Newly Discovered Paleocene and Eocene Rocks near Fairfield, California, and Correlation with Rocks in Vaca Valley and the So-Called Martinez Formation or Stage

By Earl E. Brabb, Donn Ristau, David Bukry, Kristin McDougall, Alvin A. Almgren, LouElla Saul, and Annika Sanfilippo

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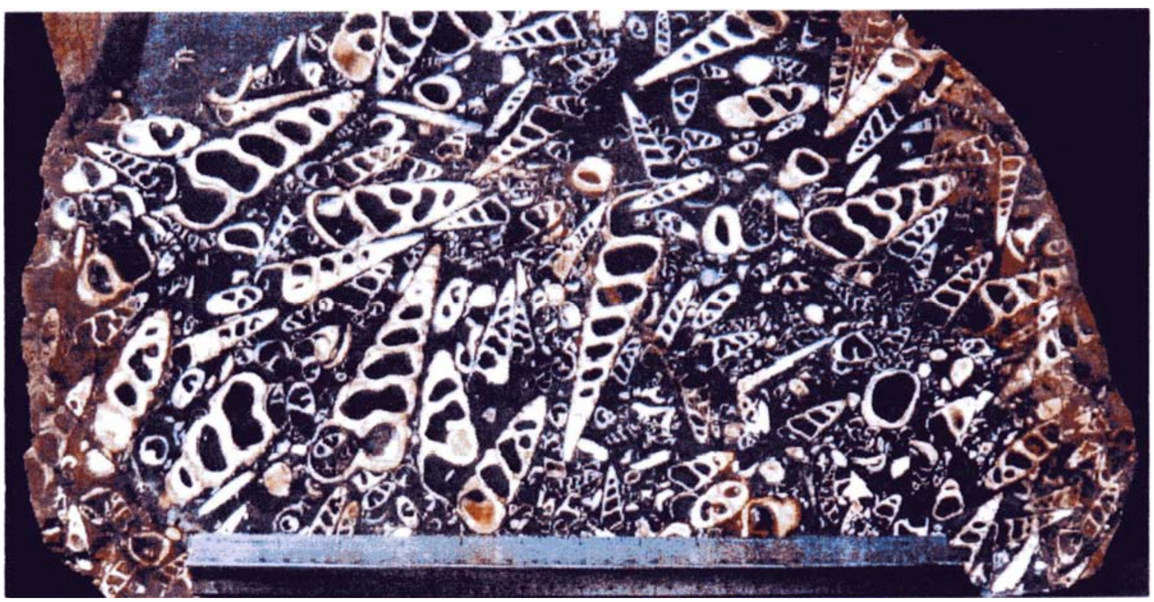

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Cover: Sandstone with Turritella infragranulata pachecoensis from locality 03CB5241 on the southwest flank of Cement Hill; view of slab prepared by Skyler Phelps, Auburn. LouElla Saul identified and dated the fossils (from figure 1B).

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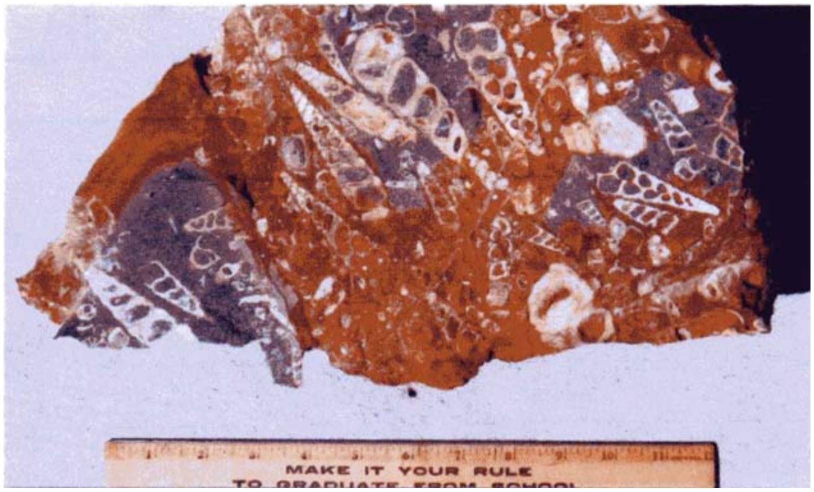
Introduction

Discovery of a 3-foot thick sandstone bed with abundant Turritellid gastropods of late Paleocene age (fig. 1) about 4 miles northeast of Fairfield and on the southwest flank of Cement Hill, Solano County (fig. 2, area 1) provides an opportunity to reevaluate the relationships of lower Tertiary formations in this part of California. Cement Hill is named for travertine deposits in and on top of sandstone of Late Cretaceous age (Hart, 1978). In this report, the current study area where the Paleocene fossils were recently discovered is referred to as lower Cement Hill and is located in section 7 of the U.S. Geological Survey Fairfield North 7.5' minute quadrangle, Township 5 North, Range 1 West. Lower Cement Hill is about 23 miles north of the so-called Martinez "formation" or stage area (Weaver and others, 1941) of late Paleocene age near Martinez (fig. 2, area 2). The Martinez "formation" and stage have played a significant role in the development of early Tertiary stratigraphy in this part of California. The discovery of correlative rocks at Cement Hill was unsuspected and may be helpful in defining the extent of this so-called formation or stage.

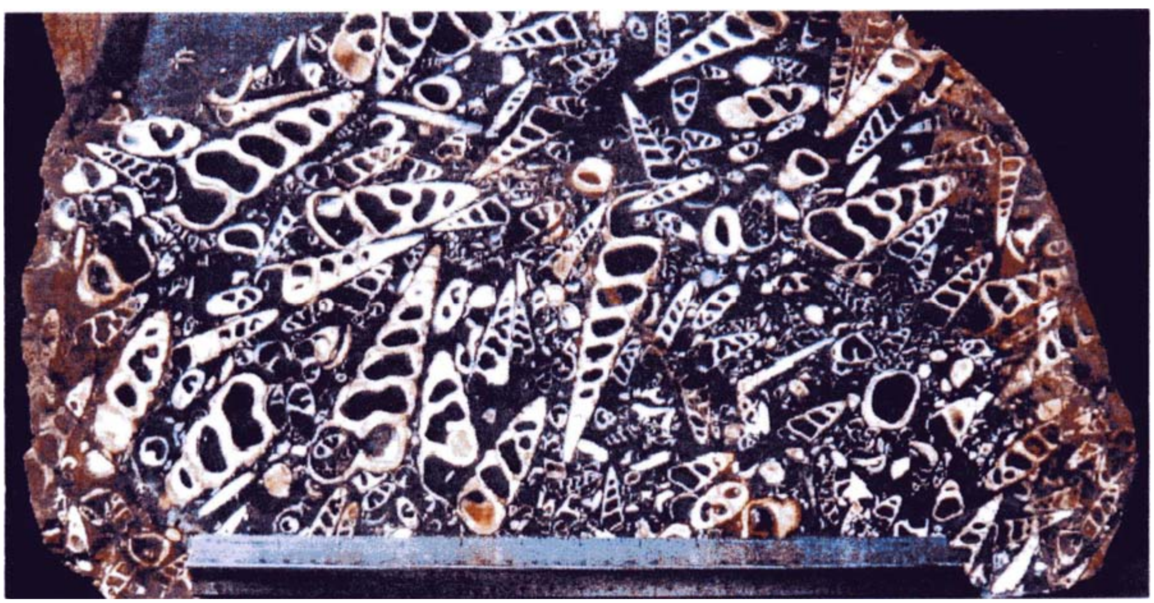
Coccolith identification and correlations are by David Bukry, foraminifer identifications and correlations by Alvin Almgren and Kristin McDougall, gastropod identification and correlation by LouElla Saul, and Radiolaria identifications and correlations are by Annika Sanfilippo.

Previous Work

The rocks that are the focus of this report were mapped by Weaver (1949) as Domengine Sandstone of Eocene age and by Sims and others (1973) as Late Cretaceous based partly on unpublished mapping by Exxon geologists Howard Sonneman and John Switzer. Part of the Sims and others map is shown in fig. 3. The dominance of Late Cretaceous rocks in the area, including the rocks regarded as Eocene by Weaver (1949), was supported by several collections of Late Cretaceous foraminifers identified by Chevron and Exxon paleontologists and virtually surrounding the lower Cement Hill area. The age of most of these samples was verified by Alvin Almgren from the original Chevron and Exxon slides. Except for the tiny outcrop of sandstone with Paleocene fossils, the existence of complexly folded and faulted Tertiary rocks would probably never have been discovered without the excavations that accompanied a preliminary geologic investigation for development of a housing area (Ristau,1966).



A



B

Figure 1. Sandstone with *Turritella infragranulata pachecoensis* from locality 03CB5241 on the southwest flank of Cement Hill. A, View of rock surface. B, View of slab prepared by Skyler Phelps, Auburn. LouElla Saul identified and dated the fossils.

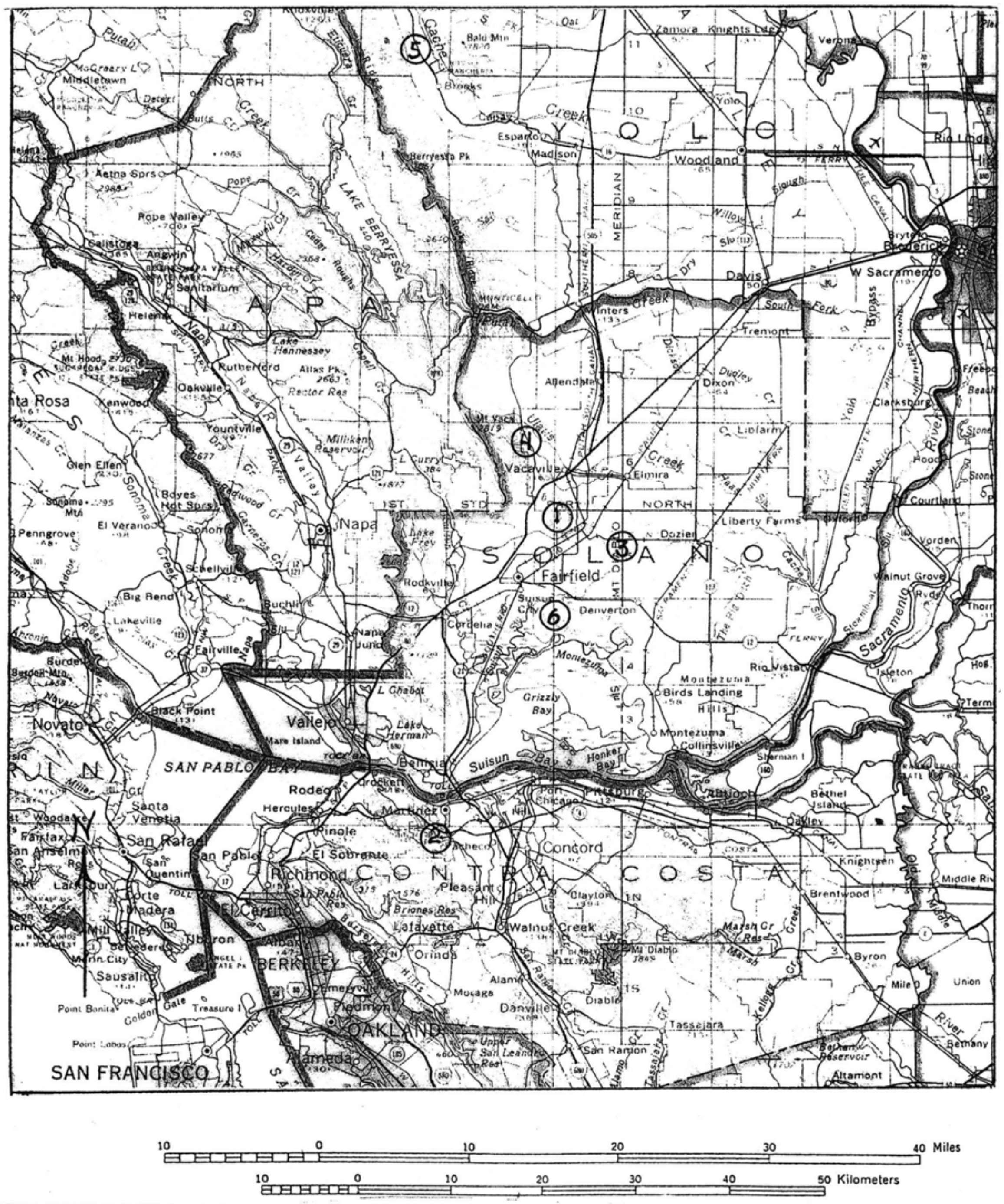


Figure 2. Map showing localities discussed in this report: (1) Lower Cement Hill area northeast of Fairfield; (2) Type area for Martinez Stage; (3) Peabody Road, Vacaville Junction, and Travis Field area; (4) Vaca Valley and Oakdale School area; (5) Type area for Capay "shale" near Brooks; and (6) Potrero Hills.

