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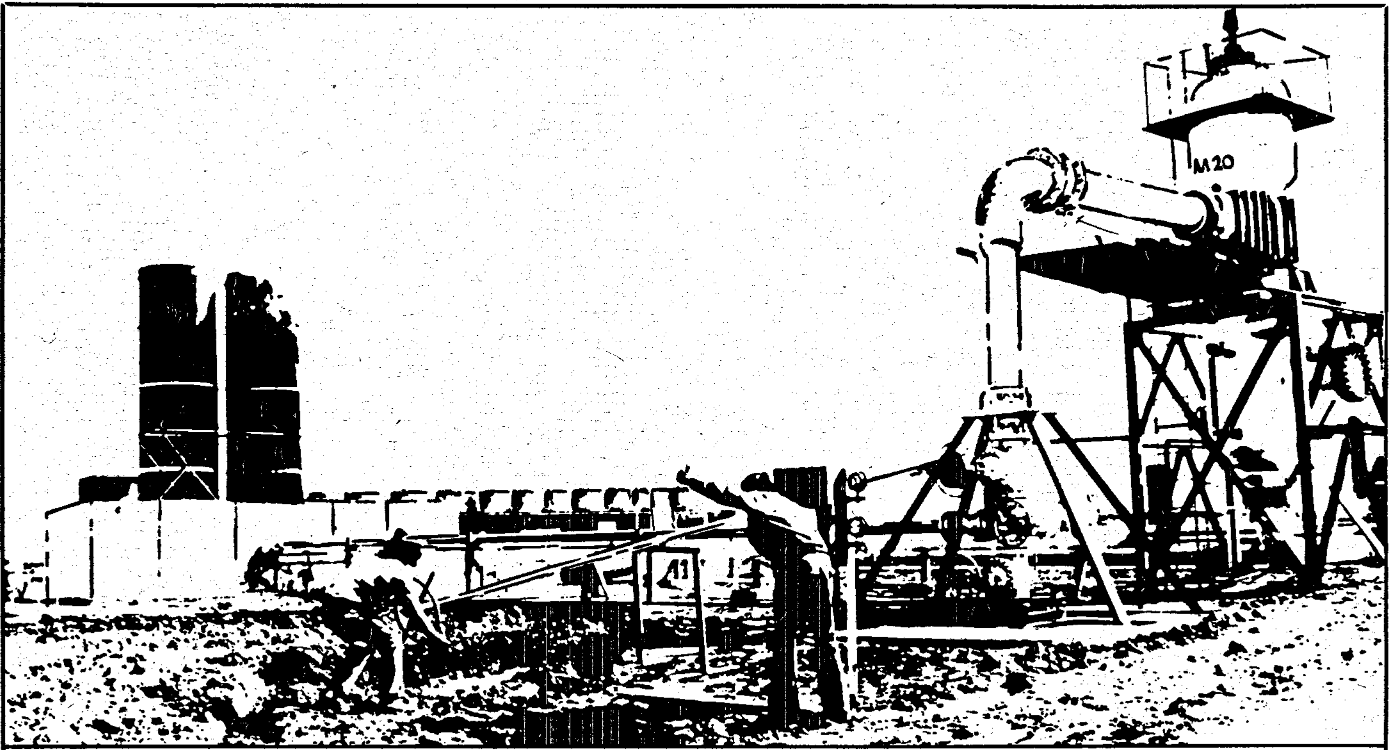

MICROFAUNAL EVIDENCE OF AGE AND DEPOSITIONAL ENVIRONMENTS OF THE CERRO PRIETO SECTION (PLIO-PLEISTOCENE), BAJA CALIFORNIA, MEXICO

James C. Ingle, Jr.
Department of Geology
School of Earth Sciences
Stanford University
Stanford, California 94305

