Geology of the Western Half of the
Santa Rosa Plateau Ecological Reserve,
Riverside County, California

By:

Daniel M. Loera, Jr.

A thesis submitted to the faculty of
California State University, Fullerton
In partial fulfillment of the requirements for the degree of

Bachelor of Science

In

Geology

Department of Geological Sciences
California State University, Fullerton
September 2003
Geology of the Western Half of the
Santa Rosa Plateau Ecological Reserve,
Riverside County, California

By:
Daniel M. Loera, Jr.

Department of Geological Sciences
California State University, Fullerton
September 2003
ABSTRACT

The Santa Rosa Plateau is located at the northern end of the Peninsular Range, just east of the Santa Ana Mountains and 2.4 km southwest of Murrieta, California. The erosionally dissected plateau is bound to the east by the Elsinore fault and is characterized by several basalt-capped mesas. There are no published comprehensive geologic investigations of the Santa Rosa Plateau and currently available geologic maps (most at a scale of 1:250,000) are insufficient for detailed work. This study provides (1) detailed geologic data in the form of mapped contacts, faults, folds, dikes, and other field relations; (2) interpretations of the data in terms of the intrusive, structural, depositional, and erosional history; and (3) a detailed geologic map (at a scale of 1:12,000) and report for the western half of the Santa Rosa Plateau Ecological Reserve. The information gained from this field study will compliment Steve Turner’s field study of the eastern half of the reserve.

The oldest rocks in the study area are metasedimentary rocks of the Bedford Canyon Formation (Jurassic) and metavolcanic rocks of the Santiago Peak Volcanics (Jurassic). These rocks are intruded by the San Marcos gabbro (Cretaceous) and by granitic rocks similar to the Bonsall tonalite and Woodson Mountain granodiorite (Cretaceous). The Santa Rosa Basalt rests upon Tertiary (?) arkosic deposits and potential paleosols, granitic rocks, and the Bedford Canyon Formation. The variability of rock types underlying the Santa Rosa Basalt suggests that the basalt was not confined to a river valley, but may have flowed onto a broad and relatively flat surface. Erosion of this surface resulted in an inverted topography, where the basalt covered and helped to
preserve areas of low relief that are now the basalt-capped mesas of the Santa Rosa Plateau. Several NW-striking dikes are found in the study area and are sub-parallel to the Elsinore fault zone. Though age data for the dikes are lacking, they are interpreted to have formed as a result of the regional NE-SW extension that occurred 7-16 Myr ago during the clockwise rotation of the Transverse Ranges and the development of the Los Angeles basin. At least one N-S striking right-lateral strike-slip fault is found along the eastern boundary of the study area where it offsets drainages and the basalt on the west side of Mesa de la Punta. Its orientation relative to the Elsinore fault zone suggests that it may be a Riedel shear and drainages offset by the fault suggest that the fault has been active in the Quaternary.
INTRODUCTION

This report presents the findings of fifteen days of geological field work conducted in the western half of the Santa Rosa Plateau Ecological Reserve, which lies at the northern end of the Peninsular Range (Figure 1), just east of the Santa Ana Mountains and 2.4 km southwest of Murrieta, California (Figure 2). The erosionally dissected plateau covers an area of approximately 32 km$^2$ and is bound to the east by the Elsinore fault zone (Figure 2). Topographic relief on the reserve is generally low and is characterized by rolling hills and four basalt-capped mesas: Mesa de Colorado, Mesa de la Punta, Mesa de Burro, and a small unnamed mesa just north of Mesa de Burro. Outcrop exposure on much of the reserve is poor due to cover by soil and dense vegetation such as grasses, sage, and chaparral.

There are no published comprehensive geologic investigations of the Santa Rosa Plateau and currently available geologic maps (most at a scale of 1:250,000) are insufficient for detailed work. Therefore, the purpose of this study was to (1) gather detailed geologic data in the form of mapped contacts, faults, folds, dikes, and other field relations; (2) interpret the data in terms of the intrusive, structural, depositional, and erosional history; (3) and produce a detailed geologic map (at a scale of 1:12,000) and report for the western half of the Santa Rosa Plateau Ecological Reserve. The information gained from this field study will be combined with the information from Steve Turner’s field study of the eastern half of the reserve to produce a geologic report/guidebook that will be presented to the Visitor’s Center at the Santa Rosa Plateau Ecological Reserve.
GEOLOGIC SETTING

One of the most prominent geological features of the region is the Elsinore fault zone. It is one of several major branches of the San Andreas Fault system in southern California. The Elsinore fault zone is a NW-striking group of right-lateral strike-slip faults that form a pronounced topographic and structural boundary between the Santa Ana Mountains to the west and the Perris Block to the east (Figure 2) (Kennedy, 1977). The fault zone begins in Corona and extends for more than 200 km south, beyond the border with Mexico, where it is known as the Laguna Salada fault zone (Mueller and Rockwell, 1995). The Elsinore fault zone is relatively young (2.5 Ma) and the total horizontal offset along the fault zone is approximately 15 km, with an average horizontal slip rate of 5-6 mm/yr (Hull and Nicholson, 1992). The northern Elsinore fault zone is marked by a distinct 2-5 km wide, NW-SE trending valley known as the Elsinore-Temecula trough (Figure 3). The Elsinore-Temecula trough extends 75 km from the Los Angeles basin southeast to Agua Tibia Mountain (Hull and Nicholson, 1992).

The Santa Ana Mountains are part of the Peninsular Range batholith – an elongate body of igneous rock consisting of hundreds of plutons that were intruded side by side, leaving few areas of country rock between them (Woyski and Howard, 1987). The southern portion of the Santa Ana Mountains consists of five major rock units: Bedford Canyon metasediments (Jurassic); Santiago Peak metavolcanics (Jurassic), San Marcos gabbro (Cretaceous), Bonsall tonalite (Cretaceous), and Woodson Mountain granodiorite (Cretaceous).
The Perris Block (Figure 2) lies between the Elsinore fault zone to the southwest and the San Jacinto fault zone to the northeast. It is approximately 48 km long in a north-south direction and 35 km wide in an east-west direction (Larsen, 1948), and is composed primarily of metasedimentary rocks of the Bedford Canyon Formation, Santiago Peak volcanic rocks, and Cretaceous batholithic rocks. The Perris Block also contains Cenozoic valley fill sediments and scattered outcrops of Miocene basalts, similar to those found on the Santa Rosa Plateau (Woodford et al., 1971). Six erosion surfaces are sculpted on to the Perris block (Woodford et al., 1971). Of these six erosion surfaces, the Perris Surface is one of the oldest and most extensive on the Perris block. The Perris Surface is also cut onto the southeast corner of the block containing the Santa Ana Mountains and Santa Rosa Plateau (Woyski and Howard, 1987).

