2018 Annual Meeting of the
CSULB MARS Project (Monterey and Related Sediment

From Paradise to Sweeney Road:
Siliceous and Organic-Rich Sediment of the Los Angeles, Santa Barbara & Santa Maria Basins

Field Trip Leader:
Richard Behl
California State University Long Beach

Contributors:
Wanjiru Njuguna, Yannick Wirtz, Michael Gross

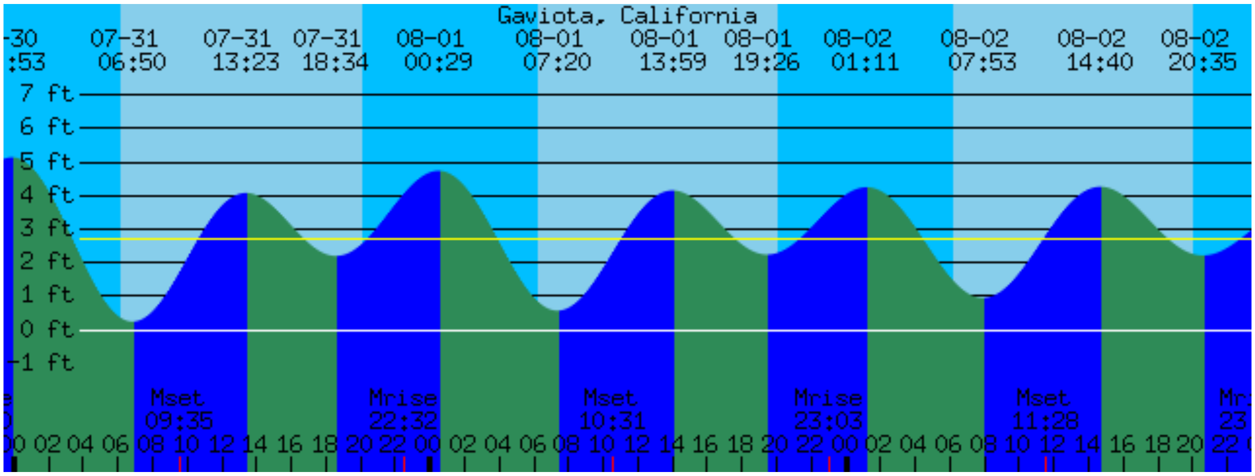
July 31-August 1, 2018

Acknowledgments

This year's field trip shares results from the Masters theses of Wanjiru Njuguna and Yannick Wirtz at California State University Long Beach (CSULB) and with our colleagues Drs. Michael Gross and Karl Föllmi and their students. Material pertinent to Arroyo Burro Beach and Sweeney Road are contained in Behl and Gross (2018), SEPM Field Trip Guidebook #14: "Stratigraphy, Diagenesis and Structural Deformation of the Monterey Formation, Central California Coast" that was provided to meeting participants. Material regarding the Point Dume to Paradise Cove succession in Malibu and Haskells Beach is presented in this guidebook and is largely derived from Wanjiru Njuguna's Masters thesis, a field guide prepared with preliminary data prepared for the 2015 Pacific section AAPG conference, and a recent article by Laurent, De Kaenel, Spangenberg, and Föllmi (2015): "A sedimentological model of organic-matter preservation and phosphogenesis in the Miocene Monterey Formation at Haskells Beach, Goleta (central California)".

We would like to thank the sponsors of the CSULB MARS Project (Monterey and Related Sediments) industry affiliates program for support of the research expenses and student salary for these projects and the work still underway.

Tides are critical for good access, visibility and safety at our beach stops. The tides dictate our schedule. The official field trip is &-31 and 8-1, but an additional day of data is provided for those who may stay on.



2018 MARS Project (Monterey and Related Sediments) Annual Meeting & Field Trip
Long Beach, CA and Santa Barbara County
July 30-August 1, 2018

Science Symposium
Day 0: July 30, Start 9 AM.
CSULB Hall of Science, Room 382

All-day symposium with ~30-45-minute presentations by graduate students and staff of the MARS Project on aspects of sediment compositional characterization, stratigraphy, lateral variation, geochemistry, diagenesis, fluid flow and deformation, and mechanical properties of siliceous and dolomitic sedimentary deposits.

Presenters:
- Rick Behl
- Alex Sedlak
- Jack Farrell
- Ryan Weller
- Maia Davis
- Megan Mortimer-Lamb
- Leo Giannetta

Food and Drinks at Tantulum Restaurant at 5:15 PM.

Field Trip Itinerary:
Day 1: July 31
Depart from Best Western Golden Sails Hotel at 8:30 AM

Drive 1.5-2 hours

Stop #1: Paradise Cove, Malibu Beach (sedimentology of mixed sandstone, diatomite and porcelanite, varied mechanical stratigraphy expressed in joint set development and intensity, with examples from different combinations of rock types)

Box Lunch at Paradise Cove

Drive 1.5 hours *(possible brief stop at Point Mugu)*

Stop #2: Arroyo Burro Beach, Santa Barbara (interbedded chert, porcelanite and organic-rich mudstone with expressions of brittle mechanical stratigraphy at multiple scales, simulateous extension (joints and normal faults) with contraction (folds and reverse faults))

Drive 40 minutes

Lodging at Hotel Corque in Solvang, dinner in small groups (suggestions: Succulent Café, Root 246, Mad & Vin in the Landsby Hotel)

Day 2: August 1
Depart from Hotel Corque at 7:30 AM

Drive 40 minutes

Stop #3. Haskell's/Naples Beach, Santa Barbara (diatomite to diatomaceous mudstone, phosphatic mudstone, chert, and deeply incised submarine canyon with shale breccia fill)

Box Lunches at beach

Drive 50 minutes

Stop #4: Sweeney Road, Lompoc (controls of primary compositional stratigraphy on the opal-A to opal-CT transition and consequent distinct styles of deformation)

Participants return home or to Solvang for overnight.

2018 MARS Project (Monterey and Related Sediments) Annual Meeting & Field Trip
Participants List

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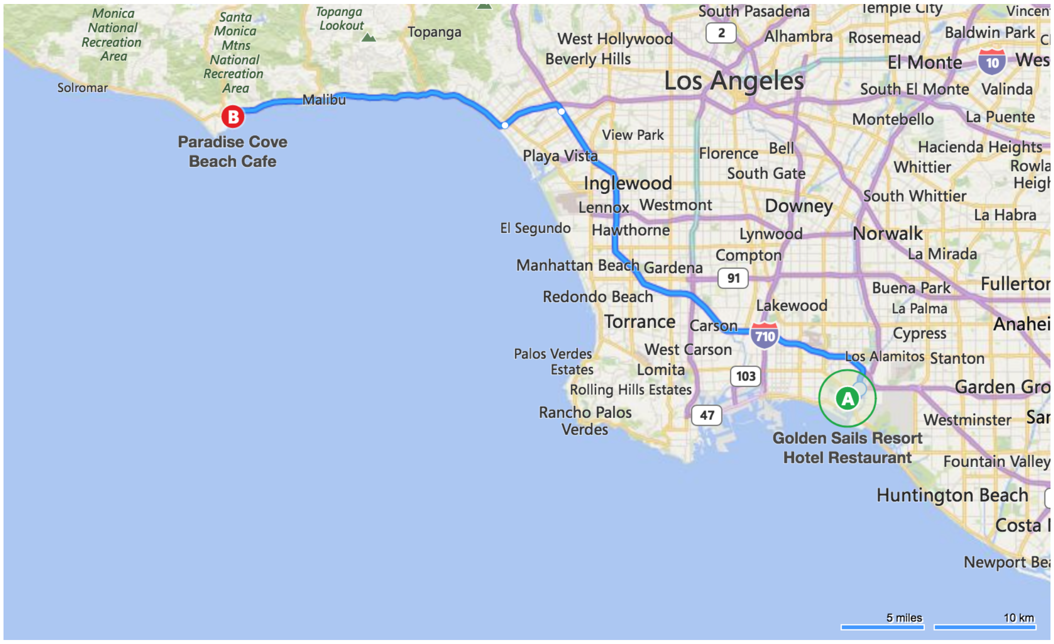
Driving Maps and Instructions

A **Golden Sails Resort Hotel Restaurant, 6285 E Pacific Coast Hwy, Long Beach, CA 90803, United States**

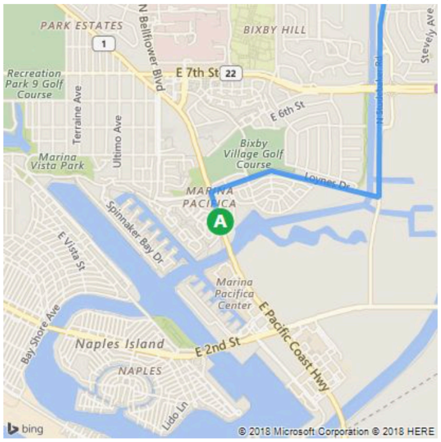
B **Paradise Cove Beach Cafe, 28128 Pacific Coast Hwy, Malibu, CA 90265**

1 hr 51 min, 53.6 mi
Heavy traffic (59 min without traffic)
Via I-405 N, CA-1

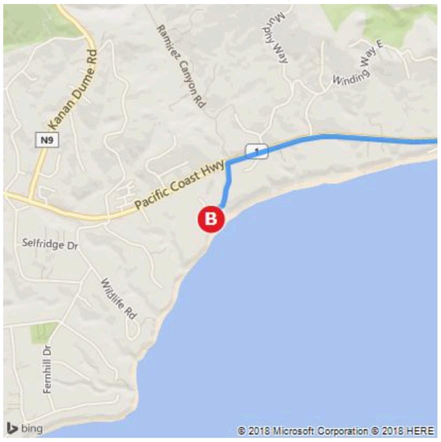
1. Depart CA-1 / E Pacific Coast Hwy toward Loynes Dr	0.1 mi
2. Turn right onto Loynes Dr	0.8 mi
3. Turn left onto N Studebaker Rd	1.7 mi
4.Take ramp left for I-405 N	28.4 mi, 24 min
5. At exit 53B, ramp right for I-10 West toward Airport / Santa Monica	4.1 mi
6. Road name changes to CA-1: Pacific Coast Highway	18.1 mi, 24 min
7. Turn left onto Paradise Cove Rd, Arrive	0.3 mi



A **Golden Sails Resort Hotel Restaurant, 62…**



B **Paradise Cove Beach Cafe, 28128 Pacific…**

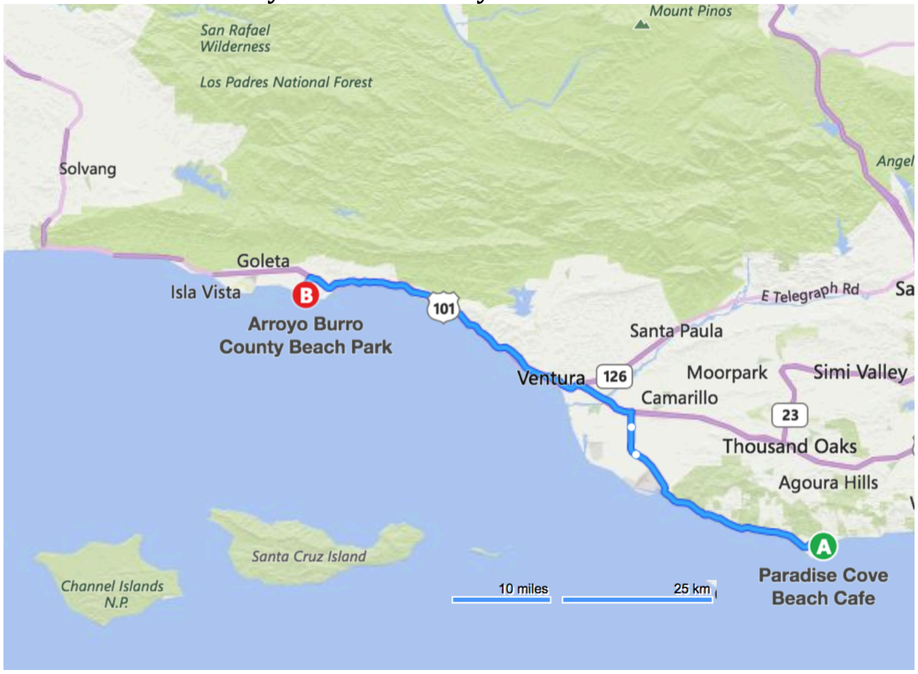


A **Paradise Cove Beach Cafe, 28128 Pacific Coast Hwy, Malibu, CA 90265**

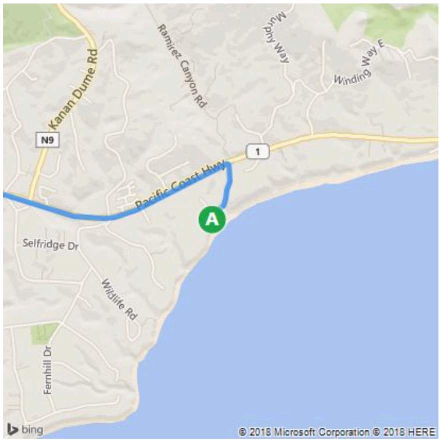
B **Arroyo Burro County Beach Park, Santa Barbara, California,**

1 hr 52 min, 71.2 mi
Heavy traffic (1 hr 13 min without traffic)
Via CA-1, US-101 N

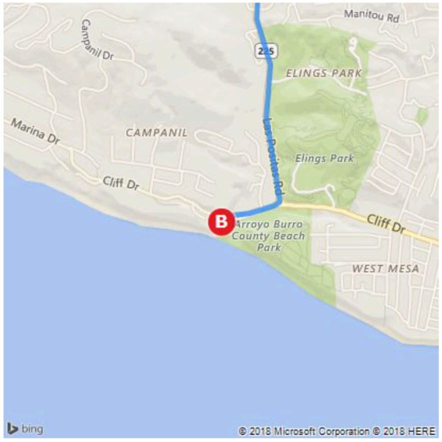
1. Depart Paradise Cove Rd 0.3 mi
2. Turn left onto CA-1 / Pacific Coast Hwy 24.2 mi, 27 min
3. Keep straight toward S Rice Ave 0.6 mi
4. Keep straight onto S Rice Ave 2.6 mi
5. Keep straight onto N Rice Ave 1.5 mi
6. Take ramp right and follow signs for US-101 North 39.7 mi, 34 min
7. At exit 100, take ramp right toward Las Positas Rd 0.2 mi
8. Bear left onto Calle Real 0.1 mi
9. Turn left onto CA-225 / Las Positas Rd 1.8 mi
10. Turn right onto Cliff Dr 0.3 mi
11. Arrive at Arroyo Burro County Park on the left



A **Paradise Cove Beach Cafe, 28128 Pacific…**



B **Arroyo Burro County Beach Park, Santa …**

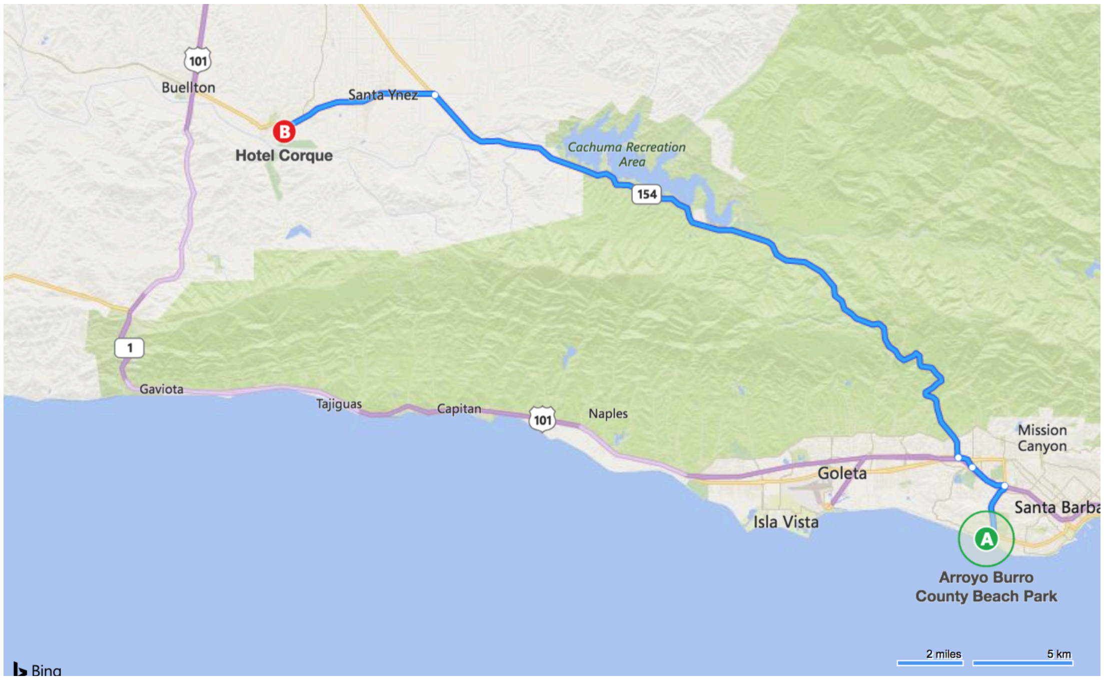


A **Arroyo Burro County Beach Park, Santa Barbara, California, United States**

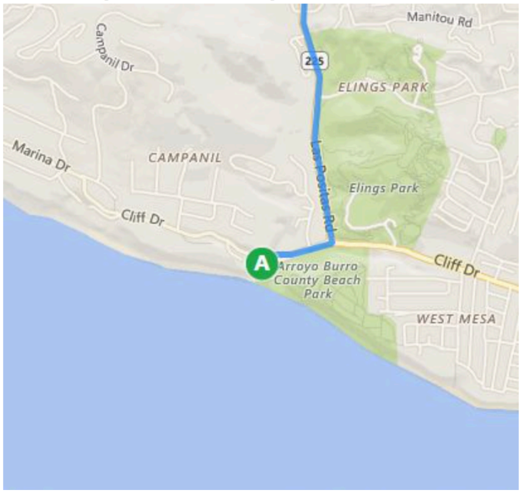
B **Hotel Corque, 400 Alisal Rd, Solvang, CA 93463, United States**

