THE TERTIARY SEQUENCES ON THE FLANKS OF MT. DIABLO:
A RECORD OF SUBDUCTION TO TRANSFORM

NCGS FIELD TRIP - Saturday June 2, 2012
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View of the Neroly Sandstone in the canyon east of the Keller Landfill (Photo Stephen Edwards)
1. INTRODUCTION

The field trip will focus on the Tertiary outcrops on the flanks of Mount Diablo. (Map 1). Mount Diablo at 3849 feet (1173 meters) is one of the highest peaks in the Coastal Ranges of central California (fig.1). The mountain is the central structural uplift of the region and is composed of Coast Range ophiolite and Franciscan assemblages of Jurassic and Cretaceous age (Map.2). Tephra deposits in the upper Tertiary succession indicate that the structure is very young in age and most of the uplift occurred in the last 3 million or so years (Unruh et al., 2007). Early workers have interpreted Mount Diablo as a piercement structure (Taff 1935; Pampeyan 1963). More recent studies have proposed that the mountain is a complex overturned anticlinal fold and thrust structure (Crane 1995 and Jones et al.1994). Unruh and Sawyer (1995) and Unruh (2007), on the other hand, have suggested that Mount Diablo fold and thrusts originated as a contractional structure related to movements of the strike slip faults that border the mountain.

In its regional stratigraphic setting, the outcrops on the northern and southern flanks of Mount Diablo are the uplifted margin of the Sacramento basin (fig.4). This basin is the northern part of the Great Valley fore arc basin which originated during late Mesozoic times on the western margin of the continent between the subducting Farallon and North American plates and the Sierra Nevada magmatic arc (fig.2). Dickinson et al., 1979; Ingersoll 1979; Dickinson 1981; Graham et al. 1984; Moxon 1988,1990; Atwater 1989; Busby 2012 and others have developed the model for the evolution of the plate boundary in California. A progressive shallowing in the angle of the subducting Farallon plate occurred at the end of Cretaceous and continued into the early Tertiary. This event moved the volcanic arc farther to the east from the Sierra Nevada magmatic arc to form a high volcanic plateau in Nevada which Busby (2012) has named the “Nevadaplano” (figs. 6A and 6B). Also in the early Tertiary the depocenter of the basin was located in a graben formed by a series of north-south extensional faults. (figs. 5A & 5B). The lower Tertiary rocks in the basin are composed of a cyclic succession of deep water submarine fan and canyon fill sediment and shallow water deltaic, estuarine and fluvial rocks (fig. 3).

Fig. 1 Mount Diablo looking west from Danville.
During the early Tertiary the forearc marine basin was mainly supplied by sediment from large fluvial drainage systems from the east and northeast (fig. 2, Cecil et al., 2010, Dumitru et al., 2012, Dickinson 2013). These sediments were often subarkosic but contrasted with those of the Mesozoic and mid to upper Tertiary in lacking large volumes of volcanic detritus because of the distant eastward location of the volcanic centers. (fig.6A)

Major changes on the western plate margin also took place in the Oligocene at 27 Ma when the triple junction between the Pacific and Farallon plates intersected the subduction zone with the North American plate (Sharman et al 2013). The plate relationship changed from convergence in the late Mesozoic and
early Tertiary to a transform at the plate boundary in the mid Tertiary. Busby (2012) also postulated that in the mid Tertiary the eastward trailing plate under the California and western Nevada, steepened or rolled back which combined with extension within the slab, created a volcanic arc at the crest of the Nevadaplano and adjacent to the fore arc basin (fig. 6B). Volcanilithic detritus, which had been largely absent in the lower Tertiary succession, now appeared in the succession from volcanism associated with new mid Tertiary calderas and stratovolcanoes. Eruptions generated large volumes of silic ignimbrites that filled the drainage channels that fed into the Sacramento basin during this time (fig.7). Spreading across the valley floor, the silicic volcanilithic detritus can be seen in the successions within the subsurface of the Sacramento basin and in the outcrops along its western margin. Contemporaneously, the marine fore arc basin evolved into a continental one as the Sacramento Valley became a broad alluvial plain.

In the late Tertiary (late Miocene, 12 Ma) the extension in the trailing subducting Pacific plate under the Sacramento Valley was replaced by a NW-SE transtension (Busby 2013). This created what has been termed an “andesite flood” from the Nevadaplano into the basin. This also resulted in the break up of the subducting plate along its western edge forming the Sierran microplate (figs 6B & 7). The volcanic centers at the crest of the Sierra Nevada produced large volumes of andesitic sourced debris flows, lahars, and ash falls that once more filled the drainage into the Sacramento basin. The resulting bluish colored volcanilithic sandstone is widespread in both the Sacramento and San Joaquin basins. On the western plate margin, the northward migrating triple junction in the late Tertiary also produced local volcanic centers such as the one in Sonoma County. Contemporaneous uplifts in the Coast Ranges associated with the San Andreas transform system eventually cut off the access of the Pacific Ocean into the Sacramento Valley.

During the late Tertiary and more recent times, the present day topography emerged and the Sacramento and San Joaquin rivers established their drainage systems into the ancient Tertiary depocenter adjacent to the present day Delta region. In this setting the Coast Ranges with its Mesozoic Franciscan and granitic basements, together with the local volcanic centers, added a new provenance of detritus into the basin.

The main objectives of the field trip are to study the Tertiary section along the north flank of Mount Diablo to find evidence in the rocks for these volcanic events in western Nevada and along the crest of the Sierra Nevada. In addition, the Tertiary rocks should also record major change from subduction to transform that look place in Oligocene times.

2. SETTING OF THE FIELD TRIP

The main focus of the field trip is the Tertiary succession exposed in the foothills on the flanks of Mount Diablo (Maps 1 and 2). The rocks on the south flanks of Mount Diablo are steeply tilted away from the structure and often over turned and faulted. On the north flanks of the mountain, Cretaceous and Tertiary sedimentary sequences dip at about 30 degree angle away from Mount Diablo in a northerly dipping homoclinal block (Map 2 & fig. 8). The rocks are disrupted by a series of small-scale, north-south high angle faults and thrust faults. In the Los Medanos Hills the rocks are also folded into a complex anticline due to the structure at depth rising to the surface at this location.

The lower Tertiary succession is over 2270 meters (7500 feet) and can be subdivided into a series of transgressive and regressive, unconformity bounded sequences (Johnson (1964), Almgren (1978), Sullivan and Sullivan (2012). These T-R sequences are comprised of alternating successions of bathyal submarine canyon mudstone fill deposits and submarine fan sandstones alternating with shallow marine sandstones and neritic shales (fig. 3). This thick succession of lower Tertiary rocks represents the uplifted southwestern margin of the sequences present in the depocentral graben of the fore arc basin. In contrast, the thickness of overlying upper Tertiary rocks in these outcrops is about 330 meters (1000 feet) which is an extremely attenuated succession when compared to the much thicker succession preserved in the subsurface depocenter. This indicates that the depocenter moved eastward in the late Tertiary (figs.5A and 5B).

The Tertiary succession is best exposed on the south flank at Castle Rock Regional Park and in the Rock City within the Mount Diablo State Park (Maps 1 and 2). The south flank is separated from the northern
flanks by the Concord and Clayton faults. The best exposures along the north flanks are in the Keller Canyon Landfill, Black Diamond Mines Regional Preserve and the sand mine operation at Byron. Black Diamond is centrally located on the north flank outcrop belt (Maps 1 and 2). Eastward of the Preserve the succession dips into the subsurface of the Sacramento Valley. The Brentwood oil and gas field, one of the large producing fields in the basin, is located just a few miles to the east. To the north of these outcrops is the Rio Vista field, the largest and most productive of the fields (fig. 4). West of the Rio Vista field are the Potrero Hills which rise above the valley floor. The hills trend east to west which is contrary to the general north-south trend of the regional structures. Eocene rocks are exposed at the surface is this eastward plunging asymmetric anticline. The main north–south faults in the basin are the Midland and Kirby Hills fault that bound the Rio Vista sub basin depocenter in the early Tertiary (fig 5A and 5B). The southern extension of both these faults have been identified in the outcrop, the Midland fault has been correlated with the Bushy Creek fault by Crane (1995) and the Kirby Hills fault with the Kirker fault (Map 2). The Mesozoic rocks in Coast Ranges define the western margin of the basin.

Map 1. Field trip route and stops. Castle Rock (stop 1) is located on the south flanks of Mount Diablo. Between Castle Rock and Lime Ridge (stop 2) is the Concord fault. The stops along the north flanks begin at Keller Canyon Landfill (stop 3). The stops in the Black Diamond Mines Regional Preserve include Somersville town site (stop 4), Sidney Flat (stop 5), Markley Creek (stop 6), Star Mine (stop 7) and Oil Canyon (stop 8). After the Preserve the field trip continues southward to Deer Valley road (stop 9) and Byron (stop 10).
Map 2. Geological map of Contra Costa County after Graymer et al. 1994
Fig. 3 Tertiary succession exposed on the north flanks of Mount Diablo and in the Sacramento basin. The early Tertiary sequences were deposited in the marine fore arc basin during subduction. The mid and late Tertiary formed in a continental fore arc basin during transform.
Fig. 4 Location of the major gas fields in the Sacramento Valley
Fig 5A Isopach map of the lower Tertiary succession. The depocenter is located in graben bounded by N-S faults.
Fig. 5B Isopach map of the upper Tertiary succession. The depocenter center moved eastward in the late Tertiary.
Fig. 6A Tectonic setting in the early Tertiary showing subducting plates on the western plate boundary, the Great Valley marine fore arc basin and the Nevadaplano High volcanic plateau.
Fig. 6B The Tectonic setting in the mid to late Tertiary showing the transform boundary, the trailing Sierra Nevada microplate and the volcanic centers in Nevada and the crest of the Sierra Nevada
CENTRAL CALIFORNIA (over 230 km, after Basin and Range extension is restored):

![Diagram](Fig. 7. West to east cross section of Central California showing the trailing plate under Sierra Nevada and Nevada in mid and late Tertiary times creating rhyolite calderas in central Nevada due to east-west extension.)

HIGH PLATEAU SLOPING WESTWARD IN EARLY CENOZOIC TIME
(from Busby and Putirka, 2009)

FIELD TRIP ITINERARY
STOP 1 CASTLE ROCK REGIONAL RECREATIONAL AREA

Exit I-680 on Ygnacio Valley Road in Walnut Creek and drive east. The sulfur smell in the vicinity of John Muir Hospital is derived from nearby hot springs. After about 5 km (3 miles) turn right on Walnut AVENUE at direction sign to Mount Diablo. After 3 km (2 miles) enter Oak Grove Road traffic circle, then exit right onto Castle Rock Road to the Orchard Staging Area and trail head on the right. Limited parking is also available a short distance along Castle Rock Road.