The Santa Rosa Plateau lies at the southern end of the Santa Ana Mountains and includes the four basalt-capped mesas of the Santa Rosa Plateau Ecological Reserve (Mesa de Colorado, Mesa de la Punta, Mesa de Burro, and the un-named mesa north of Mesa de Burro), as well as Redonda Mesa and Miller Mountain, which are located west of the reserve (Figure 4). Other outcrops assumed to be the equivalent of the Santa Rosa Basalt have been found on the hogbacks 8.5 km northeast of the Santa Rosa Plateau and on Elsinore Peak 8 km northwest of the plateau (Figure 4)(Woyski and Howard, 1987).

The plateau is one of four well-preserved erosion surfaces in the southern Santa Ana Mountains. Its surface resembles the Perris Surface of the Perris Block and apparently was formed at about the same time (Mann, 1955). Woodford et al. (1971) suggest that
the Perris Surface lies between the Santa Rosa Basalt and the underlying basement rocks and arkosic deposits. Interestingly, outcrops of the Santa Rosa Basalt (except for the Elsinore Peak outcrop) and outcrops of basalt on the hogbacks are in a NE-SW trending line, thus suggesting (1) that the basalt may have flowed in a linear swath, such as in a river valley across the Elsinore fault, and/or (2) offset along the northern Elsinore fault zone is relatively small since there appears to be little offset of the basalt from one side of the fault zone to the other.

The study area is the western half of the Santa Rosa Plateau Ecological Reserve and encompasses an area 4.5 km long by 4 km wide (Figure 5). Two basalt-capped mesas, Mesa de Colorado and Mesa de la Punta, are located in the southwest and southeast corner of the study area, respectively (Figure 5). Rock types found in the study area include Bedford Canyon metasediments, Santiago Peak metavolcanic rocks, San Marcos gabbro, granitic rocks similar to the Bonsall tonalite and the Woodson Mountain granodiorite, Tertiary (?) arkosic deposits and potential paleosols, and the Santa Rosa Basalt.
DESCRIPTION OF ROCK UNITS

BEDFORD CANYON FORMATION

The Bedford Canyon Formation is a sequence of mildly metamorphosed black to dark gray argillites and slates that grade into relatively pure quartzites, sporadic beds of pebble conglomerate, and thin lenses of dark gray limestone (Larsen, 1948). The Bedford Canyon Formation forms large masses in the western part of the northern Peninsular Range batholith and is found as small bodies and screens between plutons to the east and southeast of the Santa Ana Mountains. The argillites and slates underlie low hills and valleys yielding poor outcrops that are less resistant than the massive quartzites, which form steep slopes and good outcrops (Larsen, 1948). The total thickness of the Bedford Canyon Formation cannot be determined because it is overlain unconformably by the Santiago Peak Volcanics and there are no exposures of its base (Woyski and Howard, 1987).

In the western half of the study area, the Bedford Canyon Formation is composed primarily of dark gray argillites and slates that underlie low, rolling hills and valleys. The argillite is rough and pitted on weathered surfaces and often contains elongate 1-4 cm long argillite clasts, but bedding is usually indistinguishable. Quartzite beds and limestone lenses are rare in this area, but when present they range from 4 to 10 cm thick. The general attitude of the Bedford Canyon Formation in the western half of the study area is N5°W, 38°E.
In the eastern half of the study area, the Bedford Canyon Formation consists of dark gray argillites and slates and is commonly interbedded with white to gray quartzite, lenses of dark gray limestone, and sporadic beds of pebble conglomerate. Outcrops of the Bedford Canyon Formation are scattered throughout this area, forming steep slopes and more prominent hills than in the western half of the study area. The quartzites are composed of gray, fine to coarse grained, subangular to subrounded quartz grains. The dark gray limestone typically occurs as discontinuous beds or lenses. Pebble conglomerate beds are centimeters to meters thick and contain subangular argillite clasts and 1 to 6 cm long elongate quartzite pebbles (Figure 6). Outcrops of the Bedford Canyon Formation in the far eastern side of the study area often contain beds that are tightly folded (Figure 7). The general attitude of the Bedford Canyon Formation in the eastern half of the study area is N47ºW, 49º-67º E.

SANTIAGO PEAK VOLCANICS

The Santiago Peak Volcanics of late Jurassic age are mildly metamorphosed dark green to black andesites and quartz latites with some rhyolites, basalts, and slates (Larsen, 1948). These volcanic rocks are among the most resistant to erosion in the region, forming high mountains and ridges. They extend for over 120 km, from the northeastern flank of the Santa Ana Mountains to south of Encinitas. The Santiago Peak Volcanics form a discontinuous belt that is approximately 20 km at its widest (Walawender et al., 1991) and is broken in a few places by younger sediments or by younger granitic rocks (Larsen, 1948). The Santiago Peak Volcanics unconformably overlie the Bedford
Canyon Formation and their total thickness is not known, but Larsen (1948) suggests that this group of volcanics must have been thousands of feet thick.

The study area contains one body of Santiago Peak Volcanics that underlies the prominent hill just south of Tenaja Road on the western side of the study area (Plate 1). This exposure of Santiago Peak Volcanics is composed of mildly metamorphosed dark green to black andesite with sporadic outcrops of olive-green slate. A block of columnar meta-basalt was found on the prominent hill underlain by these volcanics, suggesting that some basalt is present in this body (Figure 8). Additionally, this exposure of Santiago Peak Volcanics is cut by at least one aplite dike located on the east flank of the prominent hill underlain by the volcanics (Plate 1).

