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THE EL CIEN FORMATION, STRATA OF OLIGOCENE AND EARLY MIOCENE AGE IN BAJA CALIFORNIA SUR

*Shelton P. Applegate**

ABSTRACT

A new stratigraphic unit, the El Cien Formation, is proposed for the beds surrounding and to the east of El Cien, Baja California Sur. The historic and stratigraphic reasons for this designation are discussed. The formation is divided into three members: the Cerro Tierra Blanca Member, the San Hilario Member, and the Cerro Colorado Member. The paleontological evidence suggests a Zemorrian-Saucesian age or late Oligocene-early Miocene designation for this new formation.

RESUMEN

Una nueva unidad estratigráfica, la Formación El Cien, se propone para las capas de los alrededores y al oriente de El Cien, Baja California Sur. Se discuten las razones históricas y estratigráficas para tal designación. La formación ha sido dividida en tres miembros: Miembro Cerro Tierra Blanca, Miembro San Hilario y Miembro Cerro Colorado. La evidencia paleontológica sugiere una edad del Zemorriano-Saucesiano o del Oligoceno tardío-Mioceno temprano para esta nueva formación.

INTRODUCTION

This paper is the result of several years of field work in the El Cien area. Field studies were carried on from 1974 to 1983 in the area east of the transpeninsular highway.

Most of the work was done in the summer or early fall, the time of hottest weather when dry roads make most of the area accessible.

Abbreviations:

Ma B.P. - millions of years before present

IGM - Instituto de Geología, Universidad Nacional Autónoma de México

LACM - Los Angeles County Museum

UCMP - University of California Museum of Paleontology

THE MONTEREY PROBLEM IN BAJA CALIFORNIA SUR

In 1915, while working with a Swiss colonization company's expedition in Baja California, Arnold Heim discovered strata which he tentatively correlated with the Monterey Formation of California, named by Blake (1856) for beds of diatomaceous and siliceous shale near the town of Monterey, California. The southernmost exposure of the Monterey is in Orange County, California. Heim (1915, 1921, 1922) reported the presence of the Monterey in southern Baja California in several publications.

* *Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, Delegación Coyoacán, 04510 México, D.F.*

In 1921, Darton spent several months in Baja California and visited the localities of Heim and noted similarities with the Monterey Formation of southern California.

Beal (1948), publishing on field work done in 1921, recognized that the so-called Monterey beds in the La Purísima area (Figure 1) were of formational rank and named them the San Gregorio Formation. No type locality was designated but a composite section of exposures in Arroyo La Purísima was presented. This section presumably extends from 8 km below La Purísima to the arroyo's mouth near Rancho San Ramón. The name San Gregorio is thought to be taken from Rancho San Gregorio and not from Arroyo San Gregorio, although strata of this type exist in this arroyo. Rancho San Gregorio is between Arroyo San Gregorio and Arroyo La Purísima. In addition in this area there are two localities cited by Heim (1922) that have outcrops of the same formation (the Rancho San Ramón locality and the Arroyo Cadegomo outcrops). The Arroyo Cadegomo outcrops were reported by Heim (*op. cit.*) to extend from La Ventana up to Casas Viejas, a distance of 8 km. For these strata he used the term Ventana Shale, which could be the available name for the San Gregorio Formation, but he never formalized it.

In the La Purísima area the three authors gave some localities different names. On the La Purísima River for example, Heim (*op. cit.*) discovered beds near the abandoned Rancho San Ramón. Darton (1921) called this locality the west side of the Big Bend. Beal (1948) does not mention this locality but says that the

San Gregorio beds extend to tidewater. This is not true because the San Ramón locality is an isolated remnant below tidewater and no similar beds are exposed within several miles of tidewater's upper limit. The exact place where tidewater begins is easily seen and there is no indication that it has changed. Darton (*op. cit.*) refers to several places which must be a part of the Arroyo Cadegomo outcrops of Heim. These are: 9.6 km below La Purísima, 16 km below La Purísima and a few kilometers from tidewater. The tide today extends about 250 m upstream from the San Ramón locality.

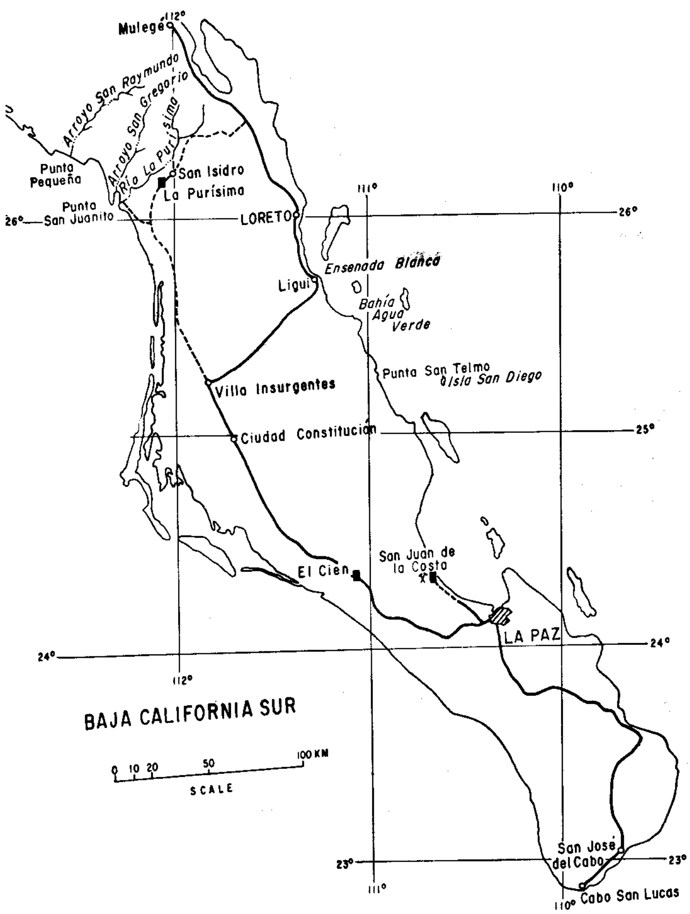

Figure 1.- Map showing the most important areas discussed within the text.

Hanna (1930) described the silicoflagellate *Rocella gemma* and said it came from Rancho San Gregorio near La Purísima. A ranch of this name is present between the San Ramón locality and Arroyo San Gregorio.

Other localities where the San Gregorio Formation has been found in the La Purísima area are given by Darton (*op. cit.*); along the valley of Arroyo San Gregorio for a kilometer or more; 16 km southwest of La Purísima (Purísima La Vieja); smaller outcrops in the same valley above Purísima La Vieja; and Arroyo San José and San Raimondi? (Raymundo) 56 km northwest of La Purísima.

Beal (1948) reported similar strata from 45 km northwest of La Purísima in Arroyo Cadeje, about 25 km from the coast, and two other localities that are in Arroyo San Raymundo.

Beal (*op. cit.*) gives this generalized section for the San Gregorio Formation in the Arroyo Purísima:

> " Feet
> 50 – Chocolate colored diatomaceous shale weathering white.
> 100 – Thin bedded greenish silicified shale weathering white.
> 200 – Greenish silicified shale.
> 350 Total. "

In our studies, we have discovered no area in which the outcrops fit Beal's (*op. cit.*) generalized section, although all these types of strata occur in the La Purísima area. The diatomites are, however, light tan. The thin bedded greenish silicified shale presumably refers to banded green and white tuffs. The greenish silicified shale may relate to the beds at the Rancho San Ramón locality (possibly the youngest beds in the sequence).

It is the present author's opinion that the San Gregorio Formation of Beal is valid, although a more precise type section would be useful. The long distance and lithologic differences are sufficient to warrant a separate name for these beds which have little in common with the Monterey Formation of California, a conclusion reached by Beal 36 years ago.

Since Beal's 1948 publication, Mexican and United States geologists have continued to use the term Monterey for the beds near La Purísima, and much farther south, near San Hilario. Complicating the nomenclature, Mina (1957) suggested the hispanization of Monterey to Monterrey. Lozano (1975) followed this suggestion changing the spelling of the name in Baja California to Monterrey, but in his charts he uses Monte-rey. The spelling is of academic interest only for no one has suggested changing the spelling of Monterey, the U. S. formation, which is named for the town in California.

PAST WORK IN THE SAN HILARIO AREA

Heim (1915) reported strata 6.4 km west of San Hilario which he referred to the Monterey shale and mentioned the presence of *Globigerina* and the scales of Ganoids, which the present author believes that should have been teleosts. Heim thought that the strata at San Hilario were continuous with the underlying orbitoidal foraminiferal beds of the Tepetate Formation which he considered to be also on top of the same strata (Figure 2).

Darton (1921) stated: "In the vicinity of the oasis of La Purísima and San Hilario I found small exposures of strata so closely resembling the Monterey Formation

