamber exists (Coleman et al., 2004; Glazner et al., 2004; Glazner and Bartley, 2006). Evidence advanced for this mechanism includes intrusions with a progression in ages representing long periods of time, numerous internal contacts, and thin concordant panels of host rock with the same fabric orientation as the surrounding plutonic rock (Glazner et al., 2004). The Tuolumne

Intrusive Suite to the north and northeast of the BVCS (Fig. 2) is one locality for which such a model of incremental assembly has been hypothesized.

There is little evidence that the BVCS was constructed by the incremental amalgamation of dikes. The granodiorite of Illilouette Creek is locally sheeted on the meter scale, but the sheets are restricted to an area of ~100 m^2, and the unit otherwise lacks obvious internal contacts. The composition of the granodiorite of Ostrander Lake changes gradationally, without obvious contacts, except for where the unit is sheeted with the El Capitan Granite rafts (Fig. 3; Plate 1).

Glazner et al. (2004) and Glazner and Bartley (2006) also suggest that host rock bodies in most plutons, which have been called xenoliths by many, are actually in situ rafts that have not been detached by stoping and have remained intact between successive incremental intrusions. In contrast, metasedimentary xenoliths in the granodiorite of Ostrander Lake, which are located within meters of each other, have foliations oriented at high angles to one another. The two xenoliths in the granodiorite of Illilouette Creek are separated by ~2 km. In one, foliation strikes northwest, parallel to the dominant of the two magmatic foliations in the granodiorite, and in the second, foliation strikes northeast, at a high angle to both of the foliations in the granodiorite. In addition to the discordance of foliations, there are no large metasedimentary bodies in the study area, so it is difficult to envision how the xenoliths remain attached at depth. Thus, I conclude that the xenoliths were displaced from their original position and orientation by stoping.

In contrast to the Glazner et al. (2004) model for incremental assembly of dikes in which a steady-state magma chamber is not formed, other studies have hypothesized (e.g., Pitcher and Berger, 1972; Davies, 1982; Hutton, 1982; Bateman, 1985; Castro, 1986; Duke et al., 1988; Lagarde et al., 1990; Brun et al., 1990; Clemens and Mawer, 1992; Petford, 1996) that magma chambers may form by sufficiently rapid intrusion of dikes into the crust so that the magmas do not completely crystallize before the next intrusion. Thermal modeling indicates that dike-fed magma chambers may be melt-rich over a long enough period of time that the magma becomes homogenized and internal contacts may be cryptic, and thus, indistinguishable in the field (Clemens and Mawer, 1992; Petford, 1996; McNulty et al., 1996; Yoshinobu et al., 1998). Dike-fed magma chambers in the shallow crust are commonly emplaced as laccoliths (Corry, 1988). Unfortunately, the three-dimensional shape of the BVCS in the field area is not known because of the relatively small topographical relief.

Field evidence for pluton construction by a series of dikes includes the preservation of dikes in host rocks and the margins of a pluton (e.g., Yoshinobu et al., 1998; Johnson et al., 2001). There are no dikes of the granodiorite of Illilouette Creek in either the El Capitan Granite or Taft Granite. Illilouette Creek rocks are mingled with the McGurk Meadow unit, but granodiorite dikes do not extend into the McGurk Meadow rocks past the mingled zone. Relations in the mingled zone imply that the Illilouette Creek was constructed from multiple pulses of magma. The granodiorite of Ostrander Lake forms a sheeted zone with the El Capitan Granite (Fig. 3; Plate 1) that is adjacent to the contact with the granodiorite of Illilouette Creek, but there are no Ostrander Lake dikes in the Illilouette Creek rocks. Similarly, no dikes of Bridalveil Granodiorite intrude the host rocks (Fig. 3; Plate 1). In summary, the BVCS may have been constructed by dikes, but there is little direct field evidence to support diking.

In contrast to the models in which magmas ascend through the crust as dikes, diapirism has long been advanced as an ascent mechanism to explain large magma bodies (e.g., Mrazec, 1927; Marsh, 1982; Bateman, 1985). Miller and Paterson (1999) hypothesized that plutons may ascend to crustal levels as visco-elastic diapirs. These diapirs consist of one or more bodies of magma that ascend during regional deformation through rheologically complex crust. In many circumstances, it is difficult to evaluate whether a pluton was constructed by one large magma pulse, multiple diapiric pulses, or a series of dikes because homogenization of the magmas and fabric formation typically occur at the emplacement level. Thus, features of ascent can be overprinted and/or removed by continuing magmatic flow (Brun et al., 1990; Lagarde et al., 1990; Clemens and Mawer, 1992; Paterson et al., 1998; Miller and Paterson, 1999). Due to the relative homogeneity of the BVCS units, and other evidence presented above, it is likely that a large magma chamber was constructed at the level of emplacement.

Significance of foliation patterns

Magmatic fabrics may give insights into a number of features of plutons, including the shapes of intrusions and magmatic flow processes. Fabrics can also be useful in providing "snapshots" of the regional strain field (Paterson et al., 1998).