SAN MARCOS GABBRO

The San Marcos gabbro occurs as small plutons and screens in the San Luis Rey, Elsinore, and Corona quadrangles (Larsen, 1948). The gabbro intrudes the Bedford Canyon Formation and the Santiago Peak Volcanics and appears to be the oldest rock of the Cretaceous Peninsular Range batholith (Larsen, 1948). The gabbro typically weathers to spheroidal boulders and forms areas of low relief; however, the quartz-free gabbro weathers to distinctive conical peaks. The compositional and textural variability of the San Marcos gabbro, even at outcrop scale, is one of its most distinguishing characteristics. Its grain size ranges from 0.5 to 20 mm and its composition can range from gabbronorite to calcic olivine norite to quartz biotite norite (Woyski and Howard, 1987).
San Marcos gabbro is found in the southern half of the study area where it weathers to medium gray spheroidal boulders that dot a landscape of broad flats and gentle slopes along the north side of Mesa de Colorado. Contacts between the gabbro and the Bedford Canyon Formation and Tertiary (?) arkosic deposits are not well defined because the gabbro is poorly exposed in the flat region north of Mesa de Colorado. The gabbro is dark gray on fresh surfaces, coarse grained, and some outcrops display a porphyritic texture with plagioclase phenocrysts that range from 1 to 3 cm. The gabbro also contains trace amounts of pyrite.

GRANITIC ROCKS SIMILAR TO BONSALL TONALITE AND WOODSON MOUNTAIN GRANODIORITE

The Bonsall tonalite intrudes the San Marcos gabbro and is in turn intruded by the Woodson Mountain granodiorite, which are all Cretaceous in age (Woyski and Howard, 1987). The tonalite is widespread in the San Luis Rey and Elsinore quadrangles where it underlies an area of 400 square kilometers (Larsen, 1948). The tonalite weathers to a low, rolling terrain with grayish outcrops and is characterized by abundant inclusions (Walawender et al., 1991). The tonalities are medium gray, coarse-grained, and composed of 50%-60% andesine, 20%-25% quartz, 5%-20% biotite, 5%-15% hornblende, and less than 10% orthoclase (Woyski and Howard, 1987). The inclusions are composed of the same minerals as the tonalite, but with a greater proportion of mafic minerals (Woyski and Howard, 1987).
Typical Woodson Mountain granodiorite is not found in the eastern part of the Peninsular Range batholith, but a similar and probably related granodiorite is widespread. The granodiorite is light gray and resistant to erosion, forming many hills strewn with spheroidal boulders that can reach over 3 m in height (Larsen, 1948). In areas of low relief, the boulders protrude above the soil, but on steeper slopes the boulders often are piled one on top of the other.

Granitic rocks in the study area are similar to the Bonsall tonalite and Woodson Mountain granodiorite. For the purposes of this study, the Bonsall tonalite and Woodson Mountain granodiorite were mapped as a single “granitic” unit. However, it is suspected that the observed differences in the relief and outcrop character of the granitic rock can be used to distinguish the Bonsall tonalite from the Woodson Mountain granodiorite in the study area.

The Sylvan Meadows area (Figure 5) of the Santa Rosa Plateau Ecological Reserve is an area of low relief that is punctuated by scattered boulders that rise above the surface of the soil. The rock in the Sylvan Meadows area is medium gray, medium to coarse grained, and composed of 30% quartz, 2% alkali feldspar, 58% plagioclase, 6% biotite, and 4% hornblende. Normalized percentages of quartz, alkali feldspar, and plagioclase classify this rock as a medium-gray hornblende-biotite tonalite (Figure 9), suggesting that this area is underlain by the Bonsall tonalite.
The granitic rock that forms higher relief in the study area, such as the bouldery hills surrounding the northern half of Sylvan Meadows (Figure 10) is light gray, medium to coarse grained, and composed of 40% plagioclase, 30% quartz, 10% alkali feldspar, 10% hornblende, and 5% biotite. Normalized percentages of quartz, alkali feldspar, and plagioclase classify this rock as a medium-gray biotite granodiorite (Figure 9), suggesting that this area is underlain by the Woodson Mountain granodiorite.

APLITE DIKES

The study area contains numerous aplite dikes that cut the granitic rocks of Sylvan Meadows, the Santiago Peak Volcanics, and the Bedford Canyon Formation; no dikes were found that cut the Santa Rosa Basalt or the Tertiary (?) arkosic deposits. The dikes are typically white to light gray and have a sugary texture. Some of the dikes contain alternating white and light gray bands that are 1-2 cm wide, parallel to the walls of the dike, and sometimes folded (Figure 11). The dikes range from a few centimeters to 2 meters wide and one dike extends for over 2 km, but most of the dikes usually do not exceed 1 km in length. The dikes form many of the linear ridges in the Sylvan Meadows area and in the area south of Sylvan Meadows that is underlain by the Bedford Canyon Formation. The dikes consistently strike northwest and where the dip can be measured they dip 32°-34° E. One mafic dike (Figure 11) was found cutting granitic rock in the Sylvan Meadows area at GPS Station 14. The dike is 4 m long, 20 cm wide and strikes northwest (roughly 135°), consistent with the orientation of other dikes in the study area.
TERTIARY (?) ARKOSIC DEPOSITS AND POTENTIAL PALEOSOLS

Sparse outcrops of arkosic deposits and potential paleosols underlie the Santa Rosa Basalt along the north side of Mesa de Colorado (Plate 1). Fairbanks (1893) was the first to note that arkosic deposits underlie many of the mesa-forming basalts of the Santa Rosa Plateau. He described these deposits as coarse, friable sandstone that is rich in kaolinitic matter and closely resembles a granite decomposed in situ. He also stated that some sandstone contains pebbles of quartzite, mica schist, aphanitic rocks, and granitic rocks. Engel (1949) found similar arkoses and arkosic gravels underlying basalt flows in the Elsinore Mountains. He considered these beds to be Paleocene based on their lithologic similarity to beds of the Martinez Formation of central California. Dickerson (1914) originally described the Paleocene sedimentary rocks of the Santa Ana Mountains and assigned them to the Martinez Formation. Woodring and Popenoe (1945) later re-classified these Paleocene sedimentary rocks of the Santa Ana Mountains as a separate and new formation – the Silverado Formation.