43 min, 33.1 mi
Light traffic (43 min without traffic)
Via CA-154, CA-246

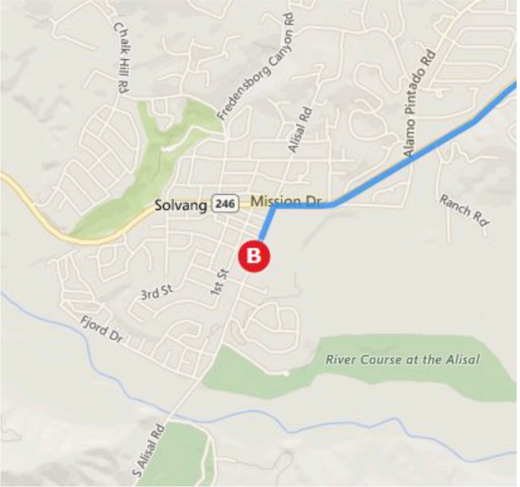
1. Depart Cliff Dr., turn right	0.3 mi
2.Turn left onto CA-225 / Las Positas Rd	1.8 mi
3. Turn left onto Calle Real	486 ft
4. Take ramp left and follow signs for US-101 North	1.2 mi
5. At exit 101B, take ramp right and follow signs for State St	0.2 mi
6. Bear left onto Calle Real	0.4 mi
7. Turn right onto CA-154 / San Marcos Pass Rd	23.9 mi, 25 min
8. At roundabout, take 3rd exit onto CA-246 W / Mission Dr Pass	5.0 mi
9. Turn left onto Alisal Rd	0.2 mi



A **Arroyo Burro County Beach Park, Santa …**



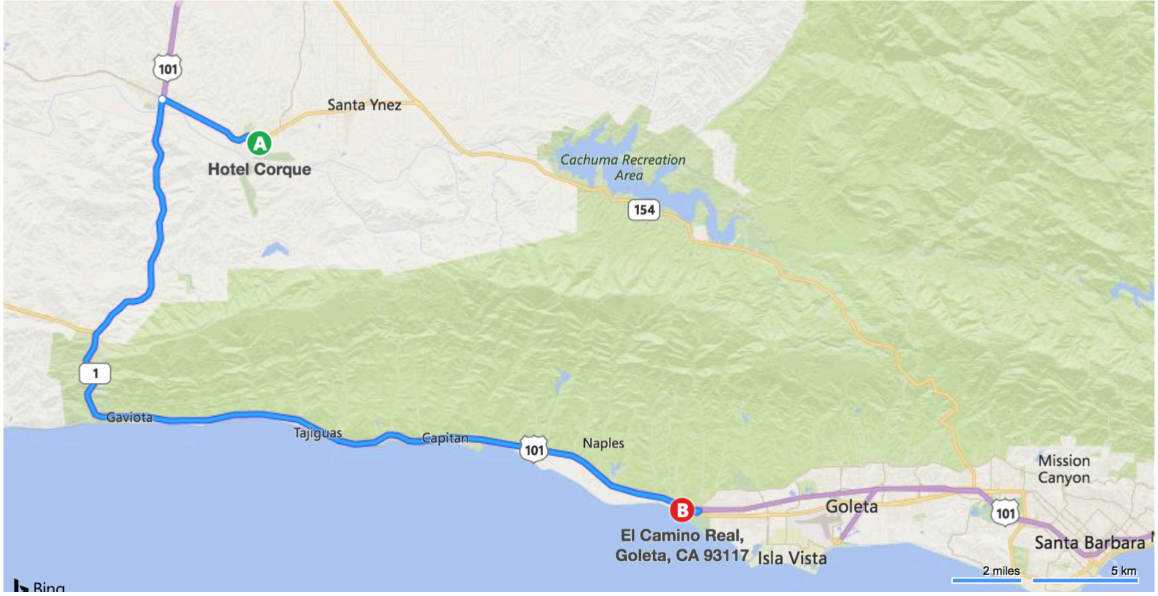
B **Hotel Corque, 400 Alisal Rd, Solvang, C…**



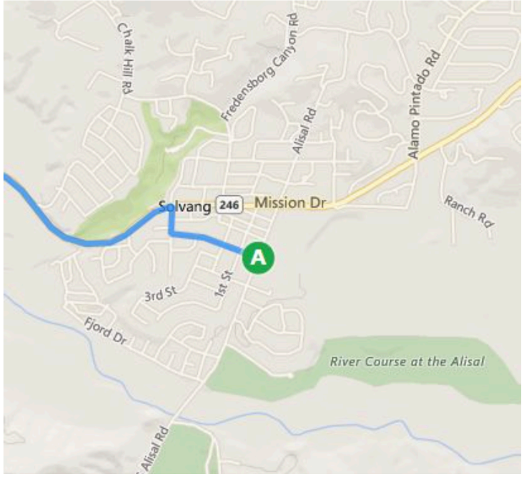
A Hotel Corque, 400 Alisal Rd, Solvang, CA 93463, United States
B El Camino Real, Goleta, CA 93117 , Haskells Beach

43 min, 34.2 mi
Light traffic (37 min without traffic)
Via US-101 S

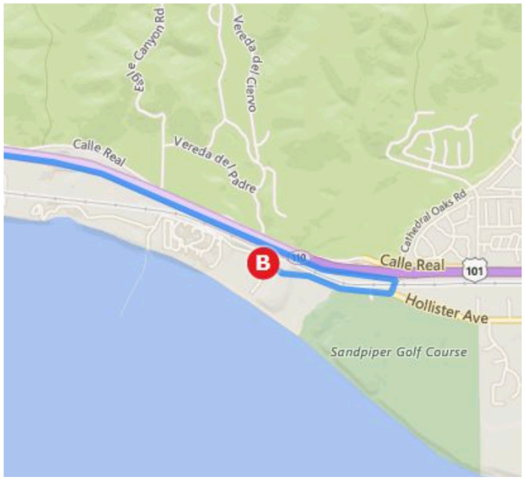
1. Depart Oak St toward 1st St 0.4 mi
2. Turn right onto 5th St 0.1 mi
3. Turn left onto CA-246 / Mission Dr 3.0 mi
4. Take ramp left for US-101 S 29.8 mi, 32 min
5. At exit 110, take ramp right for Cathedral Oaks Rd toward Hollister Avenue / Winchester Cyn Rd 0.4 mi
6. Turn right onto Cathedral Oaks Rd 308 ft
7. Turn right onto road 0.5 mi
8. Turn left into parking for Public Beach Access. Arrive



A Hotel Corque, 400 Alisal Rd, Solvang, C…



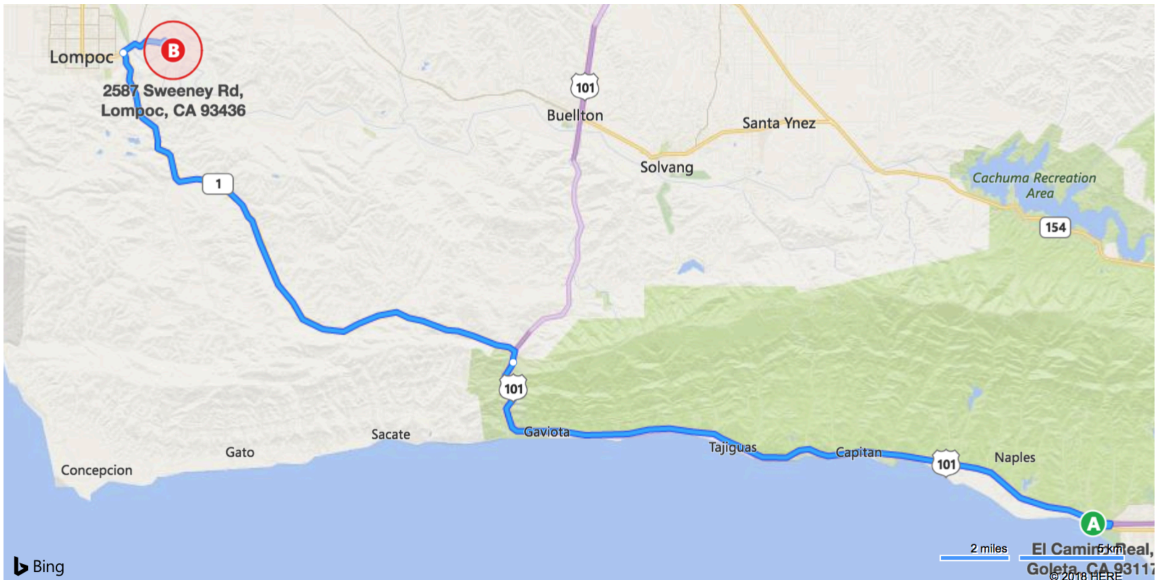
B El Camino Real, Goleta, CA 93117



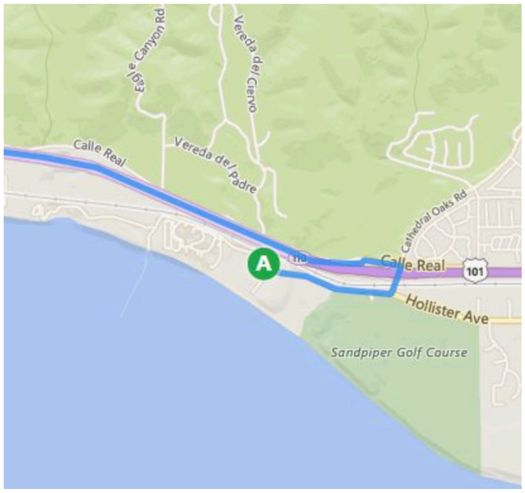
A **El Camino Real, Goleta, CA 93117 , Haskells Beach**
B **2587 Sweeney Rd, Lompoc, CA 93436**

56 min, 42.2 mi
Light traffic (48 min without traffic)
Via US-101 N, CA-1

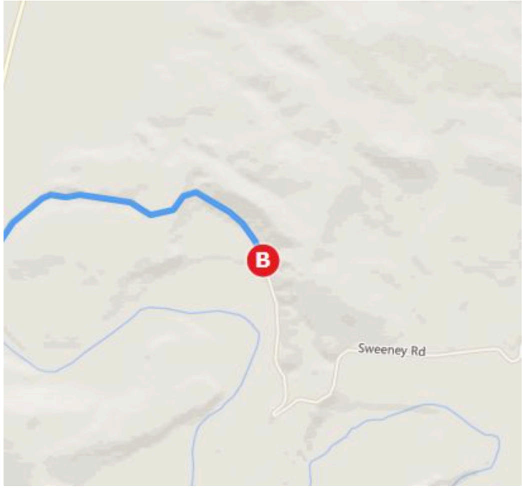
1. Turn right toward Cathedral Oaks Rd 0.5 mi
2. Turn left onto Cathedral Oaks Rd 0.1 mi
3. Turn left onto Calle Real 0.1 mi
4. Take ramp left and follow signs for US-101 North 21.4 mi, 22 min
5. At exit 132, take ramp right for CA-1 toward Lompoc / Vandenberg AFB 0.3 mi
6. Turn left onto CA-1 17.9 mi, 23 min
7. Turn right onto CA-246 0.4 mi
8. Turn right onto Sweeney Rd 1.5 mi



A **El Camino Real, Goleta, CA 93117**



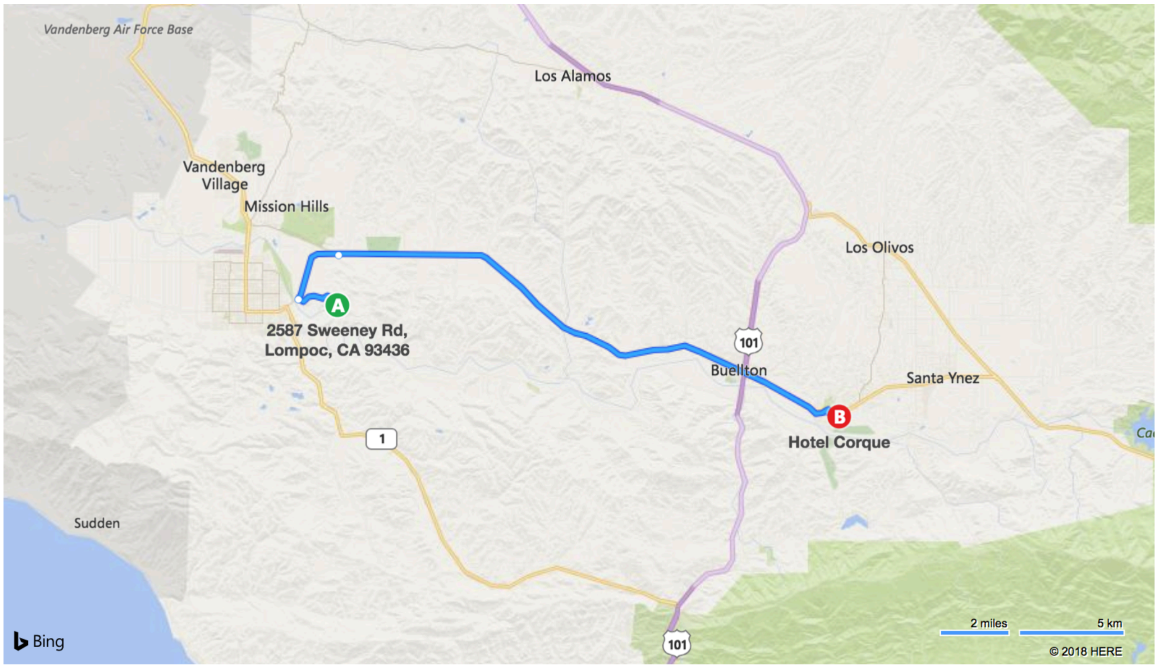
B **2587 Sweeney Rd, Lompoc, CA 93436**



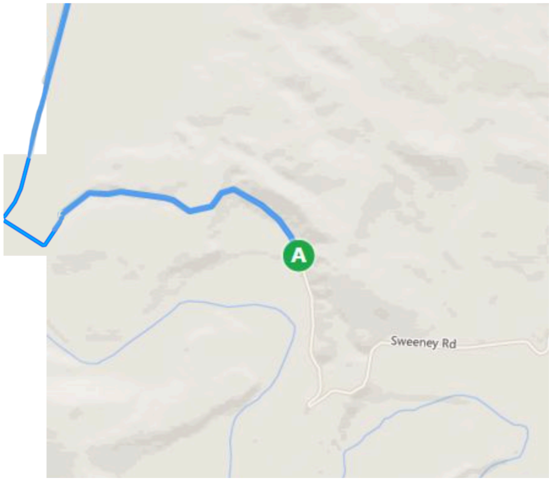
A **2587 Sweeney Rd, Lompoc, CA 93436**
B **Hotel Corque, 400 Alisal Rd, Solvang, CA 93463, United States**

37 min, 20.8 mi
Light traffic (30 min without traffic)
Via CA-246, CA-246 E

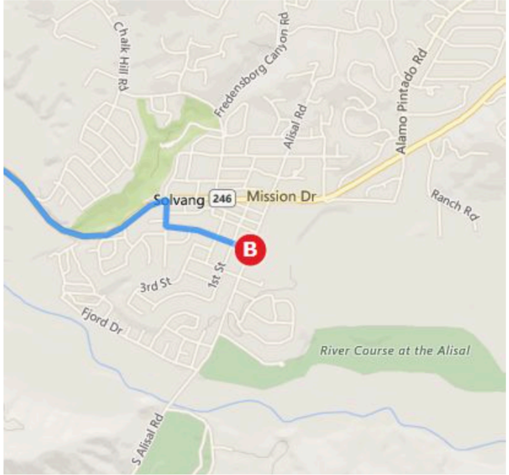
1. Depart Sweeney Rd toward CA-246	1.5 mi
2. Turn right onto CA-246	2.2 mi
3.At roundabout, take 1st exit onto CA-246	16.6 mi, 25 min
4. Turn right onto 5th St	0.1 mi
5. Turn left onto Oak St	0.4 mi
6. Arrive at Hotel Corque	



A **2587 Sweeney Rd, Lompoc, CA 93436**



B **Hotel Corque, 400 Alisal Rd, Solvang, C...**



Mixed Siliciclastic-Siliceous Succession Miocene Monterey/Modelo Formation, Paradise Cove to Point Dume, Malibu Beach, Los Angeles Basin

Richard Behl and Wanjiru Njuguna
California State University Long Beach

Introduction:

This excursion to the Point Dume-Paradise Cove Upper Miocene section examines a splendidly exposed, mixed-clastic-biogenic succession of the Monterey Formation in a beautiful setting at the northern edge of the Los Angeles basin. This location records a transition from organic-rich phosphatic mudrocks (c.f., Nodular Shale) to interbedded porcelanite and siliceous mudrocks to sandstone and diatomite at the boundary between the rifted and rotated Western Transverse Ranges and the translating Inner Continental Borderland. Changes in lithology, grain-size and assemblage of sedimentary structures document the depositional history from initial isolation and condensed sedimentation through input of coarse clastics, likely derived from both the Tarzana or Puente Fans and more local sources. Located between the onshore Malibu Coast fault and the offshore Anacapa-Dume fault, the study area has a complex tectonic history and displays excellent examples of perpendicular extension and shortening at a variety of scales and mechanical behaviors (Figure 1).

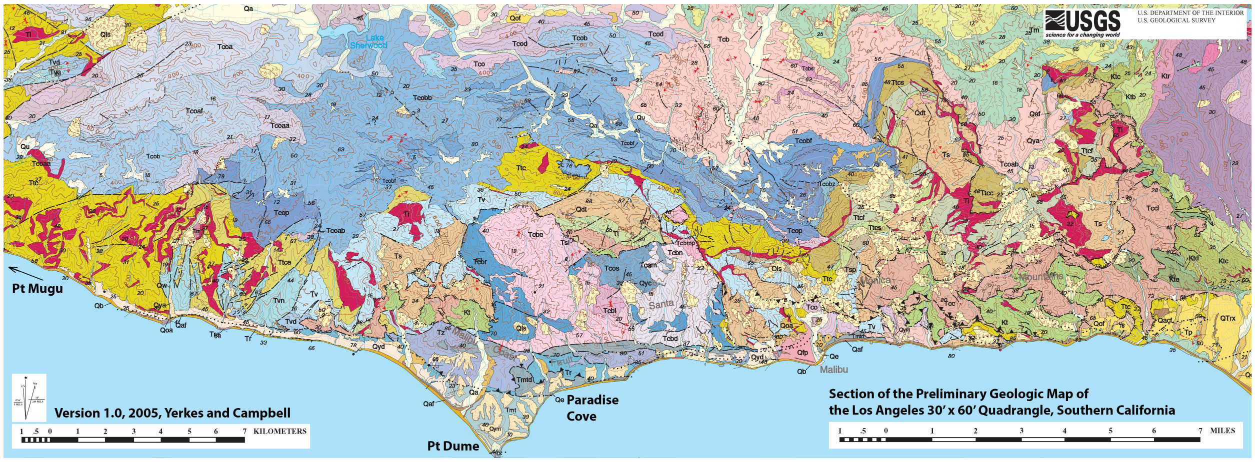


Figure 1. Geologic map of the Malibu coast (Yerkes and Campbell, 2005).