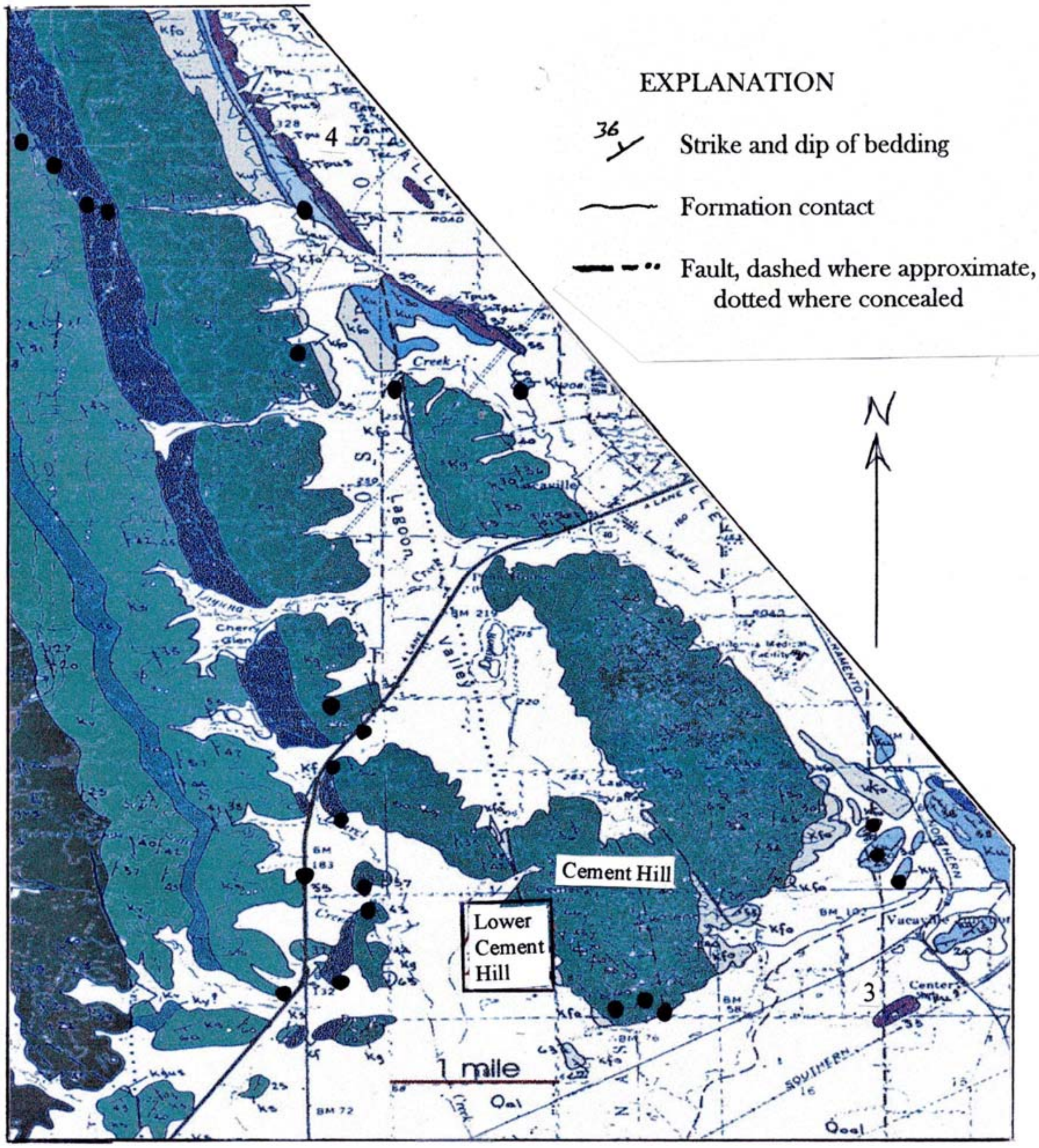


Figure 3. Part of the geologic map by Sims and others (1973) showing the geologic setting of the Cement Hill area. The green areas have different formations of Cretaceous age. Purple areas have rocks of Paleocene age in the Vacaville Junction (3) and Vaca Valley-Oakville School areas (4); see also fig. 2). Black dots show places where Chevron and Exxon geologists and E. Brabb collected Late Cretaceous foraminifers with ages confirmed by A. Almgren. Lower Cement Hill is where rocks significantly younger than Cretaceous were recently discovered.

New Work in Cement Hill Area

The current study area is part of a subdivision in the Fairfield North quadrangle for which grading commenced in 2002. Elevations within the subdivision development area vary from approximately 100 to 200 feet above mean sea level, with the 200-foot contour elevation targeted as the upper limit of grading for roadway and subdivision improvements.

Several samples of mudstone and siltstone from test pits and borings were sent to Alvin Almgren before grading began to determine the age of the rocks beneath the mapped alluvium. He provided ages of Late Cretaceous E and F-2 zones, late Paleocene E zone, and early Eocene C and B zone, all based on foraminifers (zones from Goudkoff, 1945 and Laiming, 1940). Because the test pits and borings were scattered in an area with only a small ledge of sandstone containing the *Turritella* exposed, the structural relationships of these samples could not be determined. The *Turritella* was examined by LouElla Saul and determined to be *Turritella infragranulata pachecoensis* correlative with planktic foraminifer zone P4, the Martinez “stage” of Weaver (1953), and with other late Paleocene formations in California.

As grading began in 2002 on roads and housing pads, more and more sandstone, siltstone, mudstone, and shale above and below the *Turritella*-bearing sandstone were exposed. At one point in time, nearly 2,000 feet of what seemed like nearly continuous section was present in various outcrops throughout the site, with the Paleocene sandstone marker bed in the approximate center of the section. Many of the finer-grained rocks had foraminifers clearly visible on the rock surfaces, offering the possibility that this section might become the “Rosetta stone” for Paleocene rocks in central California, an area where rocks of this age are uncommon and generally sparsely fossiliferous. Accordingly, dozens of samples were collected for possible microfossil analysis. A preliminary "stratigraphic section" was pieced together based on the rocks exposed in the cuts (fig. 4). A conglomerate in shale overlying the sandstone with *Turritella* and the presence of a white sandstone similar to the Domengine Sandstone provided the incentive to speculate that the conglomerate above the *Turritella* beds might represent the beginning of Eocene deposition.

As grading progressed, more nannoplankton samples were collected and sent to David Bukry. About one-half of the 40 samples have nannoplankton that provided ages for the rocks (zones from Okada and Bukry, 1981; Bukry, 1991; and Bukry and others 1998). Additional samples for foraminifers were sent to Alvin Almgren and Kristin McDougall. The approximate location of the samples from preliminary scraper cuts, trenches, and other excavations are shown on figure 5. The rich character of the foraminifer faunas identified by K. McDougall is documented on table 1. All the fossils were used to make a new geologic map, shown in figure 6. For convenience in discussing this complex area, the geology is divided into 6 blocks, A through F shown on figure 7. Almost all of the rocks uncovered in the Lower Cement Hill area are now concealed by concrete roads, curbs, sidewalks, house foundations, and fill.

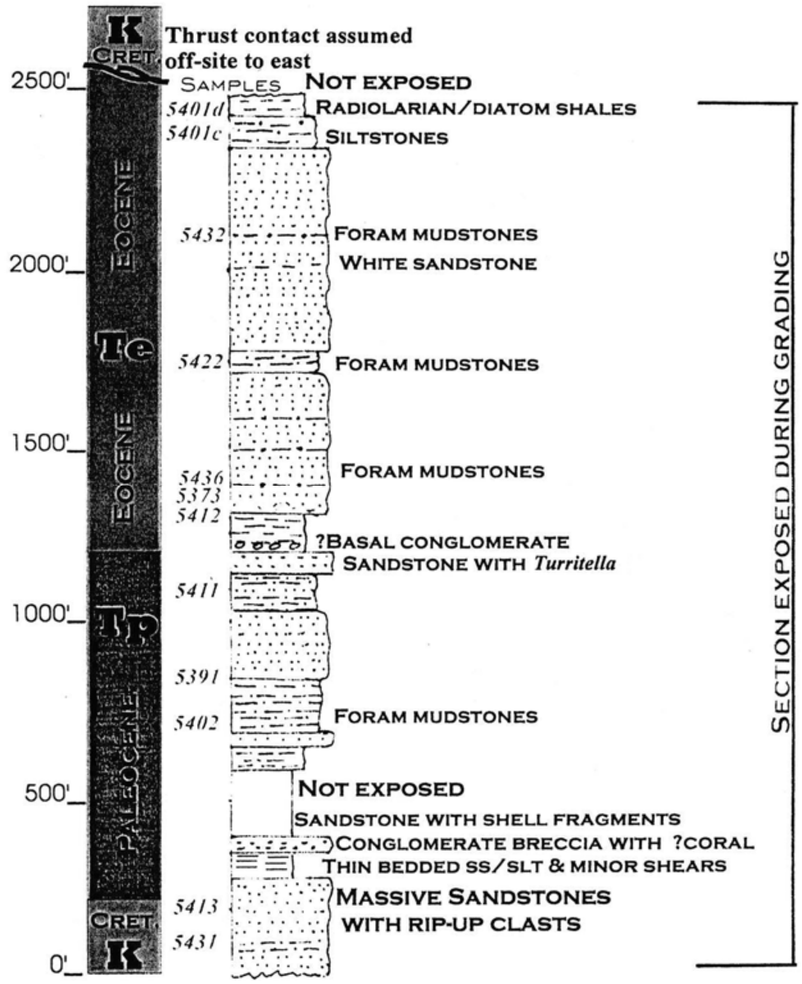


Figure 4. Original stratigraphic column for the lower Cement Hill area is based on limited paleontologic data and an assumption that faults in the section did not greatly displace the rocks. This column had to be completely revised when the rocks thought to be Eocene near the top of the column turned out to be partly overturned Late Cretaceous and Paleocene age and the rocks thought to be Paleocene below the *Turritella* bed turned out to be Eocene. Faulting with extensive displacement has disrupted the lower Cement Hill area into several different tectonic blocks.

Structural Blocks in the Area

The six structural blocks are bounded by extensively brecciated shear zones, some of which have been partly filled with calcite. At least two of the blocks are overturned. The blocks are discussed from East to West.

Block A

This block in the eastern portion of lower Cement Hill has about 20 feet of overturned and highly sheared, dark-gray to black shale and siltstone, with Late Cretaceous coccoliths, foraminifers, and the following radiolarians at localities 02CB5401D and E.:

Afens liriodes Riedel and Sanfilippo

Alievium superbum (Squinabol)
Amphipyndax pseudoconulus (Pessagno)
?Amphipyndax tylotus Foreman
Archaeodictyomitra lamellicostata (Foreman)
Clathropyrgus titthium Riedel and Sanfilippo
Cryptamphorella conara (Foreman)
?Dictyomitra crassispina (Squinabol)
Lithomelissa hoplites Foreman
Myllocercion acineton Foreman
Pseudoaulophacus floresensis Pessagno
Pseudoaulophacus lenticulatus (White)
Stichomitra asymbatos Foreman
?Theocampe salillum Foreman
Theocapsomma comys Foreman

Annika Sanfilippo believes that these are correlative with the Late Cretaceous Campanian Stage, *Amphipyndax pseudoconulus* Zone of Riedel and Sanfilippo (1974) emended by Foreman (1977) as the *Amphipyndax enesseffi Zone*. For additional reference, see the report by Sanfilippo and Riedel (1985). The shale with radiolarians also contains rare coccoliths of Late Cretaceous age.

The rocks with Late Cretaceous fossils seemingly grade into a similarly-overturned 10-foot thick siltstone, sandstone, and glauconitic sandstone and a 70-foot thick siltstone containing CP 4 late Paleocene coccoliths at locality 03CB5401C. These rocks are truncated by highly sheared siltstone in which the bedding is intensely deformed and distorted at the western boundary of Block A. The eastern boundary of Block A is concealed beneath alluvium but is assumed to be a fault because all the Cretaceous rocks uphill seem to be upright.