The arkosic deposits and potential paleosols that underlie the basalt on the north side of Mesa de Colorado are confined to a zone that is 12-24 m thick and rests on the Bedford Canyon Formation, as well as on granitic and gabbroic rocks. This unit is mostly covered by slope wash and vegetation, and forms a gentle slope along the north side of Mesa de Colorado. Interestingly, the arkosic and other deposits were not found along the south side of Mesa de Colorado where basalt appears to rest directly upon granitic basement rock. However, outcrop exposure on the south side of the mesa is limited by dense
vegetation and private development. It is possible that the arkosic and other deposits underlie the basalt on the southern side of Mesa de Colorado, but were not found in the course of this study. Vertical cliffs and dense vegetation made it difficult to determine whether these deposits underlie the basalt on Mesa de la Punta.

The arkosic deposits consist of greenish gray siltstone, micaceous siltstone and sandstone, and gravel with a coarse arkosic matrix. The greenish-gray siltstone (Figure 12) is clay-rich and contains a few arkosic and quartzite pebbles. The micaceous siltstone and sandstone directly underlie potential paleosols and are light tan to red, very fine- to fine-grained, and contain sporadic lenses of gray coarse-grained sandstone that has been metamorphosed to quartzite (Figure 13). The arkosic gravel consists of subangular quartzite clasts (2-10 cm) set in a matrix of medium- to coarse-grained quartz and feldspar sand. An outcrop of arkosic gravel at GPS Station 79 (Plate 1) contains subangular gravel to cobble size basalt clasts set in a reddish matrix of coarse quartz and feldspar sand that resembles granite decomposed in situ (Figure 14). Fairbanks (1893) described a similar deposit containing basalt boulders in the upper portion of the sandstone underlying Mesa Redonda.

At least three outcrops of a 1-2 m thick mottled “red” unit are found underneath the basalt on the north side of Mesa de Colorado. This unit is clumpy or nodular, indurated, and vertically ranges in color from mottled red and white (Figure 15) to orangish red or brick red (Figure 16). The nodules are 0.5-1.5 cm in diameter and may be preserved peds, which are individual aggregates of soil particles commonly found in paleosols (Buol et
al., 1980). Sub-angular gravel 1-8 cm in diameter and coated with clay is common throughout this unit. The gravel consists of quartzite, arkosic siltstone and sandstone, and fragments of the Bedford Canyon Formation. All outcrops of this unit are located along the north side of Mesa de Colorado and are underlain by the micaceous siltstone and sandstone described in the previous paragraph. I interpret this unit to be a paleosol based on the presence of peds, the reddish color, and the clay-coated gravel – all of which are characteristic of a paleosol that formed in a subtropical climate (Ramirez et al., 2002).

One small (0.5 m thick) outcrop of soft, dark gray shale was found directly underlying the basalt on the north side of Mesa de Colorado at GPS Station 84 (Plate 1). This shale may be similar to the carbonaceous shale beds of the Paleocene Silverado Formation. Interestingly, the arkosic deposits, potential paleosols, and carbonaceous shale that underlie the basalt on Mesa de Colorado are similar to units A through C of the Silverado Formation (Schoellhamer et al., 1981).

SANTA ROSA BASALT

The mesa-forming basalts of the Santa Rosa Plateau were first described by Fairbanks (1893) and were later mapped by Engel (1949) and by Larsen (1948), and were named by Mann (1955). The basalt caps several erosionally dissected mesas on the Santa Rosa Plateau. Larsen (1948) described petrographically similar basalts capping the hogbacks located 8.5 km northeast of the Santa Rosa Plateau and Mann (1955) discovered other outcrops of this basalt on Vail Mountain and on the Wildomar horst. Additionally,
Woyski and Howard (1987) note the presence of Santa Rosa Basalt on Elsinore Peak located 8 km north of the Santa Rosa Plateau.

Two basalt-capped mesas, Mesa de Colorado and Mesa de La Punta, are located within the study area (Figure 5). The Santa Rosa Basalt on Mesa de Colorado and Mesa de La Punta is relatively flat lying and dips gently to the southeast. The basalt ranges from 12 to 24 m thick on the north side of Mesa de Colorado and from 48 to 55 m thick on the south side of the mesa. The basalt on Mesa de la Punta is 24-36 m thick. The basalt weathers to a reddish-brown soil that supports grasses and sparse oak trees. Depressions on the flat surface of the basalt create seasonal vernal pools on Mesa de Colorado where rainwater collects and supports various wildlife and vegetation (Figure 18). The age of the basalts is not well defined. Hawkins (1970) determined an age of 8.3 +/- 0.5 Ma by potassium-argon analysis. However, more recent dating by Morton and Morton (1979) has yielded ages of 6.7±0.2 and 7.4±0.4 Ma.

The Santa Rosa Basalt consists of a lower alkalic series and an upper tholeiitic series (Kennedy, 1977). The lower alkalic basalts contain many vesicles and are comprised of several thin (5 cm to 1 m) (Figure 19) flows that often have yellowish orange spots where feldspar phenocrysts are altered. The upper tholeiitic basalts contain fewer vesicles and are comprised of several thicker flows (1 m to 2 m)(Figure 20) that contain olivine phenocrysts that are altered to reddish-brown iddingsite. Mann (1955) described the Santa Rosa Basalt as consisting of 4 or 5 successive flows that were probably highly fluid due to their thinness and regularity. Field work completed during the course of this study
confirms that the basalt flows are thin, but at the road cut through the lower alkalic basalts at GPS Station 76 (Plate 1) on Los Gatos Road on the southern side of Mesa de Colorado, there appears to be at least 8 flows in this lower series alone (Figure 19).