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ABSTRACT

Microfossils including benthic and planktic foraminifera, ostracodes, calcareous algae, fish skeletal material, and fragments of pelecypods were found in 14 core samples from depths of 185 to 1952 m in the Cerro Prieto geothermal field, providing evidence of both the age and depositional history of sediments comprising the 3000-m-thick Pliocene and Pleistocene section in this area. Ostracodes of brackish water and marine origin constitute the most common microfossils present in this sequence occurring in 8 samples; *in situ* littoral and neritic species of benthic foraminifera occur in 5 samples with planktic species present in 2 samples. Distributional patterns of ostracodes and foraminifera together with previously analyzed lithofacies (Lyons and van de Kamp, 1980) indicate that the Cerro Prieto section represents an intertonguing complex of alluvial, deltaic, estuarine, and shallow marine environments deposited along the front of the Colorado River delta as it prograded across the Salton Trough during Pliocene and Pleistocene time. Foraminiferal evidence indicates that a sand and shale unit commonly present at depths between 700 and 1100 m represents a significant mid-Pleistocene marine incursion in the Cerro Prieto area. Tentative correlation of the Cerro Prieto section with the well dated Palm Springs Formation of the Imperial Valley, California area suggests that the Pliocene/Pleistocene boundary occurs at a depth of approximately 2000 m in the area of well M-93. Reworked specimens of Cretaceous foraminifera and fragments of the Cretaceous pelecypod *Inoceramus* were found in five samples further substantiating the Colorado Plateau provenance of a significant portion of the Colorado River deltaic sediments in the Cerro Prieto area.

INTRODUCTION

Thirty core samples from twenty wells drilled in the Cerro Prieto geothermal field, Baja California, Mexico (Figs. 1 and 2) were analyzed for microfossils with the aim of clarifying the age, provenance, and depositional history of sediments forming the stratigraphic column in this area. Microfossils including foraminifera, ostracodes, calcareous algae, fish skeletal material, and fragments of pelecypods were found in 14 samples from 11 of the 20 wells studied, with microfossils occurring at well depths ranging from 185 m to 1952 m; samples were not analyzed for nannofossils. Emphasis was placed on analysis of foraminifera due to their well established environmental preferences.

Seismic evidence and drilling records indicate that an average of 3000 m of unlithified sediments and indurated sedimentary rock of Holocene, Pleistocene, and Pliocene age overlie granodioritic basement rock in the central area of the Cerro Prieto geothermal field, with the sedimentary column thickening to the northeast and thinning to the southwest (Lyons and van de Kamp, 1980). The various Plio-Pleistocene lithofacies forming this sequence represent a complex of intertonguing non-marine and shallow marine sediments deposited along the southwestern margin of the Colorado River delta as it prograded into and ultimately filled the Salton Trough in the northern portion of the Gulf of California rift system (Lyons and van de Kamp, 1980). Pleistocene tectonic and volcanic activity are thought to be responsible for both faulting of this sequence as well as the present geothermal activity in the Cerro Prieto area.

Age and environmentally diagnostic microfossils have been found in many upper Cenozoic formations of the Imperial Valley-Mexicali Valley-Colorado

River area (Fig. 1) as detailed by Tarbet and Holman (1944), Arnal (1961), Merriam and Bandy (1965), Smith (1970), and Ingle (1974), providing particularly useful information for reconstructing the most recent geologic history of this tectonically active region. Specifically, the occurrence and distribution of Plio-Pleistocene species of foraminifera have not only provided direct evidence of marine deposition but have also allowed variations in depth of water and subsidence to be analyzed (Ingle, 1974). In addition, occurrences of Cretaceous foraminifera redeposited in Plio-Pleistocene Colorado River deltaic deposits of the Salton Trough from exposures in the Colorado Plateau (Merrian and Bandy, 1965) provide concrete evidence of the provenance of these sediments as well as insight into the development of the Colorado River drainage system (Lucchitta, 1972).