Two magmatic foliations are recognized in the granodiorite of Illilouette Creek. The presence of two magmatic foliations in a single outcrop has only been reported from a few plutons. As reviewed by Paterson et al. (1998, 2004), multiple fabrics have been attributed to: formation of metastable orthogonal linear fabrics under pure and simple shear (Willis, 1977); differential rotation of minerals with different axial ratios during non-coaxial strain (Blumenfeld and Bouchez, 1988); and formation of orthogonal foliations where minerals become aligned parallel to unequal elongation components during coaxial flow (Jekez et al., 1994; Schulmann et al., 1997). These explanations all assume that the two fabrics formed by the same processes at the same time. Because magmatic fabrics may record internal processes, emplacement, and/or regional strain, it is also reasonable to infer that two foliations formed via different processes at different times (Paterson et al., 1998). Thus, multiple magmatic fabrics may record different processes and strain increments during construction of a pluton (Paterson et al., 2004).

In the granodiorite of Illilouette Creek, the dominant northwest-striking foliation is discordant to host rock contacts and is interpreted to record regional strain (see Structure of BVCS Section) (Fig. 3; Plate 1). The weaker east-west foliation is generally concordant to host rock contacts, and thus probably formed due to internal magmatic processes and/or emplacement of the granodiorite (Fig. 3; Plate 1).

Two foliations are also found in the ca. 92 to 88 Ma (Coleman et al., 2004) Half Dome Granodiorite of the younger Tuolumne Intrusive Suite to the northeast. The Half Dome Granodiorite has a north-south-striking foliation that is interpreted to be related to internal processes and an east-west-striking foliation that is interpreted to reflect regional strain (Paterson et al., 2004; Teruya, 2005; Zak et al., 2007). The contrasting orientations of the northwest-striking regional foliation in the granodiorite of Illilouette Creek and the east-west-striking regional foliation of the Half Dome Granodiorite suggest that the regional strain field changed from one of northeast-southwest shortening to north-south shortening between ca. 99 and 92 Ma. This relationship is best shown by the relationship between the Illilouette Creek and Half Dome Granodiorites, but it is further supported by the northwest-striking regional foliation in the Bridalveil Granodiorite (see below), the youngest intrusion in the BVCS in the study area.

The foliation of the granodiorite of Ostrander Lake is variable in strike, but is generally north-south in the study area except near its contact with the granodiorite of Illilouette Creek and in the south near Ostrander Lake (Fig. 3; Plate 1). The foliation is interpreted to have formed by both internal processes and regional strain that vary in relative importance throughout the granodiorite. Where foliation is roughly north-south-striking, it is interpreted to reflect regional strain, and where it becomes concordant to the east-west-striking contact with the granodiorite of Illilouette Creek it is interpreted to reflect internal processes. The northeast- to east-west-striking foliation in the southern part of the study area is also interpreted to reflect internal processes.

The approximately 1-km-wide body of Bridalveil Granodiorite in the northern part of the field area has a northwest-striking foliation that is discordant to its host rock contacts (Fig. 3; Plate 1) and is interpreted to reflect regional strain. The small irregularly shaped body of Bridalveil Granodiorite (Fig. 3; Plate 1) has a west-northwest- to northwest-striking foliation that is subparallel to its northern and southern contacts and is highly discordant to its eastern and western contacts (Fig. 3; Plate 1). Thus, foliation in this body is also interpreted to reflect regional strain.

In summary, foliation in the BVCS results from both internal processes and regional strain, which vary in relative importance. The dominant and weak foliations in the granodiorite of Illilouette Creek are interpreted to reflect regional strain and internal processes, respectively. Foliation in the granodiorite of Ostrander Lake is interpreted to reflect both regional strain and internal processes, and in the Bridalveil Granodiorite it records regional strain. The regional strain foliation identified in the granodiorite of Illilouette Creek, granodiorite of Ostrander Lake, and Bridalveil Granodiorite compared to the regional strain foliation in the Half Dome Granodiorite implies that the regional strain field changed between 99 and 92 Ma. The granodiorite of Illilouette Creek is the only unit of the BVCS that has been dated, and thus it is used to confine the upper age of the change of the strain field.

Rheology and Development of the BVCS and Host Rocks

Significance of the Heterogeneous Zone in the Taft Granite

Magma transfer zones serve to channel the flow of melt to higher levels in a magmatic system. The heterogeneous zone within the Taft Granite, described above, is interpreted to be a magma transfer zone for the following reasons: its steep, relatively narrow geometry; the co-existence of several different rock types; widespread interaction between mafic and felsic magmas resulting in mingled contacts; and atypically strong magmatic deformation.

The magma transfer zone is attributed to the magmatism associated with the emplacement of the Taft Granite, as described by Ratajeski et al. (2001) for the diorite of the Rockslides. The tonalite and Taft Granite are co-magmatic as evident by the compositional layering with diffuse boundaries between the tonalite and granite. Inclusions of El Capitan Granite within the Taft Granite and tonalite suggest that the El Capitan Granite was solidified at the time the units were intruded. The intruding tonalite apparently partially melted and remobilized the El Capitan Granite and allowed for mechanical mixing, as shown by potassium feldspar phenocrysts in tonalite dikes and enclaves of intermediate composition next to isolated bodies of the El Capitan Granite.