CONTACT RELATIONS

The Santiago Peak volcanic rocks unconformably overlie rocks of the Bedford Canyon Formation. The contact between these two units is sharp but the change in rock type can be easily overlooked due to the similar dark color and highly fractured nature of the rocks in each unit. San Marcos gabbro, Bonsall tonalite, and Woodson Mountain granodiorite intrude the Bedford Canyon Formation. The contact between the Bedford Canyon Formation and the granitic rocks is often marked by decomposed granitic rocks that are foliated parallel to the contact and contain inclusions of the Bedford Canyon Formation. Generally, contact metamorphism is mild when present. The granitic rocks in the Sylvan Meadows area are bound to the NW and SE by rocks of the Bedford Canyon Formation (Plate 1). The mapped contact between these two units is irregular, following the base of the hills underlain by the Bedford Canyon Formation and V’ing up the drainages, suggesting that this is a shallow-dipping intrusive contact rather than a fault, which would be expressed as a more linear contact.

Tertiary (?) arkosic deposits and potential paleosols rest unconformably upon an erosional surface of basement rock consisting of the Bedford Canyon Formation, San Marcos gabbro, and granitic rocks. The Santa Rosa Basalt was extruded on to the Perris
Surface, an erosional surface cut into the Bedford Canyon Formation, granitic rocks, and Tertiary (?) arkosic deposits and potential paleosols. The contact between the Santa Rosa Basalt and the Bedford Canyon Formation, granitic rocks, and Tertiary (?) arkosic deposits and potential paleosols shows no sign of contact metamorphism, except on the south side of Mesa de Colorado, where the basalt overlies granitic rock that is reddish tan and highly decomposed.

STRUCTURAL FEATURES

Sparse attitudes taken in the Bedford Canyon Formation SE of the Sylvan Meadows area indicate that it generally strikes NW and dips 26º-71º E. Tight folding of the beds is common in the NE quadrant of the study area. No attitudes were taken in the Bedford Canyon Formation NW of the Sylvan Meadows area, but the mapped contact between the granitic rocks and the Bedford Canyon Formation indicate the formation dips W. Fracture orientations taken in the granitic rocks show a general strike of either N60ºW dipping 62ºE or N1ºE dipping 65ºE. Orientations were not taken in the arkosic deposits, but these deposits are assumed to be relatively flat lying and parallel to subparallel to the overlying basalts, which gently dip 5º southeast (Hull and Nicholson, 1992).

The study area contains one mapped fault that strikes N-S and forms the drainage along the west side of Fault Road on the eastern side of the study area (Plate 1). The fault extends at least 3 km north of the study area, where it offsets drainages and the contact between the Bedford Canyon Formation and the granitic rocks located in Steve Turner’s
study area. The fault extends at least 1 km south of the study area, forming a prominent drainage on the southern flank of Mesa de la Punta (Plate 1). In the study area, the fault is marked by the prominent drainage along Fault Road and by orangish tan to light gray fault gouge of Bedford Canyon Formation found along sections of this drainage (Figure 21). Springs located along the fault to the northeast of Monument Hill are further evidence of a fault in this area. A deflected drainage in the NE corner of the study area (GPS Station 117, Plate 1) shows right-lateral offset of approximately 108 meters. In the SE corner of the study area, the trace of the fault is marked by a scarp on the west side of Mesa de la Punta, where the basalt appears to be offset vertically by about 12 meters (Figure 22).
DISCUSSION

The oldest rocks exposed in the study area are those of the Bedford Canyon Formation that formed from marine sediments deposited during the Jurassic. These marine sediments consisted of mud, sand, very few patches of lime, and pebbles. Burial of the Bedford Canyon Formation resulted in mild metamorphism of these marine rocks.

During the Jurassic, the Santiago Peak Volcanics were extruded upon the Bedford Canyon Formation. In many places this unconformity is marked by a conglomerate that is a few meters to several meters thick and contains slate and andesitic fragments (Larsen, 1948). However, the Santiago Peak Volcanics in the study area appear to rest directly upon the Bedford Canyon Formation. Rocks of the Santiago Peak Volcanics and the Bedford Canyon Formation were then buried and underwent mild metamorphism.

During the Cretaceous, the Peninsular Range batholith intruded rocks of the Bedford Canyon Formation and the Santiago Peak Volcanics. The oldest intrusive pulse of the batholith is the San Marcos gabbro, which intruded the Bedford Canyon Formation in the study area. The granitic rocks (Bonsall tonalite followed by Woodson Mountain granodiorite) then intruded the San Marcos Gabbro, the Santiago Peak Volcanics, and the Bedford Canyon Formation in the study area.

Deposition of the Tertiary (?) arkosic deposits and carbonaceous shale and formation of the potential paleosols presumably occurred during the Paleocene, as suggested by
Fairbanks (1893) and later by Mann (1955). Some age control is provided by the stratigraphic position of the arkosic deposits, carbonaceous shale, and potential paleosols that overlie older Jurassic Bedford Canyon Formation and the Cretaceous granitic rocks, and underlie younger Miocene Santa Rosa Basalt. This arkosic and paleosol unit was deposited/formed on an erosional surface cut into the Bedford Canyon Formation, gabbroic rocks, and granitic rocks. The preferred interpretation is that these arkosic deposits, paleosols, and carbonaceous shale represent units A through C of the Silverado Formation (Schoellhamer et al., 1981) based on the lithologic similarity between this unit and the beds of the Silverado Formation. However, it is also possible that these beds are much younger than Paleocene and would therefore not be part of the Silverado Formation. Either way, the arkosic deposits suggest that this sediment was derived from a proximal source and the presence of the paleosols suggest a low-relief landscape characterized by humid subtropical to tropical climatic conditions during a time of tectonic stability that would have allowed such soils to form.

The erosion surface between the Tertiary (?) arkosic deposits and paleosol unit and the Santa Rosa Basalt is correlated with the Perris Surface of 9 Ma (Woodford et al., 1971). At the Santa Rosa Plateau, the Perris Surface appears to be cut onto the Tertiary (?) arkosic deposits and paleosol unit, as well as the basement rocks of the Woodson Mountain granodiorite, Bonsall tonalite, San Marcos Gabbro, and Bedford Canyon Formation (Larsen, 1948). However, it is also possible that the paleosols formed on top of the arkosic deposits during the time that the Perris Surface was forming.
During the middle Miocene, regional NE-SW extension occurred as a result of the clockwise rotation of the Transverse Ranges and the development of the Los Angeles basin (Ingersoll and Rumelhart, 1999). Extension of the region resulted in the formation of several NW-striking fractures, some of which could have later become part of the Elsinore and San Jacinto fault zones. Other fractures may have been intruded by aplite during the regional NE-SW extension that presumably occurred between 7-16 Ma (Bjorklund et al., 2002). However, there is no absolute or relative age control on the dikes other than they are younger than the granitic rocks, the San Marcos gabbro, the Santiago Peak Volcanics, and the Bedford Canyon Formation.