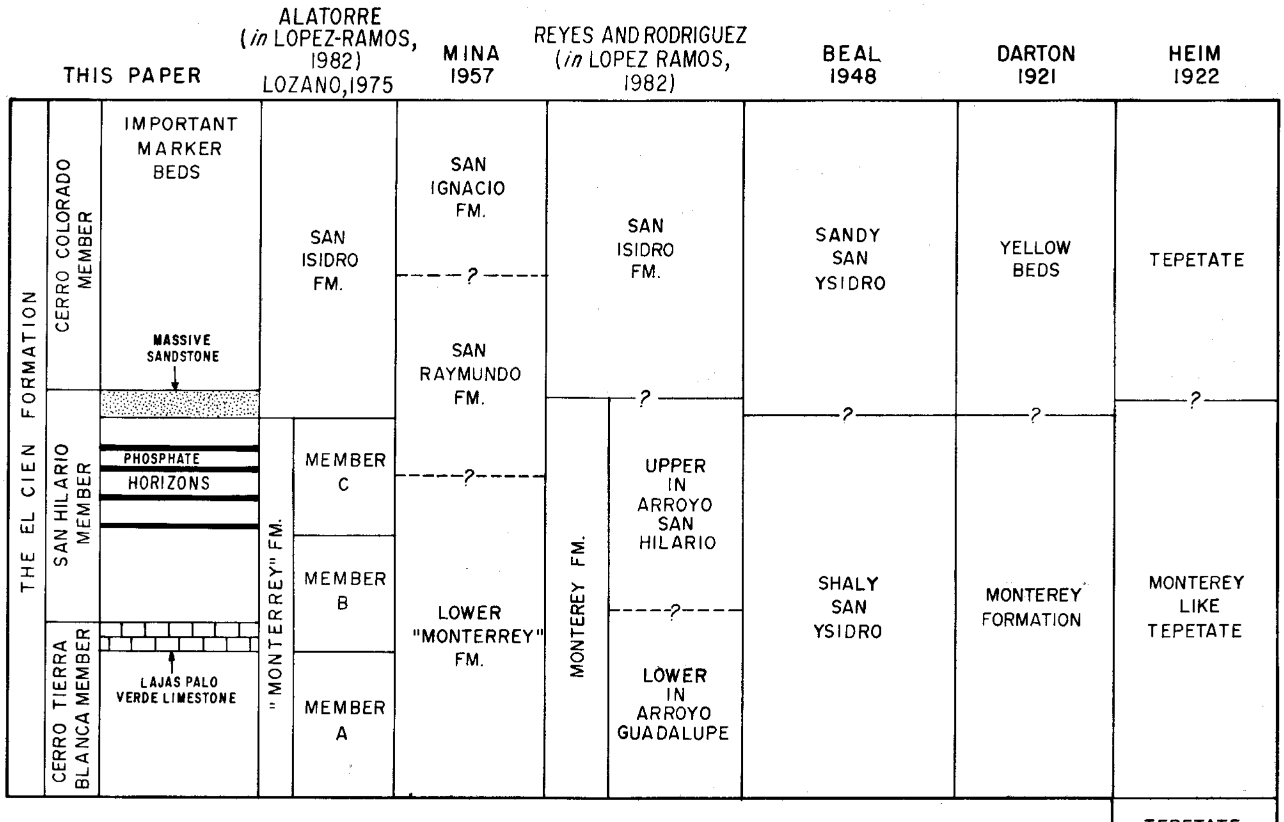

Figure 2.- The correlation of beds in El Cien area, by various authors.

of southern California that tentative correlation seems desirable". The beds in question are described as being "in an area of 2 or 3 miles, a short distance west of San Hilario and in small outcrops of steeply upturned beds appearing at intervals from a point a mile northwest of San Luis to a point 15 miles southeast of that place".

Beal (1948) stated that Heim in 1922 named the San Isidro Formation (which Beal spells Ysidro) for its exposure at the village of San Isidro, about 3.5 km northeast of La Purísima. Beal considered the San Hilario beds to be referable to the San Ysidro Formation with a lower shaly layer and upper sandy layer.

Darton (1921) referred to at least part of the San Isidro as the yellow beds, but did not consider the lower shale member exposed east of La Paz (perhaps meaning the La Paz quadrangle). Darton cited two exposures, one near San Luis, and another near San Hilario, and he further stated that the lower shale which he considered to be the Monterey Formation was mapped separately.

THE GEOLOGIC SECTIONS OF THE SAN HILARIO AREA

Heim (1922) described the following section from 4 km west of San Hilario, near the horse trail from El Tepetate.

1 - Siliceous shale about 20 m: base not visible grading into.

2 - Brown hard stratified sandstone with moulds of marine bivalves (*Chione*); thickness 2 to 3 m.

3 - Greenish, more or less sandy shale; thickness 50 to 100 m. The last unit 3 seems to be normally overlain by *Orthophragmina* sandstone.

Heim erroneously believed that unit 2 was overlain by the Tepetate Formation.

Heim's unit 3 is the basal member of the here proposed El Cien Formation, as it can be seen near the town of El Cien. The overlying hard brown stratified sandstone (unit 2) evidently refers to the marker sandstone at the top of the San Hilario Member of the El Cien Formation. The *Chione* is *Anadara vanderhoofi* Durham (1950) which is very common in this member. Unit 1 is the Cerro Colorado Member of the El Cien Formation and Heim thought these beds to belong to the Tepetate Formation.

Darton (1921) stated in the San Hilario area that the yellow beds rest on the uneven surface of the Monterey beds and that the Monterey rests on the Tepetate.

Beal (1948) gives the following section for beds on the west side of Cerro Colorado (the numbers of units are of the present author):

Unit	Description	Thickness (feet)
1 -	Terrace gravels (Pleistocene)	
	Ysidro sandstone member	
2 -	Shale, siliceous greenish gray with limestone beds	25

3 -	Sandstone, bluish gray, gravelly crossbedded	40
4 -	Sandstone, soft, fine, gray, in part fossiliferous	135
5 -	Sandstone, brown and white shale	25
6 -	Sandstone, hard, brown with fine conglomerate at top	3
	Ysidro shale member	
7 -	Shale, diatomaceous	60
8 -	Sandstone, hard, brown with fish and cetacean bones	2
9 -	Shale, diatomaceous and clay	60
10 -	Limestone, hard, white	2
11 -	Shale	50
12 -	Sandstone, gray fine diatomaceous shale beds	90
	Total:	492

Beal's (*op. cit.*) Cerro Colorado section differs somewhat from the one in this paper though similarities exist. However, his terrace gravels (unit 1) are a volcanic agglomerate, which is the so-called Comondú Formation. The shale (unit 2) is a porcellanite as is the lower gray bed (unit 3) which is a recognizable unit near the top of the presently proposed Cerro Colorado Member. The fossiliferous sandstone (unit 4) was not recognized in the present study, unless it refers to ichnofossils; however, unit 5 was correctly described. The conglomerate (unit 6) is the base of the proposed Cerro Colorado Member which extends in this area up to the Comondú Formation. The diatomaceous shale (unit 7) was not recognized, although it is felt that Beal and later authors misidentified tuffs as diatomites. The present author did not find a single diatomite bed in the Cerro Colorado section. Unit 8 is the major phosphate layer in the area, whereas unit 9, the "diatomaceous shale clay", is a water-laid tuff with some foraminifera. Unit 10 forms the top of the proposed Cerro Tierra Blanca Member, which is more complex than Beal's. The description of units 11 and 12 suggests that Beal did not describe the section below his unit 12 down to the underlying Tepetate Formation.

Beal's (*op. cit.*) description of the section at San Hilario compares poorly with the actual rock units. The present author can, for example, recognize the phosphate bed in his description but not the prominent sandstone bed at the top of the San Hilario Member.

Mina (1957) also divided these beds into two members: a lower member of 70 m thick consists of sandy mudstones, olive green in color, intercalated with yellow siltstones and fine grained quartz sandstone ranging in color from green to brown with a conglomerate at its base; an upper unit 30 m thick with silicified black mudstone is intercalated with diatomites with a thickness of 1.5 m.

Ojeda (1979) has an informative section illustrated at San Hilario. This section is capped by a black lava not exposed at Cerro Colorado. The pumice and black sand beds which are exposed correlate with his interpretation of the base of the Comondú. This is the same as the layers above the Cerro Colorado section. The present author places in the Cerro Colorado Member of the El Cien Formation the beds that Ojeda included in the San Isidro Formation. The base of these beds would be at the unconformity on the top of the sandstone bed and not at its base. The base of the San Hilario Member is on top of the silicified limestone below the phosphate beds, and above Ojeda's so-called diatomite beds. The beds below the top of limestone of what is here named Cerro Tierra Blanca Member match Ojeda's described section quite well.

Reyes and Rodríguez (*in* López-Ramos, 1982) divided the San Hilario beds into two members; a lower division in Arroyo Guadalupe consisting of mudstone which was said to be greatly folded and faulted and an upper division in Arroyo San Hilario which unconformably overlies with an angular relation of 3-6 degrees the lower member and consists of silicified black and gray mudstones showing a conchoidal fracture and contain fish scales and organic material; these beds vary in thickness from 60 to 110 m (Reyes and Rodríguez *in* López-Ramos, 1982).

Alatorre (*in* López-Ramos, *op. cit.*) divided the section into three members. The lowest, A, consists of a conglomerate, discordant on the Tepetate Formation, and extends up to a layer of limestone (which is a calcareous mudstone), which he called the Palo Verde flagstones after the hill at Palo Verde where they can be clearly observed. This member consists of mudstones and crumbly silty tuffs of a clear green color interstratified with thin beds of gypsum with a poorly preserved microfauna (not identifiable) and some clay sandstones of the same color. In Arroyo San Hilario, these layers were said to have two beds of diatomite with a thickness of 0.3 and 1.0 m, respectively. The present author did not recognize these beds.

The middle member, B, extends from the limestone layer to the base of the index bed, here considered to be the first layer of phosphate rock. It consists of mudstones of a green color, tuffaceous, with some horizons presenting abundant pelecypods interbedded with sandy biomicrites in thin beds. The odor is fetid when broken and the color is very dark green that weathers to a creamy white. The top beds are formed by black fissile mudstones with abundant lenses of intercalated phosphate with very thin beds of diatomite.

The upper member, C, is the most important from the economic point of view for it contains two beds of phosphate rock. The beds go from the base of the index bed to a conglomerate which constitutes the contact between the Monterey Formation and the overlying San Isidro Formation.

This member consists of gray black to cream shales, slightly silicified and fissile with a poorly preserved microfauna. The beds are thinly stratified with abundant transverse fractures filled with calcite and pyrite. Near its base there are two beds of phosphate. The uppermost phosphate bed lenses out to the northwest of Cerro Colorado and the aggregate maximum thickness of these beds is 1.7 m. Nevertheless, some of the test holes drilled into these layers show a thickness greater than 3 m. Alatorre (*in* López-Ramos, 1982) observed a horizon of diatomite 4 m thick in Cerro Palo Verde. He also mentioned in the area northwest of La Paz that there were abundant lenses of phosphate with a thickness, varying from 30 to 100 m.

The correlation chart of the El Cien area (Figure 2) shows the most important concepts of the present and past authors for rocks of the El Cien area. Hausback (1984) recognized the late Oligocene age of the San Gregorio Formation. He referred part of the San Hilario (El Cien) beds to this formation. The upper San Hilario beds are referred to the San Isidro Formation. The San Gregorio Formation is said to be lithologically different in the La Purísima region from the beds in the San Hilario area. The middle Miocene beds near the type locality for the San Isidro are said to lie below a basalt with a date of 14 Ma B.P. This study supports Hausback's general conclusions but restricts the San Isidro Formation to the La Purísima region. The San Hilario beds and perhaps the San Juan de La Costa beds referred to the San Isidro are here considered to be in the Cerro Colorado Member of the El Cien Formation and are of probable early Miocene age.