THE USE OF GEOLICAL PICKS OR COLLECTING SPECIMENS IS NOT PERMITTED IN THE EAST BAY REGIONAL PARKS.

Objectives
1. View the Eocene section on the south flanks of Mount Diablo in order to compare it with the equivalent rocks east of the Concord fault in the north flanks of the mountain.
2. Discuss the depositional environment of a thick sandstone succession of middle Eocene age.

Stewart (1949) named this unit the Hawkhill Formation. It is the basin equivalent of the Domengine Formation deposited on the shelf. Castle Rock is a scenic canyon along Pine Creek located in the foothills of Mount Diablo. It is bordered by Mount Diablo State Park. This stop is located in the southwest corner of the Clayton quadrangle mapped by Dibblee (1980b and Map 3). The Eocene section at Castle Rock and its continuation to Rock City in the State Park has been described by
Fig. 8 View of the north flank looking east from the Keller Canyon Landfill
Fig. 9 Below is a cross section from Shell Ridge to Castle Rock and White Canyon
Stewart 1949, Colburn 1960, and Brabb et al 1977. The lower road from the parking lot passes the headquarters on your right and crosses Pine Creek before the large picnic and recreation area. Exposures of shale in the creek have yielded nannofossils that date these rocks as Capay Shale equivalent. Beyond, the trail enters through a gate into the location of Sulfur Springs. On the west side of the trail are exposed about 150 meters (500 feet) of steeply dipping thick bedded high concentration turbidites with thin interbeds of mudstone (fig. 10). Thin mudstones have yielded nannofossils that indicate that the section is age equivalent to the Domengine Formation at Black Diamond. Sedimentary structures are numerous in the fining upward sandstone units and include ripple marks, cross bedding, flame and load structures. The upper part of the section includes very massive sandstone units containing large concretions. These sand rich turbidites are lowstand submarine fan sediments deposited on the continental slope and ocean floor.

As the trail continues up Pine Creek the section becomes poorly exposed but an additional 290 meters (960 feet) are exposed on peaks of Castle Rock on the east side of the canyon (Stewart op.cit.).

Fig. 10 Outcrop of the thickly bedded turbidites at Castle Rock.
Map 3 Geological map of Castle Rock from Dibblee 1980b
STOP 2 LIME RIDGE
Return to Ygnacio Valley Road via Oak Grove Road. Head north 1 mile on Ygnacio Valley Road to Lime Ridge Open Space. Lime Ridge is the first outcrop on the east side of the Concord fault (Map 2). Limited parking is available at an entrance to the park along the right side of main road.

Objectives
1. View the Domengine Sandstone east of the Concord fault.
2. Origin of Recent domal deposits of travertine.

Lime Ridge is made of a highly faulted section of Domengine Sandstone and Nortonville Shale. The Domengine lithofacies is quite different since the sandstone rich turbidites seen at Castle Rock are not present, the equivalent unit at Lime Ridge is composed of shallow marine, quartz rich sandstone similar to those at Black Diamond a few miles further east. The Concord fault, therefore, separates the eastern shelf facies from the western slope and ocean floor deposits (Sullivan and Sullivan 2012).

Several quarries on the ridge expose irregular domal deposits of travertine of Recent age that overlie the Domengine Formation. Some of the masses are over 6 meters (20 feet) thick and the hill is pockmarked by limestone and sand quarries (figs.11 and 12). They were formed by calcareous hot springs that are no longer active but were common along faults in this area on the flanks of Mt Diablo. The Cowell Portland Cement Company quarried the travertine deposits for cement but the resource was depleted after 38 years of exploitation. The processing plant and workers were housed in the nearby company town of Cowell. Operations opened in 1908 on this 2,000 acre site. Prior to 1915, the travertine was quarried for use in sugar refining and as a flux in smelting gold and silver ores in the Selby Smelter near Crockett. The quarrying was a large and messy operation, and noise from the blasting resulted in complaints from Ygnacio Valley residents. The crushed rock was moved to the bunkers by company railway cars where it was mixed with sand, clay and gypsum. The sand pit in the Domengine Formation is on the north face of the ridge, and can be seen as we drive further north on Ygnacio Valley Road at the intersection of Cowell Road. This mixture was then burned in kilns at high temperatures using oil that was brought in by an underground pipeline and stored in two large tanks at the northeast corner of the Cowell plant. When in full operation the plant was capable of producing 4800 barrels a day (Davis and Fenelon 1951). Finished cement was shipped to Port Chicago via a company owned railroad. It was marketed under the brand name “Mt. Diablo Cement”. The plant shut down every year from about the middle of November to end the end of April because rain made work in the quarry too difficult. By September 1932 the operation had become so large that cement dust blown downwind from the plant resulted in a lawsuit being brought by the fruit and vegetable growers of Clayton Valley. The court ordered dust arrestors installed and this resulted in the eight stacks on the site being replaced by one large 72-meter (240 feet) stack. The plant survived World War II but shut down in June 1946. The official reason given was the lack of limestone in the quarry and competition from the Kaiser Permanente Cement Plant at Sunnyvale.
Fig. 11 Outcrop of domal travertine deposits at Lime Ridge

Fig. 12 View of travertine quarry at Lime Ridge. The Domengine Sandstone is the bedrock and the Recent travertine form domal deposits in the hill.
TOP 3 KELLER CANYON LANDFILL – NORTH FLANK OF MOUNT DIABLO

Drive north on Ygnacio Valley Road; turn left (west) on Clayton Road to the intersection with Bailey Road. Turn right (north) on Bailey Road. Continue north passing the intersection of Concord Road, Bailey Road begins its ascent from the Clayton Valley into the Los Medanos Hills. Plans are under way to major construction to take place in this valley within the present location of the Concord Weapon Station. The road crosses the rail track linking the northern and southern parts of the Weapon Station. The Clayton fault crosses the road a short distance west of the entrance gate on Bailey Road. The low rock covered hills close by on both side of the road are Pliocene basalts that erupted from feeder dikes along the Clayton fault (fig. 14). Another fault marks the base of the hills (Map 2) which has up lifted the basalts (see discussion under Keller Canyon Landfill). Drive 6 km (4 miles) to the next stop. Markley Sandstone within the Los Medanos Anticline underlies the hills. After the summit, the road descends into Pittsburg (Map 1). The Keller Canyon Landfill is located on the right 6 km (4 miles) north of the railroad crossing.

The Keller Canyon landfill is located in a canyon off Bailey Road before you enter the City of Pittsburgh (Map 1). The canyon is one of a series of north-south canyons in the Los Medanos Hills. The landfill opened in May 1992 as a Class II Landfill. The facility accepts municipal solid waste, non-liquid industrial waste, contaminated soils, ash, grit and sludges. Keller Canyon Landfill is closed to the public. It is a “canyon fill” built by constructing a toe berm at the downstream mouth of the canyon. The landfill covers 2,600 acres of land; 244 acres are permitted for disposal. The site currently handles 2,500 tons of waste per day, although the permit allows up to 3,500 tons of waste per day to be managed at the facility.

Objectives
1. Markley Formation of middle Eocene age which underlies large parts of the landfill
2. Upper Tertiary succession on the north flanks of Mount Diablo
3. Neroly Formation, the aquifer for the land
4. Pliocene basalt and timing of the Mount Diablo uplift
5. The stratigraphic record as subduction on the plate boundary changes to transform

Geology in the Landfill site

Steps will be made at the site of the landfill and at the prominent ridge on the north side of the landfill to study the upper Tertiary succession composed of the Wolfskill/Tehama, Neroly and Cierbo formations. The Kirker Formation is absent in this area since it does not extend west of the Kirker Pass fault (Maps 2 and 4).

The Tertiary succession strikes northwest southeast and generally dips 30° northeast on the flanks of the Los Medanos Anticline (Map 2, and Dibblee 1980b and 1980c). The prevailing regional structural trend is complicated in this area by northwest-southeast trending anticline, which is disrupted by thrust faults (Hoffman 1992). Numerous north-south high angled reverse and normal faults also are present including the Kirker fault, which is located on the eastern side of the landfill.

The Markley Formation of middle Eocene age forms the hills south of the landfill which continue eastward to the Concord Weapon Station. The Markley Formation is made up of three members (Map 4 and fig. 18). At the base is a thick succession of Lower Markley Sandstone over lain by the Sidney Flat Shale and the Upper Markley Sandstone. The Upper Markley Sandstone appears to be thin or absent below the upper Tertiary unconformity. Bray (1996) described in detail the Lower Markley Sandstone cores from the Keller Canyon landfill (fig. 13). The formation is composed of a Bouma turbidite succession of sandstones and shales deposited in the marine forearc basin. Bray
observed that the thickness of individual beds and the proportion of sandstone decrease upward in the succession. In the uppermost part the proportion is less than 50% and sandy siltstone and mudstones becomes the dominant lithology. The thickness of the Lower Markley Sandstone is unclear because of the structural complexity related to the faults that border Mount Diablo. The Sidney Flat Shale is about 30 meters (100 feet) thick and includes diatomaceous mudstones. This part of the section will be described in more detail at the next stop in Black Diamond.

The over lying Kirker Tuff of Oligocene age is absent in the section at Keller Landfill since the unit is not present west of the Kirker fault (Map 4 & fig.13). However, it is present east of the fault and its type section is a couple of miles east of the landfill. In the type section, Primmer (1960,1965) divided the formation into a lower brown sandstone and mudstone unit some 43 meters (140 feet) thick and an upper whitish weathering, fine-grained, highly tuffaceous siltstone unit, the Kirker Tuff, that is 48 meters (175 feet) in thickness (fig. 31). The lower sandstone member is poorly exposed and Primmer (op. cit.) describes it as being made up of fine-grained, subarkosic sandstone, which become increasingly tuffaceous upward in the section. The sandstones are poorly sorted, often cross-bedded, and highly bioturbated. Interbedded mudstones in the succession contain plant debris. Other beds contain abundant molds and casts of clams as listed in Primmer (op.cit.). The Kirker Tuff member is well exposed at the type section and is made up of whitish weathering, richly tuffaceous siltstones and interbedded fine grained sandstones. (fig. 14). All of the tuffaceous detritus in these rocks is silicic in composition. The siltstone contains abundant clam molds and burrows indicating deposition in a coastal embayment.