The relative age of the magma transfer zone based on the inferred age of the Taft Granite (younger than 102 Ma, older than 99 ± 1 Ma) indicates that magma transfer zones may have existed during intrusion of the earliest phases of the BVCS, and that the suite was in part constructed from such zones. Though there is no exposure of a magma transfer zone in any of the BVCS units, such a zone may lie at depth and/or have been removed by subsequent magma intrusion. The mixture of rock types in the magma transfer zone suggests that this narrow zone tapped into different magma sources. The El Capitan Granite rafts may have been detached by stoping during the intrusion of the Taft Granite and the tonalite in the magma transfer zone.

Contact Relationships

The contacts between the granodiorite of Illilouette Creek and older El Capitan Granite, Taft Granite, and granodiorite of Turner Ridge are all sharp and steep. There must have been a significant amount of time between the emplacement of these units and the granodiorite, such that the older units were sufficiently crystallized to behave as solids (cf. Bergantz, 2000). In contrast, the granodiorite of Illilouette Creek has a gradational contact with the McGurk Meadow tonalite and quartz diorite, which shares a gradational contact with the Taft Granite. These relationships suggest that the McGurk Meadow unit was only partially crystallized when the granodiorite of Illilouette Creek and Taft Granite were emplaced. They also imply that the rheology was variable along the strike of the northern contact between the granodiorite of Illilouette Creek and its host rocks.

The contact between the granodiorite of Ostrander Lake and the Taft Granite is sharp and steep, as is the contact the granodiorite shares with the El Capitan Granite in the sheeted zone. These relationships indicate that the Taft and El Capitan Granites were behaving as solids during emplacement of the granodiorite of Ostrander Lake.

The Bridalveil Granodiorite also shares sharp and steep contacts with the El Capitan Granite, Taft Granite, and McGurk Meadow unit. These relationships indicate that the host units behaved as solids during emplacement of the Bridalveil Granodiorite.

The units of the BVCS have sharp and steep contacts between each other. This contrasts with some other classically zoned plutons (e.g., the Tuolumne Intrusive Suite) where contacts are at least in part gradational (e.g., Bateman and Chappell, 1979). The sharp contacts imply that there was a major rheological contrast between the granodiorite of Illilouette Creek, granodiorite of Ostrander Lake, and Bridalveil Granodiorite at the time the individual BVCS units were emplaced.

CONCLUSIONS

1. Field relationships suggest that rocks previously mapped as Jurassic-Cretaceous diorite are Cretaceous in age and related to the El Capitan and Taft Granites. These rocks are herein named the McGurk Meadow tonalite and quartz diorite. The McGurk Meadow unit is mingled with both the Taft Granite and the 99 ± 1 Ma granodiorite of Illilouette Creek. This relationship suggests that the emplacement ages of the intrusive suite of Yosemite Valley and the BVCS overlap.

2. Two magmatic fabrics were identified in the granodiorite of Illilouette Creek. The dominant northwest-striking foliation records regional strain, whereas the weaker east-west foliation is related to emplacement and/or magmatic processes within the unit. A similar foliation pattern is found in the younger Tuolumne Intrusive Suite to the northeast, but there the east-west striking foliation is attributed to regional strain and the second foliation to internal processes (Paterson et al., 2004; Teruya, 2005; Zak et al., 2007). This relationship suggests that the regional strain field changed from northeast-southwest shortening to north-south shortening between 99 and 92 Ma.

3. The discordance of foliation in the BVCS to host rock contacts and lack of ductile deformation in the host rock adjacent to the BVCS indicates that little to no structural aureole is present and, thus, ductile flow did not play a key role in the emplacement of the BVCS. The absence of large faults in the area indicates that dilational faulting also did not play an important role. Isolated metasedimentary xenoliths and discordant contacts suggest that stoping was an important material transfer

process during the emplacement of the BVCS. Roof uplift likely accounts for some of the remaining volume of host rocks that were displaced during BVCS emplacement.