THE SAN GREGORIO PROBLEM

The present author does not believe that San Gregorio Formation occurs south of the Arroyo La Purísima nor are the San Hilario beds over 200 km to the south. The San Gregorio beds are on the western side of the peninsula while the El Cien Formation outcrops to the east with similar beds located at Punta San Telmo (San Carlos) and San Juan de La Costa, along the Gulf of California coast.

Lithologically, the San Gregorio Formation has little in common with the strata around San Hilario. For example, at the Canal Head locality east of La Purísima, the San Gregorio contains a massive thick diatomite, and a similar 4 m bed exists between La Ventana and Casas Viejas. Nothing similar exists in the El Cien area, and even though Beal (1948) reported diatoms from Aguajito, in a diligent search only white tuffs have been found. The greenish silicified shale at San Ramón does not, as far as known, have a counterpart in the El Cien Formation. Although the lower beds at El Cien and further south do include a banded green and white tuff reminiscent of the San Gregorio, the El Cien beds are much lighter in color.

In a conversation with Brian Hausback, of the University of California at Berkeley, he remarked that unpublished radiometric data suggest that the San Gregorio Formation may be the same age as the San Hilario beds. This was later published by Hausback (1984). The shark fauna from Rancho San Ramón (San Gregorio Formation) does not support this conclusion, although the San Ramón beds could be younger than those in the area where the samples for radiometric dating were obtained.

THE EL CIEN FORMATION

The El Cien Formation is here named for the town of El Cien, 100 km north of La Paz on Federal Highway 1. The formation is divided into three members: the Cerro Tierra Blanca Member, the San Hilario Member, and the Cerro Colorado Member. The type section for the El Cien Formation is on the west face of Cerro Colorado (Figure 1), 5 km northeast of Pénjamo. The formation consists of shales, tuffs, limestones, sandstones and conglomerates ranging in color from white to tan, and from green to brown. The El Cien Formation lies unconformably upon the Tepetate Formation of Cretaceous through Eocene age and is overlain by volcanics and sandstones which generally have been referred to the Comondú Formation but are much older than beds of this series at its type locality. The age of the El Cien Formation (Figure 3), based on paleontological, stratigraphical and radiometric data is Zemorrian-Saucesian or of late Oligocene-early Miocene age, ranging from 27 to 17 Ma B.P.

THE TYPE SECTION

The type section of El Cien Formation at Cerro Colorado (Figure 4) was measured in September 1982, starting with the highest point on Cerro Colorado, which is located about 5 km northeast of Pénjamo. El Cien is 143° to the southeast of Cerro Colorado. The section follows a line running 224° to the southwest. The first leg of the section from the top ran on this line to the marker limestone, the Palo Verde flagstones. The section was then offset following the limestone to Cerro Tierra Blanca, 250 m to the east, and then measured on a line that intersected the original 224° line. This was done to obtain the most complete exposures. The beds show an average dip of 16° toward 82° to the east. The top of this section appeared to be volcanic and terrestrial and is considered to be undifferentiated Comondú Formation, although radiometric dates from other areas suggest that these volcanics are lower Miocene. The unconformity at the base of these volcanic beds rests on a green porcellanite. The porcellanite marks the top of the El Cien Formation here, but detailed mapping in the general area may reveal higher beds.

Cerro Colorado Member.- This member (Figures 4, 5 and 6) rests conformably upon the upper sandstone of the San Hilario Member. The top bed in the Cerro Colorado Member is a green porcellanite upon which rests unconformably an agglomerate containing dark silts, sands, pebbles, cobbles and boulders up to 30 cm. The sands show some bedding in places. These beds are tentatively assigned to the Comondú Formation,

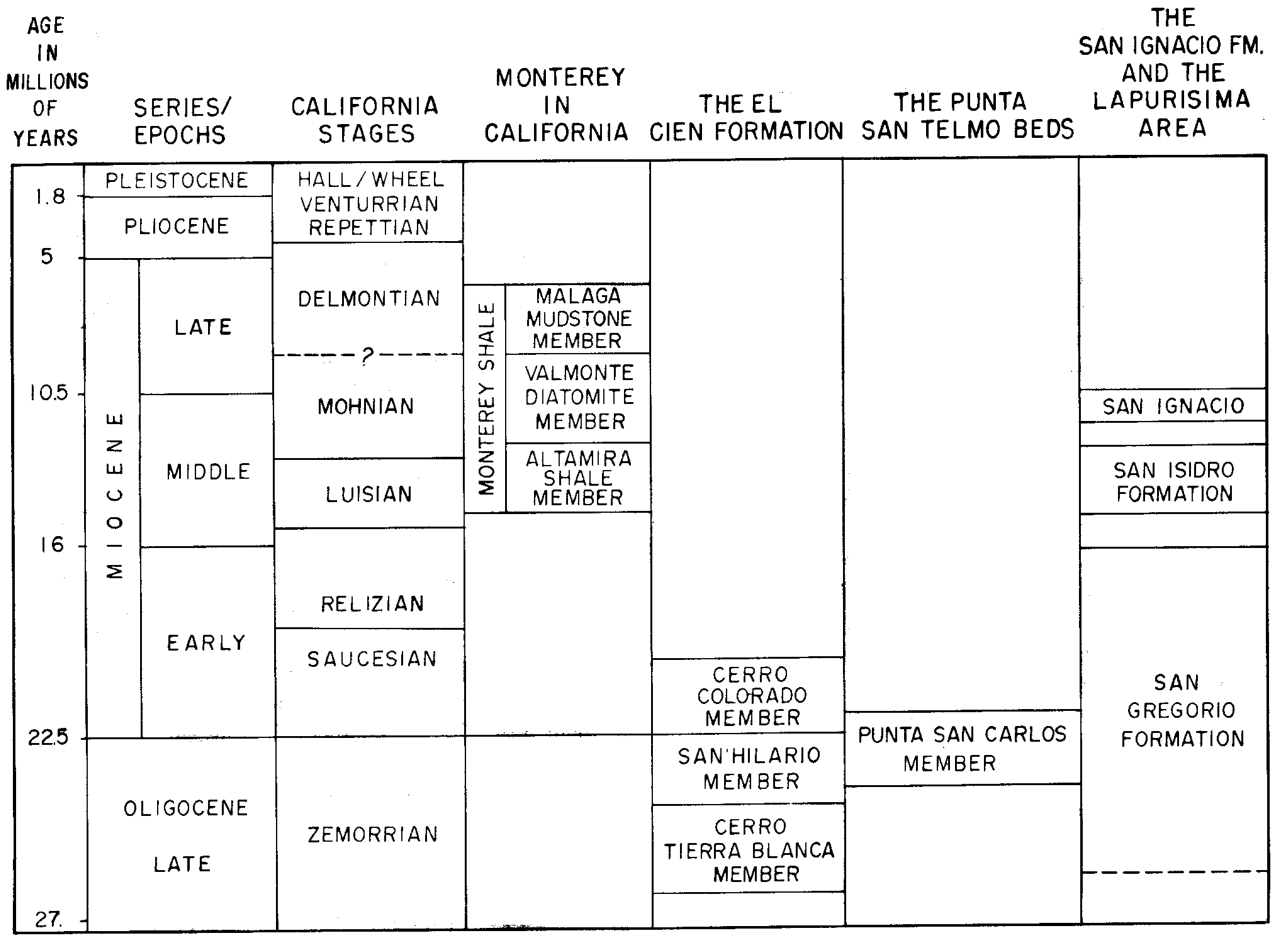

Figure 3.- Suggested time relationships in El Cien and related areas.

although in all probability they are much older than the late Miocene.

The basal unit of the Cerro Colorado Member is a pebble conglomerate which is fossiliferous and deposited under marine conditions as proven by *Anadara*? casts, sharks' and other fish teeth, and fish bone. Three other conglomerates occur in this section. The highest conglomerate also contains fish teeth and fish bone. This conglomerate is under the white tuff that is near the top of the section. Therefore, it is doubted if any of these lower beds was deposited in a purely fresh water environment. The basal conglomerate (Figure 4) is followed by a greenish tuffaceous sand with ichnolites in the form of burrows. Above this, another more platy bed also contains burrow. Next, a sandy tuffaceous limestone is overlain by another siltstone with trails and burrows in the form of tubes. The second conglomerate is followed by bluish green cross-bedded sands above which is a pinkish tuffaceous silt. A thin conglomerate is followed by a gray tuffaceous sandstone. The lack of diagnostic fossils makes age interpretations in this part of the section difficult. The volcanic origin of the sediments is evident, with tuffs predominating. The crossbedding and great variation of these beds suggest the possibility of accumulation in shallow water such as a coastal lagoon or delta. The fish fossils are marine. Radiometric dates and possible correlations with Rancho Matanzas and other areas suggest an early Miocene age for these beds.

At the stratotype the Cerro Colorado Member contains tuffs, volcanic sands, conglomerates and porcellanites. In other areas, which may be higher in the section, green cross-bedded sands with fragments of fossil wood are present. Below tuffs east of La Fortuna, erect root casts were found confirming the terrestrial nature of the upper part of the Cerro Colorado Member.