The Miocene marine section along the north flank and the adjacent Contra Costa basin is traditionally referred to the San Pablo Group. The group is composed of the three formations listed in ascending order – Briones, Cierbo and Neroly (Clark 1918). The Cierbo Formation unconformably over lies the Markley Formation. Along the north flanks of Mount Diablo this contact is marked over a wide area by a basal conglomerate. An attenuated section of Briones Sandstone was recognized in the Clayton Quadrangle by Primmer (1960, 1965) but most workers assign all of the marine sandstone beds above the Kirker Formation and below the Neroly Sandstone to the Cierbo Sandstone (Sullivan et al. 1995, Graymer et al. 1994 and McDougall and Block 2014). In the study area, the Cierbo Formation reaches its maximum thickness of 120 meters (390 feet) in the vicinity of the Kirker fault (fig. 33). The section thins eastwards to about 48 to 65 meters (175 to 210 feet) (48 to 65 meters) in the Markley Creek section. The formation can be divided into a lower unit, which is made up of brown sandstones and conglomerates approximately 57 meters (185 feet) thick, and an upper gray channel unit which is composited of thick bedded channelized, cross bedded, subarkosic and tuffaceous sandstone unit that measures about 63 meters (205 feet) in thickness. The tuffaceous sandstones are silicic in composition. Large clasts in the conglomeratic beds include a heterogeneous suite of volcanic clasts, black argillites, black cherts, and white quartzites that indicate an origin in the Sierra Nevada (Walker 2004). The metamorphic clasts in the formation suggest a mixed assemblage of Sierran and Coast Range provenance. A cross-bedded, white weathering, pumiceous tuff bed (Cierbo Tuff) in the basal part of the upper unit is an excellent marker within the formation (fig. 15). Deino and Wagener (pers. comm. 2016) have dated this tuff marker at 10.93 Ma. Tuffaceous gray colored sandstones become increasingly important in the upper part of the section, particularly in the Kirker Creek area a few miles to the east of the Keller Landfill, where they form massive cross bedded channelized unit.
MAP 4 Geology Map of Keller Canyon Landfill (after Bray 1996). Map shows location of the monitoring wells used in Fig. 13.
Fig. 13 Core logs from select monitoring wells in the Keller Canyon landfill
Fig. 14. Type section of the Kirker Tuff east of Keller Canyon Landfill. The contact with the overlying Cierbo Sandstone is above above the heads of the geologists. They are standing on outcrops of the Kirker Tuff which is very thick at this outcrop. The tuff has been dated at 29 Ma. The overlying Cierbo Tuff has been dated at 10.93 Ma which indicates a significant hiatus at the unconformable contact between the two formation.
The Neroly Sandstone of late Miocene age unconformably overlies the Cierbo Sandstone in the landfill. The base of the Neroly has been dated at about 11.1 Ma and the top 9.8 Ma (Sarna-Wojcicki and Walker 1999). The blue colored volcanioclastic sandstones of the Neroly Formation are the most obvious unit in the ridge that fringes the north side of the landfill (fig. 8). This prominent ridge can be followed along the north flanks and produces some spectacular scenery particularly adjacent to the Kirker fault a couple miles east of the landfill (front photo). These sandstones are the aquifer for the water used during the operations in the landfill.

Weaver (1949a, 1949b) described in detail the regional distribution of the Neroly Sandstone. There is a basal conglomerate and an abrupt change in lithology and depositional environment at the base of the Neroly Sandstone. The Neroly Formation reaches a maximum thickness of about 178 meters (590 feet) in the section immediately east of the Kirker Pass fault and thins abruptly westward across the fault to about 98 meters (325 feet) in the landfill (fig. 16). The formation is made up of fining upward succession of volcanic litharenite sandstones that are typically blue in color, coarse grained, trough cross bedded with pebbly layers marking the base of channels. The blue color is due to a coating on the opaque grains from authigenic montmorilloid cement as seen in the Etchegoin Formation in the Kettleman Hills and other late Tertiary formations in the Coastal Range. Lerbekmo (1957), Perkins (1987), and Wilson (2013) described the petrography of these sandstone units. They are made up predominantly of subrounded clasts of plagioclase-rich andesites (79%), quartz (17%) and trace amounts of clinopyroxene and microcline. The thin interbedded tuffaceous mudstone units are rich in fossil leaves and petrified wood. The depositional environment is a fluvial system, the sandstones are point bar deposits and thin interbedded mudstones are flood plain in origin. Thin marine sandstone beds are present near the top of the formation in the section east of the Kirker fault and in the middle of the formation in Markley Creek section. The north flank section was clearly coastal in Neroly times due to the presence of these thin marine interbeds. They probably were deposited in the last marine transgression into west edge of the Sacramento Valley. The Neroly Formation can be correlated to the
Mehrtens Formation in the subsurface and supports a provenance in the plutonic and volcanic rocks of the Sierra Nevada. Streams flowing westward from the Sierra Nevada built alluvial fans across a broad flood plain that fed into a large marine embayment at the site of the present Coastal Ranges (Buisning and Walker 1995).

The Tehama or Wolfskull Formation exposed in the hills at the north end of the landfill is composed of between 150 to 305 meters (500 to 1010 feet) of non-marine clays, silts and sands. Interbedded in the Tehama Formation are tephra beds derived from Plinian eruptions from the Sonoma volcanic field to the north (Sarna-Wojcicki 1976). They serve as important chronostratigraphic markers in the Pliocene succession of the area. In the landfill the Lawlor Tuff (4.81 Ma) is at the base of the Tehama and the Healdsburg Tuff (4.73 Ma) occurs about 15 meters (50 feet) higher in the section. Overlying the Healdsburg Tuff immediately east of the landfill is the Putah Tuff (3.4 Ma). The tephra markers are made up of ash flows and air fall out beds and represent specific eruptions from the northerly volcanic center.
The youngest rocks in the succession at the landfill site are Pliocene basaltic lavas that were observed on the drive to the landfill along Bailey Road adjacent to the Concord Naval Weapon Station (fig. 17). Ground Magnetic Surveys by Sullivan et al. (1995) in the Concord Naval Weapon Station indicate that a feeder dike system located along the Clayton fault was the source of these lateral flows. The radiometric age dating for these lavas was done by the United States Geological Survey and the Scottish Research Center and dated at between 4.8 to 6.6 Ma. The flows in the Weapon Station are at an elevation of about 92 meters (305 feet) on the southwest side of the Clayton fault. They postdate the regional folding of the Tertiary rocks since they are flat lying and fill existing stream channels on the east side of Clayton Valley. A basaltic flow has also been reported in wells in the Los Medanos gas field in T.2N R.2W S.12 (Hoffman pers. comm. 1994) on the west side of the Clayton fault.

Basaltic flows can also be found on the northeast side of the Clayton fault in the Los Medanos Hills within the boundary of the Keller Canyon Landfill. They rest on tilted Tertiary strata as young as the Wolfskill Formation. They have been found at an elevation of 350 meters (1160 feet) and provide clear evidence of Plio/Pleistocene uplift in the area. Ground Magnetic Surveys in the Los Medanos Hills shows no evidence of a feeder dike system associated with the basaltic flows but petrographic analysis indicate that they are identical in composition and show very characteristic flow banding as those in the Weapon Station (fig.17). The evidence, therefore, suggests that these lavas also originated in the feeder dikes along the Clayton fault. They must have erupted and filled the existing stream channels that were draining northeastwards. They clearly postdate the regional tilting and folding of the beds but predated the regional uplift of the Los Medanos Hills.

Fig. 17 Basaltic lava flows of Pliocene age along the Clayton fault in the Concord Weapon Station
In summary, the important observations at the Keller Canyon Landfill stop include a major change in the Tertiary succession between the Markley Formation of middle Eocene age and the Upper Tertiary composed of the Cierbo and Neroly sandstones. It is clear that the unconformity at the base of the Cierbo Sandstone marks a change in the forearc basin from marine to a more continental one. In addition, we also observed the change in the volcanic detritus derived from the Sierran magmatic arc in the Upper Tertiary from silicic sourced detritus to an andesitic one in the Neroly Sandstone. The Lawlor, Healdsburg and Putah tuffs also had a different provenance originating in the Sonoma volcanic center in the Coast Ranges. These observations will be discussed in greater detail in the stops at the Black Diamond Mines Regional Preserve.

Fig. 18 Tertiary Formations exposed in the northern part of the Black Diamond Mines Regional Preserve
Fig. 19  Zonation chart of the Tertiary Formation on the flanks of Mount Diablo and the Sacramento basin after McDougall and Block 2014.
STOP 4 - PICNIC AREA, SOMERSVILLE

Return to Bailey Road and bear right (north) to intersection with Highway 4. Enter the freeway east towards Antioch. About 10km (6 miles) east on Highway 4 to Somersville Road exit (Exit 26) in Antioch. Turn right (south) on Somersville Road through this suburb of Antioch for about 5 km (3 miles) to the entrance to Black Diamond Mines Regional Preserve. The continuation of Somersville Road in the Preserve follows the valley of Markley Creek. The valley narrows into a steep sided canyon as the creek erodes into the ridge formed by resistant upper Tertiary sandstones. Drive a short drive south to the parking lot at the terminus of Somersville Road. This stop allows us to look at a few outcrops of the Lower Markley Sandstone. It is one of the most remarkable stratigraphic units in the section because of its great thickness and the controversy centered about its provenance and depositional setting.

We will hike part of the River View Trail to view the Lower Markley Sandstone outcrops in the lower part of the member.

ONCE MORE, THE USE OF GEOLOGICAL PICKS OR COLLECTING SPECIMENS IS NOT ALLOWED IN THE PRESERVE.

Objectives

1. Type section of the Lower Markley Sandstone
2. Facies architecture and stratigraphic relationship of the Lower Markley Sandstone
3. Markley Submarine Canyon fill stratigraphic relationships within the Eocene succession.

LOWER MARKLEY SANDSTONE MEMBER - DEPOSITION IN THE LATE SUBDUCTION STAGE.

The section along Markley Creek is the type section for the Markley Formation. The formation is made up of a succession of sandstone and mudstone about 1060 to 1210 meters (3500 to 4000 feet) thick. Clark and Campbell (1942) and Fulmer (1956) divided the formation into three members; a lower sandstone member about 760 to 905 meters (2500 to 3000 feet) thick; the Sidney Flat Shale Member above is about 180 meters (600 feet) in thickness; and the upper sandstone member is about 30 to 150 meters (100 to 500 feet) thick (fig.18). Taff (1935), Laiming (1943) and Dibblee (1980b and 1980c), on the other hand, proposed a two-fold subdivision of the Markley Formation dividing the section into a lower sandstone member and an upper shale/mudstone member. The three-fold division is used in the present account.