The Monterey Formation exposed in the Point-Dume Paradise Cove area in Malibu, California is an excellent exposure of part of the middle-to-upper Miocene succession of mixed clastic-biogenic rocks of the Los Angeles basin. Stratigraphic equivalents of these rocks exist through Coastal California and large parts of the Pacific Rim (Bramlette, 1946;

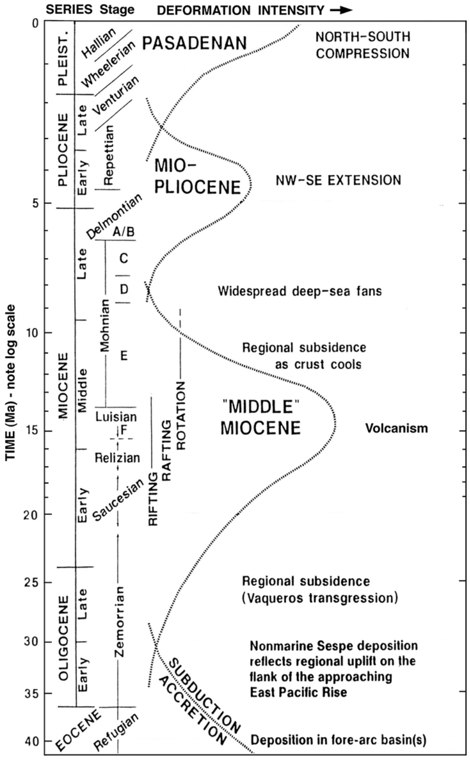


Figure 2. Chronology of major Cenozoic events for the Los Angeles basin. Curve shows intensity of tectonic activity. Modified from Wright (1991).

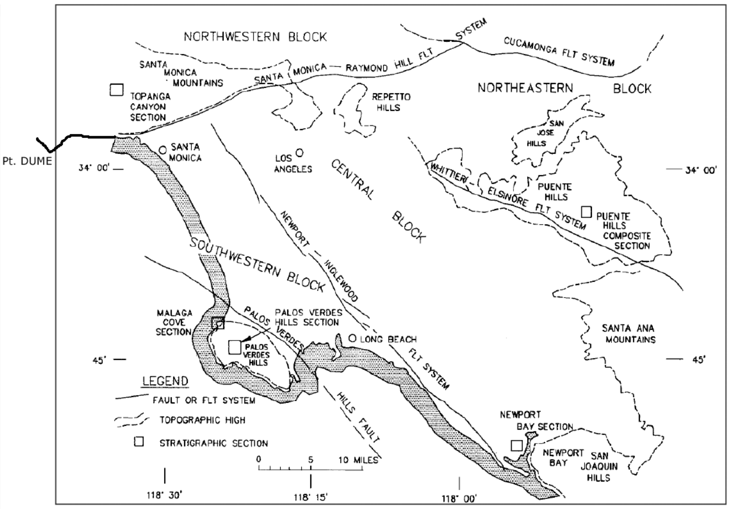


Figure 3. Four major tectonostratigraphic blocks of the Los Angeles basin (from Blake, 1991). Point Dime lies just to the west of the mapped area at the boundary of the Northwestern and Southwestern blocks.

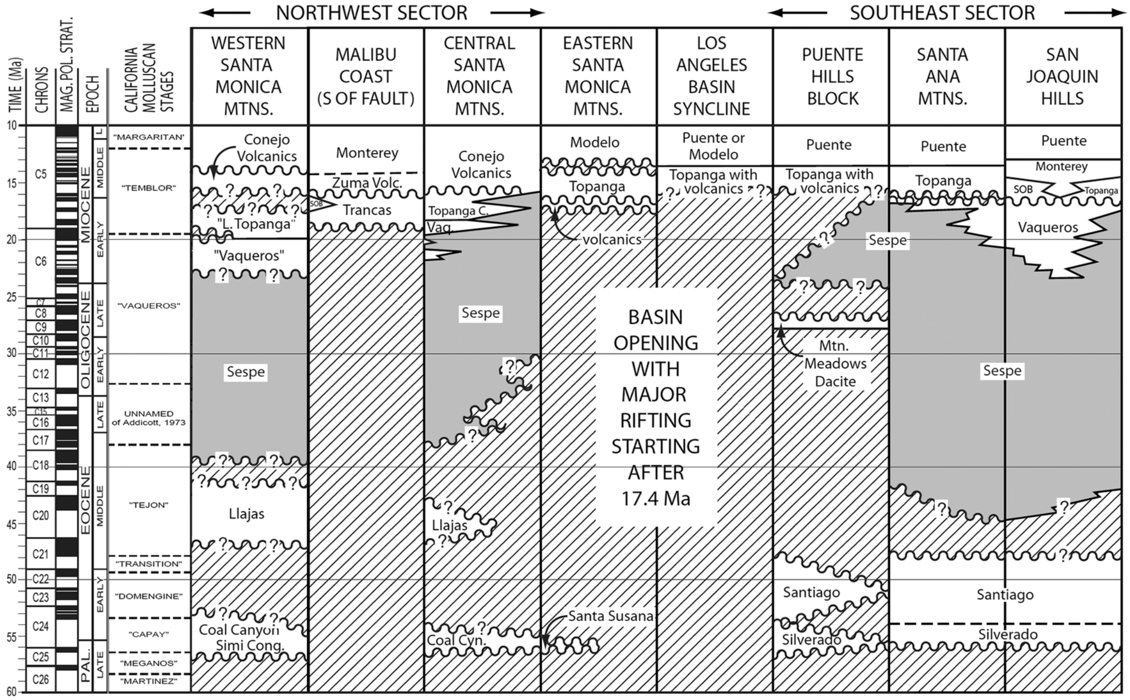


Figure 4. Chronostratigraphic diagram of time and facies relationships and formation nomenclature in the principal parts of the Los Angeles basin prior to 10 Ma (McCulloh & Beyer, 2003).

Ingle, 1981b). Although the Monterey is notable for its great biogenic content (silica, carbonate, and kerogen), there is considerable local variation in clastic content, grain-size and local stratigraphy (Bramlette, 1946; Pisciotto and Garrison, 1981). Consequently, the Monterey Formation plays multiple key roles in the petroleum systems of California – as source, seal, and both fractured and matrix reservoirs (Isaacs and Peterson, 1987). Within the Los Angeles Basin, the Monterey Formation and its stratigraphic equivalents – parts of the Topanga, Modelo and Puente formations (Blake, 1991) – are both the primary source rocks and important reservoirs. Although the Monterey Formation has been well studied in the coastal basins of central California (Santa Barbara, Santa Maria and Salinas basins) and the highly petroliferous San Joaquin basin, much less work has been done in the Los Angeles basin. In part, this may be because the middle to upper Miocene strata are generally much more detrital-rich and less "Monterey-like" in the LA basin than the purer chert, porcelanite, limestone and dolomite found in the more isolated basins. The prior focus of study of upper Miocene rocks in the Los Angeles basin has been principally on the sandstone facies (Redin, 1991). However, the detritus is heterogeneously distributed in space and time, and relatively pure "Monterey lithologies" may be intimately interbedded with clastic sandstone and mudstone (Behl, 2012; Lanners (now Schemp), 2013). Better understanding the genetic relationships and reservoir characteristics of these thinly interbedded lithofacies is an important direction for future studies.

Los Angeles Basin Tectonic Setting:

The southern Californian margin of North America and the Pacific plate has a complex tectonic history with dramatic transitions recorded by the deposits in the Los Angeles basin (Figure 2 & 4). After approximately 30 Ma, the western plate boundary of North America began a transition from a long-lived convergent margin to transform geometry by undergoing a complex sequence of faulting, rifting and block rotation (Atwater, 1970; Blake et al., 1978). The margin fragmented into a number of geologic provinces that experienced different depositional and structural histories (Figure 3 & 4). These provinces include the Continental Borderland, Transverse Ranges and Peninsular Ranges (Crouch & Suppe, 1993). In the middle to late Miocene, initial rifting was followed by strike-slip movement along newly created faults and the more localized clock-wise rotation of the Transverse Ranges, ultimately placing them in their current east-west trending orientation. At the juncture of these three provinces is the Los Angeles basin (Wright, 1991) and the location of the Point Dume-Paradise Cove study area.

Fault-bounded Regions of the LA Basin:

The Los Angeles basin is subdivided into four fault-bounded blocks (Figure 3; Yerkes, et al., 1965) that experienced different depositional histories and that developed distinct stratigraphic successions (Figure 4; Blake, 1991; McCulloh & Beyer, 2003). The Point-Dume-Paradise Cove study location is at the southern boundary of the Northwestern block, marked by the Santa Monica-Raymond Hill-Cucamonga fault system to the east and the Anacapa-Dume fault system to the west (Figure 3 & 5). Most of these fault systems are not defined by a single fault trace; instead, several sub-parallel, named and unnamed, faults

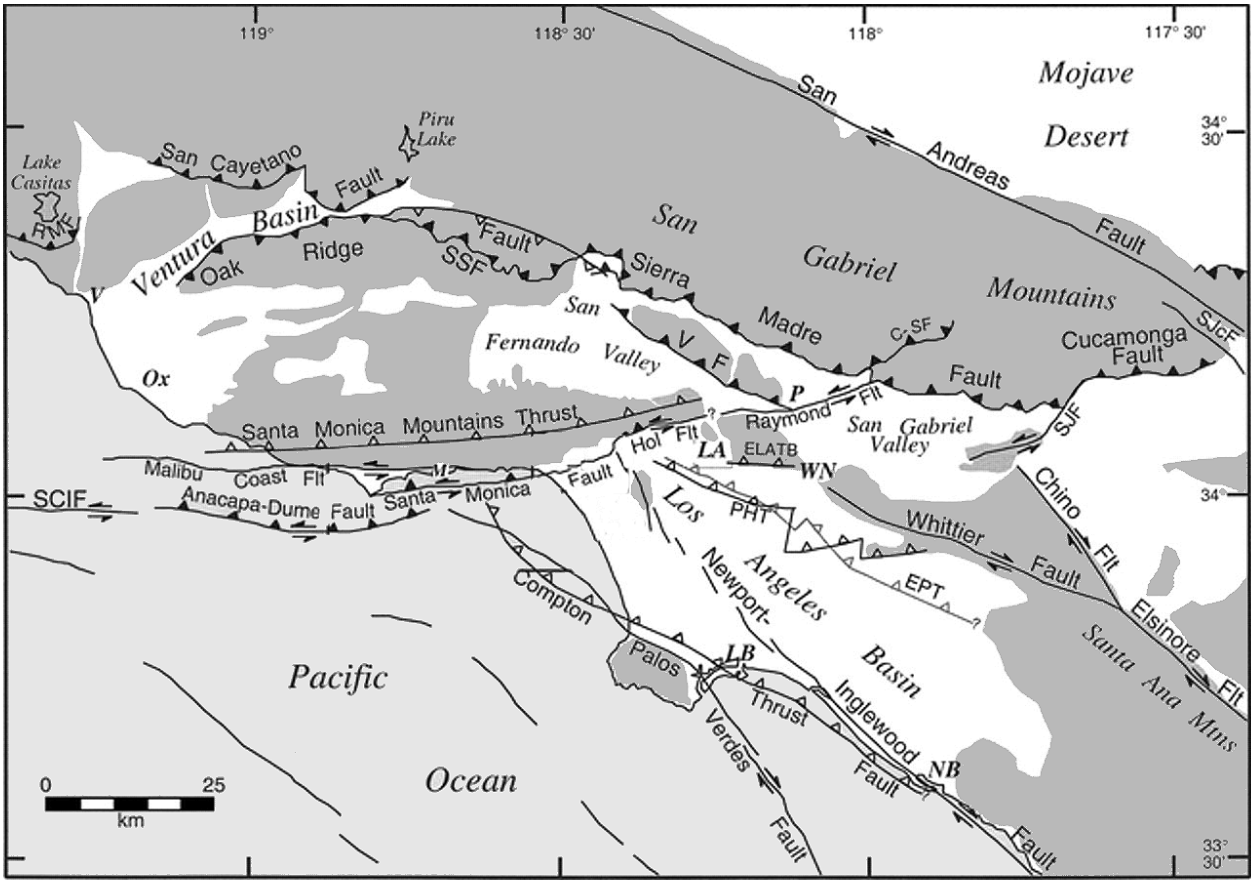


Figure 5. Regional tectonic map for part of southern California (modified from Dolan et al., 2000) showing major active faults. C-SF—Clamshell-Sawpit fault; ELATB—East Los Angeles blind thrust system; EPT—Elysian park blind thrust fault; Hol Flt—Hollywood fault; PHT—Puente Hills blind thrust fault; RMF—Red Mountain fault; SCIF—Santa Cruz Island fault; SSF—Santa Susana fault; SJcF—San Jacinto fault; SJF—San Jose fault; VF—Verdugo fault; LA—Los Angeles; LB—Long Beach; NB—Newport Beach; Ox—Oxnard; P—Pasadena; V—Ventura; WN—Whittier Narrows. Point Dume is at west end of Santa Monica fault. Downtown Hollywood is centered between Hol and Flt in figure. Dark shading shows Santa Monica Mountains.

or splays define a transition zone. Near the study location, to the north is the east-west-trending Malibu Coast fault and to the south the offshore Anacapa-Dume fault (Fisher et al., 2005; Sorlien et al., 2005). Like the Anacapa-Dume fault, the Malibu Coast fault is also linked to the Santa Monica-Raymond fault system to the east (Dolan et al., 2000; Sorlien et al., 2006). This composite fault system is the primary boundary between the Northwestern Block and the Southwestern/Central Block (Fisher et al., 2005). Besides the faults themselves, this important tectonic boundary is identified by contrasting pre-rift basement rocks - Cretaceous-Neogene sedimentary basement of the northwestern Los Angeles basin block to the north and the Jurassic schist basement of the southwestern Los Angeles basin block at Point Dume and to the south (Blake, 1991). Reconstruction of the tectonic history of this area is still controversial, but all models account for E-W extension across the basin and rotation and/or translation of the Northwestern (Santa Monica Mountain) block (Figure 6).

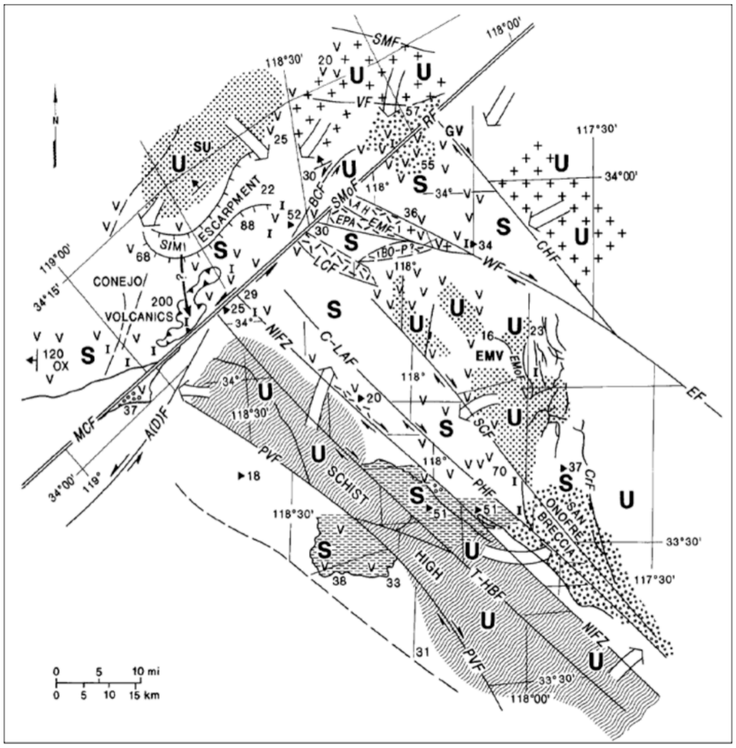


Figure 6. Middle Miocene (~14 Ma) reconstruction for the Los Angeles region. Patterns show uplifted blocks (U) and S = postulated areas of subsidence. Open arrows show inferred directions of sediment transport. Model of Wright (1991).

Stratigraphic and structural setting of the study area:

The Malibu Coast Fault is the westward extension of the Santa Monica Fault that defines the boundary between the northwestern block and the central and southwestern blocks of the Los Angeles basin. The Malibu Coast fault lies just 1-2 km north of the Paradise Cove-Point Dume study area and defines one of the most important tectono-stratigraphic boundaries in the region. North of the fault, the middle to upper Miocene sediments (Mohnian stage) are designated as the Modelo Formation, whereas south of the fault the sediments are considered the Monterey Formation (Yerkes et al., 1979). Both of these lithostratigraphic units contain fine grained siliceous and argillaceous lithologies, but sections with an abundance of sandstone are generally associated with the Modelo Formation. The Point Dume-Paradise Cove area is located on the southern region of this stratigraphic divide. The basement rock is the Catalina Schist that is overlain by the Miocene Trancas Formation or San Onofre Breccia, Zuma Volcanics and the Monterey Shale (Yerkes et. al, 1979). This succession has been penetrated by a number of onshore and offshore wells, with the closest being the Malibu #1 and Marblehead #1 wells (Figure 8).

Field Guide

Point Mugu *(* visited only if time permits after the Malibu succession)*
Formations: Vaqueros, Topanga
Age: Saucesian
Stop PM-1: Point Mugu parking lot (west of Mugu Rock)**,** then walk to east side.
Latitude/Longitude: 34.088480 N, 119.063524 W
Discussion:

Our first field trip location gives insight into the origin of the Los-Angeles and Ventura basins. We will view some of the pre-rift sedimentary deposits that were ravaged by middle Miocene extension and rifting. The lower to middle Miocene sedimentary rocks here have been variously assigned to the Vaqueros (Truex and Hall, 1969; Yerkes and Campbell, 1979) or Lower Topanga (Durrell, 1954; Dibblee and Ehrenspeck, 1993) formations. They contain Saucesian to Relizian stage benthic foraminifera (Turner and Campbell, 1979; Dibblee and Ehrenspeck, 1993). Strata of the older stage are usually associated with the Vaqueros Formation, but many of the rocks in this area display lithologic feature more characteristic of facies of the Topanga Formation.

Vaqueros and Topanga marine deposits

The light gray "Vaqueros" sandstone at Point Mugu is a medium to coarse-grained, calcareous feldspathic arenite with either thin planar stratification or low-angle cross-stratification in thick beds. The friable grains and calcareous cement give it a pitted or pocketed weathering surface. The dark siltstone or mudstone-dominated facies contains thin to medium-bedded light gray sandstone. These beds are planar-tabular with sharp tops and bases, some are texturally graded and are likely deeper-water turbidites. The mudstone/siltstone is black to dark gray brown, micaceous and remarkably hard and slatey for argillaceous Miocene sedimentary deposits. This high degree of lithification may reflect alteration by the abundant cross-cutting dikes and the associated high heat flow in the region related to emplacement of the overlying Conejo Volcanics. Note that some light-colored dikes are actually injectites/sandstone dikes.

These muddy marine sandstones and siltstones in the western part of the Santa Monica Mountains, reflect the east-to-west transition from largely nonmarine in the east to increasingly offshore marine facies during later early Miocene stages of deposition.