A previous analysis of well cuttings from 55 wells in the Cerro Prieto field disclosed the presence of ostracodes, redeposited Cretaceous and mid-Tertiary foraminifera and calcareous nannoplankton, fish skeletal material, fragments of pelecypods, and plant debris (Cotton and Vonder Haar, 1979); no _in situ_ Plio-Pleistocene species of foraminifera were identified in these samples. However, the identification of a mid-Tertiary species of planktic foraminifera, _Cassigerinella chipolensis_ (Cushman and Ponton), in samples M-11 (351 m), M-11 (470 m), and M-38 (480 m) was enigmatic inasmuch as current ideas regarding the geologic evolution of the Gulf of California preclude initial marine sedimentation in the northern portion of the Gulf prior to upper Miocene time. Hence, one of the objectives of the present study was to search for additional specimens of _Cassigerinella_ in order to confirm its anomalous presence in the northern Gulf fill. Significantly, no specimens of _Cassigerinella_ were found in any of the samples examined during this study.

Core samples examined ranged from lightly lithified sands and shales to highly indurated sedimentary rock representing hydrothermally altered sands, silts, and muds (Lyons and van de Kamp, 1980; Vonder Haar and Howard, 1979). Special care was taken with samples thought to represent material not highly altered by geothermal fluids due to the increased potential of this material for yielding microfossils. Megascopic and hand lens examination of cores suggested the following samples represent some of the least altered material available including samples M-3 (2206 m), M-5 (500-506 m), M-5 (706 m), M-5 (900 m), M-6 (700-704 m), M-9 (818-824 m), M-11 (700-705 m), M-15 (704-706 m), M-15 (1090-1095 m), M-15 (1239-1244 m), M-21 (185-191 m), M-93 (1565-1573 m), and NL-1 (1886.5-1895.5 m).

LABORATORY METHODS

Approximately 120-150 cm^3 of material was broken from the center of each core sample with special care taken to exclude drilling mud caked on the exterior of the cores. Each core sample was then crushed using an iron mortar and pestle to small pebble and grit sized particles. Crushed material was next placed in a 400 ml glass beaker and covered with a solution of Quaternary-0 (an industrial grade detergent) and water and left to soak and disaggregate for 24 hours. In a few cases samples were heated in the Quaternary-0 solution but this step proved unnecessary or alternately did not assist in disaggregating the most highly indurated material. In fact, those samples from the deeper and most hydrothermally altered portions of the Cerro Prieto sequence were generally so well indurated that processing with kerosene and/or Quaternary-0 did not break the material into smaller particles than those produced by crushing with the mortar and pestle.

After soaking and disaggregation in the Quaternary-0 solution, samples were placed on a 250 mesh screen (62 micron openings) and washed using a forced stream of water to remove clay and silt size material and retaining only sand size grains and larger unbroken particles of the original rock. Grit size and larger particles (greater than 2 mm) were removed by wet seiving the material through appropriate screens reducing the sample to dissaggregated sand-sized particles and/or broken sand-sized particles of the most well indurated sands and shales. This material was then washed into a filter paper and dried at 50°C.

Washed and dried sand size material was then poured slowly into a 400 ml glass beaker filled with carbon tetrachloride (CCl_4) in order to separate lighter fragments including foraminiferal tests from heavier material by floatation. Floated material was next decanted into a filter paper for drying and the remaining heavier material washed into a separate filter paper. The floated separate was placed in a small corked vial, in turn placed in a larger labeled vial along with the dried heavy separate to await analysis. Any material larger than 2 mm remaining after the washing process was placed back in the original sample bag.

Washed, floated, and dried sample material was examined as follows. Initially, floated separate was poured onto a black metal picking tray and systematically searched for microfossils at 50X and 80X using a binocular microscope. All microfossils[1] found were picked using a wet sumi brush (no. 350) and placed on individually numbered 60-square cardboard microfossil slides using water soluble gum tragacanth glue. After examination of the floated separate, the remaining heavy separate was scattered onto the black

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[1] With the exception of carbonaceous plant material common in many samples and common fragments of ostracode valves in sample M-5 (706 m).

picking tray in portions just large enough to cover the tray with a single layer of particles and also examined for microfossils. It was necessary to search both the floated and heavier separates of each sample because not all microfossils were separated by floatation in CCl_4. For example, most redeposited specimens of Cretaceous foraminifera filled with calcium carbonate and filled specimens of Elphidium gunteri Cole in sample M-93 (1944-1952 m) did not float. Alternately, floatation in CCl_4 recovered very rare specimens of unfilled foraminifera and ostracodes in several samples which might otherwise have been missed during examination of the more voluminous amounts of heavy separate.