This Lower Markley sandstone member of middle Eocene age is the thickest unit in the formation. It underlies the rolling hill and saddle topography (fig.22) that characterizes the landscape south from Sidney Flat to the townsit of Somersville in the Black Diamond Mines Regional Preserve. Clark (1918), Fulmer (1956) and Dibblee (1980a) showed that the Lower Markley Sandstone is composed of a cyclic succession of sandstones and mudstone units. The sandstone units are typically 90 to 180 meters (300 to 600 feet) thick separated by thin shale and mudstones units tens of feet in thickness. The massive sandstone units form strike ridges while inter bedded mudstone and siltstone units within the member form recessive intervening saddles (fig.22). Fulmer (1956) in his mapping recognized this sandstone/mudstone architectural pattern and subdivided the Lower Markley Sandstone into five sandstones ridge forming units that were labeled A to E (fig. 18). This same architecture can be recognized in the subsurface well logs and will be discussed below.
The only good section of the Lower Markley Sandstone in the Preserve can be seen in a prospect adit on the hillside east of Somersville Road in S 3 T.2E R.1E. Elsewhere in the area, exposures are poor and are typically composed of the occasional outcrop of the more massive, brown colored, highly weathered, and thickly bedded sandstones. Our stop at Somersville will be to view a typical exposure of the member along the River View Trail north from the townsite. Along the trail the more massive units form the ridges and the mudstone beds the saddles in the hillside exposures. The sandstones are matrix supported and weakly consolidated and readily weather to a sandy soil. More massive sandstones, where better cemented, stand out as resistant beds. In the lower part of this section, they contain many concretionary structures that create a cavernous and honeycomb weathered profile in the sandstone cliffs. This feature is particularly well displaced in the hillside exposures above this trail. Both the adit and outcrop sections reveal that the formation is made up of Bouma sequences of Ta and Tb sandstones grading upwards into siltstones and mudstones. Sandstone beds generally range from one to five feet in thickness. The sandstones are fine to medium grained, poorly sorted, subarkosic micaeous sandstones. The micas are very evident in hand specimens. Rip up clasts are common in these sandstones. Mudstone and siltstone beds typically range from a few inches to a couple of feet in thickness. The mudstone and siltstone are not as thickly developed in the section and form saddles between the sandstone ridges. They contain abundant plant fragments and are non calcareous. Carbonized wood fragments are common in the siltstones, while gastropods and pelecypods are occasionally found in calcareous concretionary units. Some beds in the section are highly deformed due to slumping, which suggests deposition occurred on a slope.

Fulmer (1956) has described the petrography of these subarkosic sandstones in some detail. They are rich in angular quartz, plagioclase and potassium feldspar, muscovite, hornblende and lithic fragments in a mud rich brown colored matrix. Morris (1962) also gave details of the mineralogy and
listed the composition as 50-65% quartz, 10-25% potassium feldspar, 25-5% plagioclase feldspar, and smaller amounts of muscovite, biotite, rock fragments and glaucophane. The matrix in these rocks is made up of very fine-grained brown stained clays of volcanic origin which Fulmer described as an interstitial “paste”. The mineralogy indicates a granitic provenance as the most likely source for the detrital grains and volcanic centers in Nevada for the ash matrix. Fulmer (op. cit.) also lists in details the heavy mineral suite from the formation. They include hornblende; ilmenite and epidote are the most common minerals with minor amounts of garnet, zircon, sphene, rutile, amphibole, biotite and tourmaline.

Fulmer (op. cit.) observed that the Lower Markley Sandstone stratigraphically thins southeastward as the lower units onlaps onto the Nortonville Shale (fig. 24). The Lower Markley Sandstone also gradually changes facies to the southeast. The massive sandstones pass laterally into siltstones and mudstones (figs. 23, 24, and 26). This facies change can be seen in the topography since the prominent sandstone ridges become more subdued and eventually in the southeast of the Preserve the member underlies a wide valley occupied in part by Sand Creek. South from Sand Creek, the Lower Markley Sandstone is seen in discontinuous exposures along the west side of the Sacramento Valley in the vicinity of Brentwood until the entire formation is over lapped by the overlying Neroly Formation in Kellogg Creek north of Byron (Map 6). In the exposures in the sand mines, the Sidney Flat rests directly on the Nortonville Shale (fig. 40).

Westward in the outcrops from Black Diamond, the Lower Markley Sandstone forms the steep rolling hills south of Pittsburg. Good exposures are again rare but numerous monitoring wells in the Keller Canyon landfill are drilled into the upper part of the formation (figs. 13). Bray (1996) described the Lower Markley Sandstone cores from the Keller Canyon landfill. He observed that the thickness of individual beds and the proportion of sandstone decrease upward in the succession. In the uppermost part the proportion is less than 50% and sandy siltstone and mudstones becomes the dominant lithology. The thickness of the Lower Markley Sandstone to the west of the Concord Weapon Station is unclear because of the structural complexity related to the faults that border Mount Diablo. Graymer et al. (1995) and McDougall and Block (2014) showed that it is not found on the south flanks of Mt. Diablo. The western margin of the basin is faulted and eroded which complicates the interpretation of the depositional system particularly in interpreting provenance.

Weaver (1948) in his mapping found that the Markley Formation is also widely distributed in the outcrops in the Coastal Range northwards from Mount Diablo into the Potrero Hills, Montezuma Hills and the English Hills. He showed that the formation maintains its thickness northwards into the Carquinez Strait quadrangle. On the north side of American Canyon it is nearly 1540 meters (5100 feet) in thickness. In the middle of the section is this area is 60 to 360 meters (200 to 1200 feet) of Jameson Shale which is probably equivalent to the Sidney Flat Shale (Blueford and Brunner 1984). Northward, the sandstones in the member become coarser grained and cross-bedded with interbedded lenticular conglomerates. Fulmer (1956) interpreted this facies change was due to the provenance of the Lower Markley Sandstone was to the northwest.
Fig. 21 Lower Markley Sandstone outcrop River View Trail, Somersville

Fig. 22. Google Earth view looking east across the Preserve. The beds are dipping northward (to the left). The Lower Markley Sandstone produces a ridge and vale topography reflecting the sandstone with shale interbedded architecture of the member. The member thins eastward due to on lap on the Nortonville Shale and Domengine Sandstone. The member also has increasing numbers of shale beds eastward.
The Lower Markley Sandstone continues into the subsurface of the Sacramento basin where it is recognized by its electric log characteristics (figs. 23, 24 and 26). The Lower Markley Sandstone architecture is again defined by thick sandstone beds typically between 120 and 150 meters (400 to 500 feet) in thickness made up of fining upward units of turbidite sandstones and siltstones. Interbedded in the succession are mudstone marker beds that represent marine flooding surfaces that can be traced widely across the basin of deposition. The mudstone units are typically 15 to 18 meters (50 to 60 feet) thick. The Lower Markley Sandstone is thickest and sand dominated on the west side of the depocenter. The member thins eastwards and southward due mainly to it on lapping onto the Nortonville Shale and only the youngest part of the section extends eastward to the margin of the basin marked by the Midland fault (fig. 16). There is again a lateral facies change as the section becomes fine-grained eastward and southward in the basin (Edmondson et al. 1967a and 1967b). The Lower Markley depositional system of thick sandstone units bounded by flooding surfaces marked by thinner beds mudstones and siltstones probably represent a series of third order transgressive/ regressive sequences.

Fig. 23. North to south cross section from T. 4N R. 2E to T.3N R. 2E in the subsurface of the Sacramento basin. The cross section continues southward in fig. 35
Fig. 24 North–south cross section from T.2N R.1E to T.1S R.3E in the depocenter of the basin to its margin at the Midland fault. The Lower Markley Sandstone thins eastward and southward and is absent east of the Midland fault.
Fig. 25 Isopach map of the Lower Markley Sandstone
Previous interpretations in the literature has identified the Lower Markley Sandstone continuing beyond the depocentral graben into area of the gas fields on the east side of the basin. This occurred because Miocene sandstones were incorrectly placed into the Lower Markley Sandstone or identified as “Markley-Nortonville undifferentiated” in these wells (Bowen 1960, Bailey 1966, Edmondson 1967). For example, in the California Oil and Gas Volume 3, the Miocene unit is labeled as Markley Sandstone in the Roberts Island (T.1N R.5E), River Island (T.4N R. 4E), and Poppy Ridge gas fields (T.6N R.5E) gas fields. In Grand Island (T.5N R.4E) and Harte (T.2N R.6E) gas fields (fig. 7) it is labeled as “Markley-Nortonville undifferentiated”. The Lower Markley Sandstone is absent east of the Midland fault and is restricted to the depocenter of the basin (figs. 24, 25, 26).

Fig. 26 West to east cross section from Black Diamond across the depocenter of the Sacramento basin bounded by the Midland fault. The Lower Markley Sandstone thins eastward through onlap on the Nortonville Shale. The sandstone also thins into shales eastward in the depocenter.
The Lower Markley Sandstone was, therefore, deposited in the late stages of subduction in the forearc basin. McDougall and Block (2014) indicated that deposition was at outer neritic depths. The abundance of slump structures would suggest that the depositional setting was a delta front on the shelf margin or submarine fan system at the base of the continental slope. The basin underwent rapid tectonic subsidence and deposition during middle Eocene times in order to accommodate a thick accumulation of turbidite sands and muds. The original distribution of the Lower Markley Sandstone on the west and north sides of the basin cannot be determined with certainty because firstly, the basin is faulted on the west side, secondly, the succession is eroded to the north by the Markley Submarine Canyon and the upper Tertiary unconformity (Harding et al., 1960 and Edmondson et al. 1967b). The provenance for the much of the Eocene sediment has been open to some discussion. (Nilsen and Clark 1975, Cherven 1983, DeGraaf-Surpless et al. 2002, Cecil et al. 2010, Sullivan and Sullivan 2012) proposed a provenance was from the Sierra Nevada plutons. Fulmer (1956), however, determined a source to the northwest while Cherven (2013, 2015 pers. comm.) has proposed a provenance from the Salinian terrane to the southwest. All these interpretations recognized that the section thins and the lithofacies are less sand-rich and more distal eastwards within the depocenter and there was a granitic provenance. Dumitru et al. (2012), has provided the most recent work in a study of the zircon assemblages in the middle Eocene rocks in the Cordilleran belt. This study found that the Lower Markley sands were derived from northeast (fig. 2). The zircon population from these deposits was a mixture indicating a provenance from the Sierra Nevada batholith, Idaho batholith and the Challis volcanic center. The study proposed a major north–south drainage, the Princeton River which flowed into the northern end of the Sacramento basin. Clearly, more work is needed in order to determine the lithofacies relationships within the Markley submarine fan and the provenance of the sediment.