Basin rifting, volcanism and igneous intrusion

Pervasive and irregular dikes and sills of varied composition cross-cut the sedimentary strata at different orientations. These are middle to late Miocene diabase and mafic hypabyssal intrusive rocks of gabbroic and dioritic composition that fed the Conejo Volcanics during basin rifting. Eight K/Ar radiometric dates of the Conejo Volcanics were made by Turner (1968, 1970) and Turner and Campbell (1978), then corrected by Stanley et al. (2000) to range from approximately 14.4 to 16.6 Ma. Similar intrusive and extrusive igneous rock rim and underlie the Los Angeles basin from the San Joaquin Hills to the El Modeno and Glendora Volcanics. Note evidence for post-intrusion bedding-parallel slip along sedimentary strata shown by laterally offset sections of dikes.

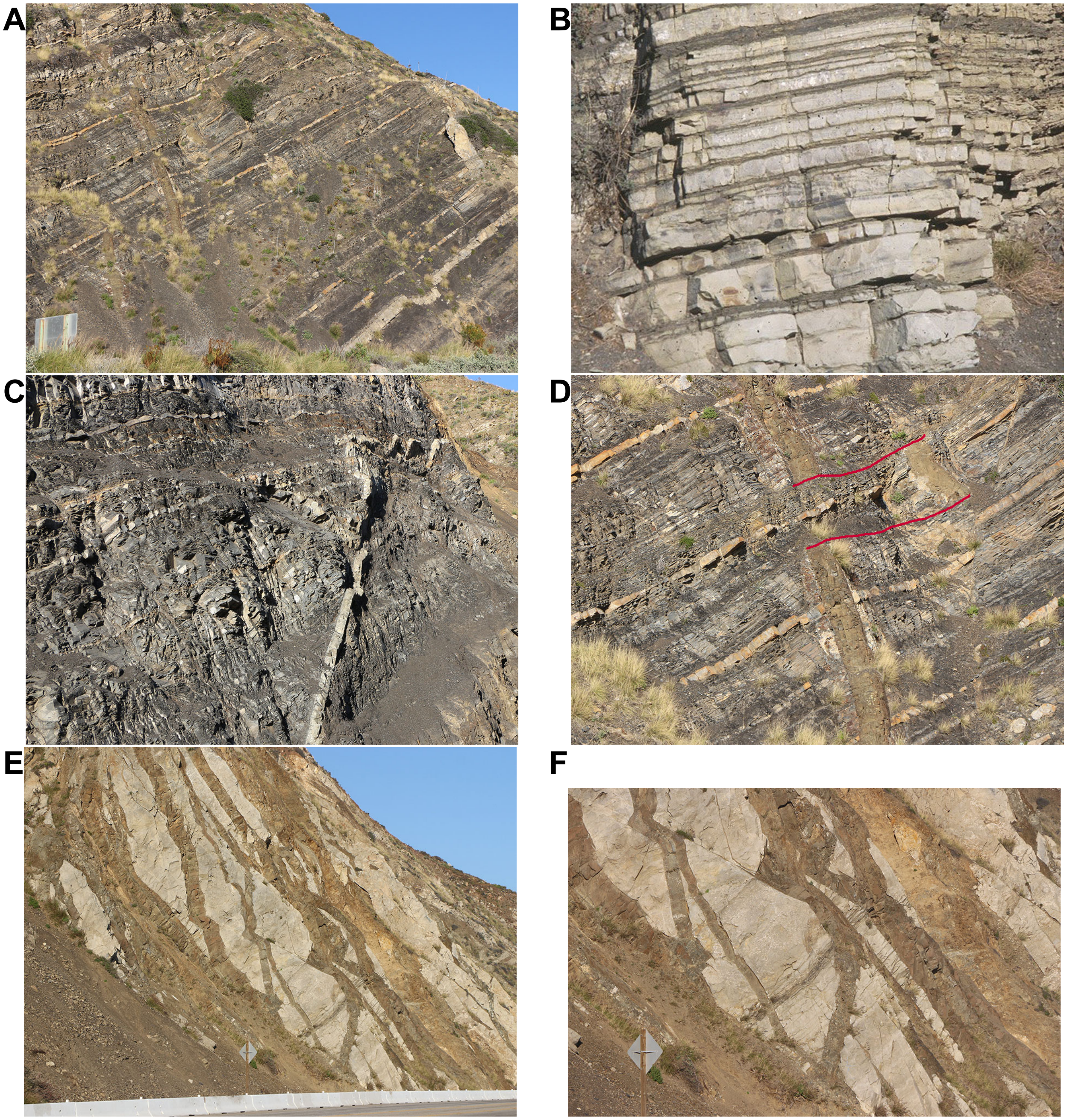


Figure 7. Point Mugu. A-D. from parking lot west of Mugu Rock. E-F from east side.
A. Predominantly fine-grained clay shale to siltstone facies of the Saucesian Vaqueros/Topanga formation with thin sandstone turbidites. B. Sand-rich set of turbidite beds displaying fining and thinning-upwards stacking pattern. C-D. Fine-grained facies cut by dikes. Note offset of section of weathered mafic dike along bedding. E-F. Sand-dominated facies cut by swarm of dioritic to gabbroic dikes.

Point Dume to Paradise Cove succession

Overview/Previous Work:

The Paradise Cove Stratigraphic sequence is a relatively unstudied exposure that appears to be a nearly complete succession of a portion of the Monterey Formation. Hoots (1930) describes a composite stratigraphic succession of the Modelo Formation in the eastern Santa Monica Mountains, some 10's of km from the Point Dume-Paradise Cove area. Yerkes and Campbell (1979) briefly describe the stratigraphic sequence in the area of Paradise Cove as being similar to that of the western Santa Monica Mountains but with enough key differences to separate it stratigraphically. The stratigraphic sequence begins with the Catalina Schist as basement material and is overlain by intercalated Zuma Volcanics, Trancas Formation followed by the Monterey Shale. The age of the section based on radiometric dating of the Zuma Volcanics is 15 +/- 1 Ma (Berry et al., 1976; King Stanley et al., 2000). Benthic foraminiferal data from the USGS/Chevron database indicate a middle to upper Miocene age (Mohnian Stage) for the entire section, between ~13.5 – 7.1 Ma. New diatom biostratigraphy data by Diane Winter (pers. comm, 2015) refine the age of the upper half of the section to D. hustedtii-D. lauta zone, subzone D (~9.2-9.9 Ma). Middle upper Miocene is also indicated by the presence of *Thalassionema schraderi*. The lower part of the section only roughly dated as middle to upper Miocene (upper Mohnian stage).

Well log data collected from the exploratory well Sovereign Oil Co. Malibu 1, confirmed the sequence of rocks as either Catalina Schist or San Onofre Breccia, Zuma Volcanics, Trancas Formation and the Monterey Formation. However, there is no detailed description of the lithology and members that make up the Monterey Shale in this area (Yerkes & Campbell, 1979). Lithologic notes or interpretation on a well log of Malibu #1 by King and Preston (geologists) indicate that San Onofre Breccia and volcanics were cored below the Monterey Formation section (Figure 8).

Stratigraphy

For her Masters thesis, Njuguna (2016) described and measured the lithostratigraphic succession from Point Dume to Paradise Cove in conjunction with acquiring a rich spectral gamma ray, thin-section petrography, XRD mineralogy and TOC dataset. Four major lithostratigraphic units are identified plus a volcanic unit at the base of the section (Figure 9). In vertical order, from the top as we will walk, they are:

Cherty Diatomite member: Cyclically interbedded massive and laminated diatomite alternating with thin-bedded and nodular opal-CT chert and cherty porcelanite.

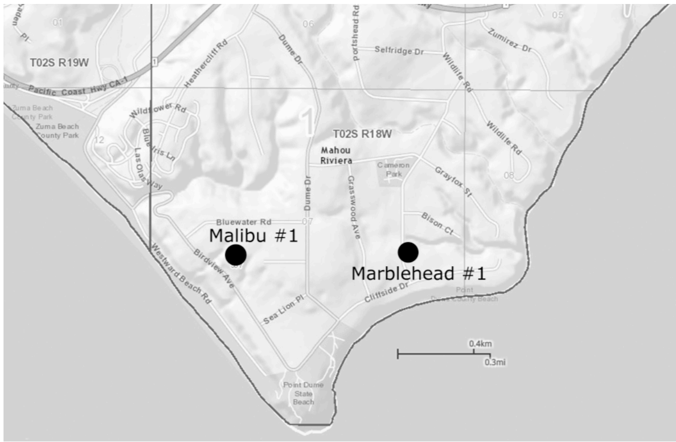
Mixed Clastics member: Thinly to thickly interbedded sandstone, diatomite and siliceous/calcareous mudstone with local intervals of intraformational folds and conglomerate.

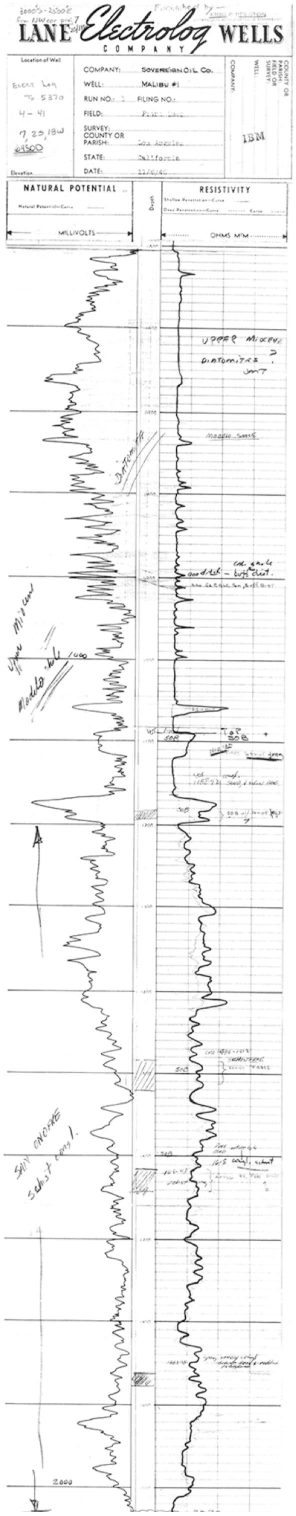
Porcelanite and Shale member: Thinly to thickly interbedded opal-CT porcelanite to cherty porcelanite and organic-rich, phosphatic to siliceous mudstone.

Dolomitic Phosphatic Shale member: Medium to thickly interbedded organic-rich phosphatic mudstone and dolostone. Minor opal-CT porcelanite or chert.

Zuma Volcanics: Basaltic and andesitic flows, breccias, pillow lavas, and aquagene tuffs.

Figure 8. Annotated well log from Malibu #1, drilled within a half kilometer of the middle part of the measured section from Point Dume to Paradise Cove. This well drilled ~1,100’ of Monterey Formation and logged the lower 500’, likely equivalent to the lower part of the measured section. The well also penetrated San Onofre Breccia, Las Trancas Formation and Zuma Volcanics. The former two are not encountered in the measured section. Map shows the location of Malibu #1 and Marblehead #1.





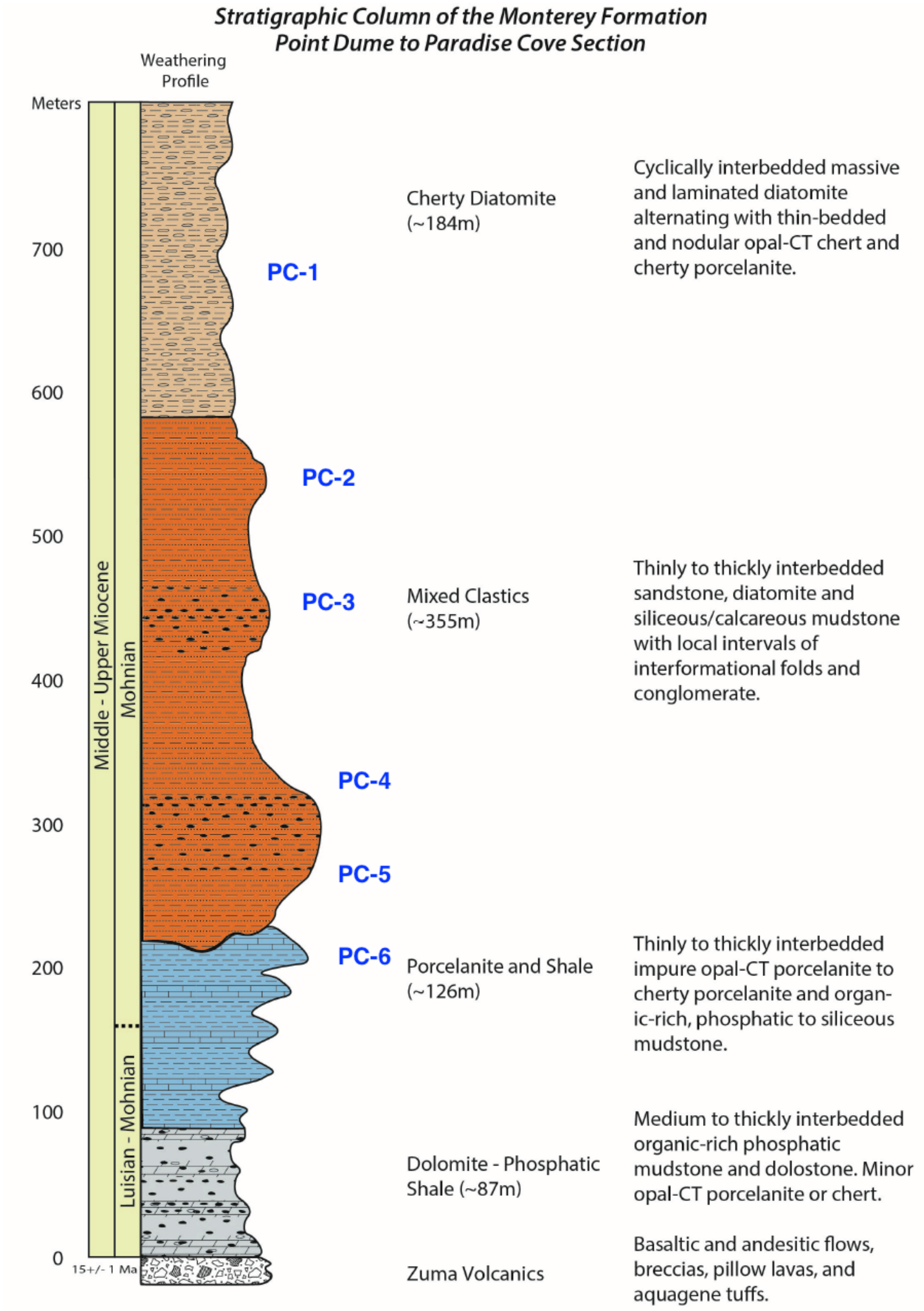


Figure 9. Stratigraphic column for the Point Dume to Paradise Cove section (Njuguna, 2016) showing the identified members and locations of field trip stops.

Because of the timing of today's tides (you know what waits for no man…or woman…), we will progress through the succession from top to bottom, from Paradise Cove to Point Dume (Figure 10). Due to tides and time, we will probably only reach Stop PC-4 to PC-6 before having to return to Paradise Cove. We start our down-section tour just south of the Paradise Cove fault, a mapped splay of the Malibu Coast-Anacapa Dume system. The fault is hidden in the canyon at Paradise Cove, but we can see the vertically-upturned Monterey strata in the footwall. This zone of deformation marks the top of the measurable section. Alternately, at another time, if you wish the progress through the section in proper stratigraphic order, you could start at Point Dume and work your way northeastward to end at Paradise Cove.

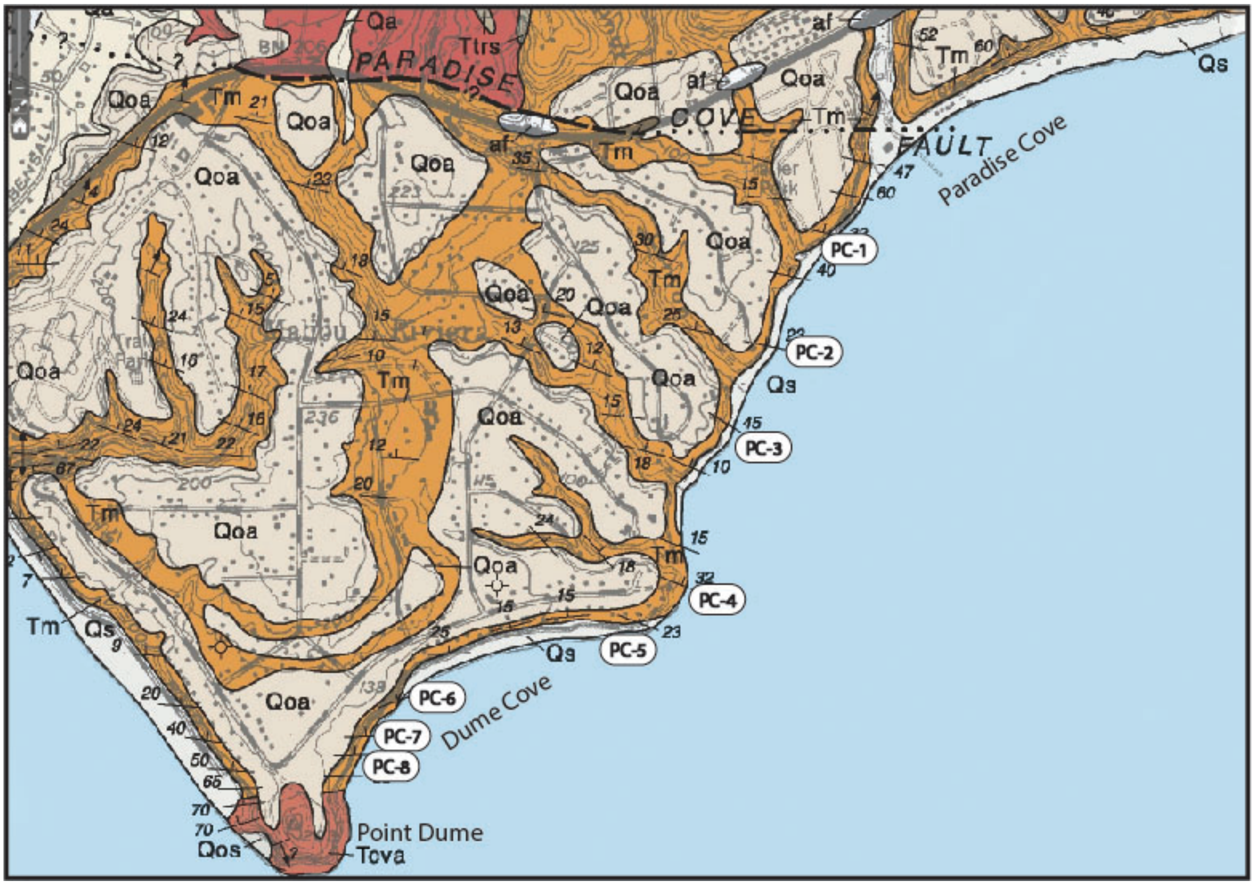


Figure 10. Field trip stops between Paradise Cove and Point Dume, keyed to stratigraphic column and Field Stop descriptions and photographs. Displayed on geologic map modified from Dibblee and Ehrenspeck (1993).