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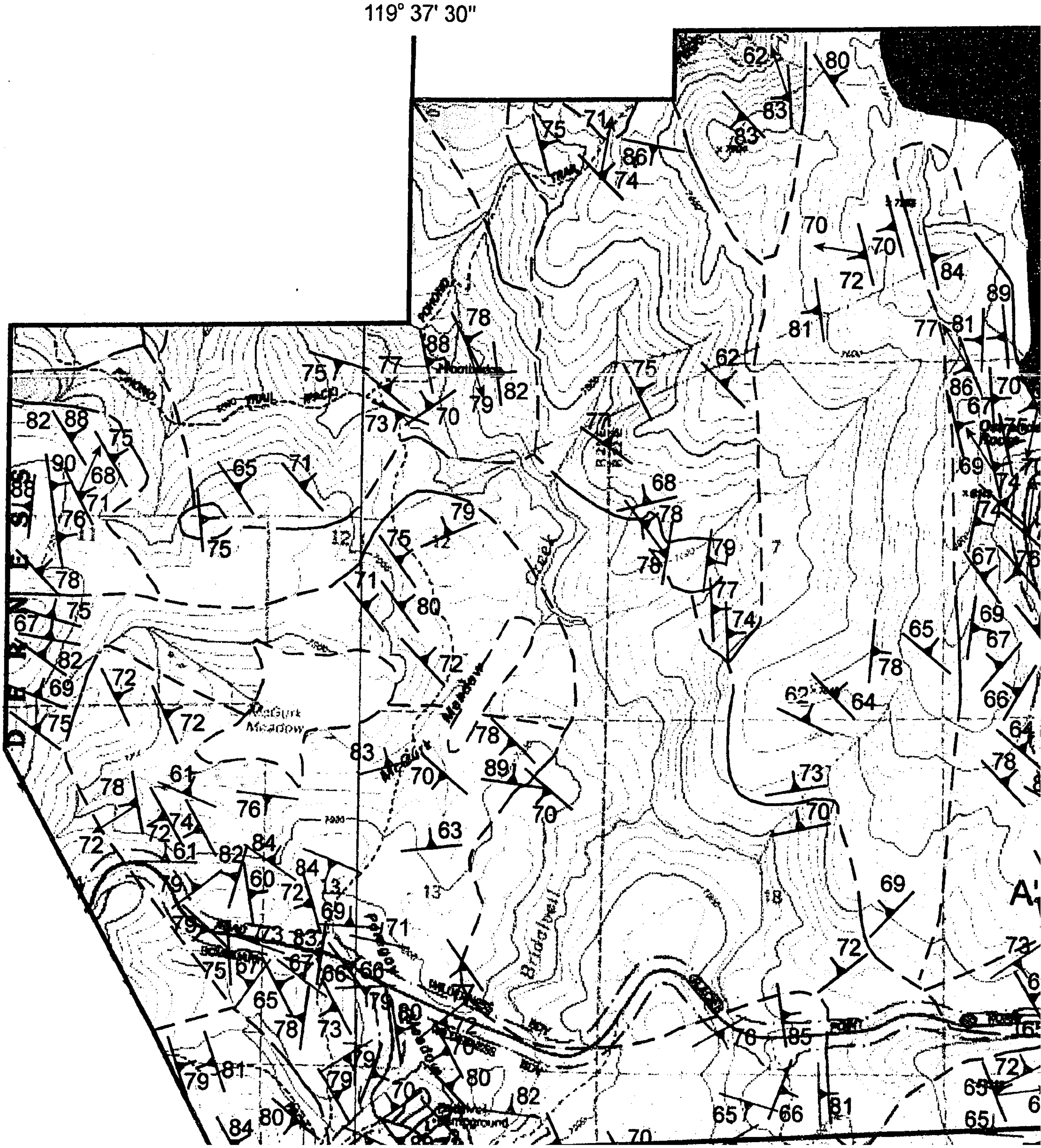
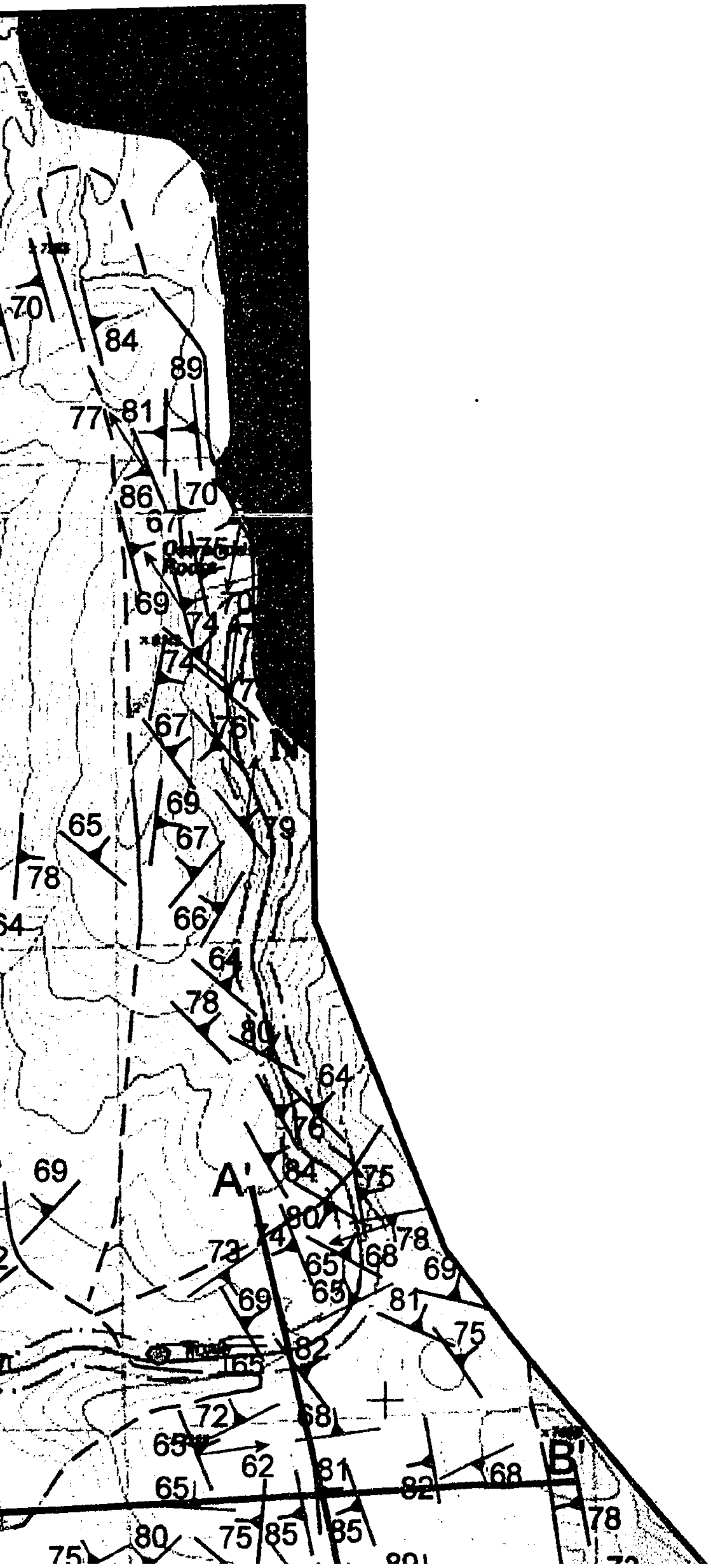
Plate 1: Geologic Map and Struct Intrusive Suite and Host Rocks,