STOP 5 - SIDNEY FLAT – HEADQUARTERS OF THE PRESERVE.

After viewing the Lower Markley Sandstone at Somersville, we will retrace our steps and drive the short distance south along road to the park entrance and headquarters. The canyon of Markley Creek opens into a broad strike valley of Sidney Flat formed by the under lying shales near the top of the Eocene succession. Proceed to the parking lot at headquarters’ office which are located on the east side of the road.

Objectives
1. The contact between the Eocene and Post Eocene rock
2. Type section of the Sidney Flat Shale

While standing in the parking lot, the view to the northwest shows the fence line on the western escarpment that approximates the contact between the Sidney Flat Shale and the Upper Markley Sandstone. Above is the post Eocene section with the Neroly Sandstone capping the ridges on both sides of the canyon (fig. 27).

Sidney Flat Shale member of the Markley Formation

The underlying Sidney Flat Shale member occupies the strike valley in which the headquarters is located. A good section is exposed in the creek bed across from the Headquarters. McDougall and Block (2014) assigned an age for this member as late middle Eocene age, (CP-14a and A-1 zone). Clark and Campbell (1942), Fulmer (1956), Jeffries (1983) and Barron et al. (1984) described the section. It can be correlated with the Kellogg Shale in the Byron area and the Kreyhagen Shales in the San Joaquin Valley. It is conformable with the under lying Lower Markley Sandstones and the
contact is marked by a regional flooding surface that can be traced throughout the Sacramento basin.
(figs. 23, 24, and 26). In the exposures in the creek west of the headquarters, the member can be divided into a lower and upper units separated by the diatomaceous shale marker. The upper and lower units are composed of shale, mudstone with interbedded siltstone representing a distal turbidite unit. Good assemblages of foraminifera are found in calcareous concretions in the lower part of the member. The middle unit of Sidney Flat Shale is made up of a whitish gray weathering diatomaceous shale and mudstone unit that is about 26 meters (85 feet) thick. The beds are rich in diatoms, fish scales, thin-shelled clams and carbonaceous plant debris. This marker unit forms resistant ridge in the middle of the strike valley (fig. 27).

The Sidney Flat Shale can be correlated from the outcrop belt into the subsurface and the depocenter of the basin. The Sidney Flat Shale in the basin is made of three stratigraphic units similar in lithology and thickness to those observed in the type section. The upper unit is most variable in thickness, typically is about 105 meters (350 feet) thick but is absent in some areas in the eastern part of the depocenter due to erosion at the base of the upper Tertiary unconformity. The Sidney Flat Shale is only thinly represented east of the depocentral graben. It thins markedly east of the Midland Fault where it rests directly on Nortonville Shale or Ripken Sandstone. The contact between these shales is an unconformity and the Lower Markley member is probably absent due to non-deposition on the shelf east of the depocentral basin (fig. 26). The Sidney Flat Shale, however, is hard to distinguish in the wells logs from the Nortonville Shale where the Ripken Sandstone is absent on the east side of the basin without microfossil data (fig. 28).

![Fig. 27. View eastward across Sidney Flat. The stratigraphic interpretation is based on Primmer (1964). The Kirker Tuff is thought to be absent on this ridge. The area is under investigation.](image-url)
Jeffries (1983) and McDougall and Block (2014) based on their paleontological studies proposed that the Sidney Flat Shale was deposited in the basin at bathyal depths under oxygen deficient conditions. It was deposited during the late subduction stage of the marine forearc basin.

The relationship between the Sidney Flat Shale and the mudstone fill of the Markley Submarine Canyon.

The age relationship these two shale units in the succession has been a matter of discussion since Davis (1953) in a brief abstract first recognized and named the Markley Submarine Canyon. Davis assigned a “pre late Eocene” age to the mudstone fill. One of the immediate concerns that arose was that it was an unfortunate name selection since the submarine canyon fill is not related to the Markley Formation. Also, the term “Markley Canyon” is frequently used in the literature for a steep sided valley, a geographic feature, along Markley Creek in the Black Diamond Preserve. The age assigned by Davis also implied a possible correlation with the Sidney Flat Shale. This Sidney Flat
Fig. 29 Isopach map of the Markley Canyon (after Almgren 1978)

Shale unit considered to be middle Eocene in age and found in the southern part of the basin while the Markley Submarine Canyon was restricted to the northern part (figs 28 and 29). A period of mapping and exploration followed the origin studies of the submarine canyon with the discovery of some major gas fields associated with the stratigraphic relationships at the canyon margins (fig. 4). The canyon was traced for about 20 km (12 miles) in a north to south direction on the west side of the basin to its...
terminus in T.4N. (fig. 29). The incisionment by the submarine canyon into older rocks and the filling of the system with impervious muds has resulted in many sandstone reservoirs serving as stratigraphic trap. Gas fields were found along the margins of its margin in the central part of the basin include Liberty Island, Maine Prairie, and Millar gas fields (fig. 4).

Almgren and Schlax (1957) of Union Oil Company, as part of this exploration, discovered from micropaleontological evidence that the “pre late Eocene” or middle Eocene age reported from the fill was derived from pebbles that had been eroded from the wall of the submarine canyon. Instead, they proposed an Oligocene age based on in situ foraminifera collected from subsurface cores. Many eminent micropaleontologists, such as Stinemeyer and Beck, disagreed with this new age for the fill (Almgren pers. comm. 2014). Nahama and Weagant (1984), and Sullivan and Sullivan (2005), based on the uncertainty of the paleontological evidence and on the abrupt termination of the Markley Canyon at T.4N suggested that the submarine canyon may well have continued southward to link up with the Sidney Flat Shale. Additional support came from Oil Company paleolog files that frequently gave a middle or upper Eocene age for the lower part of the fill. Based on this evidence and on stratigraphic correlation, Sullivan and Sullivan (2005) proposed that the lower part of the Markley submarine canyon fill may be middle Eocene age. This interpretation would make lower part of the Markley fill the same age as the Sidney Flat Shale of Black Diamond and it represented a southern extension of the submarine canyon. Subsequently, following many discussions with Almgren and Filewicz (pers. com. 2014-2015), it has come abundantly clear that the middle Eocene age in the fill was most certainly due to sample contamination. The Sidney Flat Shale is, therefore, considered to be older than the Markley submarine canyon fill and was deposited in the depocenter and not in a submarine canyon.

The Markley Submarine Canyon system runs approximately north to south in the subsurface from T14N to T4 N (fig. 29). It is centrally located in the basin but meanders on the western side following a path situated between R3E and R4E (fig. 29). Almgren (1978) listed its distance to be about 130 km (80 miles), width is between 9 to 14 km (5 to 8 miles) and depth of about 755 meters (2500 feet). It widens and deepens southwards toward the depocentral area. Nahama and Weagant (1984) described the submarine canyon having many tributaries and terraces. However, erosion at the base of the overlying late Tertiary unconformity has greatly modified details of the original submarine canyon topography.

Almgren and Schlax (1957), Almgren (1978), and Almgren and Filewicz (1984) proposed that submarine canyon was eroded and established in the late Eocene and filled with mud-rich sediment during the early Oligocene (CP16a to CP16b, fig. 19). The submarine canyon was eroded on the shelf and slope of the fore arc basin during a lowstand of sea level. The system was filled with mud-rich deposit in the transgressive and highstand that followed. The submarine canyon can be readily recognized in the wells in the basin since it has an erosional unconformity at its base and the fill produces a flat elog response within a sand rich succession. Pepper-Kittreidge and Wilson (1978) showed that the submarine canyon eroded into rocks as old as Early Cretaceous. Dumitru et al. 2012 and Dickinson 2013 have proposed that the north–south Princeton and the Markley Submarine Canyon trends were the conduit for sediment from the Idaho batholith and Challis volcanic field.

The dating of the Oligocene age for the Markley Submarine Canyon fill is of importance since it represents the last depositional sequence in the marine fore arc basin. Starting in the Miocene, the onset of transform at the plate boundary began change to produce major changes along the western margin of the North American plate (figs 6A and B)
STOP 6 TERTIARY SECTION ALONG MARKLEY CREEK
Objectives
1. Tertiary section in the canyon of Markley Creek.
2. Kirker Tuff and Upper Markley relationship.
3. The mid to late Tertiary section in the subsurface of the Sacramento basin.
4. Further stratigraphic evidence for the change at the plate boundary from subduction to transform.

The Tertiary section above the Sidney Flat Shale is exposed along both sides of the road in the canyon of Markley Creek (the use of Markley Canyon in this context should not be confused with the Markley submarine canyon of Oligocene age discussed below in this guide). For safety reasons, it is best to access the outcrops on the west side where the section is well exposed in a quarry. These outcrops are accessed through a gate at the former Devil’s Mountain ranch house. We will, however, view the section from River View Trail on the east side of the canyon.

The Upper Markley Sandstone of middle Eocene age is the youngest member of the Markley Formation as defined by Clark and Campbell (1942) and Fulmer (1956). The type section is here in the canyon of Markley Creek. Clark and Campbell (op.cit.) gave the thickness of Upper Markley Sandstone in this outcrop at no more than 30 meters (100 feet) but Fulmer (op. cit.) gave a thickness at about 135 meters (450 feet). The problem in defining its thickness of this part of the section is that the contact with the underlying Sidney Flat Shale is gradational and is not exposed due to landslides covering the contact. There has been much debate among workers if this sandstone-dominated section includes both the Upper Markley and Kirker sandstones. The top of the section is readily defined by a white weathering white tuff that can be correlated with the Kirker Tuff of Oligocene age.

The quarry on the west side of the road exposes 36 to 42 meters (120 to 140 feet) of sandstones with thin interbeds of mudstones. The road cut on the west side is a less complete section (fig.32). The total section of sandstone is about 75 meters (250 feet) in thickness. The criteria used by Dibblee (1980a) in his mapping in the Antioch South and Clayton quadrangles is that Upper Markley sandstones are subarkosic in composition and the Kirker sandstones are tuffaceous and includes ash beds. Using Dibblee’s criteria in the quarry exposure, it is extremely difficult to draw the boundary within the sandstone section below the Kirker Tuff marker. Sandstones are more tuffaceous in the upper part but the contact seems to be gradational and no hiatus or basal conglomerate is present as a division. Unfortunately, Fulmer (1956) and Primmer (1960) did not include a detailed stratigraphic section of the units in Markley Creek. They did note that the Kirker Tuff is not exposed in the road section on the east side. Fulmer (op. cit.) also illustrated in his thesis a basal Kirker conglomerate, several feet thick, in the road section. It is not present, however, in the quarry section. The sparsity of fossils in the section also made age dating difficult. However, thin inter beds of mudstones rich in plant fragments have yielded a rich assemblage of middle Eocene spores and pollen which shows that the sandstone section below the tuff marker should be assigned to the Upper Markley Sandstone.