Stop PC-1
Formation: Monterey
Unit: Cherty Diatomite member
Age: Upper Mohnian
Latitude/Longitude: 34.017363 N, 118.789377 W

Discussion:

The uppermost lithostratigraphic unit near Paradise Cove consists primarily of diatomite of various fine detrital content with lesser amounts of thin-bedded and nodular opal-CT chert and cherty porcelanite (Figure 11).

This stop is a good place to examine the scales of stratigraphic cyclicity in this formation. There is the largest rhythmic alternation between 2-5 meters-thick massive units and more thinly bedded units that have preferentially developed chert and porcelanite. This is followed by the primary diatomite or porcelanite bedding on the scale of 2- to ~10 cm, distinguished by being either thinly laminated (mm-scale) and relatively pure white or consisting of homogeneous muddy or “speckled” beds. Speckled beds are a kind of fine-grained gravity flow deposits that are unique to diatomaceous sediment. The matrix is a completely disaggregated mixture of diatoms and mud, where as the “speckles’ are still-aggregated flakes of previously laminated pure diatomite that were ripped-up and incorporated by a passing erosive turbulent flow.

Cherty porcelanites form thin continuous beds in some of the thinly bedded diatomaceous units. These are composed of opal-CT phase diagenetic silica and are characteristically coated by orange-brown weathering precipitate on naturally fractured surfaces. Gray opal-CT phase chert forms continuous thin beds and lenticular nodules by pore-filling cementation of primary diatomite. Nodules preserve the original laminations without evidence of differential compaction, indicating that pore-filling silicification occurred at or after maximum burial depth. Some chert occurences are nonstratigraphic, reflecting late-stage silicification along small faults and fractures that cut bedding at high angles.

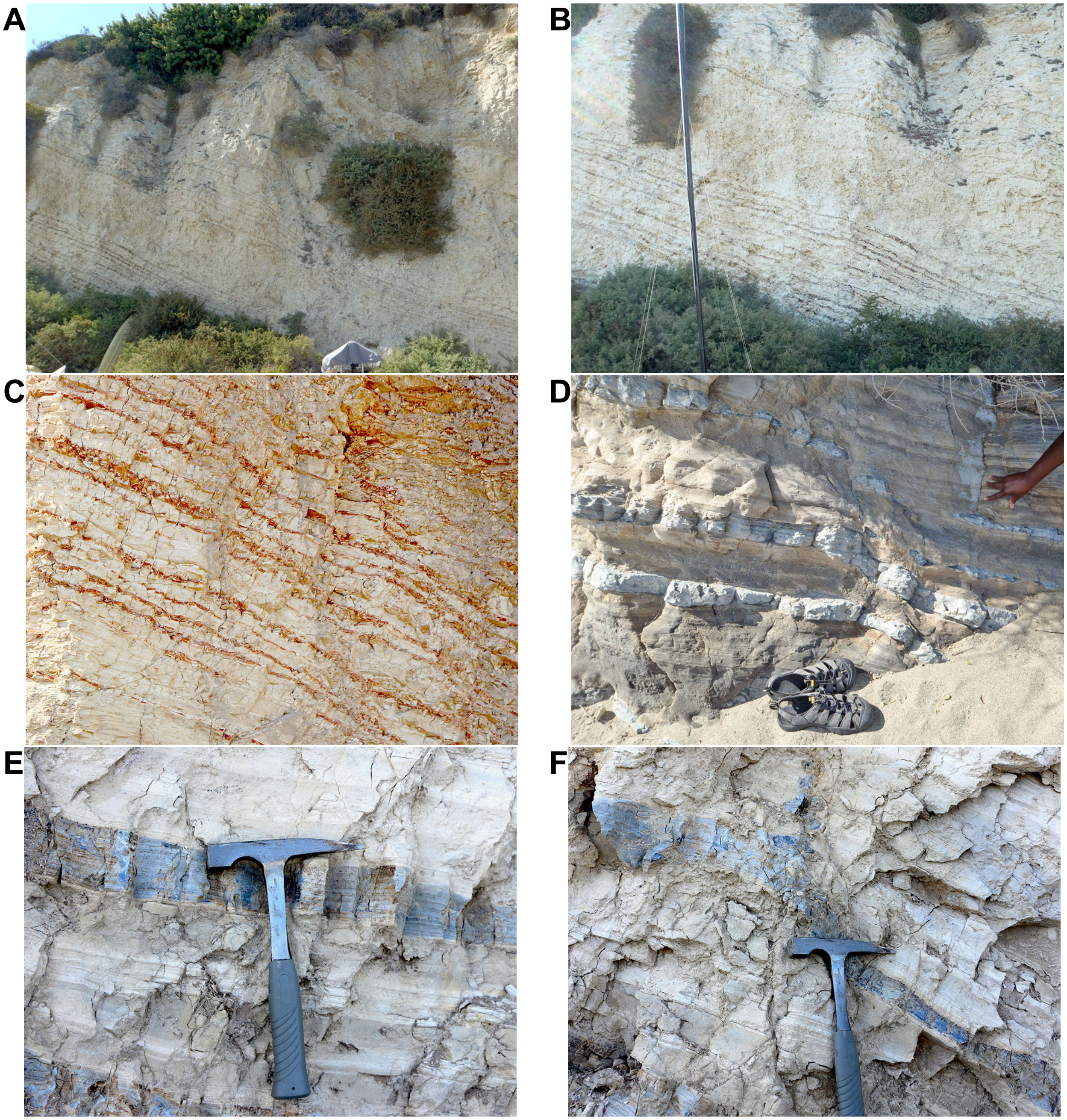


Figure 11. Field Stop PC-1. A-B. Thick bedding cyclicity between mostly massive diatomite and thin-bedded diatomite and opal-CT porcelanite or chert. C. Closer view of iron-stained continuous planar porcelanite beds. D. Opal-CT chert in muddy diatomite. E. Interbedded massive muddy diatomite, pure laminated diatomite, and opal-CT chert. F. Same lithologies as E, except for also showing chertification along small fracture zone that cuts bedding at a high angle.

Stop PC-2
Formation: Monterey
Unit: Mixed Clastics member
Age: Upper Mohnian
Latitude/Longitude: 34.014968 N, 118.790884 W to 34.014140 N, 118.791703 W

Discussion:

This is the upper portion of the Mixed Clastics lithostratigraphic member. This member consists of thinly to thickly interbedded sandstone, diatomite and siliceous or calcareous mudstone with minor conglomerate (Figure 12). Intraformational folds, microfaults, sedimentary breccias and the occurrence of scoured contacts and lenticular beds indiate downslope transport across an unstable slope. This stop spans ~50m stretch of cliff exposure.

This location presents the uppermost thick sandstone bed in the member. The coarse-grained, almost 2-meter-thick bed contains broken and transported mudstone slabs. Most of the sandstone is friable, porous and apparently quite permeable, as it is highly stained brightly orange by present-day groundwater flow out to the cliff face. However, large calcareous concretions are well preserved in their unweathered state and show *thalassinoides* trace fossils.

Just downsection from the top of the unit, we encounter the characteristic three-part lithofacies of the member – thinly interbedded sandstone, diatomite and mudstone. The sandstone can be planar bedded or show an undulating to lenticular geometry. It is generally well-sorted, medium-grained and displays cross-lamination. Some beds are graded and others display spectacular flame structures at their bases. The diatomite is typically finely laminated, but not always, and the diatomaceous or siliceous mudstone is generally massive. Some of the muddy layers are speckled beds containing pure diatomaceous flakes.

Further downsection in this interval, the planar-bedded strata become intercalated with numerous isoclinal intraformational folds or slumped beds. Some of the deformed layers have been broken up into synsedimentary breccias.

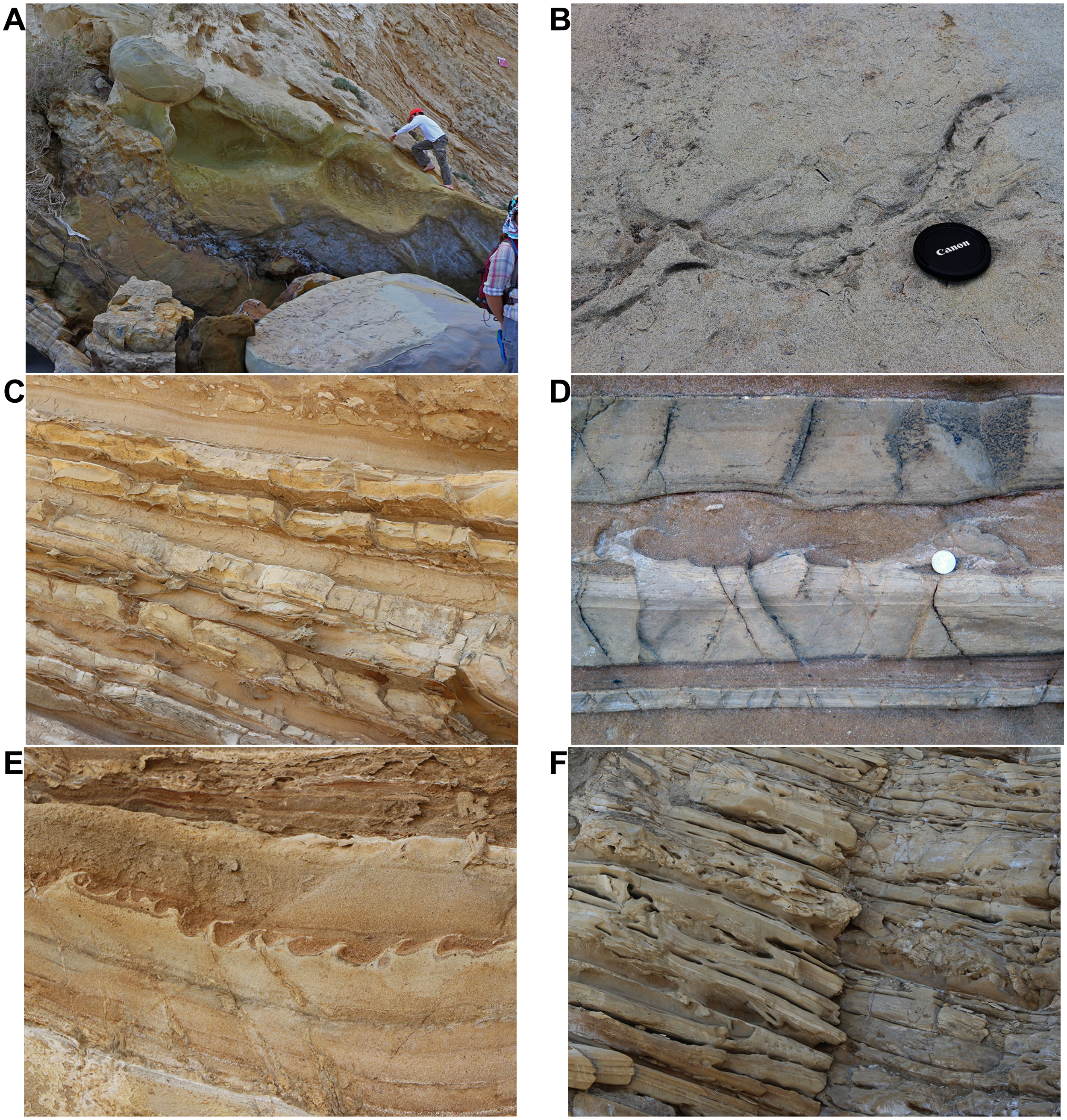


Figure 12. Field Stop PC-2. Features of the upper Mixed Clastics member. A. 2-meter-thick bed contains broken and transported mudstone slabs. B. Thallasinoides trace fossil preserved in cemented concretion. C. Thinly interbedded sandstone, diatomite and diatomaceous mudstone. Note recessive weather of friable sandstone. D-E. Flame structures formed at base of sandstone bed from underlying laminated diatomite. F. Isoclinal intraformational folds (slumps) displayed by more resistant diatomaceous lithologies, with sandstone weathering into recessive layers.

Stop PC-3
Formation: Monterey
Unit: Mixed Clastics member
Age: Upper Mohnian
Latitude/Longitude: 34.012191 N, 118.792694 W

Discussion:

This stop is located near the middle of the Mixed Clastics member. Here, too, we find the characteristic three-part lithofacies with thinly interbedded sandstone, diatomite and mudstone(Figure 14). The dark sandstone beds at the resistant prominence are cemented with dolomite or calcite. They mostly form flat-bottomed, ripple-topped strata 3-4 cm high, with low-angle trough cross-lamination. Ripple cross-lamination indicates that paleocurrents were from the east or southeast during the late Miocene (Figure 13). What was the source of these rippled beds? We think that they are most likely overbank spill from the westward bifurcating channel of the Tarzana Fan that would have run south of this location.

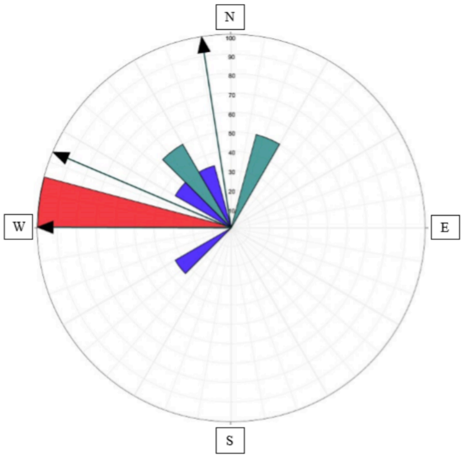


Figure 13. Ripple cross-lamination-derived paleocurrent data, corrected for rotation and bedding orientation from 3 beds in the Mixed Clastics member (Njuguna, 2016).

Mudstone in this interval is calcareous as well as siliceous, and some are dolomitic. Abundant visible benthic foraminifera indicate an upper Mohnian stage for this interval. Again, note the alternation between massive siliceous mudstone, laminated siliceous/diatomaceous mudstone and sandstone.

This interval contains vein structures or intrastratal microfaulted zones (IMZ). These are bed-confined, near-vertical structures found in diatomaceous deposits around the Pacific Rim, that form by gravitational extension on a slope. Their orientations are synsedimentary indicators of the prevailing shallow stress field (downslope gravitational pull). So, they may be useful to map the direction of the paleoslope.

As we continue to walk downsection, we will start to see thicker, laterally continuous, planar bedded sandstone deposits. Surface weathering and discoloration of some of these gives the impression of lenticularity that may reflect small channelization.

Various degrees of transport are shown by rounding of diatomaceous mudrock rip-up clasts involved in downslope slides or slumps. Some clasts are still quite angular, in spite of their softness and porosity. Others have become deformed or well rounded.

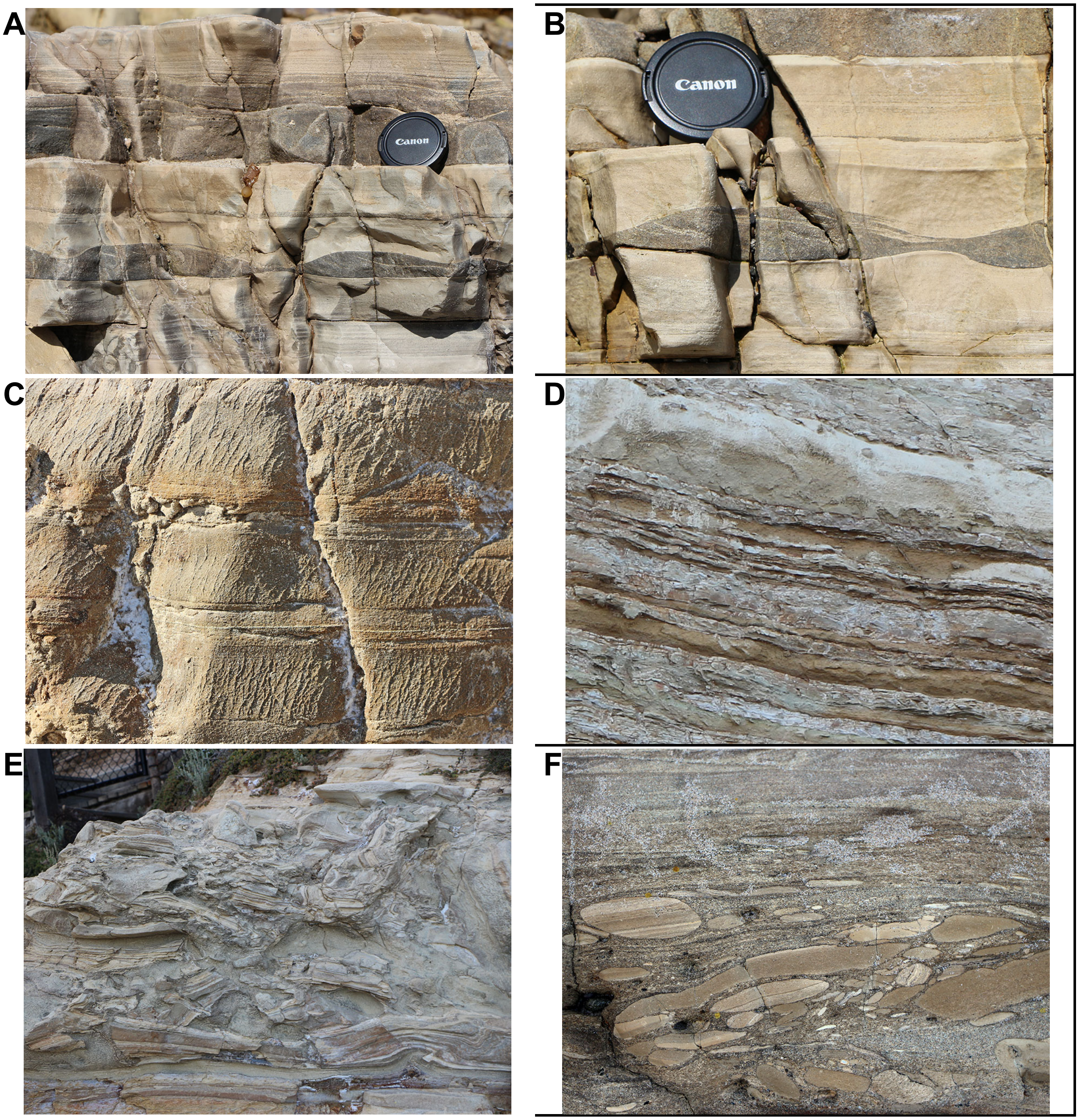


Figure 14. Field Stop PC-3. Features of the middle Mixed Clastics member. A-B. Undulatiing and lenticular, dolomite-cemented sandstone beds displaying ripple cross-lamination interbedded with massive or laminated diatomite. C. Intrastratal Microfaulted Zones (IMZ) with veins weathering out in positive relief. D. Extensive planar sandstone beds 10's of centimeters thick. E. Slumped and broken, angular diatomite slabs. F. Rounded intraformational clasts of diatomite and diatomaceous mudstone.