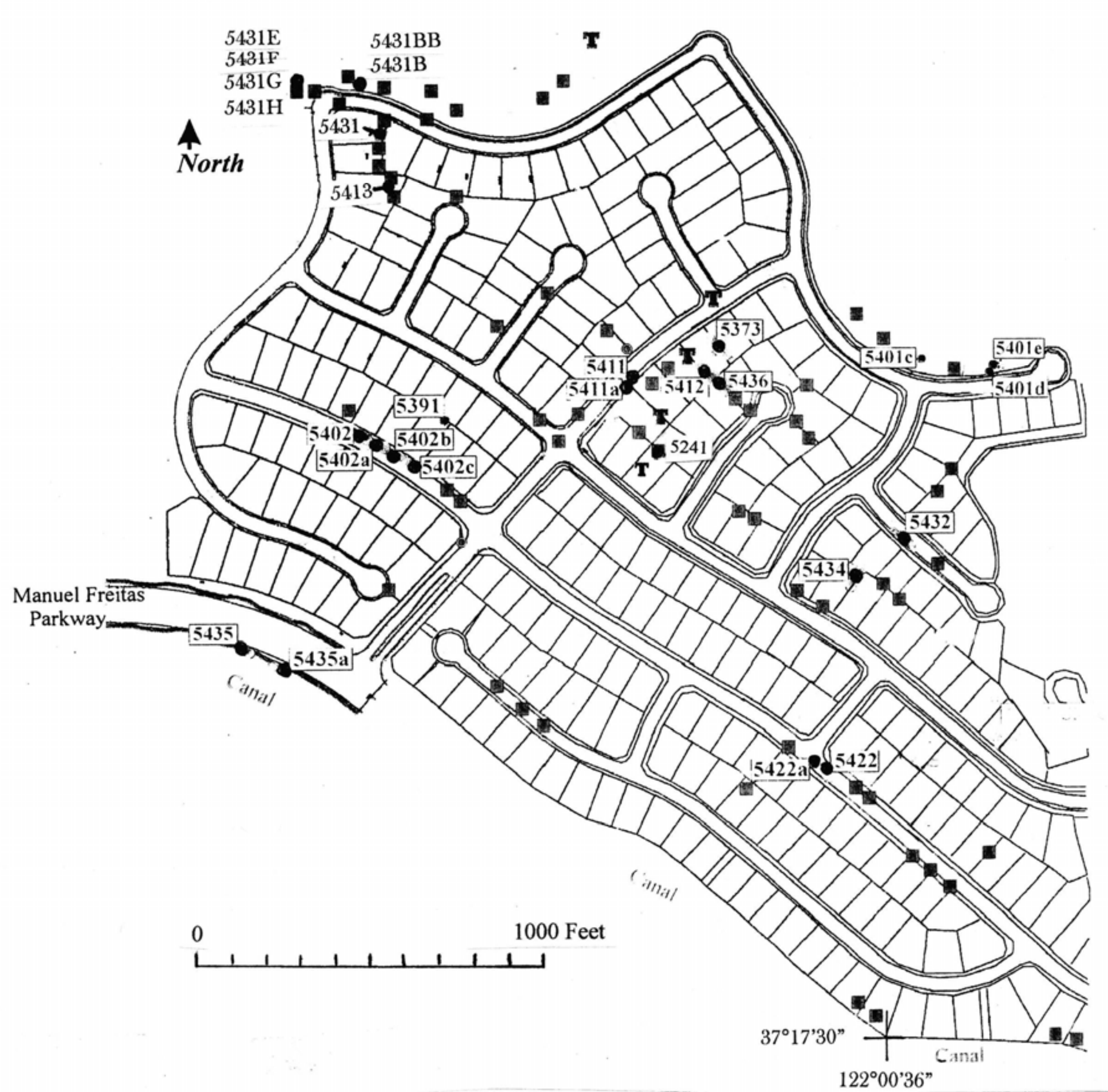


Figure 5. Subdivision layout along Manuel Freitas Parkway showing principal fossil locations relative to streets and lot lines. The gray squares indicate places where samples were collected but are barren of microfossils. The "T" shows places where *Turritella* sp. was observed and/or collected.

Table 1A Foraminifers from the lower Cement Hill area. Check list prepared by Kristin McDougall, shipment number WESP-03-04. Additional foraminifers examined and dated by Alvin Almgren but those are not on this chart and are summarized in the text.

Field numbers	03CB5401	03CB5413	03CB5402	03CB5402A	03CB5402B	03CB5402C	03CB5411	03CB5411A	03CB5412
Laboratory numbers	Mf11147	Mf11155	Mf11148	Mf11149	Mf11150	Mf11151	Mf11152	Mf11153	Mf11154
Ammodiscus incertus (d'Orbigny)	X		X			X	X		
Amphimorphina californica Cushman and McMasters						X			
Amphimorphina ignota Cushman and Siegfus					X				X
Amphimorphina spp.								X	
Anomalina keenae Martin					X	X			
Anomalina regina Martin			X	X			X		X
Anomalinoides capitatus (Gumbel)			X	X	X	X	X	X	X
Aragonia aragonenesis (Nuttall)						X		X	
Bathysiphon spp.	X	X				X	X		X
Bifarina eleganta (Plummer)					X		X		
Bulimina alazaensis Cushman				X	X	X	X		X
Bulimina callahani Galloway and Morrey			X	X	X	X	X	X	X
Bulimina macilenta Cushman and Parker			X	X	X	X	X	X	X
Bulimina trinitatensis Cushman and Jarvis			X			X		X	X
Bulimina tuxapamensis Cole			X	X	X	X	X	X	X
Chilostomella oolina Schwager				X			X	X	
Chilostomella ovoidea Reuss			X	X					
Chilostomella spp.			X						
Chrysalongonium elongatum Cushman and Jarvis			X					X	
Chrysalongonium lamellatum Bermudez				X				X	
Chrysalogonium lanceolum Cushman and Jarvis			X		X		X		
Chrysalongonium longiscatatum Cushman and Jarvis			X			X	X		
Chrysalongonium spp.							X		
Cibicides pacheocoensis Smith			X	X	X			X	X
Cibicidoides eocaenus (Gumbel)			X	X	X	X	X	X	X
Cibicidoides eponidiformis (Martin)			X	X	X	X	X	X	X
Cibicidoides grimsdalei (Nuttall)			X	X	X			X	X
Cibicidoides spp.			X			X	X		
Cibicidoides subspiralis (Nuttall)				X	X				
Cibicidoides venezuelanus (Nuttall)					X	X	X		X
Clavulina anglica (Cushman)			X	X	X	X	X	X	X
Cribrostomoides cretacesa Cushman and Goudkoff	X	X							
Coleites reticulosus (Plummer)						X			X
Cyclammina pacifica Beck	X								
Cyclammina spp.									X
Dentalina colei Cushman and Dusenbury				X		X			
Denatlina communis (d"Orbigny)					X		X	X	
Dentalina consobrina (d'Orbigny)			X		X	X			
Dentalina hexacostata Howe			X	X	X	X	X	X	X
Dentalina jacksonensis (Cushman and Applin)			X	X	X	X	X	X	X
Dentalina mucronata Neugeboren								X	
Dorothia principiensis Cushman and Bermudez			X	X	X	X	X	X	X
Ellipsoglandulina multicostata (Galloway and Morrey)					X				
Eponides dorfi Toulmin								X	
Fissurina marginata (Montagu)								X	X
Fissurina orbignyana Sequenza						X			
Gaudryina coalingensis Cushman and Hanna							X		X
Globocassidulina subglobosa (Brady)				X			X		X
Globulina globosa (von Munster)									X
Glomospira charoides (Jones and Parker)				X					X
Gonatosphaera eocenica Mallory			X					X	
Guttulina spp.						X			
Gyroidina octocamerata Cushman and Hanna			X	X	X	X		X	X
Gyroidina orbicularis d'Orbigny						X			X
Haplophragmoides spp.							X		X
Karreriella elongata Mallory			X	X	X	X		X	X
Karreriella horrida Mjatliuk	X				X	X	X		X
Lagena costata (Williamson)									X

Table 1B Foraminifers from the lower Cement Hill area. Check list prepared by Kristin McDougall, shipment number WESP-03-04. Additional foraminifers examined and dated by Alvin Almgren but those are not on this chart and are summarized in the text.

Field numbers	03CB5401	03CB5413	03CB5402	03CB5402A	03CB5402B	03CB5402C	03CB5411	03CB5411A	03CB5412
Laboratory numbers	Mf11147	Mf11155	Mf11148	Mf11149	Mf11150	Mf11151	Mf11152	Mf11153	Mf11154
Lenticulina carolinianus Cushman			X				X	X	
Lenticulina inornata (d'Orbigny)			X	X	X		X	X	X
Lenticulina limbosus hockleyensis Cushman and Applin			X	X		X		X	X
Lenticulina nuttalli Cushman and Renz								X	X
Lenticulina pseudocultratus (Cole)			X	X	X	X	X		
Lenticulina pseudovortex (Cole)						X	X	X	
Lenticulina spp.			X	X	X	X		X	X
Lenticulina terryi (Coryell and Embich)						X	X	X	
Lentiuclina vortex (Fitchel and Moll)				X	X	X	X	X	X
Lituotuba lituiformis (Brady)	X								X
Loxostomoides applinae (Plummer)			X	X	X	X	X	X	X
Marginulina exima Neugeboren			X			X			
Marginulina hantkeni Bandy				X					
Marginulina subbullata Hantken				X					X
Marginulina subrecta Franke								X	
Nodosaria deliciae Martin			X		X				X
Nodosaria longiscata d'Orbigny			X	X		X	X	X	X
Nodosaria spp.					X			X	X
Nodosarella atlantisae hispidula (Cushman)			X	X			X		
Nodosarella subnodosa (Guppy)			X						X
Nonionella frankei Cushman			X			X			
Nonion florinensis Cole			X	X					
Nuttaloides truempyi (Nuttall)			X	X	X	X	X	X	X
Oridorsalis umbonatus (Reuss)			X	X	X	X	X	X	X
Osangularia mexicana (Cole)			X	X	X	X	X	X	X
Planularia tolmani Cushman and Simonson			X					X	X
Plectofrondiuclaria paucicostata Cushman and Jarvis			X		X	X		X	X
Plectofrondicularia vaughani Cushman									X
Pleurostomella altemans Schwager			X	X	X				X
Pleurostomella biergi Parker and Bermudez					X				X
Praeglobobulimina ovula (d'Orbigny)					X				
Praeglobobulimina pupoides (d'Orbigny)			X		X	X	X	X	X
Praeglobobulimina pyrula (d'Orbigny)					X				
Pseudonodosaria conica (Neugeboren)			X			X	X		X
Pseudonodosaria inflata (Bornemann)			X		X			X	
Pullenia eocenica Cushman and Siegfus					X	X		X	X
Pullenia salisburyi Stewart and Stewart			X	X	X				
Quadrimorpnina allomorphinoides (Reuss)				X	X	X	X	X	X
Quinqueloculina triangularis d'Orbigny						X	X		X
Rhabdammina eocenica Cushman and Hanna			X						
Rotalia spp.						X			
Saccammina spp.		X						X	
Sckenekiella rubosa Israelsky				X					
Silicosigmoilina californica Cushman and Church	X		X	X	X	X	X	X	X
Spiroplectammina directa (Cushman and Siegfus)			X		X				X
Spiroplectammina richardi Martin			X			X	X	X	X
Spiroloculina texana Cushman and Ellisor				X	X		X	X	
Stilostomella adolphina (d'Orbigny)			X						
Stilostomella lepidula (Schwager)			X						
Stilostomella spp.								X	
Trifarina advena californica Mallory						X			X
Tritaxilina colei Cushman and Siegfus		X	X	X	X	X	X	X	X
Trochammina globigeriniformis (Parker and Jones)	X					X	X		
Turrilina brevispira ten Dam			X	X	X	X	X	X	X
Uvigerina alabamensis Cushma and Garrett				X		X			X
Vaginulinopsis asperuliformis (Nuttall)			X	X	X	X	X	X	X
Vaginulinopsis saundersi (Hanna and Hanna)			X	X					
Vaginulinopsis vacavillensis (Hanna)						X			X
Valvulineria jacksonensis welcomensis Mallory				X	X				
Valvulneria spp.						X			
Verneuilina triangulata Cook					X	X			