Structure of the Northwestern Margin
ocks, Central Sierra Nevada Batholith



Explanation

☐ Quaternary

■ Sentinel Granodiorite

▨ Bridalveil Granodiorit

☐ Granodiorite of Ostra

▨ Granodiorite of Ostra

▨ Granodiorite of Illilou

▨ Granodiorite of Turne

▨ McGurk Meadow Tor

☐ Taft Granite

▨ El Capitan Granite

■ Metasedimentary Xe

Symbols

stern Margin of the Buena Vista Crest
ada Batholith, California

Explanation

☐ Quaternary

■ Sentinel Granodiorite

▨ Bridalveil Granodiorite

☐ Granodiorite of Ostrander Lake with El Capitan Rafts

▨ Granodiorite of Ostrander Lake

▨ Granodiorite of Illilouette Creek

▨ Granodiorite of Turner Ridge

▨ McGurk Meadow Tonalite and Quartz Diorite

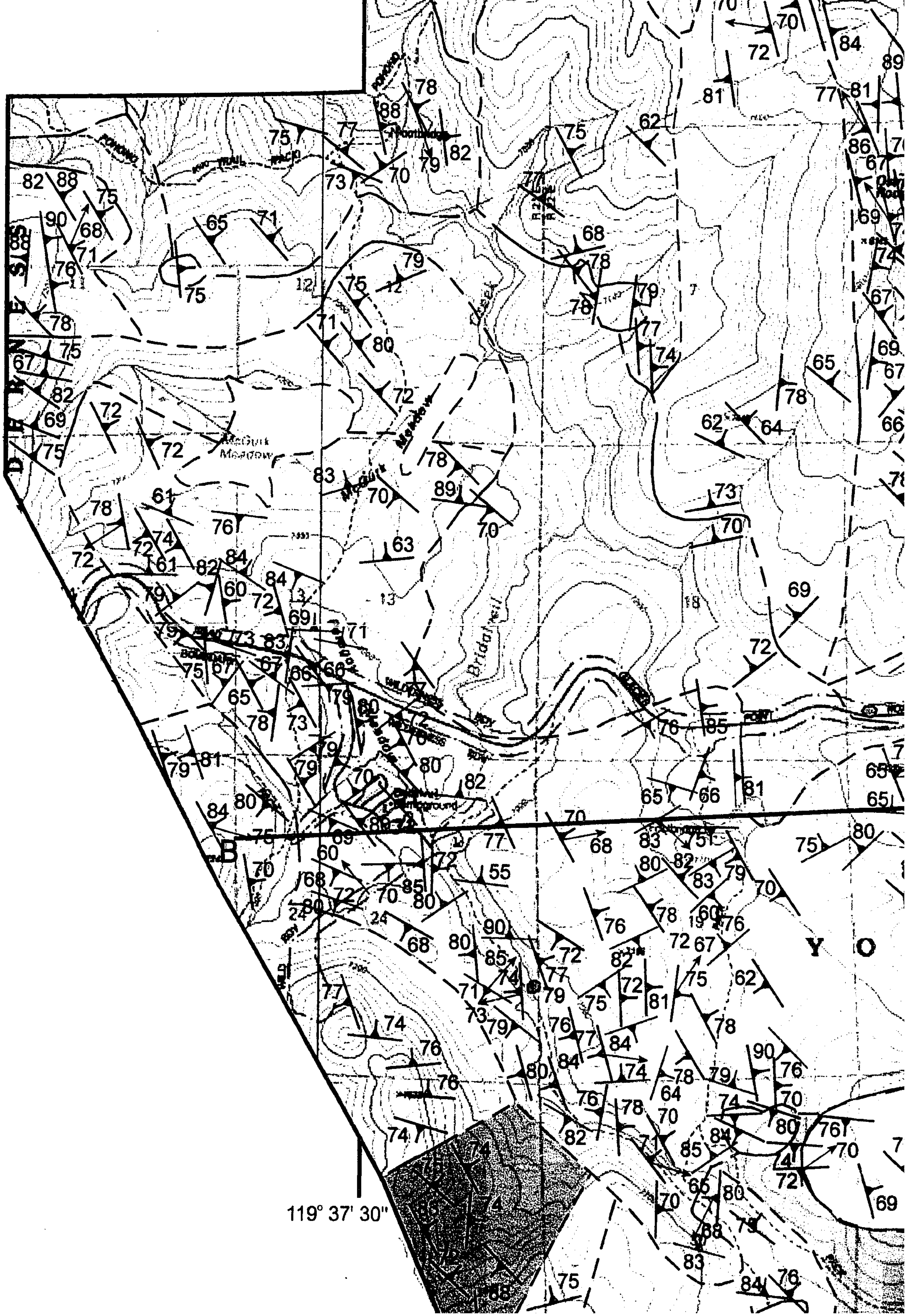
☐ Taft Granite

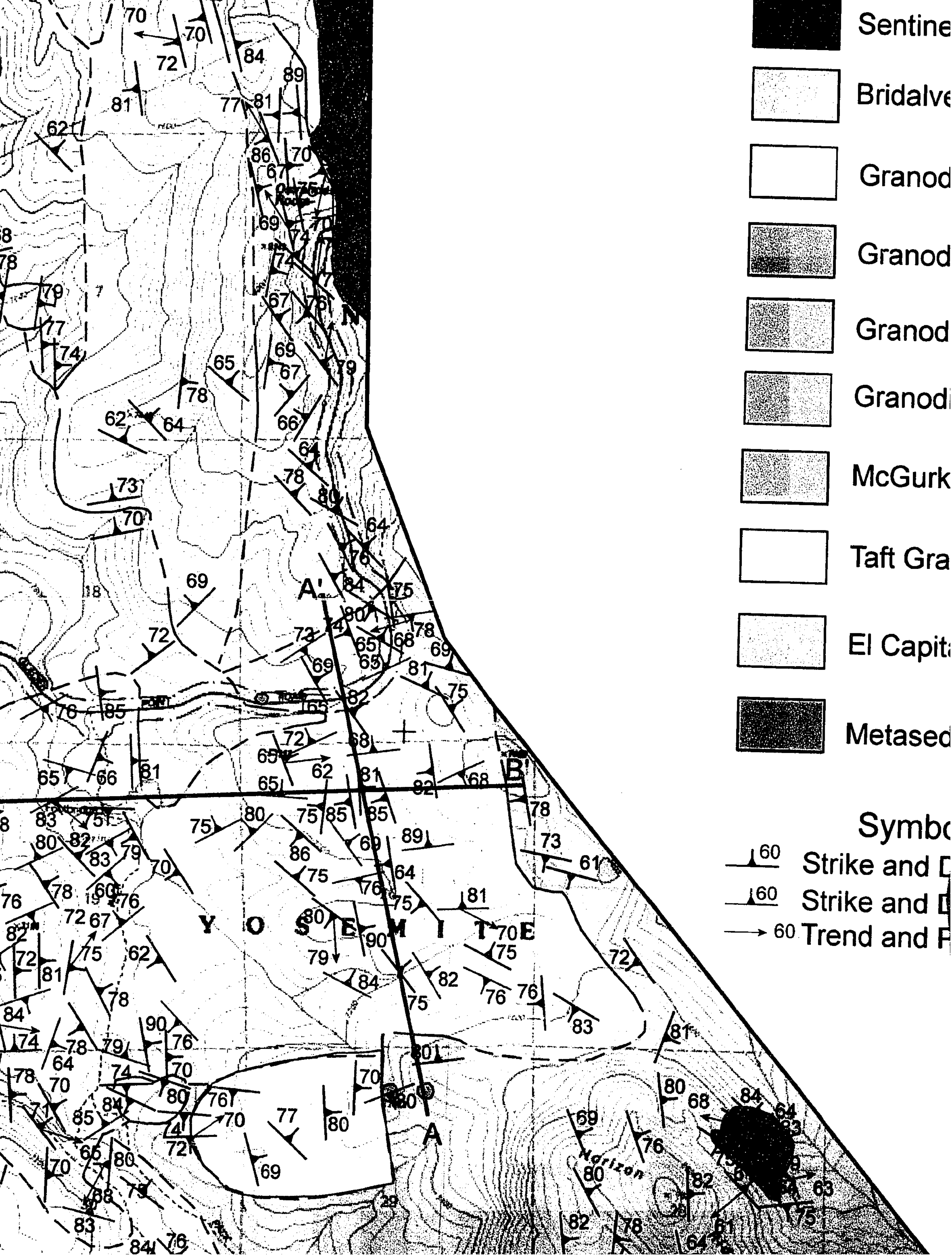
☐ El Capitan Granite

▨ Metasedimentary Xenoliths

Symbols

Strike and Dip of Foliation


D E R N E S S
McGurk Meadow
McGurk
Meadow
Bridalveil
Creek
Bridalveil Campground
B
Y O
12
13
18
24
19
119° 37' 30"


Sentine
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Taft Gra
El Capita
Metased
Symbo
60 Strike and D
60 Strike and D
60 Trend and P
A
A'
B'
N
Y O S E M I T E
Horizon