In the present study the Cerro Colorado Member is confined to beds below the lavas, pink tuffs and volcanic breccias. More detailed field studies might refine this upper contact. The member is extensively exposed between the oasis of San Hilario and the top of the Ten Minute locality. The Cerro Colorado Member is extensively exposed in the hill to the east of Rancho Matanzas and in the area near La Fortuna and San Bartolo. East of Rancho Matanzas and east of La

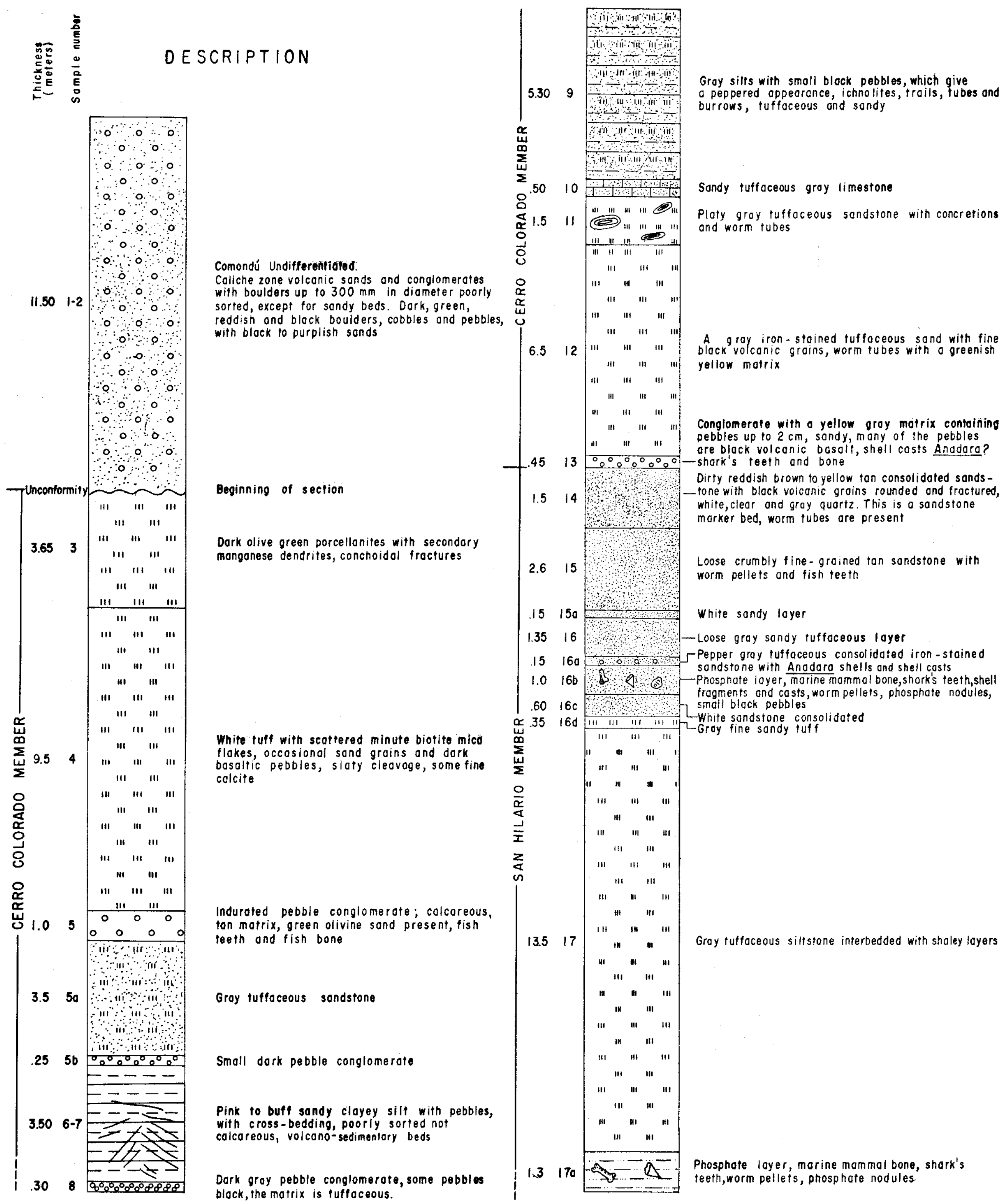

Figure 4.- Composite type section of El Cien Formation and its members at Cerro Colorado.

Fortuna there are localities with oysters, barnacles and turritellas.

San Hilario Member.- The beds above the flagstones of Palo Verde (Figures 4 and 7), which include the phosphate layer and are capped by the prominent marker sandstone, are named for their exposure on the east side of Arroyo San Hilario. This is directly opposite the town of San Hilario on the west bank of the arroyo

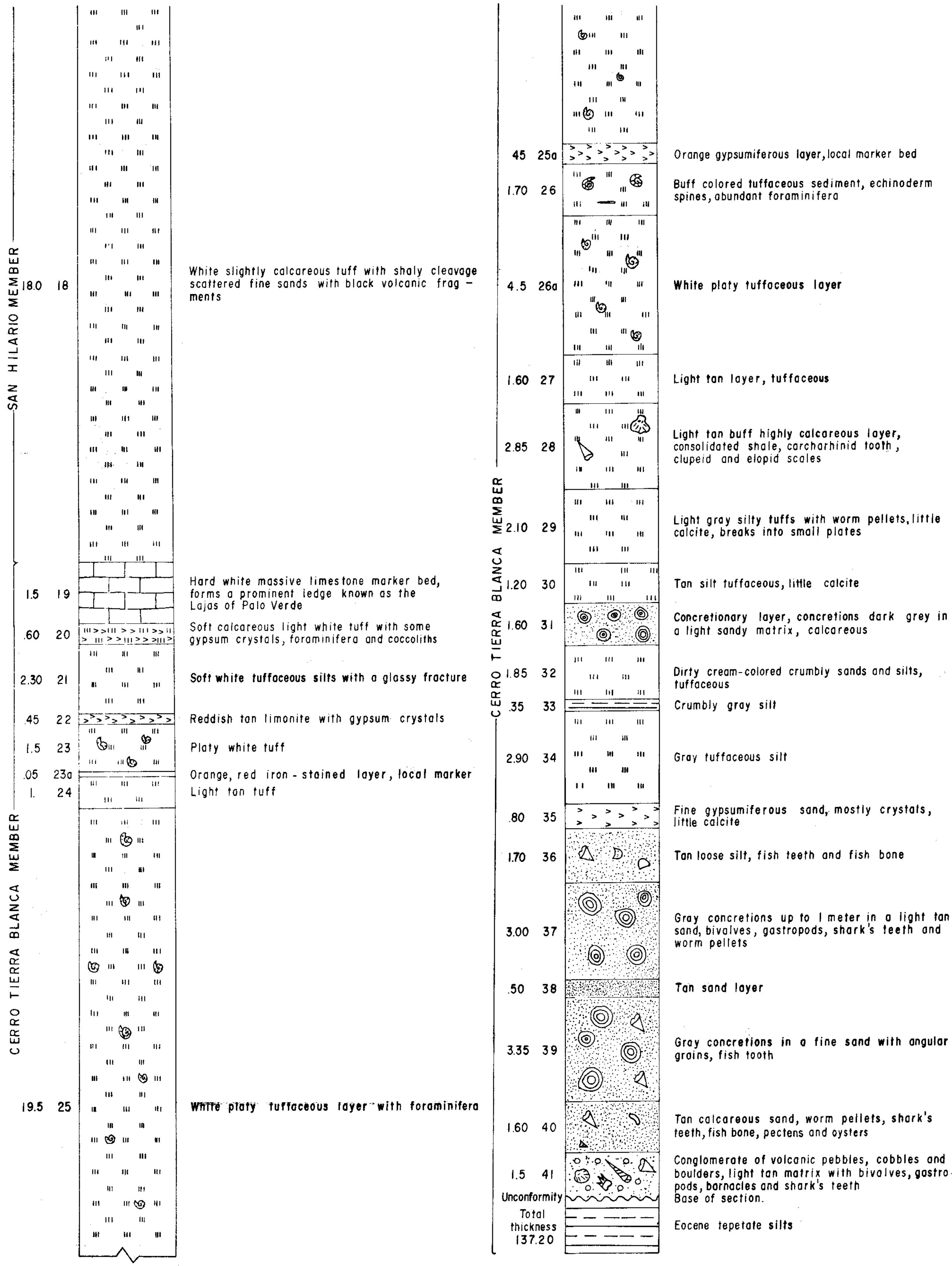

Figure 4.- Composite type section of El Cien Formation and its members at Cerro Colorado (*continuation*).

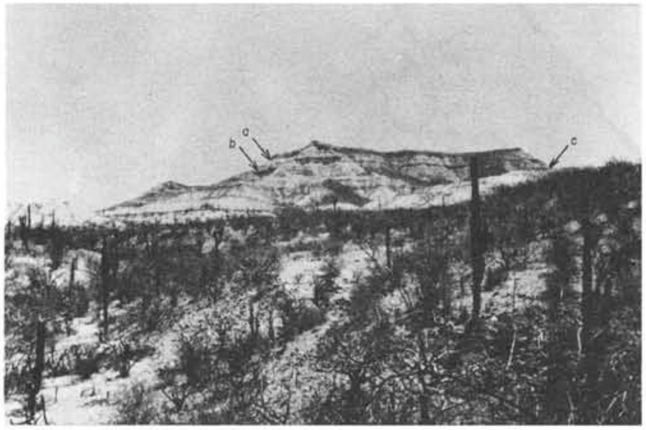

Figure 5.- The type area for El Cien Formation at Cerro Colorado as seen from the west; a) is the top of the Cerro Colorado Member, b) is the top of the San Hilario Member and c) is the top of the Cerro Tierra Blanca Member.

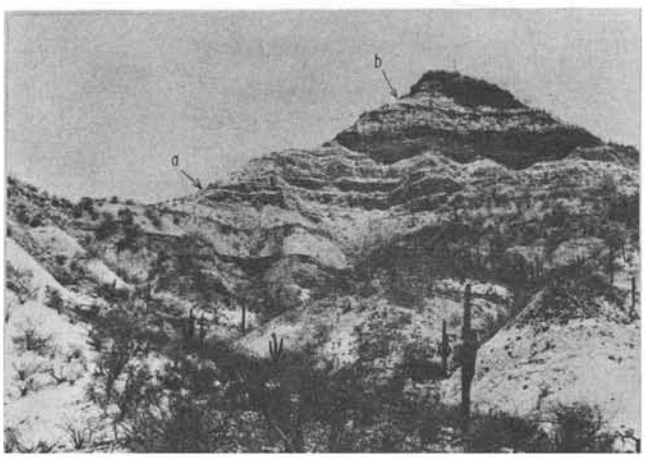

Figure 6.- The Cerro Colorado Member at the type section as seen from the west; a) the base and b) the top.

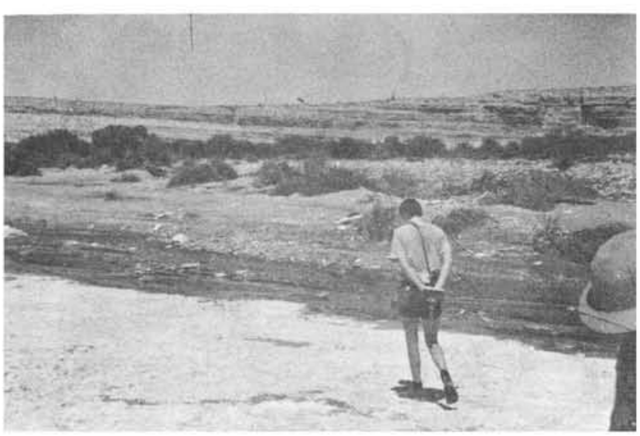

Figure 7.- The San Hilario Member of El Cien Formation, as seen from the limestone flags of Palo Verde in Arroyo San Hilario.