FAUNAL ANALYSIS

The general and specific occurrences of microfossils found in the Cerro Prieto samples studied are detailed on Tables 1 and 2; 16 of the 30 samples examined proved to be barren of the microfossil groups analyzed. Generally, barren samples are from well depths below 800 m, including the deeper portions of the Cerro Prieto sequence most highly affected by circulating geothermal fluids. However, not all deep samples were barren, with ostracodes and foraminifera found at 1944-1952 m in well M-93 (Fig. 3). Because the material analyzed was carefully extracted from core samples it is reasonable to assume that all microfossils found represent in place (in situ) occurrences and do not involve contaminated assemblages common to samples of well cuttings. Cotton and Vonder Haar (1979) discuss likely examples of sample contamination in their study of cuttings from Cerro Prieto wells, noting that deep occurrences of ostracodes in their samples likely represent downhole displacement by recirculating drilling fluids. The assumed in situ nature of microfossil occurrences in the core samples analyzed during this study substantially increases their value for both age and environmental determinations.

Ostracodes represent the most abundant microfossils found during this study with foraminifera generally rare. However, sample M-93 (1944-1952 m) contains common filled specimens of the benthic foraminifera Elphidium gunteri Cole. Preservation of all microfossils ranged from moderate to excellent with the exception of filled and abraded tests of Cretaceous foraminifera reworked and transported from the Colorado Plateau area. Even filled Plio-Pleistocene specimens of foraminifera such as those found in M-93 (1944-1952 m) were readily identifiable although dissolution and/or abrasion allowed only generic identification of some specimens of foraminifera in other samples (Table 2).

Foraminifera

Foraminifera are shelled protozoans of the class Sarcodina and constitute the best known and most widely utilized group of microfossils for age and environmental determination in marine sediments of Cenozoic age. Benthic or bottom dwelling forms include species which secrete a calcareous "shell" or test as well as species constructing agglutinated tests of mineral and/or biologic particles held together with a secreted organic cement.

Both *in situ* Plio-Pleistocene foraminifera as well as reworked Cretaceous foraminifera were found in Cerro Prieto samples (Table 2). *In situ* Plio-Pleistocene foraminifera were found in five samples including benthic species of Buliminella, Elphidium, Epistominella, and Nonionella (Table 2). Significantly, most of these specimens were found within a predominantly shaly unit at depths between 700 and 1100 m suggesting a marine origin for these sediments. This interpretation is further strengthened by the occurrence of planktic species of *Globigerina* and *Globigerinita* within the same unit (Table 2) as discussed in a later section of the report.

Reworked Foraminifera

Reworked specimens of Cretaceous foraminifera were first reported from Colorado River deltaic sediments by Merriam and Bandy (1965) with later workers also noting their presence in Pliocene and Pleistocene marine and nonmarine sediments of the Imperial Valley (Lucchitta, 1972). Cotton and Vonder Haar (1979) previously documented the presence of reworked Cretaceous foraminifera and calcareous nannoplankton in the Cerro Prieto deltaic sequence. Rare filled and abraded specimens of the Cretaceous planktic genera *Hedbergella* and *Heterohelix* as well as a single specimen of the benthic genera *Gavelinella* were found during this study at well depths ranging from 185 to 916 m (Table 2). These occurrences are thus consistent with earlier reports of Cretaceous microfossils in Colorado River deltaic sediments thought to represent material eroded from upper Cretaceous Mancos Shale exposures in Utah and Colorado and transported to the Salton Trough area by the Colorado River (Merriam and Bandy, 1965; Lucchitta, 1972; Ingle, 1974). Interestingly, broken and abraded fragments (prisms) of the common Cretaceous pelecypod *Inoceramus* were also found in the Cerro Prieto cores (Table 2) providing additional evidence of the provenance of the Plio-Pleistocene delta sediments from the Colorado Plateau region.