■ Sentinel Granodiorite

▨ Bridalveil Granodiorite

□ Granodiorite of Ostrander Lake with El Capitan Rafts

■ Granodiorite of Ostrander Lake

▨ Granodiorite of Illilouette Creek

▨ Granodiorite of Turner Ridge

▨ McGurk Meadow Tonalite and Quartz Diorite

□ Taft Granite

▨ El Capitan Granite

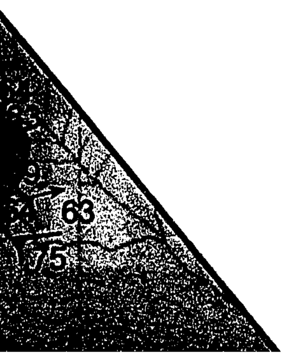
■ Metasedimentary Xenoliths

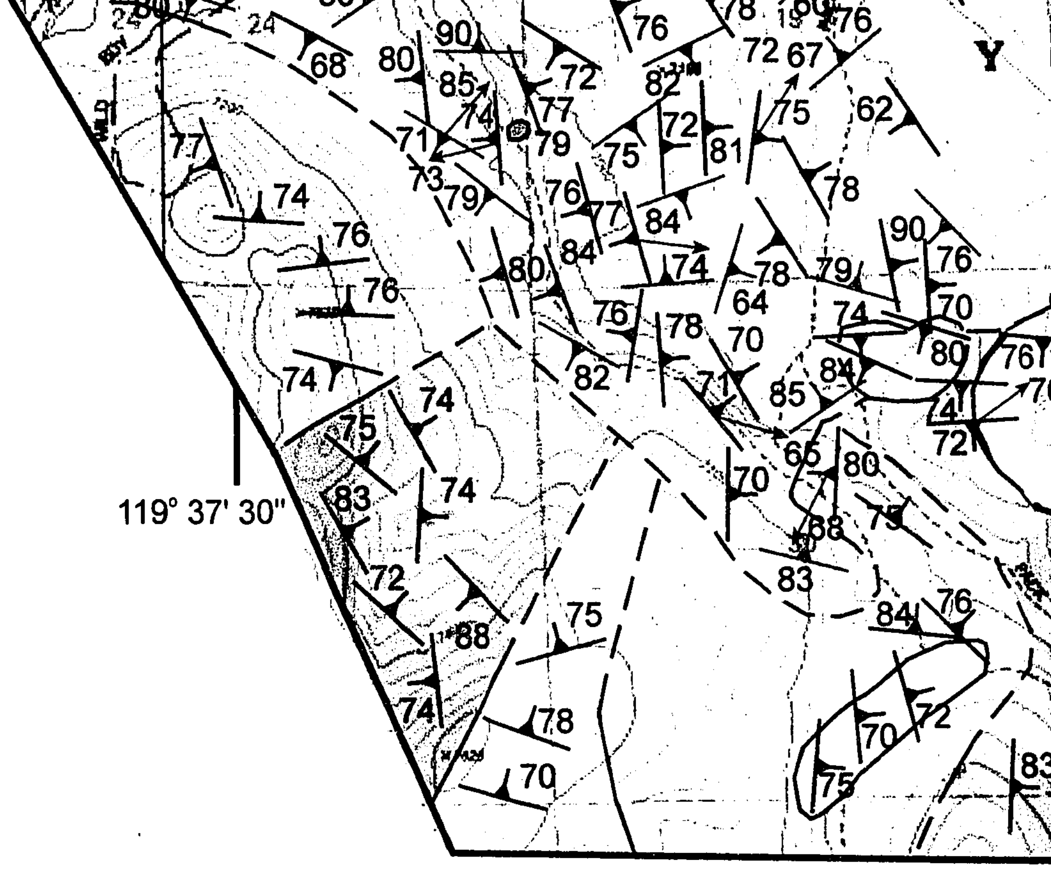
Symbols

Strike and Dip of Foliation

Strike and Dip of Weak Foliation in Granodiorite of Illiouette Creek

60 Trend and Plunge of Lineation

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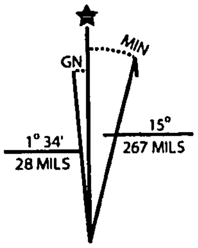
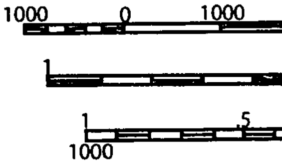
119° 37' 30"