(Figure 7). The east bank is informally known as the Ten Minute locality of the El Cien Formation $\left(\frac{118}{\mathrm{IGM}}\right)$. This member is important from an economic point of view as it contains the productive phosphate beds in this area.

The base of the San Hilario Member is set above the flagstones of Palo Verde.

The San Hilario Member at Cerro Colorado (Figure 5) shows a number of facies changes from that in Arroyo San Hilario (Figure 7). At San Hilario three phosphate beds have been reported (Ojeda, 1979). The section at Cerro Colorado lacks the black tuffaceous siltstones which must correlate with the 18 m bed of calcareous tuffs; the lower phosphate layer is the thickest in this locality which agrees with Ojeda's (*op. cit.*) section at San Hilario.

In the San Hilario section of Arroyo Colorado the present author found no diatomites and the beds which past workers called diatomites are white tuffs for which he cautions identifying beds in this area as diatomites by field examination alone. Samples must be examined microscopically.

The uppermost sandstone of the San Hilario Member at Cerro Colorado contained only shell fragments. At the Ten Minute locality $\left(\frac{118}{\mathrm{IGM}}\right)$, Applegate and Wilson (1976) identified several gastropod casts as well as *Anadara vanderhoofi* from this bed. Between the sandstone and the upper phosphate layer at the Ten Minute locality the beds contain a large quantity of silicified fossil wood. Collected pieces range up to 20 cm in length and 15 cm in diameter. At Rancho Matanzas, which lies to the east of El Pilar (Figure 8) and is about 22 km north of Cerro Colorado, extensive beds of fossil wood are known to occur. Logs up to 4 m and more than 31 cm in diameter were found. If these beds can be correlated, then the shell beds of Rancho Matanzas (lower Miocene; M. C. Perrilliat, personal communication), which lie above the wood as do similar shell beds at San Hilario, may represent a shallow water facies in the Cerro Colorado Member of the El Cien Formation.

Cerro Tierra Blanca Member.- This member (Figures 4, 5 and 9) is named for a prominent hill slightly to the east of Cerro Colorado (Figure 9), forming part of Cerro Colorado, but large enough to distinguish. The top bed of Cerro Tierra Blanca Member is a hard limestone (Figures 7 and 9). This limestone is known as the flagstones of Palo Verde and was traced by Ojeda (1979) from Cerro Palo Verde to El Coyote.

The conglomerate at the base of the section crops out to the southwest of Cerro Tierra Blanca, about 0.5 km. This is the fossil locality called Harley's Hideaway $\left(\frac{290}{\mathrm{IGM}}\right)$. These beds can be traced from Palo Verde to Rancho Aguajito. The conglomerate is exposed on the highway, 11 km north of El Cien (Figure 10).

In its units or groups of units, the Cerro Tierra Blanca Member consists of a basal conglomerate followed above by three concretionary layers which are

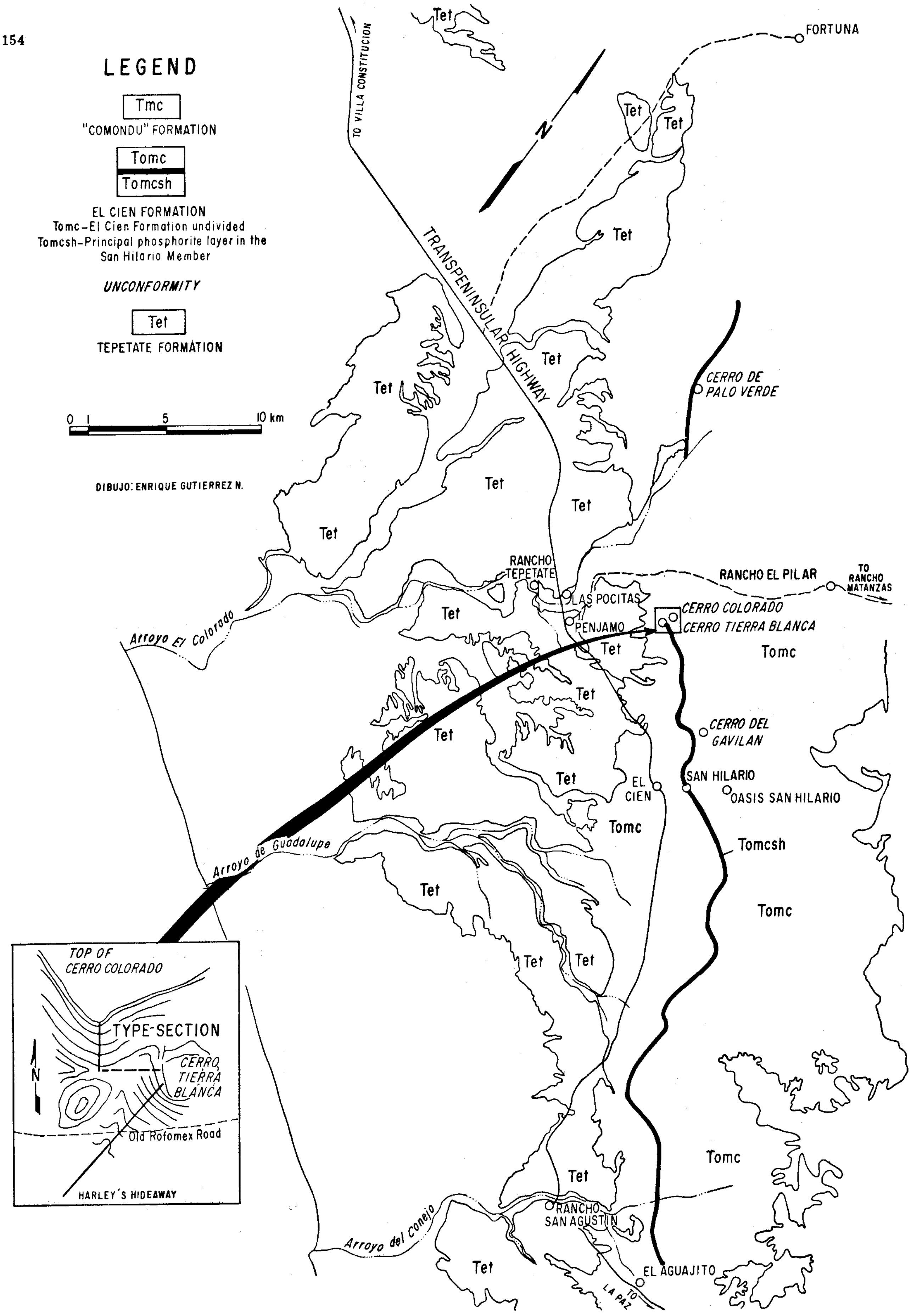

Figure 8.- Geographic distribution of El Cien Formation, type section and the principal phosphate layer, based on information supplied by Roca Fosfórica Mexicana (ROFOMEX).

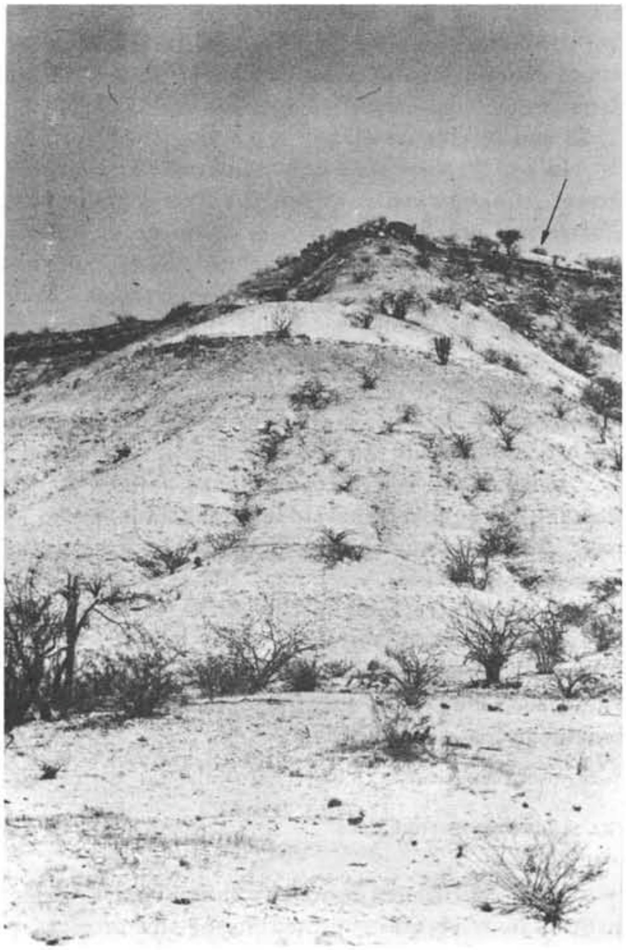

Figure 9.- The Cerro Tierra Blanca, the arrow points to the limestone flags of Palo Verde.

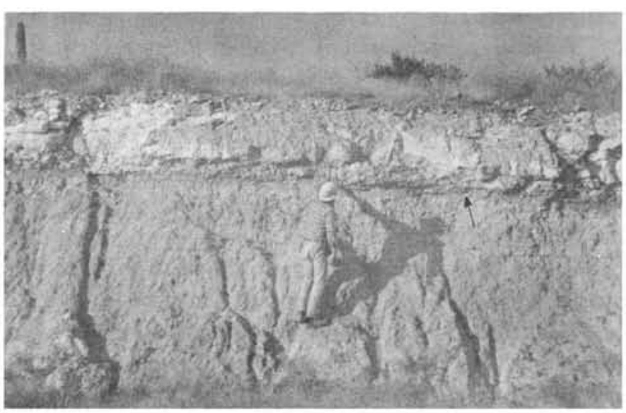

Figure 10.- The contact (arrow) between the Tepetate Formation and the Cerro Tierra Blanca Member of El Cien Formation, 11 km north of El Cien.

interspersed with sandy layers that become finer up section. The thickest group of beds lies above the uppermost concretionary layer and contains gypsum and tuffaceous elements. In general, one might consider this section as going from very shallow to deep water with fine grained sediments, except for the fact that the basal conglomerate contains a deep water as well as a shallow water shark fauna. Tentatively, such a mixture suggests turbidity slides carrying shallow water fossils into deep water. A similar situation was observed by the present author at Pyramid Hill, Kern County, California.