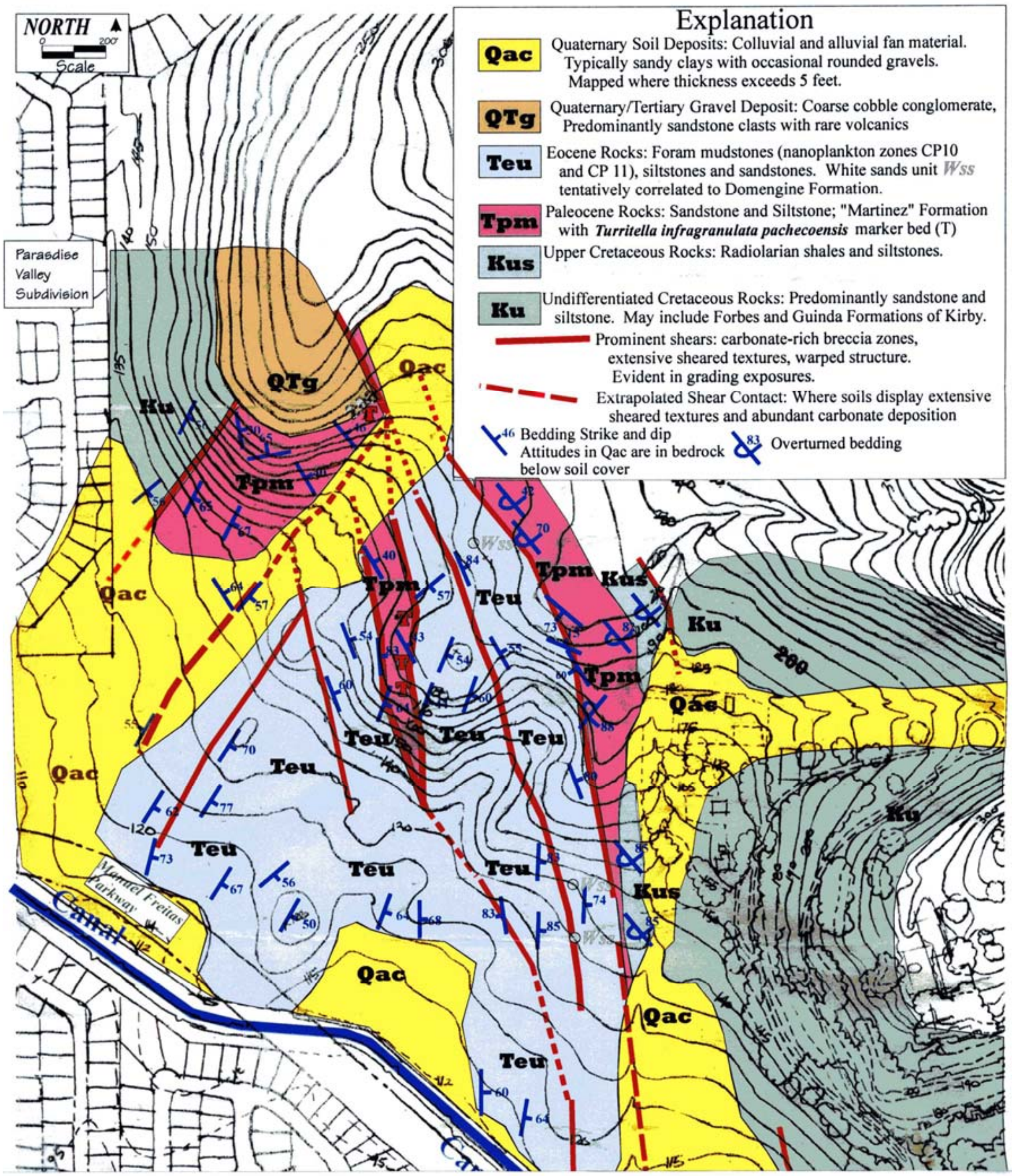


Figure 6. Revised geologic map for the lower Cement Hill area north of Manuel Freitas Parkway from extensive paleontologic, lithologic, and structural data.

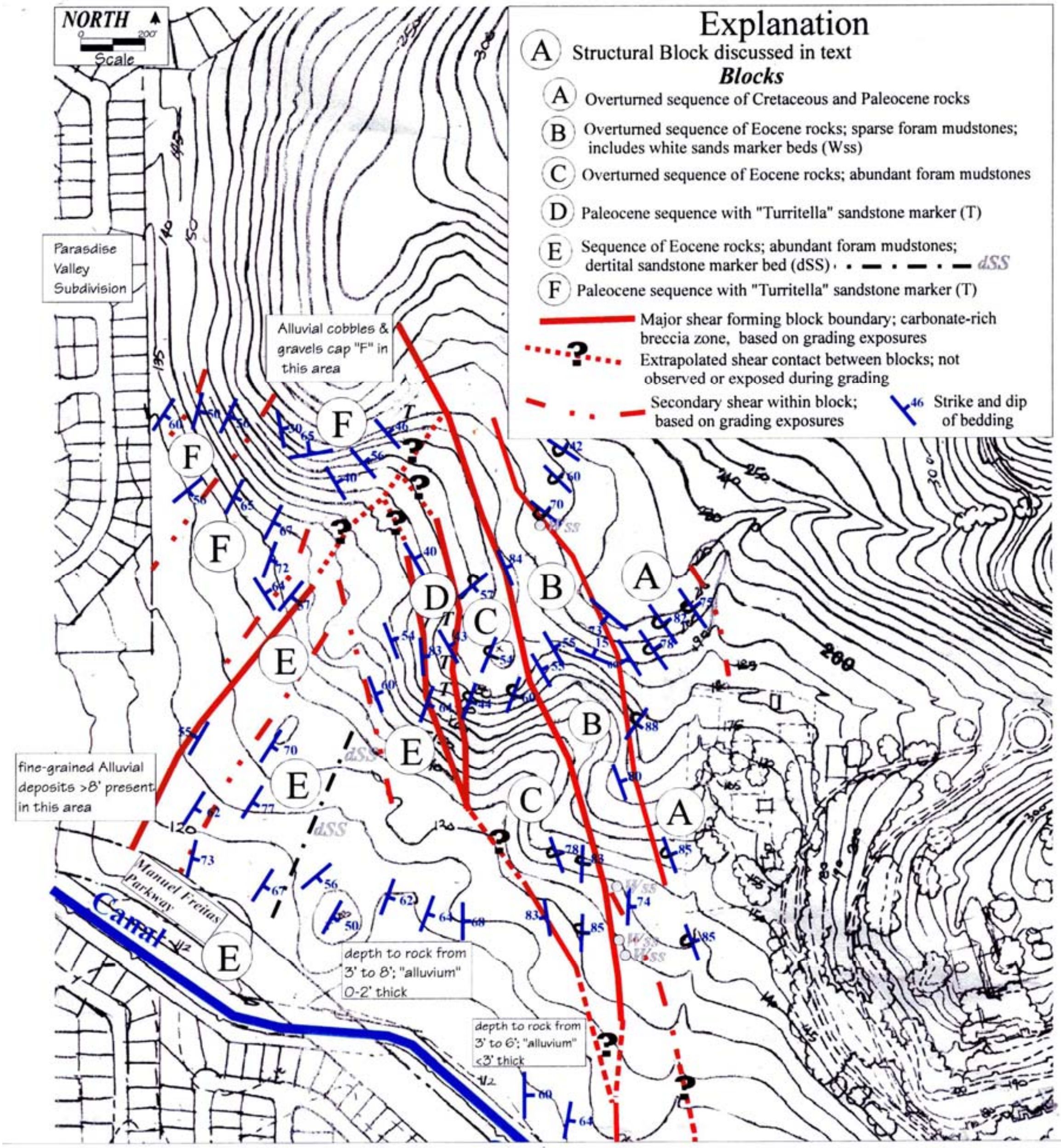


Figure 7. Division of the lower Cement Hill area into six structural blocks labeled A through F in order to discuss each block separately.

The overturned rocks with Late Cretaceous fossils in Block A seemingly grade into a similarly-overturned 10-foot thick siltstone, sandstone, and glauconitic sandstone and a 70-foot thick siltstone containing CP 4 late Paleocene coccoliths at locality 03CB5401C. These rocks are truncated by highly sheared siltstone in which the bedding is intensely deformed and distorted at the western boundary of Block A. The eastern boundary of Block A is concealed beneath alluvium but is assumed to be a fault because all the Cretaceous rocks uphill seem to be upright.

Foraminifers from the rocks with Late Cretaceous fossils in Block A were thought to be most likely Paleogene but could be as old as Cretaceous, according to K. McDougall. A.

Almgren examined foraminifers from the same locality and believes that they are Late Cretaceous E zone. Similar black shale that weathers white and contains abundant diatoms, radiolarians, and foraminifers of Late Cretaceous age has been mapped by Exxon geologists north of Vacaville Junction about 3 miles east of 02CB5401D and E (fig. 2, area 3) and along the west side of Vaca Valley northwest of Vacaville (fig. 2, area 4). This shale has been given the local name “Sacramento” shale by petroleum geologists. At those localities, discussed later in this report, the black shale also contains a prolific foraminifer fauna correlative with the Campanian Stage and E zone of Goudkoff (1945), according to Almgren (1986).

Block B

Most of the rock in block B is massive brown sandstone about 350 feet thick. A white sandstone about 50 feet thick forms the top of this sequence and is probably at least part of the Domengine Sandstone mapped by Sims and others (1973) in the Peabody Road and Travis Field areas east of Cement Hill (fig. 2 area 2). Locality 02CB5432 in the middle of the sequence contains early Eocene CP 10/11 coccoliths.

The rocks of Block B strike predominantly north to northwest and dip steeply to the northeast. A prominent zone of highly sheared sandstone interpreted as a fault zone about 100 feet wide extends at least along the north-south extent of the outcrop area and marks the boundary between Blocks B and C.

Block C

Block C consists mostly of at least 400 feet of well-bedded sandstone and siltstone. Several interbeds of greenish-gray mudstone and shale contain foraminifers and coccoliths of early Eocene age. However, strata at the base of the sequence contain the youngest floras, indicating that Block C is overturned. Shale and mudstone at localities 03CB5373 and 5434 contain early Eocene CP 10 coccoliths, whereas localities 03CB5412 and 5436 contain early Eocene CP 11 coccoliths. Locality 03CB5412 also contains a rich foraminifer fauna correlative with the late Penutian Stage to early Ulatisian Stage, according to K. McDougall. Localites 02CB5422 and 5422A from the middle part of Block C have CP10 /11, undivided, coccoliths.

Bedding in Block C strikes nearly north and is overturned to the east. Several small-scale folds and faults are present within Block C, and other folds and faults are suspected.

Block D

This block consists mainly of massive brown sandstone about 100 feet thick. Within this sandstone is a well-cemented 3-foot thick sandstone bed with abundant *Turritella infragranulata pachecoensis.* This bed was traced throughout the extent of Block D where it had to be removed or buried in order to create level building pads and streets.

The eastern part of Block D is a highly sheared and contorted mixture of sandstone and shale with fault surfaces dipping from 30 degrees to vertical. The fault zone brings rocks of Paleocene age in Block D against Eocene rocks in Block C. The western boundary of Block D consists of a 20- to 25-foot thick zone of sheared siltstone and mudstone with numerous crosscutting shears. Bedding is highly contorted and disrupted. The bedding in the remaining part of the block strikes northwest and dips moderately to the northeast.

Block E

The rocks in Block E are mainly well-bedded sandstone with many interbeds of siltstone, mudstone, and shale with a total thickness of at least 500 feet. One greenish-gray mudstone and glauconitic mudstone within Block E is about 200 feet thick and has localities 03CB5402, 5402A, 5402B, 5402C 03CB5391, 03CB 5411, 5411A and 03CB5412 with early Eocene CP 10 coccoliths. Rich foraminifer faunas of early or middle Eocene age, late Penutian to early Ulatisian benthic foraminiferal stages, were found in these same samples, according to K. McDougall.

The rocks at the western boundary of Block E are not exposed but are covered with alluvium that has extensive shear zones and secondary carbonate extending in a northeast-southwest direction. We interpret these shears and carbonate as masking a major fault truncating Blocks C, D, and E.

Block F

Approximately 300 feet of laminated sandstone with interbeds of siltstone comprise the lower part of Block F in the northwest part of the lower Cement Hill area. Some sandstone is thicker-bedded and has rip-up clasts of mudstone at a few localities near the western edge of the property where the oldest beds were concealed by houses in the adjacent subdivision and alluvium during our work. The rocks strike predominantly northeast-southwest and dip fairly steeply to the southeast.