The Upper Markley Sandstone member is composed of brown to gray weathered, thickly bedded sandstones with thin interbedded mudstones and siltstones. The sandstone beds are typically between one to three feet in thickest, frequently cross-bedded (fig.34B). One bed in the section has biotite flakes concentrated along the surfaces of the inclined laminae. Siltstones are rippled or planar bedded with inter beds of mudstone (fig. 35D). Mud rip up clasts are common (fig.35A). The sandstones are fine to medium grain, poor sorted, lithic in composition, rich in subangular grains of quartz, feldspar, muscovite, biotite, a small amount of mafic minerals and lithic fragments in a brown mottled matrix of volcanic origin. The petrography of these sandstones is similar to those observed in the Lower Markley. Fulmer (1956) described in detail the sandstone petrography of Upper Markley and lists the heavy
mineral assemblage to include hornblende, epidote, ilmenite, sphene, garnet, zircon, rutile and amphibole. Limonitic concretions are also common in some beds.

Foraminifera are extremely rare; McDougall (pers. comm.) reported *Nonionella multicamerata* from the Upper Markley Sandstone in the type section, a form that is normally found in the middle to late Miocene. Fossil mollusks are absent in the lower part of the section but marine clams such as *Acila* are present in some of the upper beds in the quarry and the same fossiliferous bed is present on the ridge to the west (Primmer 1960). Bioturbation is common throughout the section. The occasional thin mudstone beds in the succession frequently contain plant fragments. These beds yield a rich and diverse assemblage of middle Eocene spores and pollen (pers. comm. Fisk 2015) and can be compared to those found in the Ione Sandstone of Eocene age on the east side of the Sacramento basin. In correspondence, Fisk reported “fern spores -- *Lygodium kaulfussi* and *Cicatricosisporites* sp. The first taxon is apparently restricted to the Middle Eocene and the latter is very rare after the Eocene and may be reworked in later sediments. Conifer pollen -- *Podocarpus* sp. This taxon is not restricted to the Eocene, but uncommon thereafter. Angiosperm pollen -- *Pistillipollenites* sp., *Platycarya* sp., *Momipites triradiates*, *Momopites coryloides*, *Bombacacidites* sp. All of these taxa are either restricted to the Eocene or are not found after the Eocene. In addition, the abundance of *Carya*, *Corylus*, *Myrica*, *Tilia*, *Salix*, and *Ilex* suggest Middle Eocene. The absence of pollen from grasses (Poaceae) and composites (Asteraceae) is also a strong indicator that these samples are not Miocene, since once the grasses and composites appear in the fossil record, they are typically abundant”.

The combination of cross bedded sandstones, bioturbation (fig. 35C), mud rip up clasts, mudstones that contain both a rich assemblage of spores and pollen, as well as the occasional benthic foraminifera and clams, suggest a high energy shallow marine environment. The probable setting would be a coastal deltaic system containing fluvial or distributary channels. The fine-grained volcanic matrix probably had a source in the Nevadoplano volcanic provenance.

Elsewhere in the area west of the Preserve, this upper unit of the Markley Formation is not well exposed but where the top unit of the Eocene is seen in gully exposures, and in the cores from the Keller Canyon landfill, it is not composed of thick sandstone beds typical of the Upper Markley Sandstone but made up of distal turbidites mudstones and thin interbeds of siltstone and sandstone (figs.13 and 30). This predominantly mudstone unit of Eocene age was mapped by Dibblee (1980b and 1980c) in the Concord and Honker Bay quadrangles to the west and labeled as ” Kreyenhagen claystone”. The unit is similar to the upper beds of the Sidney Flat and may be the lateral equivalent or it interfingers laterally with the Upper Markley Sandstone. Another interpretation is that the Upper Markley Sandstone is incised into the top of the Sidney Flat Shale. Exposures are too poor to determine the exact stratigraphic relationship west of the Thomas Ranch. The Upper Markley Sandstone can, however, be traced eastward from the Markley Canyon section. The Kirker Tuff appears to be absent and the Cierbo Sandstone rests directly on this unit. (fig.33).

Church et al (1950) noted that the Upper Markley Sandstone was not present in the subsurface. However, there are similar sandstone units associated with the Sidney Flat Shale in the subsurface on the western side of the basin. They occur on the south side of the Lindsey Slough gas field and the northwest of the Rio Vista field in R. 4N T. 2E and other western parts of the basin (figs.23 and 24). The subsurface stratigraphy of this part of the section will be discussed below.
Fig. 30 Outcrop of Upper Markley Sandstone in quarry on west side of Markley Creek.

Fig. 31 Kirker Tuff in Markley creek quarry section. The tuff is very thin in this section compared to type section to the west.
Fig. 32 Section in the canyon of Markley creek. The numbers shown are the samples taken for palynology.
Fig. 33 West to east cross section of the Upper Markley member, Kirker and Cierbo formations from Keller Canyon to Markley Creek
Fig. 34 West to east cross section of the Upper Markley and Cierbo sandstones from Markley Creek to Homestead Loop, Black Diamond Mines Regional Preserve.
A Mud rip ups

B Cross bedding

C. Bioturbation

D. Mudstone and siltstone interbeds

Fig. 35. Photographs are from the Upper Markley Sandstone on the exposures in Markley Creek.
MID TO UPPER TERTIARY SECTION IN THE CANYON OF MARKLEY CREEK – DEPOSITION UNDER TRANSFORM

The Kirker Tuff of Oligocene age unconformably over lies the Upper Markley Sandstone in the quarry section. At the contact below the white weathering tuff unit is thin basal conglomerate just over a foot or two in thickness. Fulmer (1956) also illustrates a much thicker basal Kirker conglomerate in the road cut on the other side of the creek.

Basal conglomerates above unconformities are important stratigraphic markers in the succession. In the type section of the Kirker Formation it is a multisourced conglomerate up to 17 meters (50 feet) thick. In the Kirker Creek section it is composed of well-rounded pebbles of chert, quartzite, andesite and other Sierran sourced pebbles (Walker 2004). A close examination of the conglomerate in the road cut, however, reveals that it is composed predominantly of locally derived sandstone clasts (fig. 36). I would interpret that this conglomerate is not within the section but is a Recent gravel filled gully or channel. This interpretation would explain the absence of a thick conglomerate at the base of the Kirker Tuff in the quarry on the other side of the creek.

There are also some concerns about how far east the Kirker Tuff extends from Markley Creek. Patten (1947) and Primmer (1960, 1964) mapped the Kirker Formation eastward from the type section and showed that it thinned in this direction. They could only trace it eastward for a short distance from Markley Creek and within less than a mile it terminates below the Cierbo unconformity. Fulmer (1956, 1964), Dibblee (1980a) and Graymer et al (1994), on the other hand, have mapped the Kirker Tuff in the eastern part of the Preserve. Outcrops are poor, however, particularly in the ridges above the Sidney Flat Shale strike valley. Sampling of the section for palynology is under way and will hopefully resolve the stratigraphic relationships.

Fig. 36 View of the basal Kirker conglomerate of Fulmer (1956) in the road cut on the east side of Markley Creek. The conglomerate is mainly composed of angular fragments of the local Tertiary sandstones and is interpreted as a Recent gully fill.
The Cierbo Formation of Miocene age unconformably overlies the Kirker Tuff in the quarry section. A thin basal conglomerate is present at the contact. The sandstones in this formation are often brown in color and contain fossil hash. Large oysters and pecten clams are common in some beds and suggest an embayment environment. The cross-bedded, fossils rich, brown sandstone in the lower part of the Cierbo are probably beach deposits. The more massive gray colored cross-bedded channelized sandstone in the upper part are fluvial in origin. The Cierbo Tuff marker made up cross-bedded, white weathering, pumiceous sandstone can be correlated from the Keller Canyon landfill to this section. (fig.33) The section becomes increasing more landward southeastwards in the outcrops in the Preserve. In the next drainage east of Markley Creek, the Cierbo Formation is in fault contact with the Neroly Sandstone (fig.34). The Cierbo section is much coarse grained and includes many conglomeratic beds of fluvial origin. The Cierbo Formation is becoming more proximal with fewer beds of brown fossiliferous sandstones. Large clasts in the conglomeratic beds include black argillites, black chert, white quartzite, and volcanic rocks that indicate an origin in the Sierra Nevada (Walker 2004).

The contact between the Cierbo and Neroly formations can be drawn in the quarry at the lithological change from brown and gray fossiliferous sandstones and conglomerates of the Cierbo Formation to the blue channelized volcaniclastic sandstones of the Neroly Sandstone. The Neroly section thins eastwards from Keller Canyon landfill to about 48 to 65 meters (160 -215 feet) in the canyon of Markley Creek (fig. 16). Cliff exposures along the creek are made up of the Neroly Formation of late Miocene age. A sandstone bed rich in fossil clams occurs stratigraphically about 51 meters (170 feet) above the base and is exposed at the top of this ridge. The fining upward channelized sands are fluvial in origin. A nonmarine mudstone unit is present at the top of the Neroly Formation in this section (Dibblee 1980a). The Neroly can be correlated with the more proximal Mehrten Formation in the foothills of the Sierra Nevada. It represents a major change in mid Tertiary volcanism in the Sierran region from earlier predominantly rhyolitic sourced sediments seen in the Valley Springs and in the underlying Kirker-Cierbo formations to an andesitic provenance represented by the Mehrten and Neroly formation (figs. 6A and 6B. These blue and gray weathered sandstones form a very prominent west to east strike ridge at the northern end of Markley Creek canyon. The unit can be mapped eastward to Contra Loma Reservoir and westward to Kirker Pass.

The overlying Tehama/Wolfiskill formation is not well exposed in the Preserve. A small quarry above the ranch house exposes the underlying Lawlor Tuff of Pliocene age. A multisourced conglomerate occurs at the base and includes large boulders of vesicular basalt, red and black chert, tan quartzite, and porphyritic volcanic rocks. The overlying beds are made up of light brown colored rhyolitic breccia and pumiceous tuffs similar to the section seen at the landfill. In the Preserve the tuff attains a thickness of about 52 meters (172 feet).

The north flank of Mount Diablo was clearly coastal during Miocene times and in many aspects similar to its location today near the entrance to San Francisco Bay. Streams flowed westward from the Sierra Nevada over a broad alluvial plain. The Miocene marine section can be traced eastward into subsurface wells, and paleologs indicate that the Miocene shallow embayment was widespread and represented the last marine transgression into the Sacramento basin. The fore arc basin had clearly changed from a marine basin to a continental one in the mid Tertiary with the onset of transform (fig. 3).