The whole section indicates extensive volcanic activity. The igneous activity lessens as one moves up in this member. One goes from basal volcanic cobbles to sands to silts to tuffs and finally to an almost pure limestone. Field and laboratory work as well as the fossils leave no doubt that this is entirely a marine section. Since many of the fossils found in the member are species that are confined to tropical waters, there is little evidence to support the contention that this represented an area of cold upwelling waters. The town of El Cien, from which the formation takes its name, rests on beds of the Cerro Tierra Blanca Member

REGIONAL OUTCROP OF EL CIEN FORMATION

In the area studied (Figure 8) the beds of El Cien Formation crop out from Rancho El Aguajito in Arroyo San Miguel in the south, 68 km north of La Paz, to 40 km north of La Fortuna. In the north the Cerro Colorado Member is extensively exposed on the north side of the road to the northeast of La Fortuna. The three members of El Cien Formation are present in the vicinity of El Aguajito, but only the lower member is present at El Aguajito fault that cuts out the El Cien Formation. In the north all three members are known to exist at Cerro Palo Verde. Farther north on the road to La Soledad, the present author recognized the Cerro Tierra Blanca Member and the Cerro Colorado Member but the phosphate layers of the San Hilario Member were present only in a reworked conglomerate. To the east, the beds have been traced to Rancho El Pilar and Rancho Matanzas. From the top of a hill near Rancho Matanzas, the beds extending for many miles farther east were observed. On the road to the east of La Fortuna, the beds are covered by the volcanics which have been called the Comondú. Figure 10 shows the contact of the Tepetate and El Cien Formations. This contact delineates the eastern extent of the beds and is 11 km north of El Cien on Federal Highway 1.

The phosphate beds at San Juan de La Costa on the Gulf of California (Figure 1) are thought to be the same age and perhaps part of the San Hilario Member of El Cien Formation. The beds above the phosphates show similarities to the Cerro Colorado Member. The present author does not believe that stratigraphic or paleontological work has been done to make a positive correlation between El Cien area and the San Juan de La Costa area, but at least tentatively it is best to consider these beds as part of El Cien Formation.

THE RADIOMETRIC EVIDENCE FOR THE AGE OF THE EL CIEN FORMATION

Gastil and coworkers (1979) discussed a radiometric date from Rancho Sausoso, their locality 49, which is located 50 km north of La Paz. At this place there is a section of which the lower 100 m consist of tuff and tuffaceous sandstone and a greenish to brown volcanoclastic sandstone. A basalt in the upper part of this section yielded a date of 27 Ma B.P. This unit is thought to correlate with the basal Cenozoic rocks at Punta San Telmo. If this correlation is correct and if the upper marine beds are part of El Cien Formation this would give a maximum age for the El Cien Formation of late Oligocene.

From the new Loreto grade, Gastil and coworkers' (*op. cit.*) locality 38, to a few miles north of Tembabichi, the marine escarpment exposes andesite breccia, volcanic sandstones and conglomerates, and an interbedded ash yielding a date from 17 to 20 Ma B.P. These volcanic beds are above the *Anadara vanderhoofi* type locality of Durham (1950) and the desmostylid *Cornwallius* locality of Vanderhoof (1942) at Arroyo San Carlos. If these beds correlate with the Ten Minute locality near El Cien, as Applegate and Wilson (1976) believed, this would give a minimum age of around 20 Ma B.P.

At Rancho San Juan, 50 km north of the Rancho Sausoso the cross section of an anticline reveals 75 m of fossiliferous marine strata, called Miocene by Gastil and coworkers (*op. cit.*). This is overlain by a 1,000 m pink tuff and greenish brown volcanoclastic sandstone and conglomerate. A hypersthene andesite 150 m above the exposed beds gave an age of 19.8 Ma B.P. which, in general, would agree with the latter date.

To the east of Federal Highway 1, about 20 km from Cerro Colorado at El Pilar, locality 48 of Gastil and coworkers (*op. cit.*), a fossiliferous biotitic ash high in the marine section gave a date of 21 Ma B.P.

Near El Cien, close to, if not at the Ten Minute locality, Brian Hausback (personal communication, April 1983) obtained a date of 25 Ma B.P. from a tuff. Since numerous dateable tuffs exist in El Cien Formation, this should, in time, be confirmed by publication.

The evidence to date brackets El Cien Formation between 27 and 20 Ma B.P. As the Miocene-Oligocene boundary has been set at 22.5 Ma B.P. by Berggren and Van Couvering (1974) and 23.7 Ma B.P. by Palmer (1983), it appears that El Cien Formation includes this boundary, on the basis of both paleontological evidence and radiometric dates.

THE MICROFOSSILS

A number of areas has been searched for microfossils. To date the greatest success has been in the type section at Cerro Colorado. In this area according to Carreño (personal communication), the beds of the Cerro Colorado Member and the San Hilario Member do not contain microfossils. The Cerro Tierra Blanca Member does contain microfossils in beds 20, 26, 30, 31, 32, 33 and 38 (Figure 4).

In bed 20 there were only planktonic foraminifera present, *Cassigerinella chipolensis* (very abundant), *Globigerina praebulloides* s. 1, *Globigerina ouachitaensis ouachitaensis* (rare) as defined, *Globigerina angustiumbilicata* and *Globigerina* cf. *ciperoensis*. None of these species is diagnostic but they correspond to the time span around the N2/N3 Oligocene zones of Blow (1969). Moreover, the occurrence of small *Chiloguembelina* sp. probably referable to the *C.* ex group *cubensis* strengthens the upper Oligocene assignment.

In all of the other beds including number 20, the presence of abundant benthic foraminifers indicates an inner shelf environment. These species have broad stratigraphic ranges. The most abundant and diagnostic species were valvulinerids of the *V. cassitaensis* group, *Lenticulina mayi, L.* cf. *alato-lumbata, Uvigerinella californica, U. obesa* and *Nonion* aff. *costiferum.* These, according to the zonation of Kleinpell (1938) are Zemorrian-Saucesian in age.

THE MACROINVERTEBRATES

M. C. Perrilliat (personal communication) examined the invertebrates collected during this project.

The Cerro Tierra Blanca Member is represented by invertebrates collected from the basal conglomerate at Harley's Hideaway locality $\left(\frac{290}{\text{IGM}}\right)$: *Anadara* sp. (molds), *Chione (Lirophora)* sp. (molds), *Ostrea* sp., *Vertipecten* sp. cf. *V. alexclarki* Addicott, *Pecten* sp. cf. *P. (P.) santacruzensis* Arnold, *Leptopecten* sp., probably a new species, *Turritella inezana* Conrad, *Turritella* sp., *Balanus* sp.

Vertipecten alexclarki Addicott and *Pecten santacruzensis* Arnold, have been reported from the Wigay Sandstone Member of the Temblor Formation; Addicott (1973) showed an indirect evidence that this member was of late Oligocene age. *Turritella inezana* is known from the Vaqueros Formation of southern and central California which is upper Oligocene-lower Miocene. Beds containing this species were correlated by Keinpell (1938) with his Zemorrian stage. This stage was considered by Turner (1970) to be late Oligocene.

From the bone bed at the Ten Minute locality (LACM 5044) a pecten was collected referred to *Aequipecten andersoni* but this is evidently a different species, the age is probably Oligocene. From the same beds at Cerro Colorado locality $\left(\frac{1564}{\text{IGM}}\right)$, *Pecten* sp. cf. *P. (P.) vanvlecki* Arnold was collected. This species was described from the Vaqueros Formation and could be lower Miocene or Oligocene.

In the beds above the phosphate and below the top of the San Hilario Member, at the Ten Minute locality $\left(\frac{130}{\mathrm{IGM}}\right)$, were collected *Turritella inezana* Conrad, *Anadara (Cunearca) vanderhoofi* Durham.

The *Anadara vanderhoofi* is also known from Punta San Carlos, the type locality of this species; Applegate and Wilson (1976) discussed these occurrences. The age is late Oligocene or early Miocene.

The Cerro Colorado Member is represented in the collections by an important fauna from Rancho Matanzas $\left(\frac{264}{\mathrm{IGM}}\right)$: *Turritella inezana* Conrad, *Turritella ocoyana wittichi* Hertlein and Jordan, *Polinices (Neverita) recluzianus* (Deshayes) *andersoni* Clark, *Crepidula* sp.

This fauna is thought to be no younger than early Miocene; another collection from Cerro de La Estaca $\left(\frac{1580}{\mathrm{IGM}}\right)$ is thought to be early Miocene: *Turritella* sp. cf. *T. inezana bicarina* Loel and Corey, *Turritella* sp.

Another fauna was collected from 6 km west of Rancho Las Tinajitas locality $\left(\frac{1581}{\mathrm{IGM}}\right)$: *Turritella ocoyana* Conrad, *Turritella* sp. cf. *T. inezana bicarina* Loel y Corey.

The fauna is thought to be early Miocene, although *T. ocoyana* is characteristic of the middle Miocene. Therefore, there is a chance that this fauna could be early-middle Miocene.

The faunas range from late Oligocene to the early Miocene, only one locality shows the possibility of an early-middle Miocene age.

VERTEBRATES AND MARINE MAMMALS

Teleost scales are known from the Ten Minute locality and east of Rancho Matanzas. Scales are also present in the tuffs in the upper part of the Cerro Tierra Blanca Member and rarely in the lower part of the Cerro Colorado Member.

Marine turtle scutes are known in the basal conglomerate 11 km north of El Cien and at Aguajito $\left(\frac{1579}{\mathrm{IGM}}\right)$.

Porpoise or small squalodonts are known from two jaw fragments without teeth from Aguajito. Squelodont teeth are known from the thick phosphate layer at the Ten Minute locality. Whale vertebrates are common in the phosphates, from where the skull of a mysticete whale aff. *Mavicetus* was identified by Dr. Lawrence Barnes for a National Geographic Research Report (*in* Downs, 1974). This whale appears to be close to the Oligocene or possible Miocene form from New Zealand. Whale vertebrates also occur above the phosphates and below the *Anadara vanderhoofi* zone, at locality $\left(\frac{1376}{\mathrm{IGM}}\right)$.