GN
MIN
1° 34'
28 MILS
15°
267 MILS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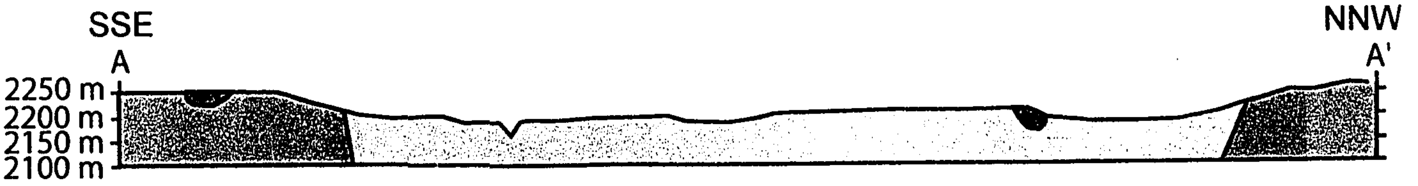
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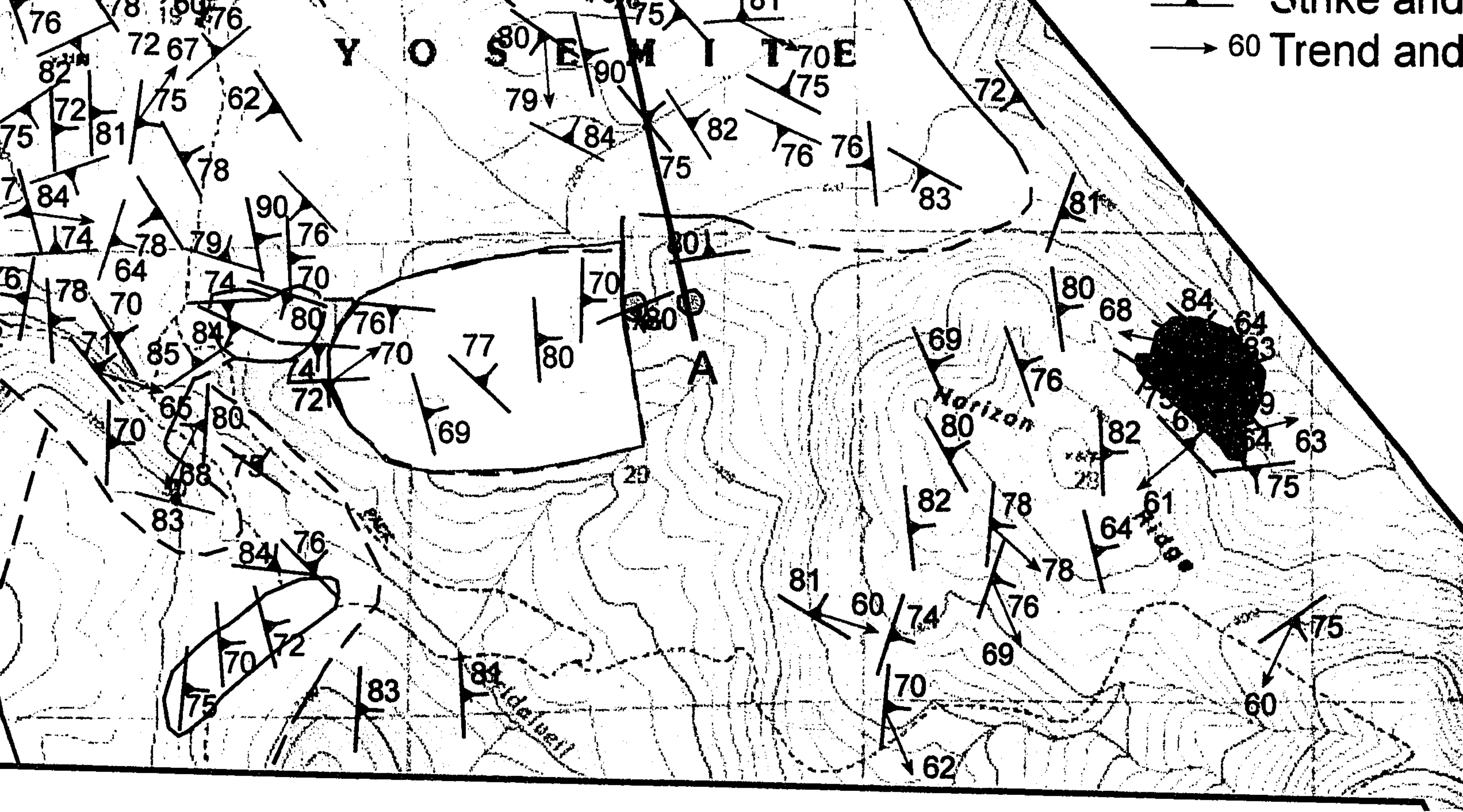
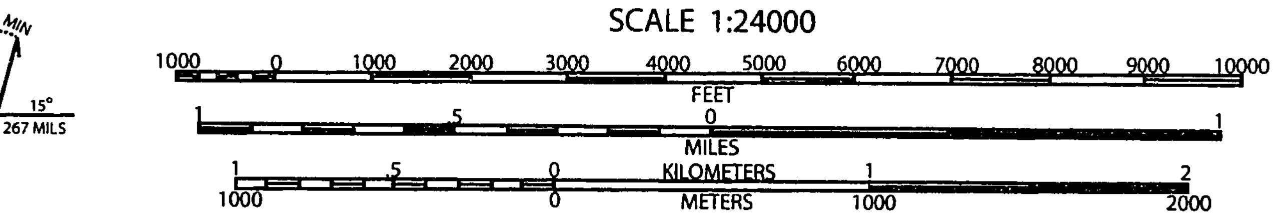
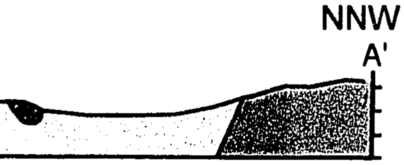
No





CONTOUR INTRVAL 40 FEET

Cross-Sections



No Vertical Exaggeration

→ 60 Trend and Plunge of Lineation