**Transitional section between the upper and lower Tertiary in the subsurface of the Sacramento basin**

The depocenter in the late Tertiary was located in south central part of the basin (fig.5B). As a result, a thick post Markley section up to 1375 meters (4500 feet) in thickness is present in the subsurface over a wide area of the Sacramento Valley. On most logs and cross sections it is labeled as
“Miocene-Pliocene nonmarine undifferentiated” and can be correlated with the formations in this outcrop section on the north flanks.

The subsurface section can be broadly subdivided in the subsurface into two groups. The lower group is composed mainly of coarsening upward sand units with interbedded mudstones and siltstones that overly the Sidney Flat Shale. It rests unconformably on these marine shales and represents a basinal shift in facies with the introduction of sand dominated sequences. The lower group is probably equivalent to the Kirker and Cierbo formations in the outcrops on the north flanks. There is some debate if the Upper Markley Sandstone may also be part of this group. The lower group reaches a maximum thickness of 365 meters (1200 feet) in this depocenter. Defining this lower group in the subsurface has always been difficult because it is often similar in well log signature to the Markley Sandstone. These sandstones may be marine in origin since a restricted marine fauna has been found in the paleolog reports from lower beds of the group (Berry 1964). Over most of the basin, however, the paleologs identify this group as non marine. It interfingers eastwards with the Valley Springs formation. The latter is a more proximal facies made up of coarser grained volcaniclastic sandstone deposited in the streams and lahars sourced in Sierra Nevada and western Nevada.

Bartow (1984) recognized a similar stratigraphic relationship on the east flanks of the Diablo Range and in the subsurface on the northern San Joaquin Valley. A marine sandstone, the Poverty Flat Sandstone of Miocene age, overlies the Kreyenhagen Shales and underlies the Valley Springs Formation in this area.

The environment of deposition in the basin is thought to have been similar to that described for the outcrop. It is interpreted as a broad alluvial plain flooded that was flooded on its margins by a shallow embayment that represented the last marine transgression into the Sacramento basin (fig 42). The streams flowing eastwards entered the coastal embayment in a series of small deltas that are identified by coarsening upward sand units. Howard (1997) and Hacker (1966) proposed that this last marine incursion occurred in late Miocene times. It represented a northern extension of the sea that had persisted in the San Joaquin basin throughout Miocene into Pliocene times. The sea entered the basin from the south and probably extended as far as north as Vacaville.

The upper Group is easily recognized by the change to a fining upward units typical of a point bar fluvial succession. It is very thick fluvial succession that is probably equivalent to the Neroly and Wolfskill/Tehama formations. Eastwards it merges with the Mehrten Formation.

In summary, the topography across the former Sacramento Valley at the onset of the transform stage was most likely subdued since the Coastal Ranges and Mt. Diablo uplifts are later features. As a result, in late Miocene times a large shallow marine embayment extended eastward into the southwest margins of the Sacramento Valley (fig. 42, Hackel 1966, Howard 1979). No details were provided but the maps in these publications that showed a shallow sea extended from the south from the San Joaquin basin into the southern end of the Sacramento Valley. It was a shallow embayment that connected to the open ocean to the southeast over across the present location of San Francisco Bay and Mt. Diablo to San Jose and beyond. It extended as far north as the Clear Lake and Vacaville. The intertonguing of bay sediments and fluvial rocks indicate that the embayment fluctuated back and forth across the area. The late Miocene was, therefore, the last marine transgression into the Sacramento Valley although the San Joaquin Valley continued to be the site of marine transgressions into the Pliocene. Eventually, the Coastal Ranges were uplifted probably due to oblique compression along the transform boundary (Atwater 1989). This restricted access of the ocean into the interior valley although the barrier has been breached in more recent times through the gap formed by the Carquinez Straits. It is of interest to note that the stratigraphic record indicates that the San Joaquin basin continued to be invaded by the sea into
Pliocene times. The probable reason for this is that the southern end of the fore arc basin deepened southwards and remained topography low.

**STOP 7 - STAR MINE GROUP CAMPSITE AT SOUTH END OF THE PRESERVE** (Section 11 T. 1N, R.1E)

Return north on Somersville Road exiting the Preserve. The first stop sign is the intersection with James Donlon Blvd. Turn right (east) for about 5 km (3 miles) on this road to intersection with Lone Tree Way. Turn right (south) on Lone Tree a short distance to exit right along Golf Course Road to intersect with Frederickson Lane. The southern end of the Preserve can be accessed from the Frederickson Lane gate south of the Contra Loma Reservoir. Parking is available on the south side of the lane.

**Objectives**

1. Domengine Sandstone at the Star Mine
2. Views of the southern end of the Preserve (fig.37)

A short hike west from the gate provides good exposures of the Sidney Flat Shale. Stewartville Road is a gravel trail that leads to the Star Mine Camp site parking lot. The road ascends through the Markley Sandstone which is poorly exposed in the nearby gullies. At the crest ridge there is a good view of the Sacramento Valley to the southeast.

Trail descends into the confluence of Lone Tree Valley and Deer Valley. Excellent exposures of the Domengine Sandstone can be seen at the base of the ridge west of the junction of Stewartville and Star Mines trails. The section is off set by a small north-south faults. The beds display bidirectional cross bedding typical of those found in tidal sand bars. The foresets are mud draped but the organic-rich muds have been oxidized at the surface to limonite stained laminations. The Prospect Tunnel is located in the valley to the north. This tunnel was driven into the hills during the 1860’s in search of commercial deposits of coal. It is about 120 meters (400 feet) in length and can be explored using a flashlight. About 60 meters (200 feet) into the adit, a gate prevents access to the deepest part of the tunnel. The portal is mainly driven into the upper member of the Domengine Formation and the section is terminated by a small fault encountered about 90 meters (300 feet) from the entrance. The section is particularly well displayed in the adit and is made up of interbeds of shale, mudstone and thin-bedded sandstone (Bodden 1981, 1983, Sullivan and Sullivan, 2012). Flaser, lenticular and hummocky cross-bedded units are common and some beds have convolute bedding. The section coarsens upwards into more massive brown sandstones many of which are highly bioturbated.

Turn left (south) on Star Mine Trail to the site of the group campgrounds. Additional exposures of lower Domengine sandstone will be seen in the Star Mine quarry south of the Group Camp site. A spectacular view from an overlook along the Star Mine Trail shows Deer Valley to the southeast which is eroded into Meganos Submarine Canyon fill (Map 2 and fig. 3). The low hills on the north side are formed by the resistant Hamilton Sandstone, and those on the south are in the Meganos “A and B” sandstones and Cretaceous formations. The view south from the overlook is toward Oil Canyon the next stop on the field trip.
STOP 8 - OIL CANYON, SOUTHWEST OF STEWARTSVILLE  (Sections 14, 15, T.1N, R.1 E)

Objectives
1. The location of the second oldest oil well in California drilled in 1864
2. View the contact of the Cretaceous and Tertiary section

Return to the Stewartville trail and head northwest toward the site of the Central Mine and the settlement of Stewartville. The town site can be identified in the valley by the mine waste at the base of the strike ridge. The valley is located in the Meganos “C” Shale and the ridge on the north side has Hamilton Sandstone unconformably overlain by Domengine Sandstone. The basal Domengine unconformity is over stepping older and older units to the west and the Capay Shale is missing in this section. The mine workings extended northward into the hills to reach the thin coal beds in the lower Domengine Member. Faulting was a problem in these mines, as it was elsewhere in the coalfield, and small vertical faults are to be seen in the outcrops of the Domengine Formation above the town site. The main drawback to the development of the Central Mine was its isolation from railroad and docking facilities. The ridge to the north of the town formed a transportation barrier between Stewartville and the loading docks on the San Joaquin River, six miles away. The problem was initially solved by means of a 545 meter (1805 foot) tunnel driven north through the ridge.

Fig. 37 View from Stewartville Ridge southeast to Deer Valley.

In 1881, the Empire Railroad was extended to Stewartville, eliminating the need for wagon haulage. Mining activities ceased in 1897 (Sullivan and Waters, 1980).
Lower Oil Canyon Trail leads off to the southwest. Oil Canyon may have got its name from the early days of oil and gas exploration in this canyon. Just under a mile up the canyon, the trail abruptly turns south close to the property line of the newly purchased Thomas Ranch by the East Bay Regional Parks. A well drilled in 1864 just beyond the boundary gate was the second well drilled in the State. The first one was drilled in 1861 in Humboldt County (it was dry); the first well in the USA was drilled in Pennsylvania in 1859. The wellhead is visible in the tall grass (fig.38). The well was drilled manually to 90 meters (300 feet) and yielded a few barrels of green colored oil. Exploration for oil continued in southern end of the Preserve in recent years in an attempt to extend the Brentwood Oil discovery. Several unsuccessful wells were drilled between 1960-1980. They were testing the contact of the Meganos Canyon fill with underlying Paleocene and Upper Cretaceous sandstones.

Stewart (1949) and Fischer (1979) have studied the lower Tertiary succession along Oil Creek. At this point in the canyon, the massive bedded sandstones of the Deer Valley Formation of Late Cretaceous age are exposed in the ridge above the creek. The Cretaceous outcrops support a dense cover of chaparral. The Martinez Formation of Paleocene age rests unconformably on the Deer Valley Formation. Returning north along the trail, the overlying Meganos “A and B” sandstones and conglomerates are exposed in the cliff. The section is highly faulted by a series of north-south faults and the vegetation helps to delineate the structures. The Meganos “A and B” sandstones and conglomerates were deposited in a submarine fan facies. Fischer (1979) described two transits through the section, the first one is located across Hill 906 on the southeast side and the other is located across the ridge on the northwest side of Oil Canyon.

Time will not permit a stop at the overlook on the Upper Oil Canyon trail which provides a scenic panorama of Mount Diablo and its northern flanks (the overlook is marked on the trail map of the Preserve and is located in the southeast corner of section 9 T.1N R.1E.

Fig. 38 Well head in Oil Canyon that dates from 1864
STOP 9 - DEER VALLEY ROAD, MEGANOS SUBMARINE CANYON VIEW
Exit the Preserve through the Frederickson Lane gate. Retrace the route back to Lone Tree Way via Golf Course Road. Turn right (south) on Lone Tree Way for about 4.5 km (3 miles) to Deer Valley Road intersection. Turn right on Deer Valley Road and head south for about 6 km (4 miles) to Deer Valley itself. On the way, you will pass Kaiser Hospital on your left, Empire Mine Road and near by the Golf Course on the right. Fine views of Mount Diablo as you head south. The Eocene outcrops are very subdued topographically in this area compared to the hilly landscape that they created to the west in Black Diamond. The hills on either side of Deer Valley Road at the Empire Road intersection are in the Domengine Formation.