Near Mesa de Borregos, 40 km north of La Fortuna a porpoise skull was found but it has not been studied, nor have the three desmostylid skulls which also were collected. These may belong to the genus *Cornwallius*. At present, the skulls are exhibited in an anthropology museum in Mexicali, Baja California Norte. Sharks' teeth in the same collection were Pliocene mixes. From another locality, *Carcharodon mexicanus* which is indicative of El Cien Formation was present.

Vanderhoof (1942) described the occurrence of the desmostylian *Cornwallius sookensis* from Punta San Carlos, near Punta San Telmo (Punta San Telmo is actually 3.2 km south of Punta San Carlos; Figure 11). *Cornwallius sookensis* had been described from the Sooke Formation of Vancouver Island, British Columbia, on the basis of three teeth. Two teeth were known from Baja California Sur. Byers (1959) described the occurrence in Unalaska of teeth identified by G. Edward Lewis as *Cornwallius* sp. and said to be of early Miocene age. Drewes and coworkers (1974) reported teeth from Unalaska, again identified by Lewis as *Cornwallius*, but stated that Durham (1950) and Clark and Arnold (1923) considered these remains to be upper Oligocene. The Sooke Formation was correlated by Durham (1944) with the Twin River Formation particularly the upper part of his *Echinophoria apta* zone. Addicott (1976) stated that his Juanian stage was proposed for the upper part of the Blakeley stage. The stratotype is the upper part of the upper member of the Twin River Formation. The Zemorrian-Saucesian boundary occurs in the upper part of the Juanian stage. The Paleogene-Neogene boundary according to Addicott (1976) was set at about 23 to 24 Ma B.P. Recently, the Geological Society of America Decade of North American Geology 1983 Geologic Time Scale (Palmer, 1983) placed the Miocene-Oligocene boundary at a date of 23.7 Ma B.P. In this paper the Berggren and Van Couvering (1974) 22.5 Ma B.P. date is used.

In the summer of 1983, Dr. John Harris, of the Los Angeles County Museum, discovered another *Cornwallius* tooth (Figures 12 and 13) at Punta San Carlos $\left(\frac{1578}{\mathrm{IGM-3688}}\right)$. The tooth is badly worn, whereas the other two teeth, figured by Vanderhoof (1942) UCMP 36079 and UCMP 36078, are more or less unworn. The

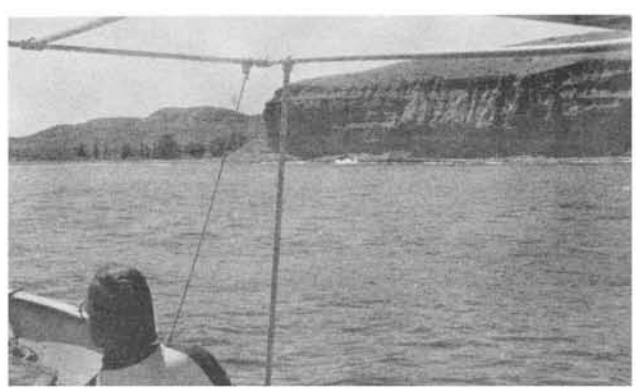

Figure 11.- The Punta San Carlos Member of El Cien Formation north of Punta San Telmo at Arroyo San Carlos.

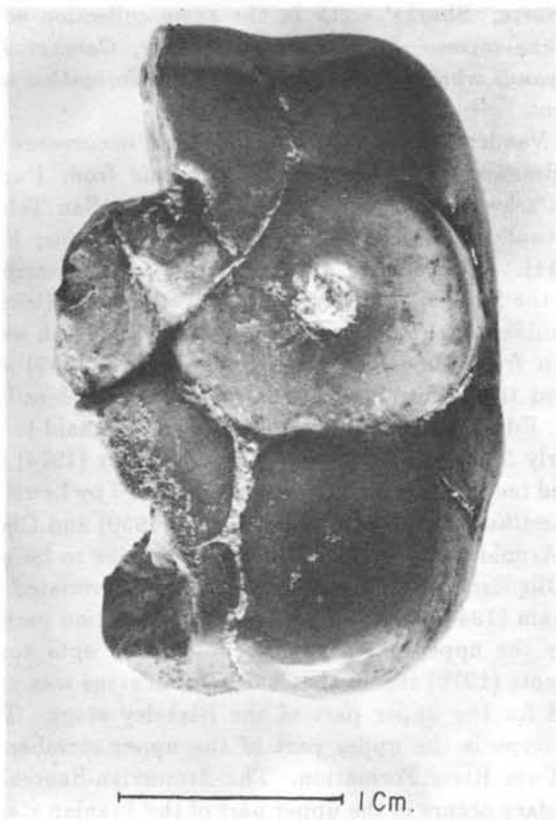

Figure 12.- Tooth of *Cornwallius sookensis* $\left(\frac{1578}{IGM-3688}\right)$, from Punta San Carlos, viewed from above.

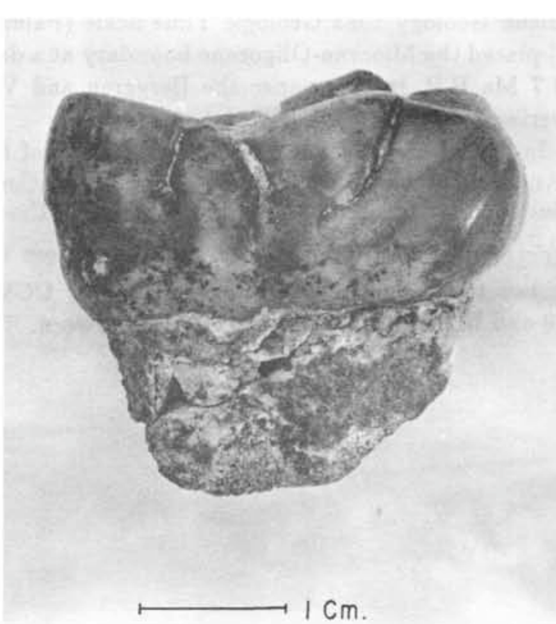

Figure 13.- Tooth of *Cornwallius sookensis* $\left(\frac{1578}{IGM-3688}\right)$, from Punta San Carlos, viewed from the side.

new specimen shows a single root. This is an upper tooth, the cusps on the outside of the tooth are broken. Postcranial material that was found in the general area of the tooth is being prepared. Above the *Cornwallius* layer and below the *Anadara vanderhoofi* layer, we discovered the badly preserved cranium of a small whale. Another whale, approximately 13 feet long, was observed in the same stratigraphic interval but about 13 km south of Tembabichi.

At San Juan de La Costa (Figure 1) in the open pits of ROFOMEX, we have seen another small whale. A skull of an unidentified whale from the same place is exhibited in the hall of the ROFOMEX office in La Paz.

The words of Vanderhoof are as true today as when he published them in 1942: "It follows that the *Cornwallius* horizon in both places represents synchronous deposition or at least deposition during the time span of a relatively short lived species. Whether the Sooke is latest Oligocene or earliest Miocene does not alter this conclusion. In any event, we must discard the term "Monterey", applied by Darton (1921), as the age of the *Cornwallius* bearing sandstones of Lower California".

THE EVIDENCE OF THE SHARK FAUNAS

The shark faunas from El Cien Formation are two in number. One is at the base of the Cerro Tierra Blanca Member where the Harley's Hideaway fauna is found locality $\left(\frac{290}{IGM}\right)$. Here over 40 species of sharks were collected. A preliminary faunal list was given in Downs (1974). The second one, the San Hilario fauna locality $\left(\frac{118}{IGM}\right)$, from the top of the main phosphate layer in the San Hilario Member, shows important evolutionary changes when compared with the first; the present author believes that a considerable time span exists between these two faunas.

The sharks which show the most easily detected evolutionary advances are of the genus *Hemipristis*, a genus that has a single large species living today in the Indian Ocean, and the tiger shark *Galeocerdo*, also represented by a single species which is known from all tropical and temperate seas; both of these genera have their origin in the early Eocene. The tiger shark *Galeocerdo* developed a special lineage, the *G. aduncus* lineage (Applegate, 1978) in the Oligocene, Miocene-Pliocene and Recent. This lineage shows a steady increase in size from sharks of about one meter in length to those that exist today which have a length of six or more meters. The genus *Hemipristis* shows a similar increase in size from the Oligocene through the Pliocene.

Figures 14 and 15 show the upper laterals of the second or third position and the lower anteriors of the left side of the jaw. The tooth terminology is according to Applegate (1965). The genus *Hemipristis* is shown in Figure 14 and *Galeocerdo* in Figure 15. The bottom row (letter a in both figures) contains the teeth of these two genera from the Oligocene beds at Harley's

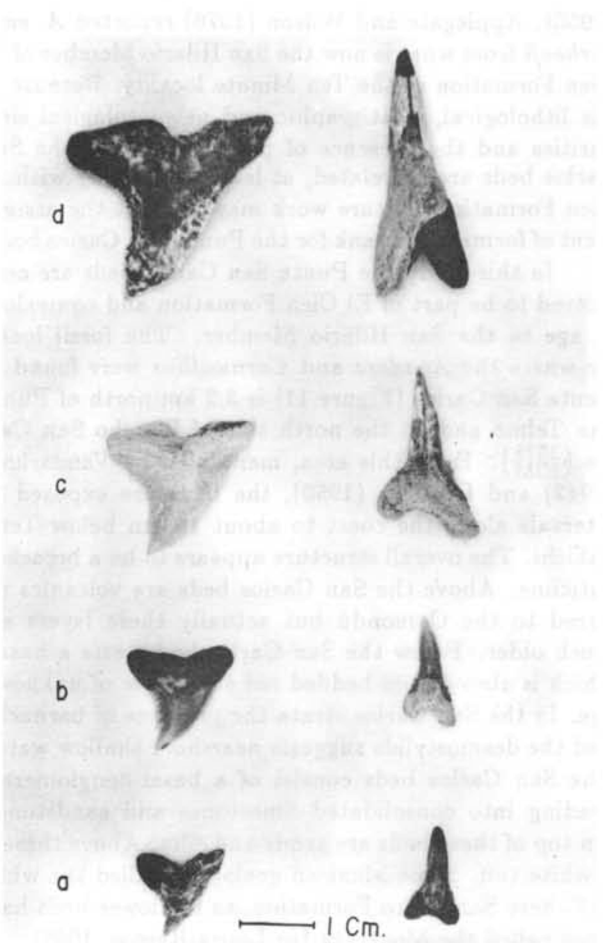

Figure 14.- *Hemipristis* teeth, second or third upper laterals and lower anteriors, from localities IGM 290, 218, and 125. Specimen numbers have not been assigned because this material is being studied for future taxonomic works.