Stop PC-4
Formation: Monterey
Unit: Mixed Clastics member
Age: Mohnian
Latitude/Longitude: 34.008193 N, 118.793775 W to 34.007934 N, 118.794104 W

Discussion:

This stop is in the lower portion of the Mixed Clastics member and underlies the thick stratigraphic interval characterized by the thinly interbedded, three-part facies of diatomite, mudstone and sandstone. This lower stratigraphic interval records a markedly higher energy of deposition and downslope transport, likely related to a phase of increased tectonism.

This interval is distinguished by the presence of both intraformational and extraformational conglomerates (Figure 15). Medium to thick-bedded sandstones contain rip-up clasts of siliceous mudrocks. A 4-5-meter thick, tabular olistostrome of broken and contorted intraformational siliceous mudrock clasts is sharply bounded above and below by planar bedding contacts. In contrast, meter-thick, lenticular to tabular extraformational conglomerates contain exotic blueschist clasts and have scoured or loaded bases. These energetic, largely mass-transport deposits are interbedded with mudstone, dolostone and finer sandstone. Some of these fine-grained deposits have slumped into highly contorted intraformational folds. The co-occurrence of the high-energy facies with dolostone and mudstone suggest episodic gravitational mass-movement alternating with intervals of greatly condensed sedimentation in a submarine slope setting.

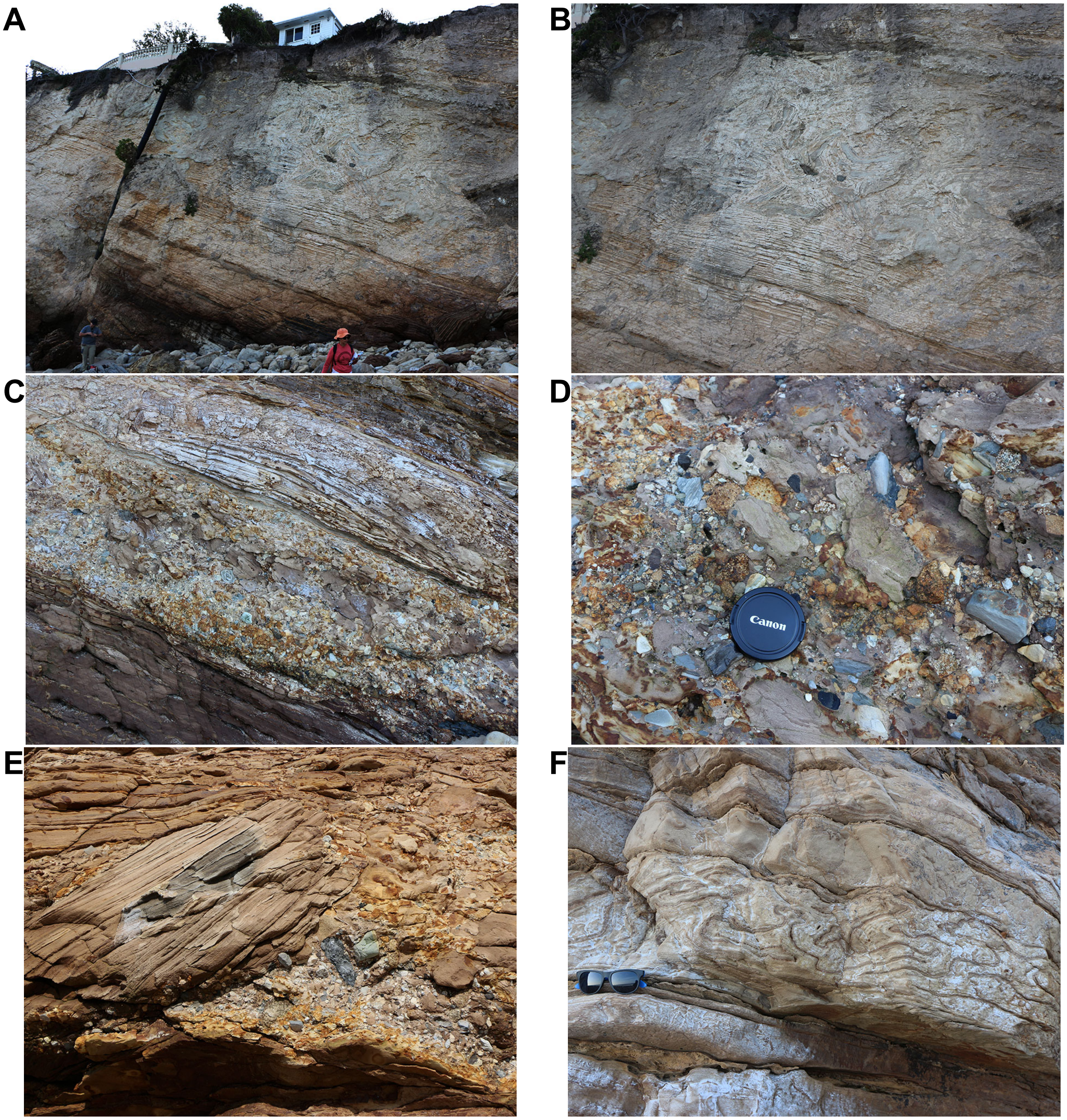


Figure 15. Field Stop PC-4. Features of the lower Mixed Clastics member. A-B. 5-meter-thick tabular olistostrome body containing chaotically organized and deformed blocks of thinly interbedded intraformational diatomaceous lithologies. C. Meter-thick extraformational conglomerate containing abundant blueschist clasts typical of the Catalina Schist and San Onofre Breccia. D. Close-up of C. E. Large dolomitic block transported along in sandy conglomerate. F. Enterolithic folding in slumped bed.

Stop PC-5
Formation: Monterey
Unit: Mixed Clastics member; Muddy Porcelanite member
Age: Mohnian
Latitude/Longitude: 34.007038 N, 118.795447 W to 34.006857 N, 118.798561 W

Discussion:

This stop is from the basal portion of the Mixed Clastics member down into the Muddy Porcelanite member. It stretches along nearly 200 meters of cliff face and beach. The lithofacies are similar to that seen in most of the member – thinly interbedded siliceous fine-grained rocks and sandstone, only now most of the diatomite has been diagenetically altered to opal-CT porcelanite and sandstone beds and lenses are less common. Some of the mudstone is less silty and more clay-rich and now contains a few phosphatic nodules and laminations, albeit as a very minor component. The association of these features – less sandy, more clay and some phosphate – suggest a slower sedimentation rate before the influx of coarse clastics observed in the previous (stratigraphically overlying) stop. However, the main features to observe in this interval are primarily tectonic and synsedimentary structural features (Figure 15).

This stratigraphic interval contains the most abundant occurrences of vein structures or intrastratal microfaulted zones (IMZ). Recall that these are chiefly bed-confined, sediment-filled tension gashes or microfaults form by gravitational extension on a slope. They are only reported to occur in diatomaceous deposits. See Grimm & Orange (1997) for an excellent paper on these features. The veins are filled with a dark, finely comminuted sediment that has lower porosity, lower permeability and greater compressive strength than the host strata. These can influence the orientation and continuity of later tectonic fractures, but they are a distinct feature from similar-looking bed-confined tectonic fracture sets.

Down to this location, we have primarily been walking southward from Paradise Cove, almost perpendicular to the east-west trend of the Malibu Coast and Anacapa-Dume faults. But at this stop, due to the wave-resistance of the conglomerates and dolomites we just passed, the coastline turns almost due east-west for several hundred meters. This provides the opportunity to observe the exposures in a new structural orientation in which we are viewing parallel to the principal N-S compressive stress, so the cliff face shows perpendicular outcrop-parallel extension. Note that brittle lithologies (opal-CT porcelanite, dolostone, and dolomite-cemented sandstone) are fractured with at least one well-developed opening-mode fracture sets. These run almost N-S, parallel to the direction of shortening across the Malibu Coast and Anacapa-Dume faults. Their opening accommodates E-W extension perpendicular to the shortening. Likewise, larger normal faults strike roughly N-S, also accommodating E-W extension. This relationship is well documented in papers by Gross at Arroyo Burro Beach (e.g., Gross et al., 1997) and Strickland (2013) at Montana de Oro State Park.

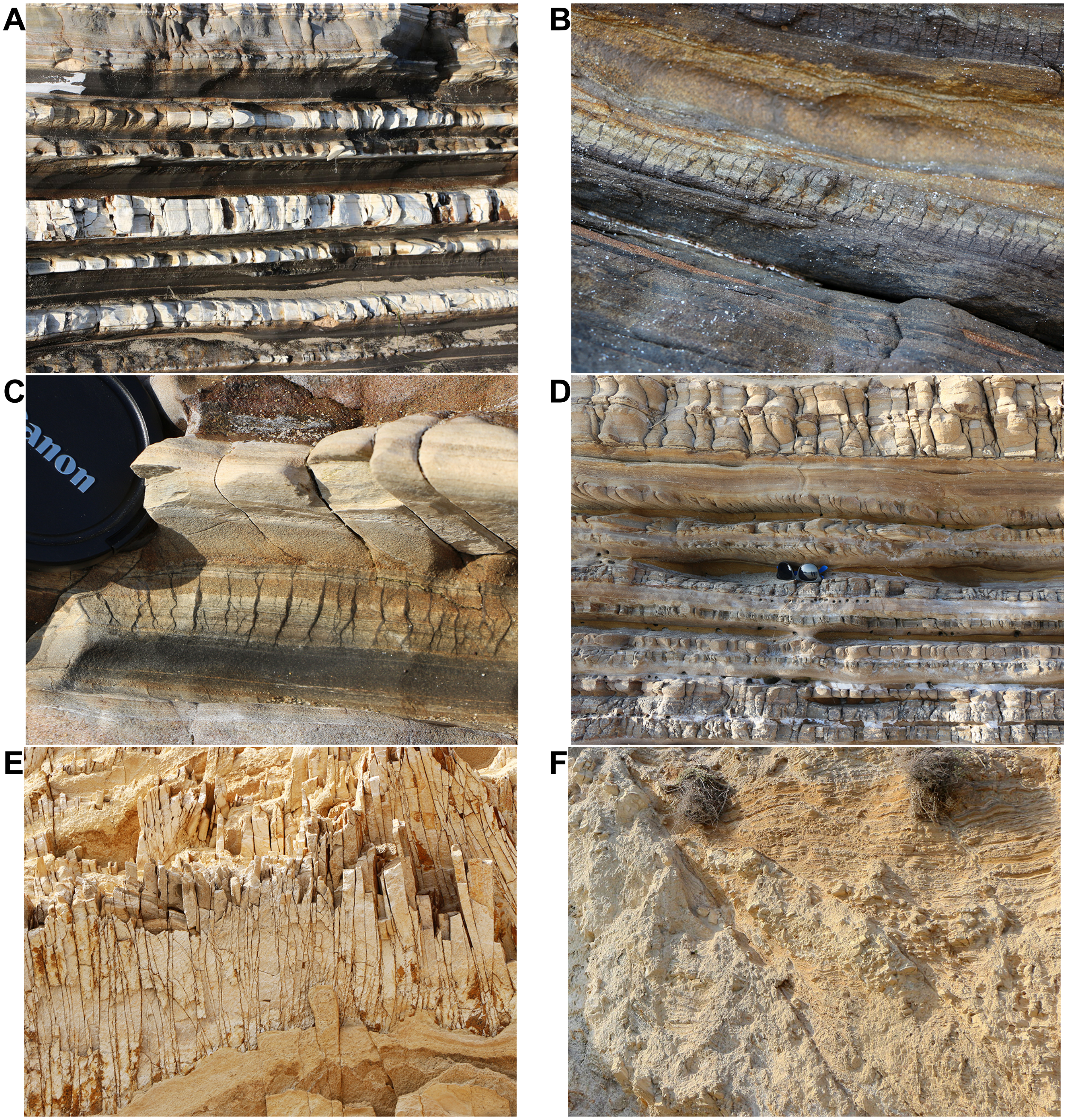


Figure 15. Field Stop PC-5 Features from the basal Mixed Clastics member where lithologies amore siliceous and generally in the opal-CT phase. A. Thinly interbedded opal-CT porcelanite and mudstone with only minor sand. B-C. Intrastratal Microfaulted Zones (IMZ) in lighter-colored, more siliceous layers are early post-depositional extensional features. In C., note different appearance and orientation of tectonic joint set in upper calcareous porcelanite bed. D. Note variation in fracture-spacing with bed thickness in the light-colored porcelanites. E. View of overhanging porcelanite bed surfaces from below, showing length and density of tectonic fractures. F. Larger, 5-10m long exposures of normal faults through cliff-face, indicating extension in the same direction as opening-mode fracture sets.

Stop PC-6
Formation: Monterey
Unit: Muddy Porcelanite member; Porcelanite and Shale member; and fault-repeated(?) Dolomitic Phosphatic Shale member
Age: Mohnian
Latitude/Longitude: 34.005554 N, 118.802773 W to 34.004826 N, 118. 803450 W

Discussion:

At this location, we encounter an amazing feature observable at many locations in California where the Monterey Formation or other organic-rich deposits crop out along unstable, steep slopes and cliffs. These black and shockingly pink rocks are "burnt shales" (Figure 16) are naturally, spontaneously combusted organic-rich rocks. Similar exposures are known throughout California, including the Palos Verdes Penninsula, Casmalia Hills, Orcutt, near Rincon Point, Santa Ynez Valley, and modern landfills. Recently, these have been investigated and apparently form by exothermic oxidation of pyrite and marcasite that trigger *in situ* shallow pyrolysis of organic-rich mudrocks and combustion of the generated hydrocarbons (Mariner et al., 2008; Boles et al., 2010). Temperatures as high as 800°C have been recorded just below the surface that triggered metamorphic recrystallization including the formation of hematite, cristobalite, illite, tridymite, cordierite, and calcic plagioclase (Eichhubl and Aydin, 2003; Boles et al., 2010). Rapid oxidation of the sulfides required for heat generation and build-up is apparently triggered by landslides or earth cracks that "instantaneously" provide oxygen to the reduced unstable mineral phases.

At this point in our walk, the coastline has turned back to the southwest and we encounter an intensely deformed zone of organic-rich and siliceous mudstone with some porcelanite and dolomite (Figure 16). The strata are tightly and complexly folded and faulted: fold axes trend generally east-west. The sense of vergence is to the south. The style of deformation indicates large amounts of layer-parallel slip during deformation because fold geometries rapidly change from concentric to kink to box folds along a single axial surface. This is the hanging wall of an unmapped reverse fault, parallel to the Malibu Coast fault, Paradise Cove fault and offshore Anacapa-Dume fault. Its scale is unknown.

The fault itself – as usual – is hidden(!) in a small, vegetated ravine, but is marked by vertically upturned beds in the footwall to the south. Slip is probably between fault-parallel, vertically-dipping beds. The beds in the footwall have been folded approximately 90° at a sharp bend from their regional dip of about 2° to the north. This fold geometry and scale is nearly identical to that seen at the top of the section where the Paradise Cove fault is mapped to intersect the sea cliffs.

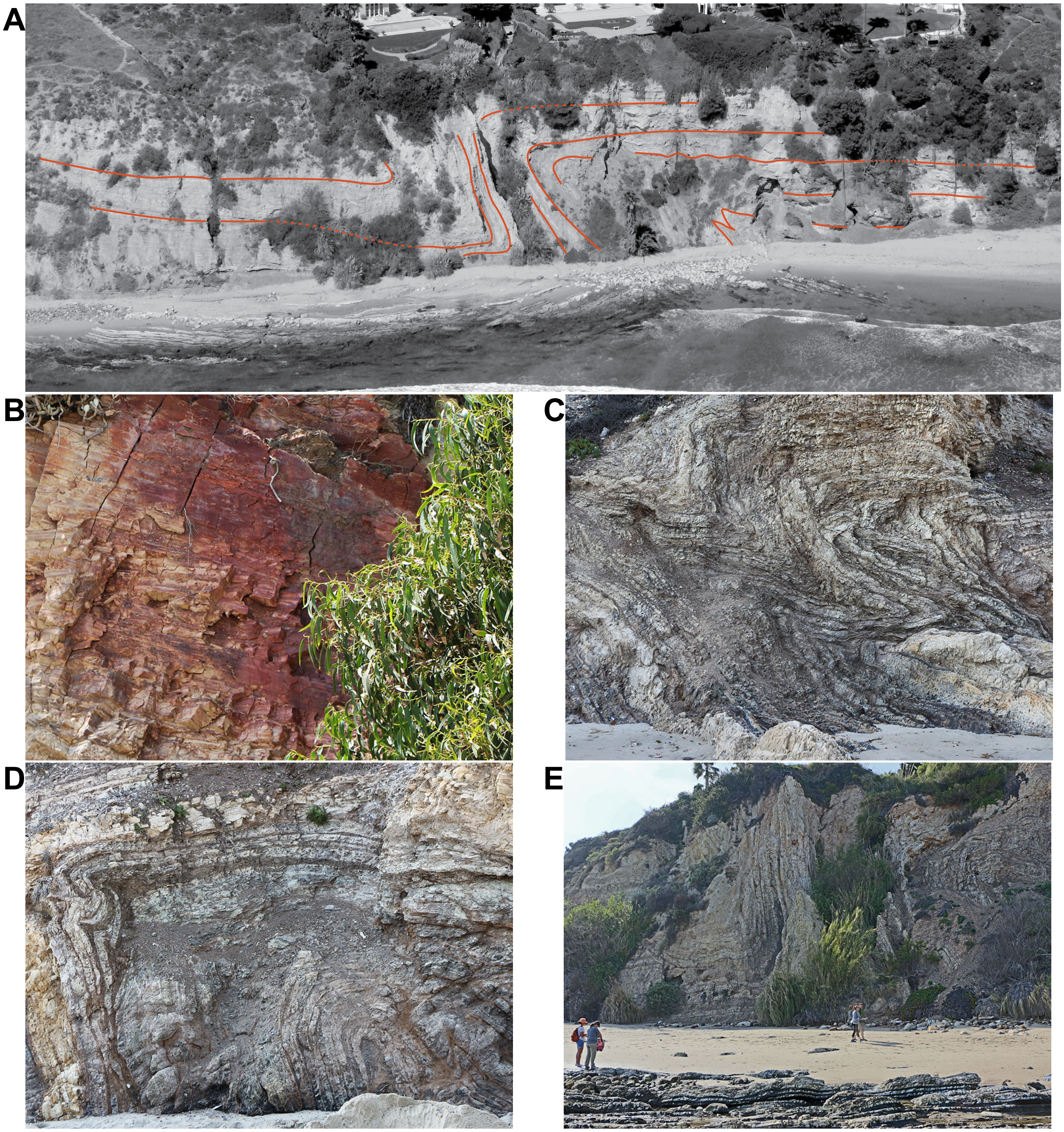


Figure 16. Field Stop PC-6. A. Annotated aerial photo (courtesy of Kenneth & Gabrielle Adelman) with black and pink “burnt shale” (B) to right of core of tight fold in right side of photo. Interpreted reverse fault in vegetated ravine. B. Close-up of pink “burnt shale”. C-D. Tight and complex foling in hanging-wall side of fault. E. View along strike of fault with vertically upturned beds in foot wall to left.