During the late Miocene, the Santa Rosa Basalt was extruded on to the Perris Surface – the erosional surface cut into rock of the Bedford Canyon Formation, granitic rocks, and the Tertiary (?) arkosic deposits and paleosol unit. The lower flows of the extrusion are alkalic and were followed by tholeiitic flows containing olivine phenocrysts. Fairbanks (1893) suggests that the basalt may have been constrained within the bed of a stream, since many of the mesas of the Santa Rosa Plateau are underlain by similar arkosic sandstones. However, arkosic deposits (and especially river cobbles) are not found everywhere underneath the basalt, suggesting that the basalt flows were not confined to a river channel. The presence of potential paleosols, which would have formed on a relatively flat surface rather than in a river channel, also supports this conclusion.

Furthermore, the basalt on Mesa de Colorado is about 3 times thicker on the southern side of the mesa, suggesting that the basalt flowed across a surface of low, but undulating/irregular relief. Post-late Miocene folding in the Santa Ana Mountains then
gently tilted (<5°) the flows of the Santa Rosa Basalt to the southeast (Hull and Nicholson, 1992). Finally, erosion removed most of the rock that formed high relief in the area, while rock underlying low relief areas was preserved by the capping basalts, ultimately resulting in an inverted topography.

Movement along the right-lateral Elsinore fault zone initiated around 2.5 Myr ago. Hull and Nicholson (1992) suggest that cumulative fault offset along the NW-striking northern Elsinore Fault zone is 10 to 15 km. However, there seems to be far less offset between the Santa Rosa Basalt (on the W side of the Elsinore fault zone) and the basalt-capped hogbacks (on the E side of the Elsinore fault zone).

The N-S trending right-lateral strike/slip fault along the eastern boundary of the study area is probably related to major movement along the active Elsinore fault zone. Its orientation and sense of offset relative to the Elsinore fault zone suggests that it may be a Riedel shear. The fault cuts the Bedford Canyon Formation, the granitic rocks, and the Santa Rosa Basalt on the west side of Mesa de la Punta. The deflected drainages and the offset of the Santa Rosa Basalt on Mesa de la Punta are evidence that this fault has been active in the Quaternary.
CONCLUSIONS

1. The study area in the western half of the Santa Rosa Plateau Ecological Reserve contains seven types of rock:

   - **Bedford Canyon Formation (Jurassic).** Composed primarily of dark gray argillites and slates, except when interbedded with white to gray quartzite, lenses of dark gray limestone, and sporadic beds of pebble conglomerate.

   - **Santiago Peak Volcanics (Jurassic).** Mildly metamorphosed dark green to black andesite with sporadic outcrops of olive-green slate.

   - **San Marcos Gabbro (Cretaceous).** Dark gray on fresh surfaces, coarse grained, and weathers to medium gray spheroidal boulders. Some outcrops contain 1-3 cm plagioclase phenocrysts.

   - **Granitic Rocks similar to Bonsall Tonalite and Woodson Mountain Granodiorite (Cretaceous).** Forms high relief (granodiorite) areas strewn with large spheroidal boulders and low relief (tonalite) areas punctuated by the occasional spheroidal boulder that rises above the surface of the soil.

   - **Aplitic Dikes (Middle Miocene (?)).** Dikes are typically white to light gray, have a sugary texture, and strike NW. Some dikes contain alternating white and light gray bands that are parallel to the walls of the dike.

   - **Arkosic Deposits and Potential Paleosols (Tertiary (?)).** The arkosic deposits consist of greenish gray siltstone, micaceous siltstone and sandstone, and gravel set in a coarse arkosic matrix. The potential paleosols range in color from mottled red and white to orangish red or brick red. They have a nodular
appearance, which may be preserved peds, and they contain clay-coated gravel.

- Santa Rosa Basalt (Late Miocene). Olivine-basalt comprised of a lower alkalic series and an upper tholeiitic series. The Santa Rosa Basalt caps two mesas within the study area: Mesa de Colorado and Mesa de la Punta.

2. Field work completed during the course of this study suggests that the Santa Rosa Basalt flowed onto an area of low relief and was not confined to a river valley. If the basalt flow had been confined within a river valley, then one would expect to find the basalt underlain by river gravels. Instead, there is great variability in the rocks that underlie the basalt. Granitic rocks underlie the basalt on the south side of Mesa de Colorado, whereas arkosic deposits (siltstone, sandstone, and arkosic gravels) and potential paleosols underlie the basalt on the north side of the mesa. The presence of potential paleosols suggests a subtropical environment where the development of such soil horizons could occur only in the absence of substantial erosion and deposition, unlike a river valley, which would be characterized continual erosion and deposition. The erosion of the basalt ultimately resulted in an inverted topography, where areas of low relief that were capped by the basalt flow are now preserved as areas of high relief – the mesas of the Santa Rosa Plateau.

3. Several NW-striking aplite dikes are found in the study area and are sub-parallel to the Elsinore fault zone. The dikes cut the Bedford Canyon Formation (Jurassic), the Santiago Peak Volcanics (Jurassic), and the granitic rocks (Cretaceous). I interpret
the dikes to have formed as a result of the regional NE-SW extension that occurred during the clockwise rotation of the Transverse Ranges and the development of the Los Angeles basin during the middle Miocene. The orientation of the NW-striking dikes is perpendicular to NE-SW extension, which fits the model of regional NE-SW extension associated with the rotation of the Transverse Ranges.