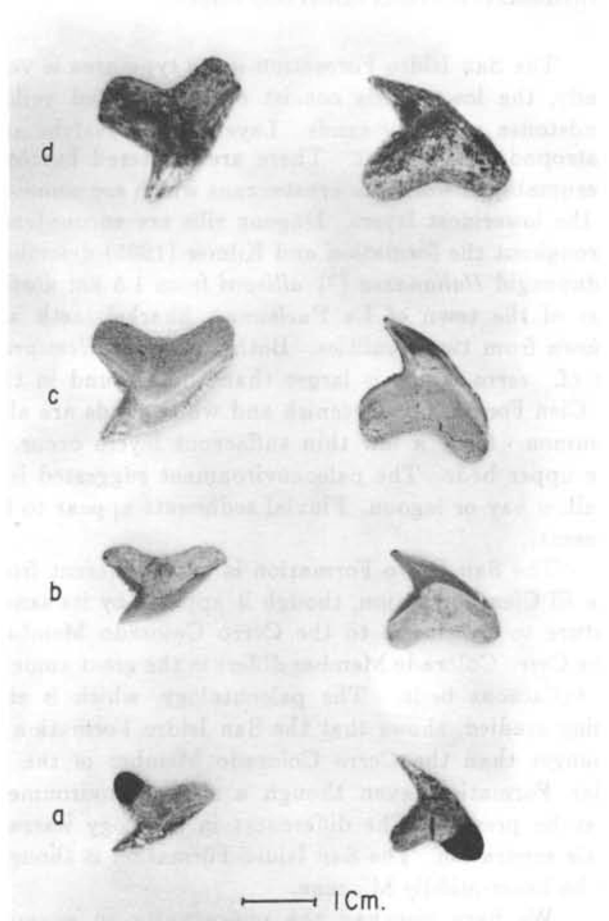

Figure 15.- *Galeocerdo* teeth, second or third upper laterals and lower anteriors, from localities IGM 290, 218 and 125. This material is illustrated for comparative purposes and not to designate taxonomic entities.

Hideaway locality ($\frac{290}{IGM}$). The next upper row (letter b) corresponds to the Ten Minute locality ($\frac{118}{IGM}$), which is thought to be Oligocene-Miocene. The next upper row (letter c), contains teeth from the early-middle Miocene at La Cocina locality ($\frac{283}{IGM}$). The top row (letter d) corresponds to the teeth from the late Miocene at Arroyo Tiburón locality ($\frac{125}{IGM}$). At a glance, it is easy to see that the teeth in these tooth positions increase in size in younger faunas.

The teeth of *Hemipristis* (left side of Figure 14) were measured. The height of those from Harley's Hideaway (letter a) was 14.5 mm, the width 14.9 mm. From the Ten Minute locality (letter b), the lateral tooth height was 17.9 mm, the width 17.6 mm. The lateral tooth from the early-middle Miocene at La Cocina (letter c) measured 22.22 mm height, 21.6 mm width. The late Miocene lateral from Arroyo Tiburón (letter d) showed a height of 30.25 mm and a width of 30.5 mm. The same increase in size was found in the lower anteriors on the right side of Figure 13, although not as spectacular. The width is unconclusive because the available teeth are from different tooth positions.

The teeth of the genus *Galeocerdo* (Figure 15) show a similar size increase, though the magnitude is less. The Harley's Hideaway tooth (letter a) shows a height of 10.5 mm and a width of 13.6 mm. The Ten Minute locality (letter b) teeth, height 10.1 mm, width 16.0 mm. The La Cocina tooth (letter c), 15.7 mm for height and 18.5 mm for width. The Arroyo Tiburón tooth (letter d) had a height of 15.8 mm and a width of 18.8 mm. In these positions, the differences between these two last rows are small but in examining a large series one gets the impression that the middle Miocene teeth from La Cocina ($\frac{283}{IGM}$) are slightly smaller than those from Arroyo Tiburón ($\frac{125}{IGM}$).

The lower teeth show a similar increase in size. In general, the present author believes that these size changes warrant specific rank and he has not had the chance to examine the European fossils needed to construct tooth sets, which is the basis of specific determinations in fossil sharks.

CORRELATIVE STRATIGRAPHIC UNITS

The San Isidro Formation in its type area is very sandy, the lower beds consist of consolidated yellow sandstones and silty sands. Layers with bivalves and gastropods are present. There are scattered burrows presumably of worms or crustaceans which are common in the lowermost layers. Dugong ribs are encountered throughout the formation and Kilmer (1965) described a dugongid *Halianassa* (?) *allisoni* from 1.5 km northeast of the town of La Purísima. Sharks' teeth are known from two localities. Both contain a *Hemipristis* cf. *serra* which is larger than those found in the El Cien Formation. Greenish and white sands are also common. Only a few thin tuffaceous layers occur in the upper beds. The paleoenvironment suggested is a shallow bay or lagoon. Fluvial sediments appear to be present.

The San Isidro Formation is quite different from the El Cien Formation, though it appears by its sandy nature to be closest to the Cerro Colorado Member. The Cerro Colorado Member differs in the great amount of tuffaceous beds. The paleontology, which is still being studied, shows that the San Isidro Formation is younger than the Cerro Colorado Member of the El Cien Formation, even though a similar environment may be present. The differences in lithology warrant their separation. The San Isidro Formation is thought to be lower-middle Miocene.

We have not had the opportunity to examine the San Raymundo Formation at its type locality. If these are the same beds that occur in Arroyo San Luis Bateque to the north and near the town of San Juanico to the south, as Mina (1957) said, then the present author believes that this formation must be early-middle Miocene, younger than the San Isidro Formation but older than the San Ignacio Formation. We see no relationship to the much older beds of the El Cien Formation.

The San Ignacio Formation is of a late-middle or early-late Miocene age. The San Ignacio Formation is capped by a 10 to 11 Ma B.P. basalt (J. G. Smith, personal communication, October 1983). *Desmostylus hesperus* and *Carcharodon megalodon*, both known from the middle to the upper Miocene, have been collected in the San Ignacio Formation. The shark fauna is still poorly known but *Isurus hastalis, Galeocerdo aduncus, Hemipristis serra* and *Carcharhinus* cf. *obscurus* have been found. It is believed that the San Ignacio Formation is younger than the San Raymundo and the San Isidro Formations, and no middle or late Miocene beds have been identified in the El Cien area though some of the Comondú volcanics could be of this age.

Punta San Carlos area.- To the north and south of Tembabichi occur beds in which the fossils *Cornwallius sookensis* and *Anadara vanderhoofi* were collected. The original *Anadara vanderhoofi* was described by Durham (1950). Applegate and Wilson (1976) reported *A. vanderhoofi* from what is now the San Hilario Member of El Cien Formation at the Ten Minute locality. Because of the lithological, stratigraphic and paleontological similarities and the presence of phosphate beds, the San Carlos beds are correlated, at least tentatively with El Cien Formation. Future work may warrant the assignment of formational rank for the Punta San Carlos beds.

In this study the Punta San Carlos beds are considered to be part of El Cien Formation and equivalent in age to the San Hilario Member. The fossil locality where the *Anadara* and *Cornwallius* were found at Punta San Carlos (Figure 11) is 3.2 km north of Punta San Telmo and on the north side of Rancho San Carlos $\left(\frac{1578}{\text{IGM}}\right)$. From this area, mentioned by Vanderhoof (1942) and Durham (1950), the beds are exposed at intervals along the coast to about 16 km below Tembabichi. The overall structure appears to be a breached anticline. Above the San Carlos beds are volcanics referred to the Comondú but actually these layers are much older. Below the San Carlos beds rests a basalt which is above cross-bedded red sandstone of unknown age. In the San Carlos strata the presence of barnacles and the desmostylids suggests nearshore shallow water. The San Carlos beds consist of a basal conglomerate grading into consolidated limestones and sandstones. On top of these beds are sands and silts. Above these is a white tuff. Some Mexican geologists called the white tuffs here San Isidro Formation, as the lower beds have been called the Monterey (*in* López-Ramos, 1982).

CONCLUSIONS

In Baja California Sur the present author confirmed the presence of upper Oligocene strata. The El Cien Formation is proposed for the beds between El Aguajito and those 40 km north of La Fortuna. These beds previously had been correlated with the Monterey or the San Gregorio Formation by other workers. The Monterey (or "Monterrey") Formation does not exist in Baja California Sur. In age the California Monterey Formation is Luisian and Mohanian, that is middle and late Miocene. The new El Cien Formation is Zemorrian and Saucesian of late Oligocene-early Miocene in age.

The San Gregorio Formation of Beal (1948) is recognized as a valid formation but is restricted to the outcrops in the La Purísima River valley and the canyons to the north of this area.

The San Isidro, San Raymundo and San Ignacio Formations are middle Miocene and have not been found in the area of outcrop nor are they part of El Cien Formation.

The general similarity of the San Juan de La Costa beds would place them within the El Cien Formation, and a correlation of these beds with the San Hilario Member is possible.

The presence of *Anadara vanderhoofi* would place the beds of Punta San Carlos (San Telmo) within El Cien time span.

The Punta San Carlos beds are included tentatively in the San Hilario Member of El Cien Formation. It is believed that with the consideration of the lithological and paleontological differences, future work may give these beds formational rank.

El Cien Formation is divided into three members: the Cerro Tierra Blanca, San Hilario and the Cerro Colorado.

El Cien Formation in its type area ranges from deep marine in the base of the Cerro Tierra Blanca Member to shallow marine in the San Hilario Member. The Cerro Colorado Member includes marine, lagoonal, and fluvial sediments as well as terrestrial beds.

The numerous tuffs, volcanic sands and conglomerates point to the fact that late Oligocene and early Miocene times were times of widespread volcanic activity near El Cien area.

The occurrence of shallow marine beds on the gulf side of the Península of Baja California and terrestrial beds on the west side indicates the existence of a gulf in early Miocene and perhaps late Oligocene times between the area of the present day Baja California and mainland of Mexico.

El Cien Formation offers an excellent area for extensive geological studies. The presence of phosphate and the possibilities of petroleum make this area of major economic importance.

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