Organic-Matter and Phosphate-Rich Deposits of the Monterey Formation and Basal Sisquoc Formation, Haskells Beach, Santa Barbara Basin.

Richard Behl
California State University Long Beach

Introduction:

This stratigraphic succession has not yet been the focus of study of MARS Project studies. Most of the insights into this succession have been gleaned from a few visits plus the published findings of Hornafius (1994) and Laurent et al. (2015) and comparison with other sections that we have studied better. Nonetheless, this section is very interesting because it records deposition in an intermediate position between a starved setting with a greatly condensed stratigraphic section to the west (Naples Beach-Gaviota Beach) and the expanded succession at Arroyo Burro where organic-rich mudstone is intercalated with highly siliceous deposits that become diagenetically altered in into chert and porcelanite. We will walk westward from the public parking near the Bacara Resort through the middle and upper Monterey into the basal Sisquoc Formation (Figure 17).

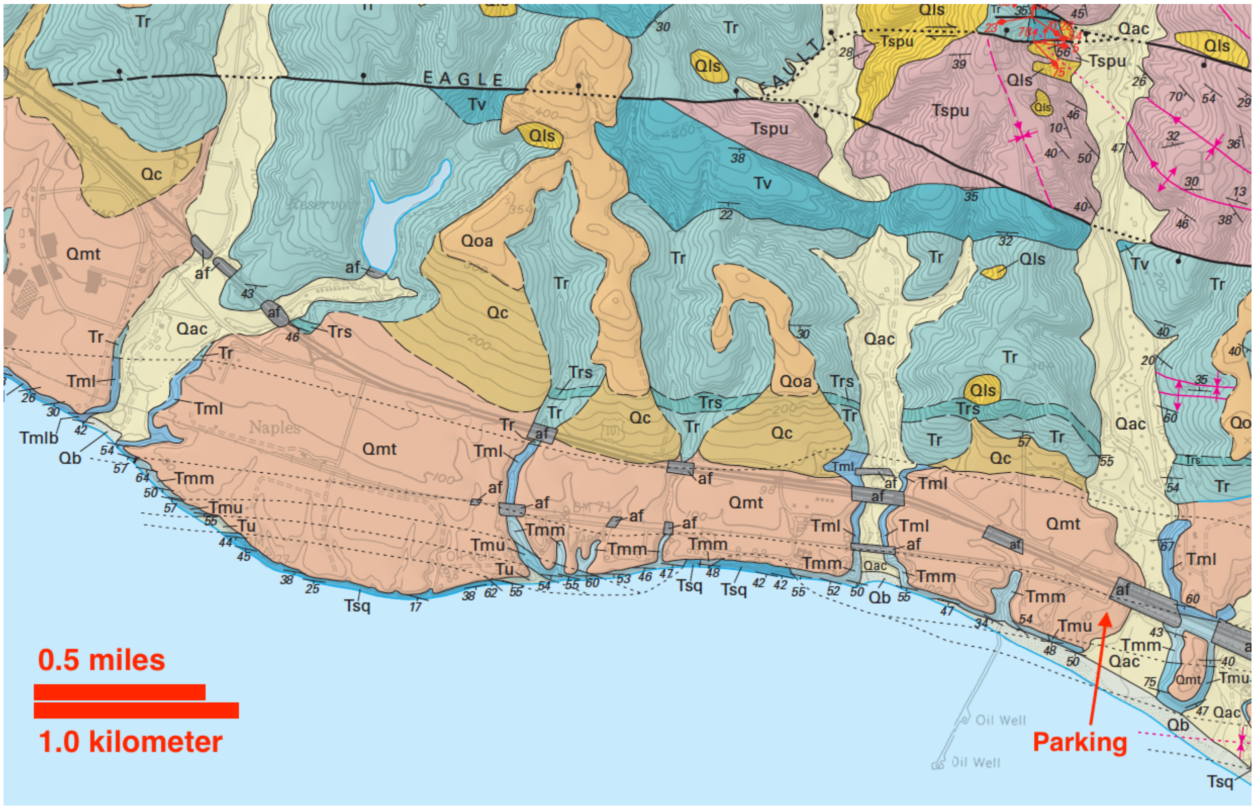


Figure 17. Geologic map of Haskells Beach and Naples Beach to the west (Minor et al., 2009). Access is from public beach access parking lot. Tsq = Sisquoc, Tmm = middle Monterey, Tmu = upper Monterey. Walk to beach, then west at low tides (< 3’ above datum).

Tectonic Setting of the Santa Barbara-Ventura Basin

The most striking structural feature of the Santa Barbara-Ventura Basin is its east-west structural orientation that lies across the predominant northwest-southeast structural grain of California (Cover page). This anomalous orientation is due to >90° clockwise tectonic rotation of the Western Transverse Range block from middle Miocene to Pliocene (Kamerling and Luyendyk, 1979; and many others). Prior to rotation, the block (including the Santa Barbara coast, Channel Islands and offshore areas) was parallel and adjacent to the continental margin of southern and Baja California. Cretaceous through lower Eocene marine forearc basin rocks were deposited along this margin. Subsequent Miocene extension and subsidence during rifting and block rotation formed numerous upper- to middle-bathyal basins along the margin, into which were deposited the Monterey Formation. A change to regional shortening (folding and faulting) across southern and central California during the Pliocene-Pleistocene epochs led to adjacent areas of great uplift and tectonic load subsidence, with corresponding high rates of localized erosion and sedimentation. This recent stage of deformation formed most of the structural traps key to the success of the regional oil fields and the deformation that you can observe at on this field trip.

Stratigraphy of the Santa Barbara-Ventura Basin

As a result of this complex tectonic history, a thick section of Cretaceous to Recent sediments over 15,000 m (50,000 ft) thick was deposited in the eastern part of the basin (Ventura Basin). About half of this sediment (6,500 m, 21,500 ft) was deposited since the middle Miocene and up to 5,500 meters (18,000 ft) during the Pliocene-Pleistocene alone, making this one of the thickest equivalent stratigraphic sections in the world. This recency of sedimentation, burial and tectonics creates a very young and still very active petroleum system. The Monterey was deposited from ~17 Ma to ~5.5 Ma in this region, although an unconformity at the top can locally truncate the formation, such as at Haskells Beach.

Depositional Setting

Although the Miocene Monterey Formation was deposited at middle to upper bathyal depths through its entire thickness in this region, there is variation in the depositional environment from banktop to slope to basin, with marked differences in composition and thickness in some of its members (Hornafius, 1990, 1994). The Luisian to lower Mohnian (upper Serravallian to Tortonian stages) phosphatic mudstone interval is extremely organic-rich. To the west, numerous phosphatic hardgrounds occur near the Luisian/Mohnian boundary) that correspond with a major depositional hiatus. The hardground interval suggests deposition, winnowing and phosphatization on a banktop during the late middle Miocene. This condensed interval is absent in coastal exposures from Haskells Beach eastward to Arroyo Burro Beach, and the interval expands and becomes first muddier, hen tricher in porcelanite and chert. This gradation represents the transition from banktop to slope to basin (Figure 18).

A general increase in detrital content at the top of the Monterey Formation into the overlying Sisquoc Formation corresponds with the increased tectonic contraction and adjacent uplift. Submarine canyon deposits that incise the Monterey Formation and are filled with Monterey chert cobble conglomerates or large blocks of Monterey lithologies within a matrix of Sisquoc mud. Phosphatic conglomerate beds with reworked Monterey clasts mark the stratigraphic contact at the base of the Sisquoc Formation.

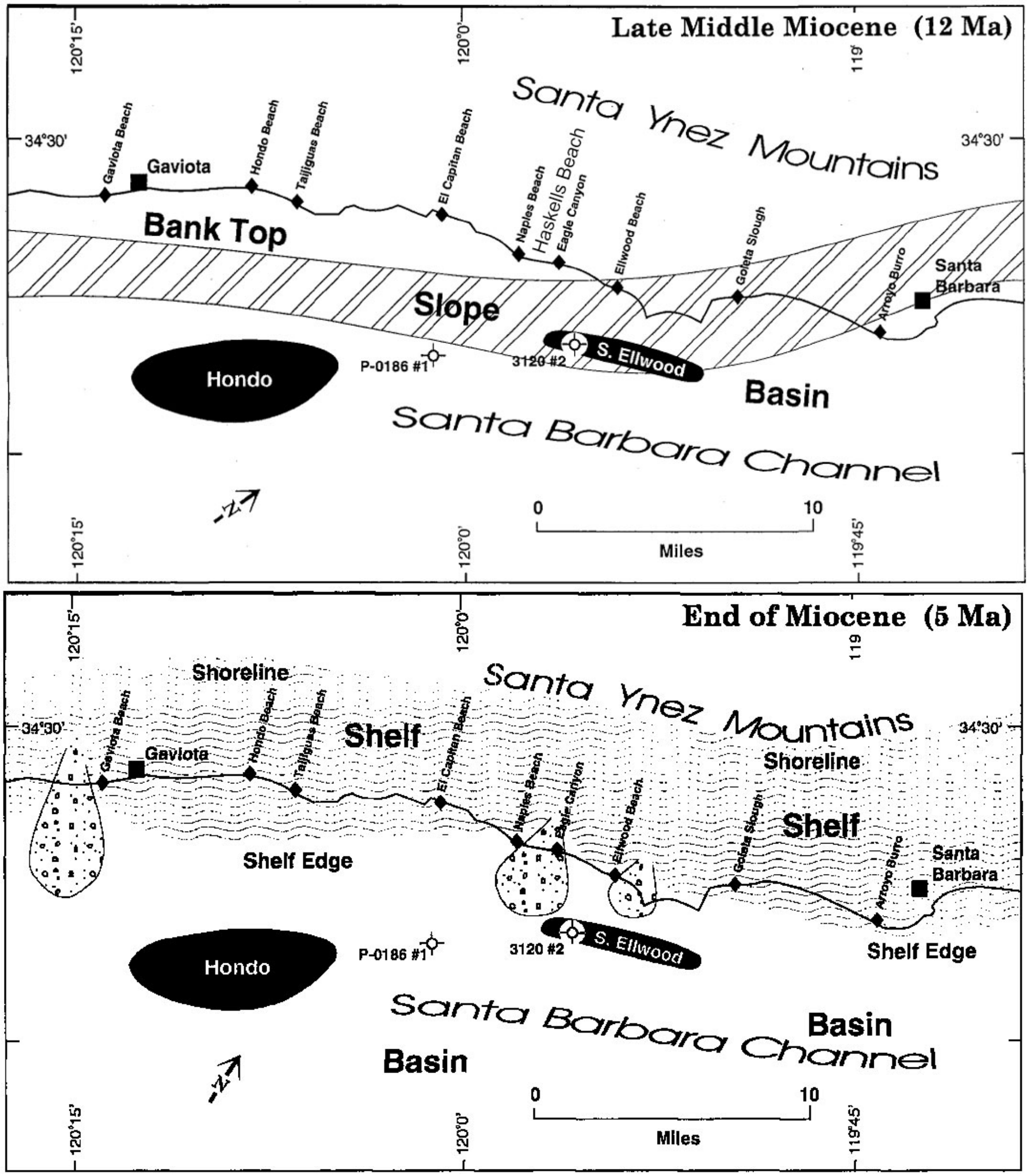


Figure 18. Paleogeographic map of a portion of the Santa Barbara coast during deposition of the Monterey Formation at Haskells Beach ~11-7 Ma) and the Sisquoc Formation (5.5-4 Ma). Modified from Hornafius (1994).

Stratigraphy

The Monterey Formation has been subdivided into members on the base of composition by a number of different workers. Isaacs' (1980, 1983) subdivision is most commonly used for this area (Figure 19), although it does not account for lateral gradations into more siliceous strata offshore or to the east (Figure 19). The Haskells Beach succession (Figure 20; Laurent et al., 2015) does not include much of the uppermost Clayey-Siliceous member that is lost in the truncating unconformity at the top of the formation. The youngest Monterey sediments here are > 7 Ma (Laurent et al., 2015), thus more than 1 Myr and greater than 100m of sediment was removed compared to other nearby locations.

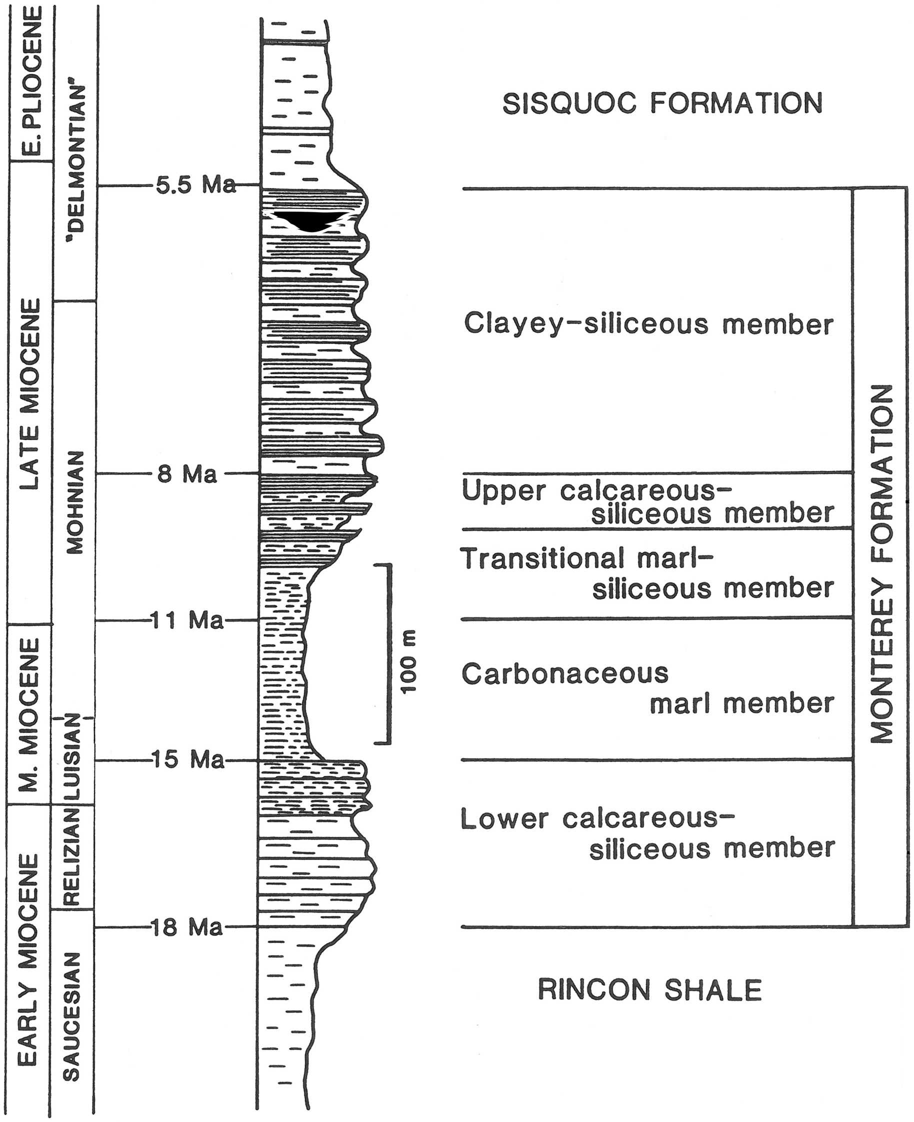


Figure 19. Lithostratigraphy of the Monterey Formation along the Santa Barbara coast west of Goleta (modified from Isaacs, 1980, 1983, etc.).

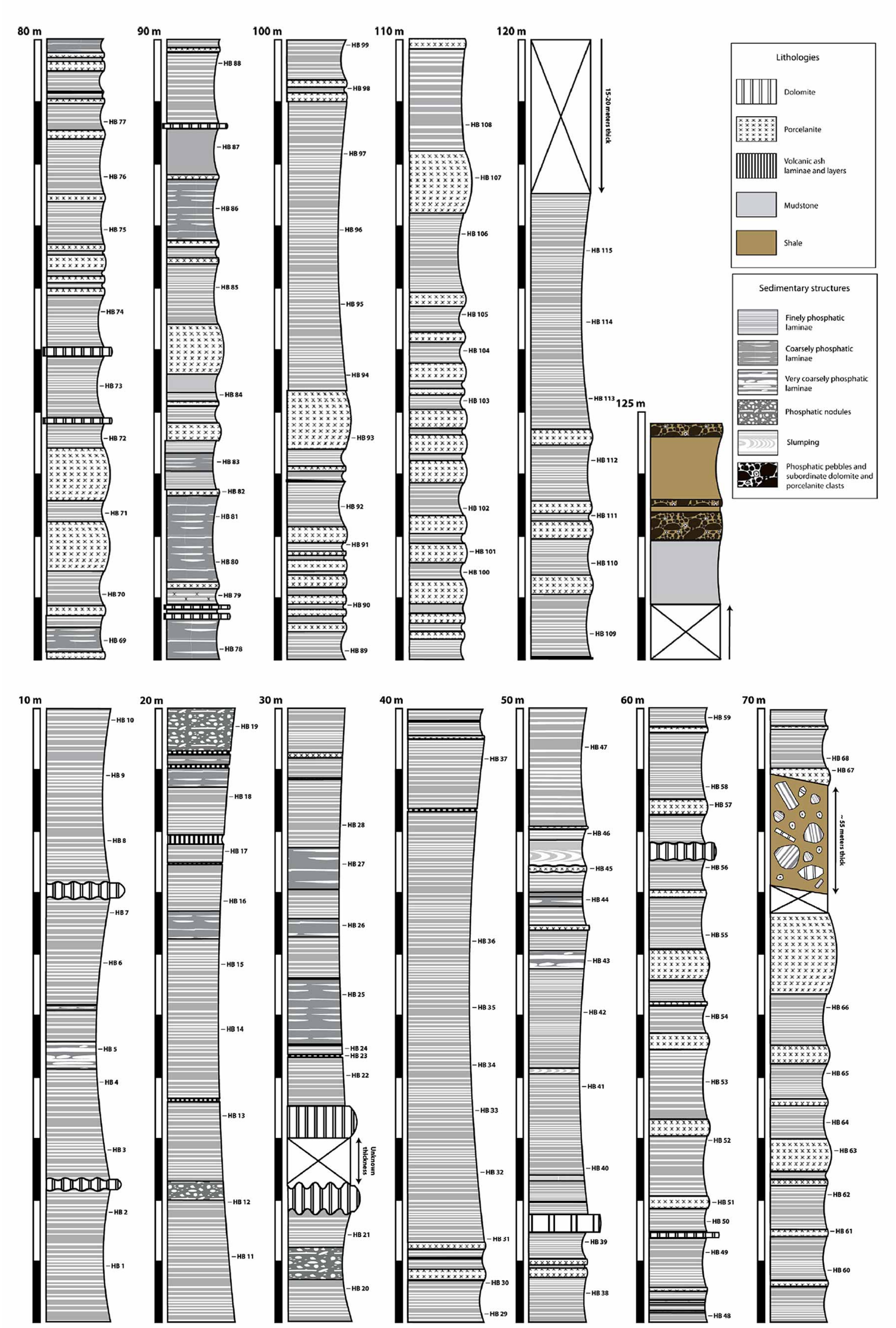


Figure 20. Detailed lithostratigraphic section in the upper part of the middle carbonaceous and phosphate-rich member and in the upper siliceous member of the Monterey Formation at Haskells Beach (Laurent et al., 2015).