Localities 03CB5431B, 5431BB, 5431E, and 5431G from siltstones in the lower part of Block F yielded arenaceous foraminifers correlative with the Late Cretaceous F-1 zone of Goudkoff, according to A. Almgren. Localities 03CB5431F and 5431H have rare coccoliths of Late Cretaceous age.

The upper part of Block F consists mainly of about 500 feet of thickly bedded to massive sandstone with interbeds of siltstone. These rocks strike and dip in about the same direction as those in the lower part of the Block. A sandstone grit at or near the base of this unit contains fragments of mollusks and what seemed from a brief examination to be a coral, but the exposure was covered before the material could be collected. The contact between the sandstone grit and the underlying sandstone beds could be a disconformity or a fault.

Turritella infragranulata pachecoensi, was recovered from sandstone near the top of Block F. A sample containing foraminifers of late Paleocene E zone age was identified by A. Almgren from a test pit in the vicinity of the *Turritella*-bearing sandstone, but the rocks with the foraminifers could not be found after the hill was excavated so that the stratigraphic position of these fossils relative to the *Turritella* was not established.

Shear zones occur near the contact between the lower and upper units of Block F, but the similar attitudes above and below this shear zone and the presence of what may be a disconformity made us reluctant to divide the unit into separate blocks.

How Do the Blocks Fit Together?

Almost none of the rocks in the various blocks have distinctive marker beds that allow us to piece the blocks together to make a continuous section. The *Turritella*-bearing sandstone is present in Blocks B and F but was not found in Block A. The white sandstone in Block B and the relative ages of coccoliths in various blocks allowed us to tentatively piece together a section (figure 7) about 2,000 feet of largely sandstone with many siltstone, shale and mudstone inter-beds ranging in age from Late Cretaceous Campanian Stage to early Eocene Cp 11. Blocks A and D are not shown because at least some or all of the rocks are duplicated in Block F. However, the Cretaceous rocks in Block A are different in age from those in Block F, suggesting that more faulting is present than we recognized. The presence of many additional shears than described and several small-scale folds should make readers cautious that the so-called section is probably duplicated in part and even more complex in structure than we realized.

Can Landsliding Explain the Structures Observed?

The alluvium in the Lower Cement Hill area before grading had a somewhat hummocky appearance and is downhill from crescent-shaped valleys that could be landslide scarps, providing the possibility that the overturned beds and faulted blocks were produced by landsliding. The outcrops uphill from the part that was graded, however, are all Cretaceous rocks seemingly in place and not overturned. No rocks of Tertiary age were found uphill from the graded area. Moreover, no alluvium was mixed in with the overturned and faulted bedrock blocks as might be suspected if landsliding produced the mixed structure. We conclude that the structures seen in Lower Cement Hill were produced by tectonic forces, not landsliding.

A glance at the regional structure north and south of lower Cement Hill (Fig. 3) provides clues about the complicated structure. North of Vacaville for at least 35 miles, Cretaceous rocks are part of a monocline dipping moderately to the east. About 5 miles south of lower Cement hill, however, Paleocene and Eocene rocks have been folded into a broad anticline with nearly an East-West strike in the Potrero Hills (Fig. 2, area 6, and Sims and others, 1973). The Potrero Hills and the complex structure in the lower Cement Hills area could have been produced by drag along a strike-slip fault. Which fault and how the structure developed is beyond the scope of this paper, but complicated structures in the Potrero Hills and adjoining areas produced by contraction, strike-slip, and thrust faults, as proposed by Unruh and Hector (2007); these could explain lower Cement Hills.

We have hesitated to use the term thrust fault for most of the faulting observed at lower Cement Hill because of the complex structure. Many high-angle faults were observed, but few thrusts were documented. We believe that compression and thrusting dominated the development of lower Cement Hill, but the evidence is not conclusive.

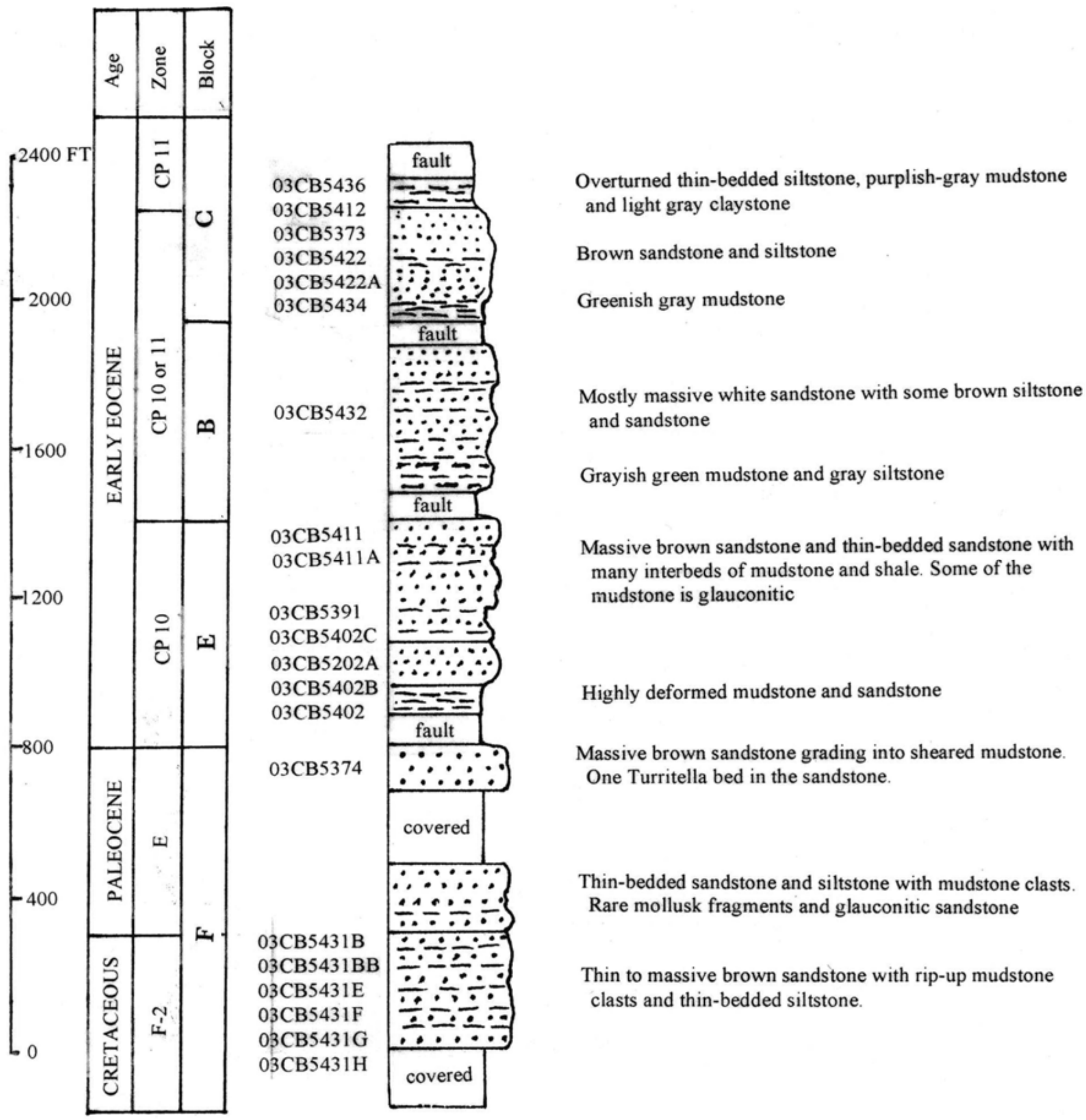


Figure 8. A new stratigraphic column for the lower Cement Hill area showing the different fault blocks, collecting localities, and an interpretation of how the faulted and in some places overturned blocks fit together. Unrecognized faulting and folding may further complicate this overview of the stratigraphic sequence

Vacaville Junction Area

The Cretaceous rocks at lower Cement Hill are exposed again along Peabody Road about one-half mile north of Vacaville Junction (fig. 3, area 3), where the white-weathering “Sacramento” shale forms conspicuous outcrops and contains abundant foraminifers and radiolarians. The foraminifers are Late Cretaceous E zone of Goudkoff (1945), according to A. Almgren. Among the foraminifers is the topotype for *Reussella szajnochae var. californica* (Cushman) described by Almgren (1959). This shale with similar faunas also crops out in a drainage ditch about 3,500 feet northeast of the Peabody Road exposures.

The shale at that locality, though, is overlain by glauconitic sandstone and olive-gray mudstone with foraminifers correlative with the late Paleocene E zone of Laiming (1940), according to A. Almgren. E. Brabb resampled these outcrops in 1992 at which time they yielded Late Cretaceous (92CB3531C and D) and late Paleocene CP7 coccoliths (92CB3531B).

At least 9 of the holes for seismic surveys in the area from about one mile southeast of Cement Hill to areas around and in Travis Field plus two surface samples yielded late Paleocene E zone faunas, according to A. Almgren (unpublished notes). This eastward extension of the Paleocene rocks from the lower Cement Hill area has been incorporated into the map by Graymer and others (2004).

Vaca Valley Area

Exxon, Chevron, and Unocal geologists all recognized rocks of Paleocene age in the Vaca Valley area northwest of Vacaville (fig. 2, area 4, and fig. 9) about 6 miles north of lower Cement Hill where the mapping by Exxon geologists H. Sonneman and J. Switzer was used for the map by Sims and others (1973). This map has two units of Paleocene age: a lower unit of massive quartz sandstone and an upper unit of silty mudstone and shale. These units were considered members within the Martinez Formation by Sims and others (1973). Field investigations in 1997 and 2002 were focused on determining the lithologic character of the Paleocene rocks, the relationships with the underlying Cretaceous sequence and overlying “Vacaville shale” of Boyd 1998), and whether these rocks have the same age, lithology, and relationships as the rocks in lower Cement Hill.

Cretaceous Rocks in Vaca Valley

The white-weathering siliceous shale called informally the “Sacramento” shale by petroleum geologists in the lower Cement Hill and Vacaville Junction areas (fig. 2, areas 1 and 3) has been mapped as a separate unit less than 50 feet thick by Sims and others along the western side of Vaca Valley (fig. 3, area 4, and fig. 9. No fossils have been recovered from the “Sacramento shale” in the southern part of this area, but the unit is bracketed by samples 03CB5352 and 03CB5353 from shale near Alamo Creek. A. Almgren considers the age of sample 03CB5352 as Late Cretaceous E zone of Goudkoff (1945) and the other sample to be probably the same age.