4. At least one N-S striking right-lateral strike-slip fault is found along the eastern boundary of the study area. The fault cuts the Bedford Canyon Formation and offsets the basalt on west side of Mesa de la Punta. North of the study area, the fault offsets the contact between the granitic rocks and the Bedford Canyon Formation. Features such as offset drainages, springs, and fault gouge mark the location of the fault. Its orientation relative to the Elsinore fault zone suggests that it may be a Riedel shear and drainages offset by the fault suggest that the fault has been active during the Quaternary.
REFERENCES

Fairbanks, H.W., 1892, Geology of San Diego County; also of portions of Orange and San Bernardino Counties, in, Yale, G.Y., editor, Eleventh report of the State Mineralogist: California State Mining Bureau Eleventh Report, p. 76-120.
Kennedy, M.P., 1977, Recency and character of faulting along the Elsinore fault zone in southern Riverside County, California: California Division of Mines and Geology Special Report 131, 12 p.
Ramirez, Pedro C., Colburn, Ivan P., and Leyva, Sonjia, 2002, Probable Lateritic Paleocene Paleosols of Southern California (Talk); 2002 GSA Cordilleran Section Annual Meeting, Corvalis, Oregon


FIGURES
Figure 1. Location of the Santa Rosa Plateau Ecological Reserve (SRPER).
Figure 2. Location of the Santa Rosa Plateau in relation to the Elsinore fault zone (after Woodford et al., 1971).
Figure 3. Location of the Elsinore-Temecula Trough along the northern Elsinore fault zone (after Hull and Nicholson, 1992).
Figure 4. The Santa Rosa Plateau lies at the southern end of the Santa Ana Mountains and includes several basalt-capped mesas (outlined in red). (Map after USGS Santa Ana sheet).
Figure 5. The study area is the western half of the Santa Rosa Plateau Ecological Reserve.
Figure 6. Pebble conglomerate found in the Bedford Canyon Formation on the eastern side of the study area.
Figure 7. Tight folds in the Bedford Canyon Formation on the eastern side of the study area.
Figure 8. Columnar meta-basalt of the Santiago Peak Volcanics in the study area.
Figure 9. IUGS classification of granitic rocks based on normalized percentages of quartz, alkali feldspar, and plagioclase. Granitic rock sample from the Sylvan Meadows area is plotted as a black triangle (▲). Granitic rock sample from high-relief area surrounding Sylvan Meadows is plotted as a black square (■).
Figure 10. Granitic rock of higher relief surrounds the north side of Sylvan Meadows, forming hills strewn with large boulders.
Figure 11. Aplite dike (A) containing white and light gray bands that are parallel to the walls of the dike. Some bands are folded (right side of the photo) and many of the dikes in the study area have an even more distinct banding than seen here. Mafic dike (B)
Figure 12. Greenish gray siltstone at GPS Station 68 shown at outcrop scale (A) and close-up (B).
Figure 13. Two photos (A and B) of an outcrop of micaceous siltstone and sandstone that contains sporadic lenses of gray coarse-grained quartzite (C).
Figure 14. Outcrop (A) of arkosic gravel containing cobbles of subangular basalt. Close-up (B) of the cobbles.
Figure 15. Mottled red and white paleosol at GPS Station 69.
Figure 16. Outcrop (A) of orangish red paleosol at GPS Station 86. The paleosol contains arkosic, quartzite, and metasedimentary gravel that are coated with clay.
Figure 17. The four basalt-capped mesas of the Santa Rosa Plateau Ecological Reserve are Mesa de Colorado in the foreground (A), Mesa de la Punta (B), Mesa de Burro, and an un-named mesa just north of Mesa de Burro (D).
Figure 18. Vernal pools on Mesa de Colorado form when rainwater collects in depressions on the relatively flat-lying basalt.
Figure 19. The lower alkalic basalts consist of thin flows containing many vesicles (A). There are at least 8 separate flows in the lower series alone (B).
Figure 20. The upper tholeiitic basalts consist of thicker flows containing fewer vesicles.
Figure 21. Fault gouge of the Bedford Canyon Formation in the drainage that runs along the west side of Fault Rd (A). The fault gouge is light gray and highly fractured (B).
Figure 22. The trace of the fault can be seen as a scarp on the west side of Mesa de la Punta. (Gray line runs along the bottom of the line created by the scarp.)
TABLES
Table 1. GPS Stations