Objectives
1. The location of the Brentwood oil and gas field
2. The location of the Meganos submarine canyon

Brentwood oil and gas field (fig. 18)
The Brentwood and East Brentwood oil and gas fields are to the east of the road. Swarbrick (1976) described the geology and history of the field. Brentwood is unique since it is the only field in the Sacramento basin that has yielded commercial amounts of oil; the others are gas fields. Discovered jointly by Shell and Occidental Petroleum in 1962. Exploration for oil and gas intensified in the Sacramento basin following the major discovery of the Rio Vista gas field in 1936. Originally the trapping mechanism in the basin was thought to be related to the N-S faults that were prominent in the southwest part of the basin. This system of faults continued southward into the Brentwood area. Shell in 1944 drilled a dry hole “Heidorn #1” close to present northeastern limits of the field in order to test the Hamilton and Domengine sandstone reservoirs that were productive in Rio Vista. Shell returned in 1961 to test the Cretaceous reservoirs in a deep well (3, 500 meters, 11, 472 feet) spudded south of the first test penetrating down to thick sandstone section of the Forbes Formation. Although, the well was abandoned encouraging gas shows in the Martinez and Forbes led to further exploration and the discovery of the stratigraphic traps at the contact of the mud filled Meganos submarine canyon.

At the intersection with Balfour Road, the road exposures on the crest of the hill immediately to the south are made up of Hamilton Sandstone (Crane and Lyon 2002 for discussion of the section). This sandstone unit is a productive gas reservoir in the Delta region. Descending down into Deer Valley, we will make a short stop a short distance south of the Chadborne Road intersection to view the topographic depression formed in the Meganos “C” Shale fill of the Meganos submarine canyon. The Meganos “A and B” sandstone and the Cretaceous section form the hills to south and Hamilton Sandstone those to the north of the valley. A north-south fault (Antioch fault/Davis fault) can be seen offsetting the lower Tertiary section to the southeast (Map 2).
A continuation of the road log along Deer Valley Road is found in another Northern California Geological Society field guide (Crane and Lyon 2002).

Meganos Submarine Canyon
An anomalously thick section of Meganos Shale of early Eocene age was known to be present in the subsurface of the Sacramento basin in the years following the discovery of the Rio Vista gas field (Soper, 1943). A better understanding of the distribution and morphology of this shale unit emerged with the development of the Brentwood field in the 1960s. Isopach maps showed that the shale occupied a subsurface erosional channel (Dickas and Payne 1984). Once the existence of a submarine channel was recognized it was extended eastward from Brentwood to the McDonald Island field, east of Stockton and northward to its termination in the West Thornton field. The Meganos submarine canyon can be traced for about 80 km (50 miles) south and west in the subsurface of the Sacramento basin. The channel width varies between 3 to 10 km (2 to 6 miles). Its southern limit is preserved in Black Diamond but its full extend in this area has been removed by erosion and uplift on the northern flanks of Mount Diablo. The submarine channel mud fill can be correlated with the Meganos “C” Shale in the outcrops of the Preserve. Almgren (1978) dated the cutting of the Meganos canyon as late Paleocene and the filling of the system as early Eocene (fig. 3).

The truncation at the base of the mud filled submarine canyon has resulted in the entrapment of economic qualities of gas and oil in four major fields in the Sacramento basin. In addition to the Brentwood field, the Dutch Slough, River Break and West Thornton gas fields are major discoveries associated with the Meganos submarine canyon (fig.4).

STOP 10 - SAND MINES AT BYRON

Drive a mile back up (north) Deer Valley Road to the intersection to Balfour Road. Turn right (east) on Balfour Road and drive 5 km (3 miles) to the intersection with Highway 4 (SR 4). Turn right
(south); drive about 11 km (7 miles) on SR 4 and its continuation in Vasco Road to the intersection of Camino Diablo Road. Turn right (west) at intersection to entrance to the Gallo (G3) sand operations (fig. 20). Park on the side of Camino Diablo Road across from the entrance.

Objectives
1. Domengine Sandstone stratigraphic relationship at Byron
2. Correlation of the Kellogg and Sidney Flat shales.
Kellogg Shale section

Southeastward from the Preserve, the Sidney Flat Shale can be traced in the sporadic outcrops between Black Diamond and Byron. In the latter area it is renamed the Kellogg Shale. The top of the Domengine Formation is exposed in the road cut. The overlying Nortonville Shale and Kellogg Shale form the strike valley between the resistant hills of Domengine Sandstone and Neroly Sandstone (Photo 8 and fig. 20). Blue colored volcaniclastic sandstones of the Neroly Formation, at the base of the upper Tertiary, are exposed in the road cuts along Vasco Road. Unfortunately, the Nortonville Shale and Kellogg Shale are no longer well exposed although 27 to 30 meters (90 to 100 feet) of laminated diatomaceous shale of the latter unit was displayed at this locality before the construction of Vasco Road (Barron et al. 1984). Slabs of the shales can still be collected on the shoulder of the road. In 1994, the section was again well displayed in a trench excavated a mile or so north of this location in the Old River Pipeline for the Los Vaqueros Reservoir.

Clearly a major stratigraphic change has occurred in the section at Byron since the Markley Sandstone that forms prominent resistant ridges in the Preserve are not traceable southeast beyond Brentwood and the Midland fault (fig. 39). The origin interpretation by Sullivan (2007) was that the unconformity at the base of the Sidney Flat Shale was related to incision at the base of a submarine canyon. As discussed at the stop in Black Diamond, Lower Markley Sandstone thins eastward and southward and does not cross the Midland fault. The north–south Midland fault emerges from the subsurface a few miles north of here (Map 6).

Fig. 39 Stratigraphic cross section northwest to southeast from Black Diamond to Byron
**Domengine Sandstone at Byron**

In this southern area, the Gallo (G3) Company is mining the Domengine Formation for glass sand utilizing a series of large open cast pits on the north side of Camino Diablo road (fig. 40). The next stop is at the entrance to the sand pit opposite Silverhills Drive. These sandstone deposits are very similar in lithology to the sandstone-rich lowstand section at Black Diamond. They are predominantly fine to medium-grained, light colored, thickly bedded, quartz-rich sandstones with thin interbeds of claystone, mudstone, siltstone and lignite. At the surface the sandstones commonly show brown limonite staining. Pyrite is a common accessory mineral in the sandstone and the source may be related to the nearby Byron Hot Springs (Childers 2009 pers. comm.). Bed sets typically are composed of a stacked sandstone beds, many of which are lenticular and channelized, with stringers of conglomerate and mud rip-ups at the channel base. Primary sedimentary structures are rarely observed in the steep cuts of the sand pits, although well preserved mud lined *Ophiomorpha* burrows are particularly common at several horizons. The mudstone and siltstone beds serve as stratigraphic markers to subdivide the section. At the top of the Domengine section the sandstone grades upward into siltstone and mudstone that are in turn overlain by Nortonville Shale and the Kellogg Shale.

**CONCLUSIONS**

The field trip focused on the Tertiary succession along the north flanks of Mount Diablo. The rocks are the uplifted continuation of the depocentral succession in the Sacramento basin. It has been estimated that in the depocenter of the basin the upper Mesozoic succession is as great as 15,000 meters (49,700 feet) by Ingersoll (1990) and the Tertiary succession is over 3000 meters (9700 feet) which makes the combined section one of thickest succession in a fore arc basin in the world. It can be concluded, therefore, that tectonic subsidence of the basement was clearly important in fore arc basin in order to accommodate this extremely thick sedimentary package. Moxon (1988, 1990) proposed that the primary causes of the tectonic subsidence in the basin were due to thermal contraction and/or flexuring of the lithosphere. Tectonic subsidence of the basement, beneath the thick sedimentary fill, resulted in a deepening of the southern portion of the Sacramento basin toward the Stockton arch and the southwestern margin. As a result, the depositional center of the basin throughout the Tertiary was maintained in the southern part adjacent to the present day Sacramento delta.

The incised valleys, submarine fan and canyon fill sequences of the lower Tertiary and the fluvial valley fill deposits of the mid and upper Tertiary all stack vertically on each other in the depocenter which clearly shows that tectonism controlled the location of these sequences in the basin (Sullivan et al. 2003). The early Tertiary sequences can also be shown to correlate with the global eustatic sea level curve of Haq et al 1988 (fig. 41). The Markley Submarine canyon fill was the last depositional event in the subduction phase at the plate boundary (figs.3 and 19). With the onset of transform plate movement in the mid Tertiary (27 Ma, Oligocene), it would appear that the regional dynamics greatly changed. The tectonic subsidence rates slowed and the marine basin became a continental one. The major north-south faults that bounded the early Tertiary depocenter in the southwest margin also ceased or were less active and the depocenter moved a few miles eastward to the south central part of the basin (figs.5A and 5B).

Tectonism associate with activity at the margins or within the trailing subducting plate also played a primary role in controlling the provenance of the sediment brought into the basin (Busby 2012, 2013). The major volcanic center of the Nevadaplano formed as changes in the trailing subducting plate created rich silicic magma in the Oligocene (26 to 24 Ma). Lahars, ash and mudflows
Fig. 40 Sand Mine in the Domengine Sandstone near Byron.

Fig. 41 Timing of events in the Early Tertiary in the Sacramento basin. The age dates are from McDougall and Block 2014.
are found in the Valley Springs formation in the basin and silicic ash in the Kirker Tuff in the Coast Range. The Sierra Nevada microplate originated as part of the rupturing of the trailing subducting plate. Transtensional rifting along the eastern boundary of the microplate in the central Sierra Nevada created a large volume of high-K intermediate volcanism. This “andesitic flood” into the basin in the late Miocene (12 Ma) from calderas along the crest of the Sierra Nevada is found in the Neroly Sandstone. Also in the late Tertiary, the migration of the triple junction created local volcanic centers in the Coast Ranges on the west side including the nearby one in Sonoma. The volcanic ash from these eruptions are present in the Lawlor, Healdsburg and Putah and of Pliocene age. Emergence of the Coast Ranges in the late Miocene resulted in Sacramento Valley no longer being invaded by major marine transgressions of the Pacific Ocean (fig. 42). The Sacramento basin became a broad alluvial plain with major drainages from Sierra Nevada to the east and the Klamath Mountains to the north. Smaller drainages entered from the west. The climate of the region began to change in the mid Tertiary as the subtropical climate of the early Tertiary changed to temperate one of today. Mount Diablo and the basin margin were eventually uplifted in the past 3 million years by tectonic activity along transform plate boundary.
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