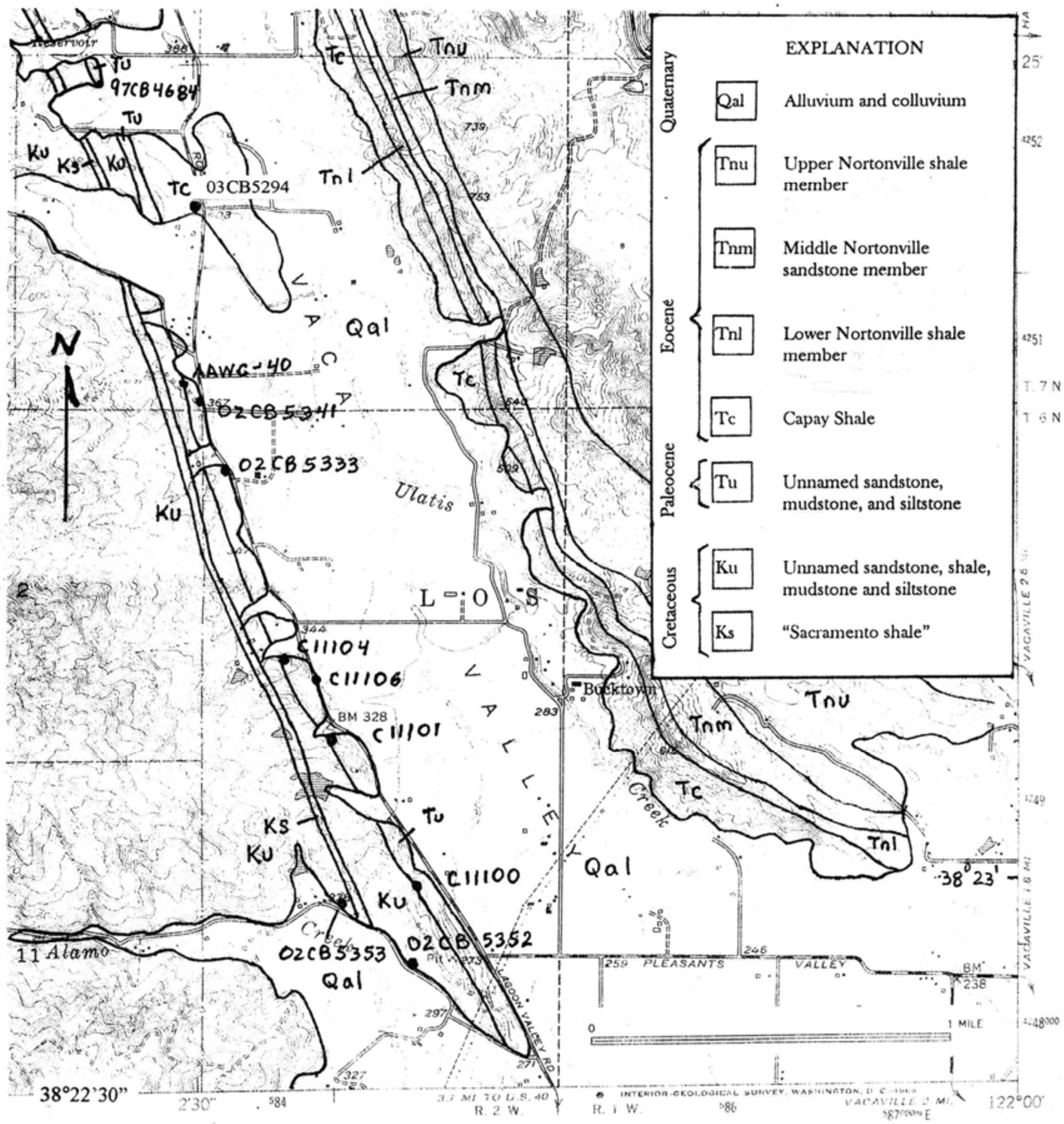


Figure 9. Geologic units and localities in the Vaca Valley area northwest of Vacaville. Dunns Peak and the hamlet of Bucktown are shown in the east-central part of the map. The general area of Bucktown and Ulatis Creek is where Mallory (1959) established the type locality for the Ulatisian stage. Numbers and letters refer to foraminifer samples collected by A. Almgren, Chevron geologists, and E. Brabb.

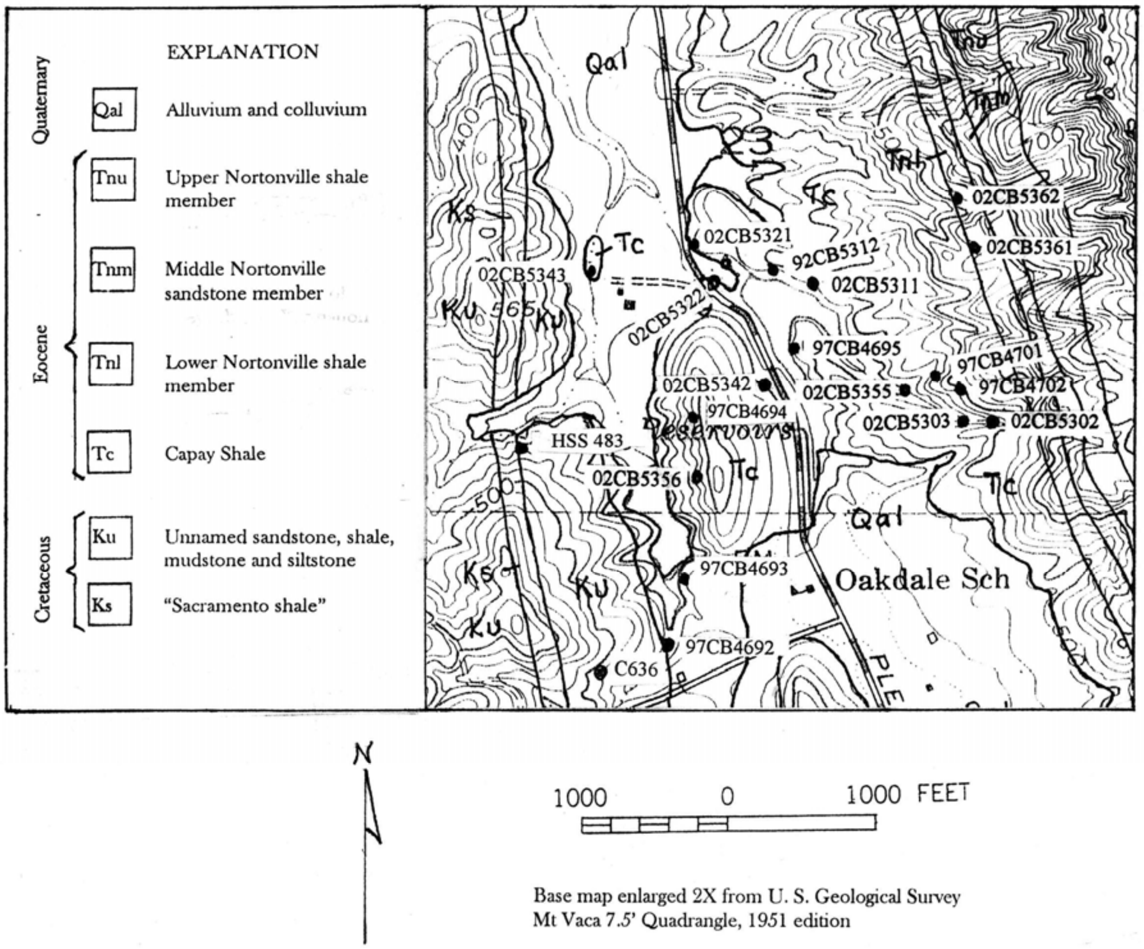


Figure 10. Locality map for the Oakdale School area and reference section for the Capay Shale. This map is a short distance north of figure 9.

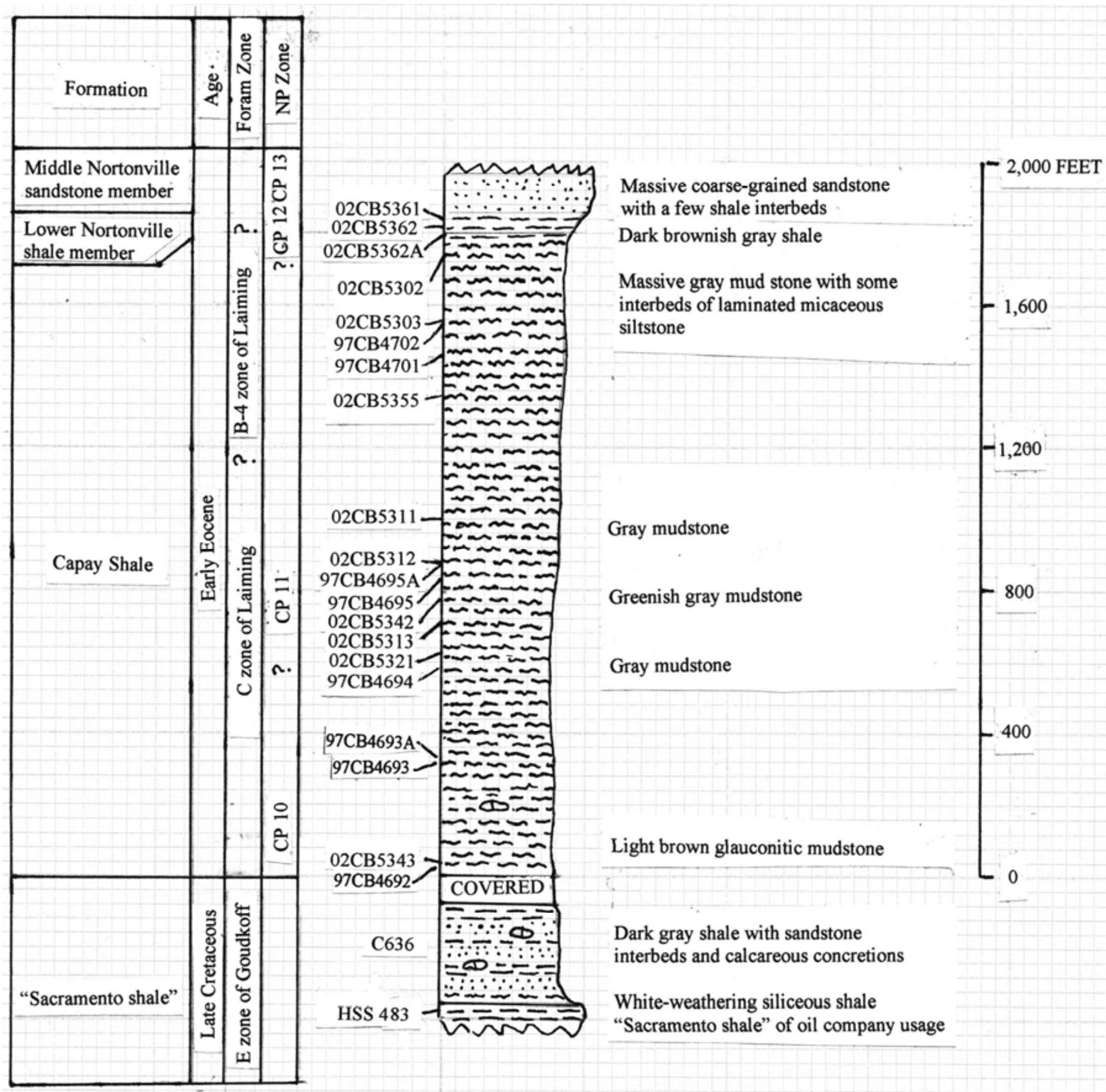


Figure 11. Stratigraphic column near Oakdale School. This column is generalized and constructed from attitudes on the map by Sims and others (1973) and from additional fieldwork.

Two samples collected by Exxon and Chevron geologists pin down the age of the "Sacramento" shale north of Vaca Valley near Oakdale School (fig. 10). Sample HSS 483 from the "Sacramento" shale is Late Cretaceous, probably lower E zone of Goudkoff (1945), according to A. Almgren. Sample C636 found in a gully about 1,600 feet southwest of Oakdale School (fig. 10) has foraminifers correlative with the Late Cretaceous E zone of Goudkoff, according to Brabb and Parker (2005). This dark-gray shale sample is about 100 feet above the "Sacramento" shale and less than 200 feet below the concealed base of a shale with Eocene fossils (see fig. 11). No samples younger than Late Cretaceous E zone were found in the Cretaceous rocks of the Vaca Valley area.

Paleocene Rocks in Vaca Valley

Paleocene rocks are generally poorly exposed in the Vaca Valley area, but the general lithology, thickness, and age were established from small outcrops in the hills between Alamo Creek and an unnamed reservoir about 3 miles to the north (fig 9). Glauconitic sandstone, probably less than a few tens of feet thick and with late Paleocene CP4 coccoliths crops out at 03CB5341. Nearly a mile north of 03CB5341, at 97CB4684, a gray mudstone below a glauconite sandstone contains late Paleocene CP7 coccoliths. No upper mudstone unit mapped by Sims and others (1973) could be found.

Chevron Petroleum Company kindly made available their foraminifer slides and notes for three samples they consider Paleocene on the west side of Vaca Valley (fig. 9). A. Almgren confirmed a late Paleocene E zone of Laiming (1940) age for samples 11100, 11101, and 11104. He also collected sample AAWC-40 in about the same stratigraphic position as the Chevron samples and obtained a similar E zone age.

Two samples from mudstone overlying the Paleocene rocks show that the Paleocene is quite thin, probably less than 100 feet thick, much thinner than Paleocene strata at lower Cement Hill. Glauconitic mudstone at 03CB5333 (fig. 9) has early Eocene CP11 coccoliths. Sample 11106 collected 800 feet north of Benchmark 328 is early Eocene D zone of Laiming (1940), according to A. Almgren, and restricts the areal extent of Paleocene rocks to a thin band along the west side of Vaca Valley. No contact with the underlying rocks of Cretaceous age has yet been seen.

A much thicker outcrop width of Paleocene rocks is shown on the map by Sims and others (1973) in the Oakland School area (fig. 10), but these rocks are of Eocene age, as documented below. No rocks of Paleocene age have been found north of locality 97CB4684 (fig. 9) where the Capay shale of Eocene age is believed to rest disconformably or unconformably on Cretaceous rocks, similar to the situation at lower Cement Hill. We support the unpublished mapping by Chevron geologists which shows Paleocene rocks as missing north of the locality where 97CB4684 was collected.