Of special concern is the fact that no reworked specimens of the mid Tertiary planktic foraminifer, *Cassigerinella chipolensis* (Cushman and Ponton) were found in any of the core samples analyzed during this study. This distinctive and age diagnostic (Oligocene to middle Miocene) species was reported by Cotton and Vonder Haar (1979) to be present in cuttings from two Cerro Prieto wells. These same authors recognized that the presence of this species, if confirmed, had significant implications for the geologic history of the Gulf of California. Currently accepted plate tectonic reconstructions of Gulf evolution (Atwater, 1970; Karig and Jensky, 1972; Moore, 1973; and others) call for initial marine incursions into the newly formed Gulf no earlier than late Miocene time (5-11 million years before the present[2]) thus precluding the presence of Oligocene through mid Miocene marine sediments in the Gulf rift from which the specimens of <u>Cassigerinella</u> might have been eroded and reworked into the Cerro Prieto. The extremely rare occurrences of <u>Cassigerinella</u> and accompanying unidentifiable juvenile Tertiary planktic foraminifera found in Cerro Prieto well cuttings by Cotton and Vonder Haar (1979) together with the absence of these species in uncontaminated core samples analyzed during this study, suggest that the anomalous occurrences of <u>Cassigerinella</u> may represent contamination from drilling mud or laboratory contamination. However, it should be noted that lower and middle Miocene marine sediments presumably representing pre-Gulf mid-Tertiary patterns of marine deposition along the Pacific Coast of Mexico are present on the peninsula of Baja California (Mina, 1956; Gastil, Phillips, and Allison, 1975; Helenes-Escamilla, 1979). In addition, mid-Miocene microfossils have been reported but not confirmed from water wells in coastal Sonora, Mexico (Gomez, 1971). Thus, there remains the remote possibility that the specimens of <u>Cassigerinella</u> reported in Cerro Prieto sediments by Cotton and Vonder Haar (1979) were derived from Oligo-Miocene marine units within the Gulf of California province. However, the northeast-southwest progradation of the

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[2] Hereafter abbreviated "m.y.b.p."

Colorado River delta into the Salton Trough further reduces the possibility of reworking of Oligo-Miocene microfossils from known mid-Cenozoic units exposed along the southwestern margin of the Gulf far to the south of the Cerro Prieto area.

Ostracodes

Ostracodes are small to microscopic crustaceans which secrete a calcareous bivalved shell or carapace; each animal produces many shells during its life cycle due to shedding of shells during each stage (instar) of its growth (Haq and Boersma, 1978). Ostracodes occur in fresh, brackish, marine, and hypersaline waters with the majority of species having a benthic habit.

Both fragments of ostracode shells as well as complete shells were found in eight of the core samples examined with abundant shells occurring in sample M-5 (706 m). No attempt was made to identify these specimens to genera or species but the moderate to little ornamentation of the shells suggests they represent shallow marine or brackish water species similar to those previously reported from the Cerro Prieto wells by Cotton and Vonder Haar (1979). The excellent state of preservation of the ostracodes including the most delicate features of the shells indicates that they represent *in situ* occurrences within the probable deltaic/marginal marine environment of deposition.

Mollusks

Rare fragments of unornamented small pelecypods (clams) were found in four samples (Table 2). The fragile nature of this material dictates that it represents in-place occurrences of broken shell consistent with the Plio-Pleistocene deltaic/shallow marine environment of deposition envisioned for the Cerro Prieto sequence.

As noted earlier, rare fragments (prisms) of the common Cretaceous pelecypod Inoceramus were found in four samples. This is the first reported occurrence of this distinctive Cretaceous fossil debris in Colorado River deltaic sediments and further substantiates the transport of significant amounts of Plio-Pleistocene deltaic sediments in the Salton Trough from the Colorado Plateau region.

Algae

A single specimen of the oogonia of the fresh water genera of algae, Chara, was found in sample M-39 (872-878 m). Oogonia of Chara are common in fresh and brackish water deposits of Cenozoic age and the occurrence of this single specimen suggests it was transported into a shallow marine or brackish environment at the delta margin.