Sedimentology

Haskells Beach exposure is unusual for the Monterey in that it is generally phosphatic and calcareous through most of the succession (Laurent et al., 2015; Figure 21). The mudstone becomes slightly more silty upsection, with increased quartz, feldspar and phyllosilicates. It contains no highly condensed interbedded phosphatic hardgrounds, but volcanic ash, dolomite and chert or porcelanite are infrequent rock types in the section (Figure 22).

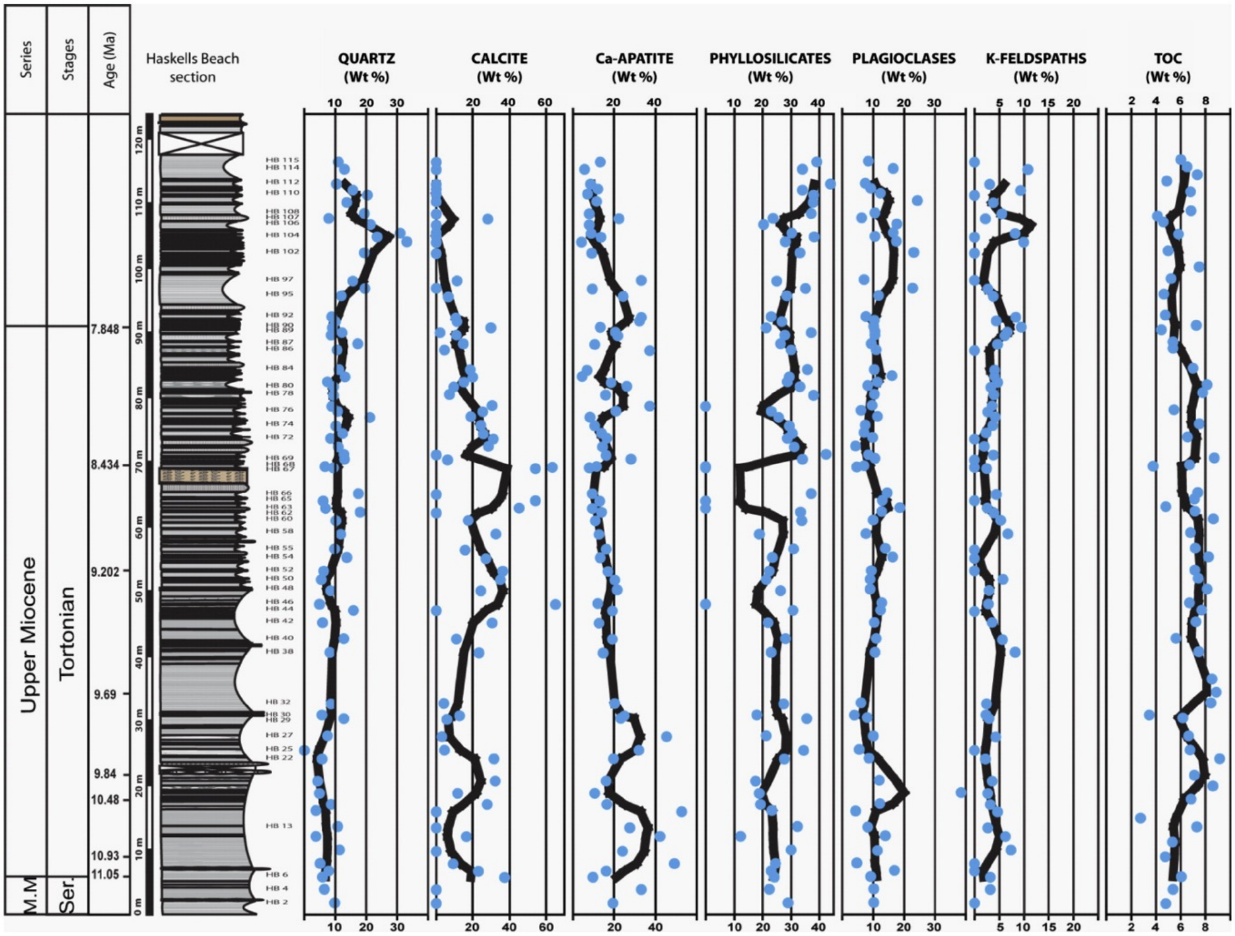


Figure 21. Mineralogic content and TOC variation through the succession at Haskells Beach. Age dates based on calcareous nannofossils (Laurent et al., 2015).

Slumps, stratal disconformities, erosive surfaces, reworked clasts and nodules, and aggregated phosphatic layers suggest that hydrodynamic conditions were important and likely variable, leading to frequent erosion and sediment reworking. Under these circumstances, organic-matter was predominantly delivered from upslope during gravity-flow events, which were followed by longer periods of low sediment accumulation and phosphogenesis of the uppermost sediment layers (Laurent et al., 2015).

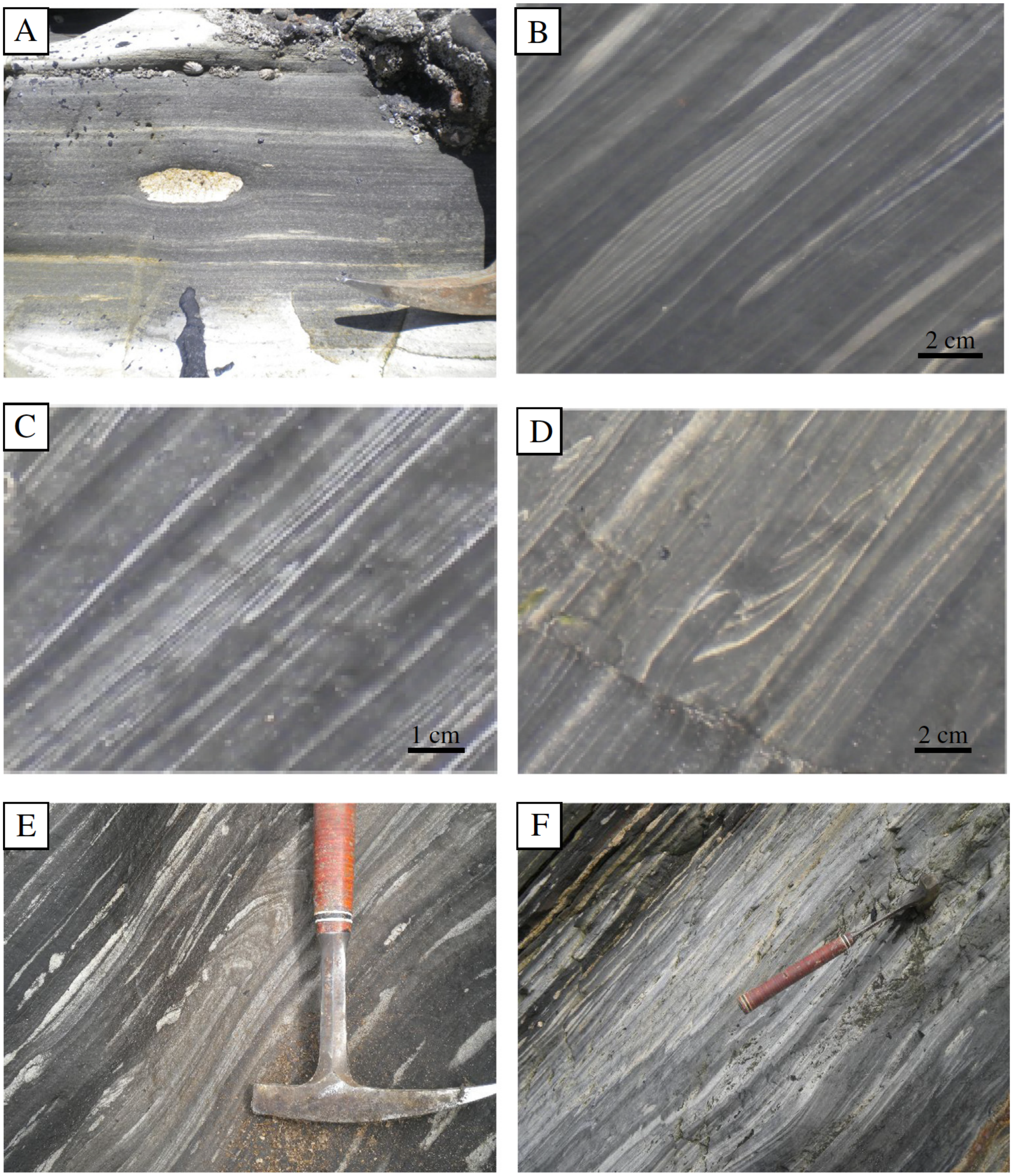


Figure 22. Sedimentary structures in phosphatic mudstone. A. Transported phosphatic nodule; B. obliquely bedded phosphatic laminae; C. discontinuous scoured laminae; D. erosive cut-off of inclined-bedded laminae; E. slumped interval affecting phosphatic laminae; F. centimeter-scale unidirectional synsedimentary faults; (Laurent et al., 2015).

The Sisquoc Formation is generallycomposed of silty diatomaceous mudstone and lies conformably above the Monterey Formation along most of the Santa Barbara coastline. At Haskells Beach, the basal Sisquoc fills a large canyon incised some 200-260 feet (60-80 meters) into the Monterey Formation. The channel is filled with large blocks of Monterey phosphatic calcareous shale, porcelanite, and dolomite in a matrix of Sisquoc mudstone (Hornafius, 1994).

Deformation

Being within the active Santa Barbara fold and thrust belt, the Haskells Beach outcrop is highly deformed. Large-scale folding under ~North-South shortening is associated with ~East-West extension. This extension is prominently displayed by North-South-oriented opening-mode fractures and veins in strong lithologies like chert, porcelanite and dolostone. However, in the mudstone-dominated section at Haskells Beach, North-South shortening and East-West extension is accommodated primarily by faulting (Figure 23).

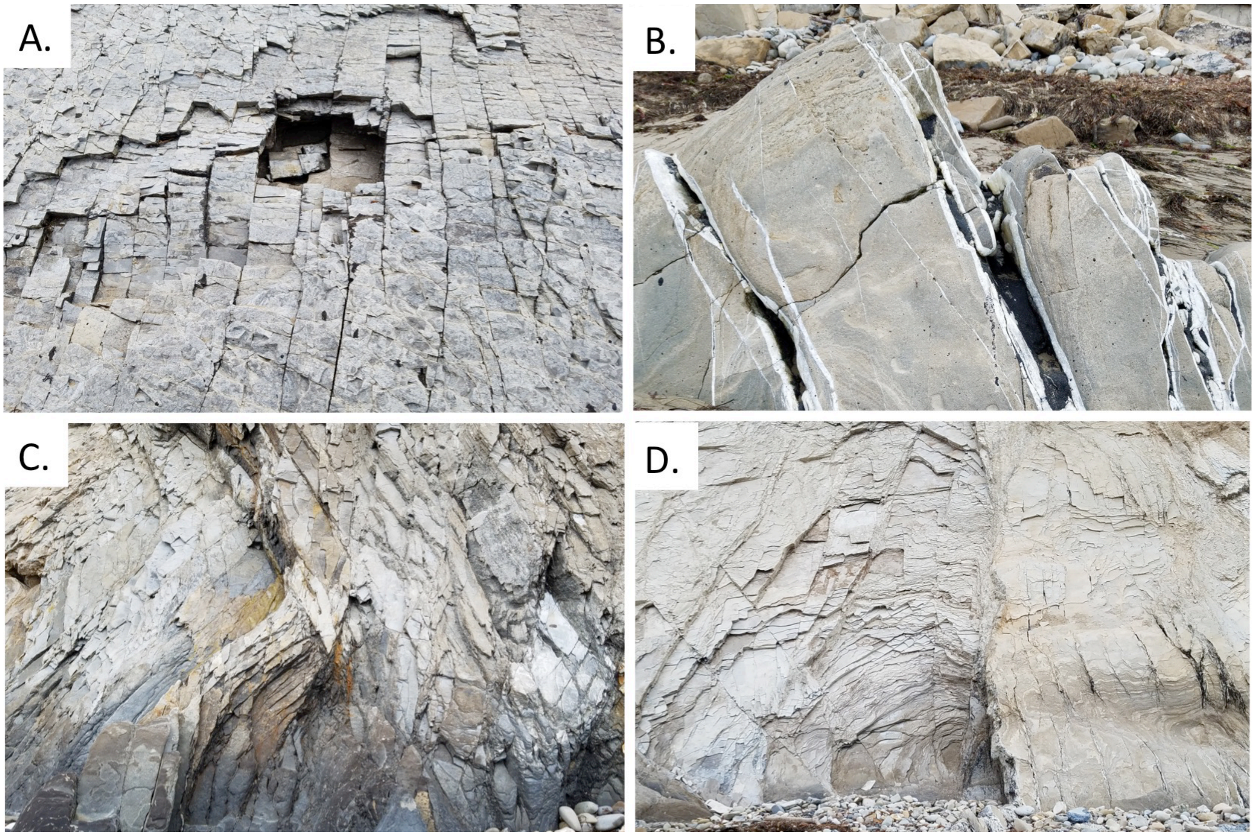


Figure 23. Different fracture styles controlled by lithology. A. opening mode fractures in chert oriented parallel to principal stress; B. opening mode fractures in dolostone bed, partially cemented by calcite, then filled with oil; C. Conjugate (Andersonian) shear fractures (faults) in mudstone; D. top view of bed surfaces separated by fault. Conjugate fracture set in mudstone to left, opening mode fracture set in dolostone bed to right.

Diagenesis/Maturation

Although silica is a minor component in most rocks in the Monterey Formation section, most is in the opal-CT phase. Opal-A only becomes dominant in the overlying Sisquoc Formation. Opal-CT generally cannot survive burial to temperatures greater than about 65-80°C without converting to quartz. Rock-Eval analysis by Laurent et al. (2015) also show that the phosphatic mudstone have not experienced high temperatures as the organic-rich rocks are immature (Figure 24).

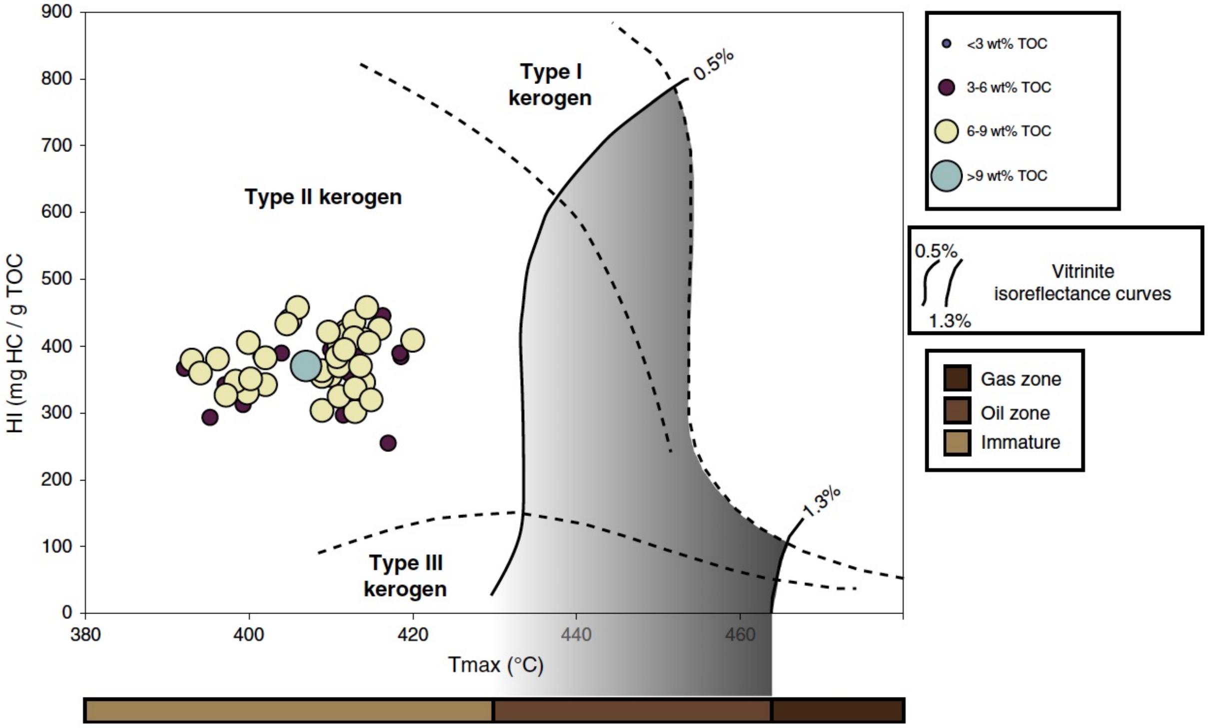


Figure 24. Hydrogen index versus Tmax of organic matter in mudstone of the Monterey Formation at Haskells Beach (Laurent et al., 2015).

History

Elwood and Haskells beaches were the site of some of the earliest producing oil fields in the region. Oil was discovered at Elwood Beach (1 km east of Haskells Beach) in 1928, and oil was discovered in 1930 in “Hydrocarbon Gulch” between Eagle and Tecolote canyons, just barely above the high-tide line at Haskells Beach, below what is today called the Sandpiper Golf Course. Production was vastly improved by building a dozen piers into the ocean and a larger discovery followed in 1934 (Figure 25). Development eventually moved fully offshore to the location of an active seep field and Platform Holly was built in 1966.

Figure 25. 1930's photo of oil piers at Haskells Beach (goletahistory.com).

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