Eocene Rocks in Vaca Valley

About 400 feet of Eocene shale on the east side of Vaca Valley southeast of Bucktown (fig. 9) and adjacent to Ulatis Creek was named informally the “Vacaville shale” in a thesis by Boyd (1949). This informal name was maintained in a later publication of his thesis (Boyd, 1998). He estimated that 1,600 feet or more of unnamed rocks lie beneath the Vacaville shale and alluvium in the central part of Vaca Valley, and about 1,000 feet of unnamed sandstone and shale are on the western side. The lower part of Boyd’s “Vacaville shale” was used by Mallory (1955) as the type for his Ulatisian Stage.

The rocks reported as concealed in Boyd’s thesis area are exposed in a nearly continuous shale section near Oakdale School (fig. 10) where the name Capay Shale was used by Sims and others (1973). A stratigraphic column was constructed for this area (fig. 11) based on attitudes and contacts on the Sims map, as modified by the reduced thickness and absence of the Paleocene rocks reported above, and additional fieldwork. The Capay Shale is estimated to be about 1,800 feet thick in this section, compared to 1,938 feet in a similar unpublished section constructed by Chevron Petroleum geologists.

The oldest sample in the Capay Shale is from a glauconitic mudstone at locality 03CB 5343 near the base of the exposed section where coccoliths are early Eocene CP10. Foraminifers at 97CB4692, 97CB4693 and 97CB4693A are not distinctive but suggest an early Eocene to possibly middle Eocene age according to K McDougall (see fig. 11 and table 2). McDougall also believes that the faunas were deposited at lower bathyal depths or abyssal depths. No nannoplankton were recovered from these samples.

Rich foraminiferal faunas (table 2) and nannoplankton floras were recovered from greenish-gray mudstone in the middle part of the Capay. Faunas at localities 97CB4694, 97CB4695 and 97CB4695A are correlative with the Penutian Stage and were deposited at baythal or abyssal depths, according to K McDougall. Early Eocene CP11 coccoliths were recovered at 02CB5342, 03CB5312, 97CB4695A, and 03CB5311. The last locality plus 02CB5321, 02CB5313, and 03CB5355 have foraminifers correlative with the B-4 zone of Laiming (1940), according to A. Almgren.

The upper part of the Capay at localities 97CB4701, 97CB4702, 93CB5303, and 93CB5302 has early Eocene CP11 coccoliths. Foraminifer faunas diagnostic of the late Penutian to early Ulatisian stage, according to K McDougall, were recovered at at 97CB4701 and 97CB4702 and are believed to have been deposited at lower bathyal depths . Sample 02CB5355 has foraminifers correlative with the B-4 zone of Laiming (1940), according to A. Almgren.

The Capay Shale, therefore, has similar faunas and floras to those in lower Cement Hill. However, the Cement Hill section has much more sandstone whereas the Paleocene sandstone has been removed by erosion or was never deposited in the Oakdale School area.

The Capay Shale is overlain by the lower informal shale member of the Nortonville member of the Kreyenhagen formation, according to Sims and others (1973). This name is probably not appropriate, however, because the Nortonville and Kreyenhagen formations were deposited in different basins and are only partly the same age. The lower shale member is overlain in turn by the informal sandstone member and an upper shale member. The shale-on-shale contact of two formations is difficult to recognize, but the uppermost Capay beds are gray mudstone whereas the shale in the Nortonville is dark-brownish-gray mudstone.

Table 2A. Foraminifera collected in the Vaca Valley area. Identified by Kristin McDougall.

Mf numbers	Mf9110	Mf9108	Mf9109	Mf9111	Mf9112	Mf9113	Mf9114	Mf9115	Mf9116	Mf9117	Mf9118	Mf9119
Field numbers	97CB4691	97CB4683	97CB4684	97CB4692	97CB4693	97CB4693A	97CB4694	97CB4695	97CB4695A	97CB4701	97CB4702	97CB4703
Alabamina wilcoxensis Toulmin	-	-	-	-	-	-	X	-	-	-	-	-
Ammodiscus incertus (d'Orbigny)	-	-	X	X	-	X	-	-	-	-	-	-
Ammodiscus pennyi Cushman and Jarvis	-	-	X	-	-	-	-	-	-	-	-	-
Ammodiscus spp.	-	-	X	-	-	-	-	-	-	-	-	-
Amphimorphina jenkinsi (Church)	-	-	-	-	-	-	-	X	-	-	-	-
Anomalinoides capitatus (Gumbel)	-	-	-	-	-	-	X	X	-	-	-	-
Anomalinoides rubiginosus (Cushman)	-	-	X	-	-	-	-	-	-	-	-	-
Anomalina garzaensis Cushman and Siegfus	-	-	-	-	-	-	X	X	-	-	-	-
Aragonia aragonensis (Nuttall)	-	-	-	-	-	-	X	X	-	-	-	-
Bathysiphon eocenicus Cushman and Hanna	-	-	X	-	-	-	-	X	-	-	X	X
Bathysiphon spp.	X	-	-	X	-	-	-	-	-	X	-	-
Bolivina explicata lodoensis Mallory	-	-	-	-	-	-	-	X	-	-	-	-
Bolivina midwayensis Cushman	-	-	X	-	-	-	X	-	-	-	-	-
Bolivina midwayensis Cushman of Mallory	-	-	-	-	-	-	X	-	-	-	-	-
Bolivina spp.	-	-	-	-	-	-	-	X	-	-	-	-
Bulimina alazaensis Cushman	-	-	-	-	-	-	X	X	-	X	X	-
Bulimina arkadelphina Cushman and Parker	-	-	X	-	-	-	-	-	-	-	-	-
Bulimina cacumenata Cushman and Parker	-	-	X	-	-	-	-	-	-	-	-	-
Bulimina macilenta Cushman and Parker	-	-	-	-	-	-	-	-	X	-	X	-
Bulimina trinitatensis Cushman and Jarvis	-	-	X	-	-	-	X	-	-	-	-	-
Bulimina tuxapamensis Cole	-	-	X	-	-	-	-	X	-	-	-	-
Ceratobulimina perplexa (Plummer)	-	-	-	-	-	-	-	-	-	-	X	-
Chilostomella cylindroides Reuss	-	-	-	-	-	-	-	-	-	X	X	-
Chilostomella ovoidea Reuss	-	-	-	-	-	-	X	-	X	-	-	-
Chrysalongonium elongatum Cushman and Jarvis	-	-	-	-	-	-	X	X	X	-	-	-
Chrysalogonium lanceolum Cushman and Jarvis	-	-	-	-	-	-	X	-	-	-	-	-
Chrysalongonium spp.	-	-	X	-	-	-	-	-	-	-	-	-
Chrysalogonium tenuicostatum Cushman and Bermudez	-	-	-	-	-	-	-	-	X	-	-	-
Cibicides felix Martin	-	-	-	-	-	-	-	-	X	-	-	-
Cibicides pseudoungerianus (Cushman)	-	-	-	-	-	-	-	-	-	-	X	-
Cibicides spp.	-	-	X	-	X	-	X	X	-	-	X	-
Cibicidoides alleni (Plummer)	-	-	X	-	-	-	-	-	-	-	-	-
Cibicidoides dayi White	-	-	X	-	-	-	-	-	-	-	-	-
Cibicidoides eocaenus (Gumbel)	-	-	-	-	-	-	X	X	X	X	-	-
Cibicidoides eponidiformis (Martin)	-	-	-	-	-	-	-	X	X	-	X	-
Cibicidoides praemundulus Berggren and Edwards	-	-	-	-	-	-	-	X	-	-	-	-
Cibicidoides subspiralis (Nuttall)	-	-	-	-	-	-	X		X	X	-	-
Cibicidoides venezuelanus (Nuttall)	-	-	-	-	-	-	X	X	X	X	X	-
Clavulina anglica (Cushman)	-	-	X	-	-	-	X	X	X	-	-	-
Cyclammina pacifica Beck	-	-	-	-	X	-	-	-	X	X	X	-
Cyclammina samanica Berry	-	-	-	-	-	X	-	-	-	-	-	-
Dentalina colei Cushman and Dusenbury	-	-	-	-	-	-	X	X	X	-	-	-
Dentalina communis (d'Orbigny)	-	-	-	-	-	-	X		X	-	-	-
Dentalina consobrina (d'Orbigny)	-	-	-	-	-	-	X	X	-	X	-	-
Dentalina soluta Reuss	-	-	-	-	-	-	X	-	-	-	-	-
Dentalina spp.	-	-	-	-	-	-	-	X	-	-	-	-
Dorothia principiensis Cushman and Bermudez	-	-	-	-	-	-	X	-	-	-	-	-
Dentalina pseudoaculeata Olsson	-	-	X	-	-	-	-	-	-	-	-	-
Dentalina pseudobliquestriata (Plummer)	-	-	X	-	-	-	-	-	-	-	-	-

Table 2B. Foraminifera collected in the Vaca Valley area. Identified by Kristin McDougall.

Mf numbers	Mf9110	Mf9108	Mf9109	Mf9111	Mf9112	Mf9113	Mf9114	Mf9115	Mf9116	Mf9117	Mf9118	Mf9119
Field numbers	97CB4691	97CB4683	97CB4684	97CB4692	97CB4693	97CB4693A	97CB4694	97CB4695	97CB4695A	97CB4701	97CB4702	97CB4703
Discorbis bantoni Mallory	-	-	-	-	-	-	-	X	-	-	-	-
*Discorbis infrequens*Plummer	-	-	X	-	-	-	-	-	-	-	-	-
Dorothia bulleta (Carsey)	-	-	X	-	-	-	-	-	-	-	-	-
Eponides dorfi Toulmin	-	-	-	-	-	-	X	-	-	-	-	-
Eponides mexicanus (Cushman)	-	-	-	-	-	-	-	-	-	X		-
Eponides plummerae Cushman	-	-	X	-	-	-	-	-	-	-	-	-
Fissurina spp.	-	-	X	-	-	-	-	-	-	-	-	-
Galvinella whitei (Martin)	-	X	-	-	-	-	-	-	-	-	-	-
Gaudrina coalingensis Cushman and Hanna	-	-	X	-	-	-	X	X	x	X	X	-
Globulina globosa (von Munster)	-	-	-	-	-	-	X	-	-	-	-	-
Globulina spp.	-	-	-	-	-	-	X	-	-	-	-	-
Globocassidulina globosa (Hantken)	-	-	X	-	-	-	-	X	-	-	-	-
Glomospira charoides (Jones and Parker)	-	-	X	-	-	-	-	-	-	-	-	-
Gonatosphaera eocenica Mallory	-	-	-	-	-	-	-	-	X	-	-	-
Gyroidina orbicularis d'Orbigny	-	-	-	-	-	-	-	X	-	-	X	-
Gyroidina soldanii d'Orbigny	-	-	-	-	-	-	X	X	X	X		-
Gyroidina spp.	-	-	-	-	-	-	-	-	-	-	X	-
Gyroidinoides globosa (Hagenow)	-	X	X	-	-	-	-	-	-	-	-	-
Hanzawaia blanpiedi (Toulmin)	-	-	X	-	-	-	-	-	-	-	-	-
Hanzawaia mauricensis (Howe and Roberts)	-	-	-	-	-	-	X	-	-	-	-	-
Haplophragmoides eggeri Cushman	-	-	-	-	X	X	-	-	-	-	-	-
Haplophragmoides glabra Cushman and Waters	-	-	-	X	-	-	-	-	-	-	-	-
Haplophragmoides spp.	-	-	X	-	-	-	-	-	-	-	-	-
Hoeglundina ecoenica Nuttall	-	-	X	-	-	-	-	-	X	X	X	-
Karreriella elongata Mallory	-	-	X	-	-	-	-	-	-	-	-	-
Karriella horrida Mjatluk			X	X	X	-	-	-	-	-	-	-
Lagena semistriata Williamson	-	-	-	-	-	-	X	-	-	-	-	-
Lagena spp.	-	-	X	-	-	-	X	-	-	-	-	-
Lenticulina altolimbatus (Gumbel)	-	-	-	-	X	-	-	-	X	X	X	-
Lenticulina carolinianus Cushman	-	-	-	-	-	-	-	-	-	-	X	-
Lenticulina inornata (d'Orbigny)	-	-	-	-	-	-	X	-	-	-	-	-
Lenticulina pseudocultratus (Cole)	-	-	-	-	-	-	-	X	X	-	-	-
Lenticulina pseudovortex (Cole)	-	-	X	-	-	-	-	X	X	X	X	
Lenticulina rosttus	-	-	X	-	-	-	X	-	-	-	-	-
Lenticulina spp.	-	-	-	-	X	-	-	X	X	X	X	-
Lenticulina terryi (Coryell and Embich)	-	-	-	-	-	-	-	-	X			-
Lenticulina turbinatus (Plummer)	-	-	-	-	-	-	X		-	-	-	-
Lenticulina ulatisensis Boyd	-	-	-	-	-	-	-	-	X	X	X	-
Lenticulina vortex (Fitchell and Moll)	-	-	-	-	-	-	-	X	-	-	-	-
Loxostomoides applinae (Plummer)	-	-	-	-	-	-	-	X	X	-	-	-
Marginulina exima Neugeboren	-	-	-	-	-	-	X	-	-	-	-	-
Marginulina glabra d'Orbigny	-	-	-	-	-	-	X	X	-	-	-	-
Marginulina spp.	-	-	-	-	-	-	-	X	-	-	-	-
Martinotiella eocenica Cushman and Bermudez	-	-	X	-	-	-	-	-	-	-	-	-
Neoflabellina semireticulata (Cushman and Jarvis)	-	-	-	-	-	-	-	X		-	-	-
Nodosarella atlantisae hispidula (Cushman)	-	-	-	-	X	-	X	-	X	-	-	-
Nodosaria deliciae Martin	-	-	-	-	-	-	-	-	-	-	X	-
Nodosaria latejugata Gumbel	-	-	X	-	-	-	X	X	X	X	X	-
Nodosaria longiscata d'Orbigny	-	-	X	-	-	-	-	X	-	X	X	-
Nodosaria macneili Cushman	-	-	-	-	-	-	X	-	-	-	-	-
Nodosaria spp.	-	-	-	-	-	-	-	X	-	-	-	-

Table 2C. Foraminifera collected in the Vaca Valley area. Identified by Kristin McDougall.