<table>
<thead>
<tr>
<th>ST. #</th>
<th>UTM Co-ordinates</th>
<th>ST. #</th>
<th>UTM Co-ordinates</th>
<th>ST. #</th>
<th>UTM Co-ordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>474,835,3,711,340</td>
<td>21</td>
<td>474,345,3,709,859</td>
<td>41</td>
<td>473,956,3,709,675</td>
</tr>
<tr>
<td>2</td>
<td>474,609,3,711,275</td>
<td>22</td>
<td>474,302,3,709,970</td>
<td>42</td>
<td>473,960,3,709,658</td>
</tr>
<tr>
<td>3</td>
<td>474,543,3,711,198</td>
<td>23</td>
<td>474,282,3,710,006</td>
<td>43</td>
<td>474,043,3,709,665</td>
</tr>
<tr>
<td>4</td>
<td>474,370,3,711,130</td>
<td>24</td>
<td>474,224,3,710,165</td>
<td>44</td>
<td>474,050,3,709,762</td>
</tr>
<tr>
<td>5</td>
<td>474,243,3,711,030</td>
<td>25</td>
<td>473,701,3,711,028</td>
<td>45</td>
<td>474,042,3,709,837</td>
</tr>
<tr>
<td>6</td>
<td>474,499,3,710,407</td>
<td>26</td>
<td>472,968,3,710,233</td>
<td>46</td>
<td>474,032,3,709,879</td>
</tr>
<tr>
<td>7</td>
<td>474,688,3,710,015</td>
<td>27</td>
<td>472,857,3,710,338</td>
<td>47</td>
<td>474,044,3,709,624</td>
</tr>
<tr>
<td>8</td>
<td>474,678,3,710,046</td>
<td>28</td>
<td>472,445,3,710,769</td>
<td>48</td>
<td>474,059,3,709,529</td>
</tr>
<tr>
<td>9</td>
<td>474,696,3,710,382</td>
<td>29</td>
<td>472,644,3,710,743</td>
<td>49</td>
<td>474,081,3,709,453</td>
</tr>
<tr>
<td>10</td>
<td>474,568,3,710,122</td>
<td>30</td>
<td>473,645,3,710,036</td>
<td>50</td>
<td>474,094,3,709,372</td>
</tr>
<tr>
<td>11</td>
<td>474,654,3,710,096</td>
<td>31</td>
<td>473,663,3,709,989</td>
<td>51</td>
<td>474,825,3,709,745</td>
</tr>
<tr>
<td>12</td>
<td>474,324,3,710,423</td>
<td>32</td>
<td>473,682,3,709,944</td>
<td>52</td>
<td>474,600,3,709,615</td>
</tr>
<tr>
<td>13</td>
<td>474,044,3,710,493</td>
<td>33</td>
<td>473,687,3,709,921</td>
<td>53</td>
<td>474,528,3,709,537</td>
</tr>
<tr>
<td>14</td>
<td>473,921,3,710,340</td>
<td>34</td>
<td>473,680,3,709,892</td>
<td>54</td>
<td>474,400,3,709,453</td>
</tr>
<tr>
<td>15</td>
<td>474,000,3,710,302</td>
<td>35</td>
<td>473,705,3,709,789</td>
<td>55</td>
<td>474,235,3,709,410</td>
</tr>
<tr>
<td>16</td>
<td>474,741,3,709,899</td>
<td>36</td>
<td>473,725,3,709,659</td>
<td>56</td>
<td>474,063,3,709,376</td>
</tr>
<tr>
<td>17</td>
<td>474,378,3,709,787</td>
<td>37</td>
<td>473,931,3,709,814</td>
<td>57</td>
<td>474,081,3,709,260</td>
</tr>
<tr>
<td>18</td>
<td>474,639,3,709,752</td>
<td>38</td>
<td>473,951,3,709,750</td>
<td>58</td>
<td>n/a</td>
</tr>
<tr>
<td>19</td>
<td>474,397,3,709,757</td>
<td>39</td>
<td>473,951,3,709,726</td>
<td>59</td>
<td>473,620,3,709,035</td>
</tr>
<tr>
<td>20</td>
<td>474,363,3,709,815</td>
<td>40</td>
<td>473,965,3,709,672</td>
<td>60</td>
<td>473,615,3,709,300</td>
</tr>
<tr>
<td>ST. #</td>
<td>UTM Co-ordinates</td>
<td>ST. #</td>
<td>UTM Co-ordinates</td>
<td>ST. #</td>
<td>UTM Co-ordinates</td>
</tr>
<tr>
<td>------</td>
<td>------------------</td>
<td>------</td>
<td>------------------</td>
<td>------</td>
<td>------------------</td>
</tr>
<tr>
<td>61</td>
<td>473,180,3,709,447</td>
<td>81</td>
<td>474,928,3,707,571</td>
<td>101</td>
<td>n/a</td>
</tr>
<tr>
<td>62</td>
<td>472,945,3,709,447</td>
<td>82</td>
<td>474,570,3,707,454</td>
<td>102</td>
<td>n/a</td>
</tr>
<tr>
<td>63</td>
<td>474,200,3,708,765</td>
<td>83</td>
<td>473,508,3,707,513</td>
<td>103</td>
<td>476,449,3,709,513</td>
</tr>
<tr>
<td>64</td>
<td>474,082,3,708,674</td>
<td>84</td>
<td>n/a</td>
<td>104</td>
<td>n/a</td>
</tr>
<tr>
<td>65</td>
<td>473,785,3,708,723</td>
<td>85</td>
<td>473,207,3,708,260</td>
<td>105</td>
<td>n/a</td>
</tr>
<tr>
<td>66</td>
<td>473,943,3,708,571</td>
<td>86</td>
<td>473,328,3,708,168</td>
<td>106</td>
<td>n/a</td>
</tr>
<tr>
<td>67</td>
<td>473,521,3,708,701</td>
<td>87</td>
<td>n/a</td>
<td>107</td>
<td>476,334,3,709,822</td>
</tr>
<tr>
<td>68</td>
<td>473,137,3,708,502</td>
<td>88</td>
<td>473,266,3,707,917</td>
<td>108</td>
<td>476,391,3,709,943</td>
</tr>
<tr>
<td>69</td>
<td>n/a</td>
<td>89</td>
<td>473,535,3,708,680</td>
<td>109</td>
<td>476,188,3,710,363</td>
</tr>
<tr>
<td>70</td>
<td>472,777,3,708,732</td>
<td>90</td>
<td>n/a</td>
<td>110</td>
<td>475,897,3,710,450</td>
</tr>
<tr>
<td>71</td>
<td>472,683,3,708,425</td>
<td>91</td>
<td>475,471,3,707,908</td>
<td>111</td>
<td>n/a</td>
</tr>
<tr>
<td>72</td>
<td>473,068,3,708,327</td>
<td>92</td>
<td>475,684,3,707,823</td>
<td>112</td>
<td>475,147,3,710,130</td>
</tr>
<tr>
<td>73</td>
<td>473,647,3,708,804</td>
<td>93</td>
<td>475,295,3,708,085</td>
<td>113</td>
<td>473,731,3,709,678</td>
</tr>
<tr>
<td>74</td>
<td>474,087,3,708,543</td>
<td>94</td>
<td>n/a</td>
<td>114</td>
<td>n/a</td>
</tr>
<tr>
<td>75</td>
<td>473,318,3,706,856</td>
<td>95</td>
<td>475,193,3,708,824</td>
<td>115</td>
<td>n/a</td>
</tr>
<tr>
<td>76</td>
<td>473,348,3,706,769</td>
<td>96</td>
<td>476,425,3,707,339</td>
<td>116</td>
<td>476,449,3,709,513</td>
</tr>
<tr>
<td>77</td>
<td>n/a</td>
<td>97</td>
<td>476,800,3,707,931</td>
<td></td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>474,099,3,706,959</td>
<td>98</td>
<td>475,289,3,709,652</td>
<td></td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>475,352,3,707,623</td>
<td>99</td>
<td>474,925,3,709,429</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>475,295,3,707,552</td>
<td>100</td>
<td>474,874,3,709,576</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>