Mf numbers	Mf9110	Mf9108	Mf9109	Mf9111	Mf9112	Mf9113	Mf9114	Mf9115	Mf9116	Mf9117	Mf9118	Mf9119
Field numbers	97CB4691	97CB4683	97CB4684	97CB4692	97CB4693	97CB4693A	97CB4694	97CB4695	97CB4695A	97CB4701	97CB4702	97CB4703
Pleurostomella spp.	-	-	X	-	-	-	-	-	-	-	-	-
Praebulimina reussi (Morrow)	-	-	X	-	-	-	X	-	-	-	-	-
Pseudonodosaria conica (Neugeboren)	-	-	-	-	-	-	-	X	-	-	X	-
Pseudonodosaria manifesta (Reuss)	-	-	X	-	-	-	-	-	-	-	-	-
Pullenia eocenica Cushman and Siegfus	-	-	-	-	-	-	X	-	-	-	-	-
Pullenia quinqueloba (Reuss)	-	-	-	-	-	-	-	-	X	-	-	-
Pullenia salisburyi Stewart and Stewart	-	-	X	-	-	-	-	X	-	-	-	-
Pyramidina rudita (Cushman and Parker)	-	-	-	-	-	X	X	-	-	-	-	-
Quinqueloculina spp.	-	-	X	-	-	-	-	-	-	-	X	-
*Rhabdammina eocenica*Cushman and Hanna	-	X	-	-	-	-	-	-	-	-	-	-
Reophax pilulifera Brady	-	-	-	-	-	-	-	-	-	X		-
Reussella elongata (Terquem)	X	-	X	-	-	-	-	-	-	-	-	-
Saccammina spp.	-	-	-	-	-	-	X	-	-	-	-	-
Saracenaria spp.	X	-	X	X	X	X	-	-	-	-	-	-
Silicosigmoilina californica Cushman and Church	-	-	-	-	-	-	X	-	-	-	-	-
Siphonia wilcoxensis Cushman	-	-	-	-	-	-	X	X	-	X	-	-
Spiroloculina lamposa Hussey	-	-	-	-	-	-	X	X	X	-	-	-
Spiroloculina texana Cushman and Ellisor	-	-	X	-	-	-	-	-	-	-	-	-
Spiroplectammina directa (Cushman and Siegfus)	-	-	-	-	X	X	X	-	-	-	-	-
Spiroplectammina richardi Martin	-	-	X	-	-	-	-	X	X	-	X	-
Stensioina beccariiformis (White)	-	-	-	-	-	-	X	-	-	-	-	-
Stilostomella adolphina (d'Orbigny)	-	-	-	-	-	-	X	X	X	-	X	-
Stilostomella lepidula (Schwager)	-		X	-	-	-	-	-	X	X	X	
Stilostomella paleocenica (Cushman and Todd)	-	-	-	-	-	X	X	-	-	-	-	-
Textularia adalta Cushman	-	-	X	-	X	X	-	-	-	-	-	-
Textularia spp.	-	-	-	-	-	-	-	-	X	-	X	-
Trifarina advena californica Mallory	-	-	-	-	-	-	-	X	X	-	-	-
Tritaxilina colei Cushman and Siegfus	-	-	X	X	X	X	-	-	X	-	-	-
Trochammina globigeriniformis (Parker and Jones)	-	-	-	-	-	-	X	-	-	-	-	-
Turrilina brevispira ten Dam	-	-	-	-	-	-	-	X	-	-	-	-
Uvigerina alabamensis Cushman and Garrett	-	-	-	-	-	-	-	-	-	X	X	-
Uvigerina elongata Cole	-	-	-	-	-	-	-	X	-	-	-	-
Uvigerina lodoensis miriamae Mallory	-	-	X	-	-	-	-	X	X	-	-	-
Uvigerina spp.	-	-	-	-	X	-	X	-		-	-	-
Vaginulinopsis nudicostata (Cushman and Hanna)	-	-	X	-	-	-	-	X	X	-	-	-
Vaginulinopsis longiformis (Plummer)	-	-	-	-	-	-	X		-	-	-	-
Vaginulinopsis saundersi (Hanna and Hanna)	-	-	X	-	-	-	-	-	-	-	-	-
Vaginulinopsis tuberculata (Plummer)	-	-	X	-	-	-	X	-	-	-	-	-
Vaginulinopsis vacavillensis Cushman and Hanna	-	-	-	-	-	-	-	-	-	X	X	-
Vaginulinopsis verruculosa Martin	-	-	-	-	-	-	X	X	X	-	-	-
Valvulineria jacksonensis welcomensis Mallory	-	-	-	-	-	-	-	-	-	-	-	-

Four samples were collected in the lower shale member of the Nortonville shale member. Localities 02CB5361 and 02CB5362 (fig. 10) and 02CB5362C (not on fig. 10 but 3 feet above 02CB5362) all contain middle Eocene CP13 coccoliths. Sample 02CB5362A was collected 3 feet below 5362 and it contains middle Eocene CP12 coccoliths. Locality 97CB4705 2.5 miles north of 02CB5362 in Pleasants Creek and 1,800 feet northeast of Pioneer Ranch (not on map) is CP13. This sample is in the uppermost part of the Nortonville shale member.

Sims and others (1973) mapped the lower member of the Nortonville shale in a continuous band southward from the Oakdale School area to the area of Boyd's thesis about one-half mile southeast of Bucktown (fig. 9). The lower shale member of the Nortonville is the upper part of the type "Vacaville" shale of Boyd. In Boyd's area (1998, fig. 1), the "Vacaville" shale is overlain by the "Dunns Peak" sandstone, which in turn is overlain by more shale assigned to the Markley Formation. No fossils were found in the "Dunns Peak" sandstone and no distinctive fossils have yet been found in the overlying so-called Markley shale near Dunns Peak.

The upper part of the type "Vacaville shale" has a 3-foot thick pebbly and glauconitc sandstone bed that marks a change from bluish-gray mudstone to chocolate-brown mudstone, a change similar to that found in the Oakdale School area between the Capay and Nortonville shales. The glauconitic sandstone also marks a substantial change in the character of the fauna and in the age, from early Eocene B-2 to B-4 zone of Laiming below the glauconite to middle Eocene A-2 zone of Laiming above the glauconite. This observation makes the use of the term "Vacaville shale" superfluous. The lower part below the glauconite is Capay Shale. The upper part above the glauconitic sandstone is the lower part of the Nortonville shale member.

Unfortunately, the use of the rock unit Capay Shale is a misnomer, because most of the Capay in the type area is sandstone and conglomerate, according to Boyd (1956), Baker (1975), and Crook and Kirby (1935). The type area for the Capay is in the Brooks 7.5' quadrangle, about 6 miles west of the town of Capay (fig. 2, area 5) and about 22 miles north of Oakdale School. However, the Capay is widely recognized as a shale unit of early Eocene age in subsurface well correlations throughout this part of California. Solution of this problem is beyond the scope of this report, other than to suggest that the Capay of the Oakdale School area might be used as a supplementary reference section to define and correlate surface exposures of the Capay Shale.

Summary for Vaca Valley Area

Paleocene rocks in Vaca Valley consist of glauconitic sandstone and mudstone less than 100 feet thick resting on Late Cretaceous shale beneath and overlain by Capay early Eocene glauconitic mudstone. The rocks are much thinner and lack the mollusks found in the lower Cement Hill area. In the Oakdale School area, the Paleocene rocks were never deposited or have been removed by erosion or faulting.

Is the Name Martinez Formation Appropriate ?

The lower Cement Hill localities are only a few tens of kilometers north of Martinez (fig. 1, area 2) where this formation was first named by Whitney (in Gabb, 1869, p. xiii) and considered to be Cretaceous. The subsequent evolution of the name is well described by Smith (1957, p. 130-135) and will not be repeated here. The term has been used mostly as a stage for rocks with Paleocene fossils, not as a lithologic unit. As Smith (1957, p. 134) points out, "no really satisfactory description of a type Martinez formation has ever been given." Even the use of "Martinez Formation, restricted" on the map by Brabb, Sonneman and Switzer (1971) and Sims and others (1973) is not good practice because of likely confusion with the Martinez Stage.

Weaver (1953) used the name Vine Hill sandstone as a substitute for Martinez Formation in the vicinity of Martinez. This glauconitic sandstone and minor siltstone has abundant mollusks including *Turritella pachecoensis* of Paleocene age indicating that it has similar lithology and is correlative with the rocks at Cement Hill and Vaca Valley. However, enough differences in the stratigraphic succession and detailed lithology in the two areas warrant caution in extending the Vine Hill to the Cement Hill and Vaca Valley areas.

Conclusions

Unnamed sandstone and siltstone of late Paleocene age with gastropods of the Martinez Stage and foraminifers correlative with the E zone of Laiming (1940) are probably faulted against sandstone of Late Cretaceous age, F-2 zone of Goudkoff (1945) in the western part of lower Cement Hill. In the eastern part of lower Cement Hill, overturned siliceous mudstone locally called "Sacramento" shale contains radiolarians correlative with the Late Cretaceous Campanian Stage, Late Cretaceous coccoliths, and foraminifers correlative with the E zone of Goudkoff (1945). These rocks are overlain by overturned glauconitic sandstone and siltstone with late Paleocene CP4 coccoliths. Reconstruction of the Tertiary section before it was faulted suggests that the late Paleocene is represented mainly by sandstone and siltstone about 500 feet thick, and the early Eocene section has about 1,500 feet of sandstone, siltstone and mudstone with CP10 and CP10/11 coccoliths, and about 100 feet of mainly shale with CP11 coccoliths.

In contrast, late Paleocene sandstone and siltstone in Vaca Valley are only a few tens of feet thick and overlie Late Cretaceous E zone shale. Almost all the Eocene rocks in Vaca Valley are mudstone and shale, lacking the sandstone present in lower Cement Hill. Although the thickness of the Eocene rocks in both areas is comparable, the Vaca Valley section has mostly CP10 coccoliths whereas the lower Cement Hill section has mainly CP11 coccoliths. We conclude that the Paleocene and Eocene rocks in Vaca Valley are not simply offset by lateral faulting from lower Cement Hill, but must have originated in different parts of the depositional basin.

Work by K McDougall (see tables 1 and 2 of this report) on 18 samples from lower Cement Hill and Vaca Valley has provided a list of at least 202 benthic foraminifer species. The diversity and abundance of this fauna must compare favorably with other Eocene and Paleocene areas in California. Although lower Cement Hill is no longer exposed, the Vaca Valley will provide challenges for paleontologists for decades to come. We took mainly small samples to document the age of the different geologic units. A project to document the character of the faunas would probably double or triple the number of species that could be collected.

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