Miscellaneous microfossils

A phosphatic fish bone was recovered in sample M-26 (1270-1275 m) and adds little to interpretation of the Cerro Prieto section; Cotton and Vonder Haar (1979) also report fish skeletal material from drill cuttings in Cerro Prieto wells.

A broken agglutinated or arenaceous tube was found in sample M-5 (500-506 m) and may represent a broken piece of an agglutinated benthic foraminifera.

DISCUSSION AND CONCLUSIONS

Age and Correlation of the Cerro Prieto Section

Previous studies of the stratigraphic sequence in the Cerro Prieto area (Puente and de la Peña, 1978; Lyons and van de Kamp, 1980) together with numerous reports dealing with the late Cenozoic depositional history of the adjacent Imperial Valley (Dibblee, 1954; Durham and Allison, 1960; Arnal, 1961; Merriam and Bandy, 1965; Downs and White, 1968; Metzger, 1968; Hunt, 1969; Smith, 1970; Lucchitta, 1972; Ingle, 1974; Woodard, 1974) all indicate that (1) Colorado River deltaic sediments began spilling into the northernmost reaches of the ancestral Gulf of California during latest Miocene or early Pliocene time (7-5 m.y.b.p.), (2) progradation of the Colorado River delta into the Cerro Prieto area of the Salton Trough occurred in mid-to-late Pliocene time (3-2 m.y.b.p.), and (3) that the bulk of the Cerro Prieto stratigraphic section was likely deposited during Pleistocene time (2-0.01 m.y.b.p.) with severance of the Gulf of California-Imperial Valley marine connection by mid-Pleistocene time (circa 1 m.y.b.p.). Microfaunal data obtained during this study support a Pleistocene age for the eastern portion Cerro Prieto section to a depth of about 2000 m with underlying sediments assigned a Pliocene age (Fig. 4); simple lithologic correlation of the Cerro Prieto sequences east and west of the Michoacān Fault (Fig. 4) suggests the Pliocene/Pleistocene boundary may occur at an approximate depth of 1500-1600 m west of this fault (Fig. 4). All of the species of benthic and planktic foraminifera found in the Cerro Prieto core samples (Table 2), exclusive of reworked Cretaceous specimens, are still living in the marginal eastern Pacific Ocean today consistent with a general Plio-Pleistocene age for this sequence.

Biostratigraphic correlation of the Cerro Prieto section with the much studied Imperial Valley California Plio-Pleistocene sequence to the north (Fig. 1) is aided by the occurrence of a distinctive species of benthic foraminifera, Elphidium gunteri Cole, in sample M-93 (1944-1952 m). Significantly, Elphidium gunteri Cole occurs in common to prolific abundance within marine sediments of the Plio-Pleistocene Palm Springs formation and underlying Pliocene Imperial formation of the Imperial Valley, California (Arnal, 1961; Merriam and Bandy, 1965; Ingle, 1974). Recent paleomagnetic studies of the Palm Springs formation (Opdyke, Lindsay, Johnson, and Downs, 1977) indicate that the Olduvai event (1.8 m.y.b.p.), commonly utilized to identify the Pliocene/Pleistocene epoch boundary (Berggren and van Couvering, 1974), occurs in the upper half of the Palm Springs formation close to the stratigraphically highest occurrence of beds containing an impoverished marine megafauna (Woodard, 1974) and Elphidium gunteri Cole (Arnal, 1961; Ingle, 1974).

Thus, correlation of the horizon containing common specimens of Elphidium gunteri Cole in Cerro Prieto sample M-93 (1944-1952 m) with the youngest occurrence of this species in the Palm Springs formation to the north suggests that the Pliocene/Pleistocene boundary (1.8 m.y.b.p.) may be located close to a depth of 2000 m beneath the eastern part Cerro Prieto geothermal field (Fig. 4). Stratigraphically higher sediments can in turn be assigned a Pleistocene age on the basis of stratigraphic superposition, assumed rates of sedimentation, and the presence of littoral marine microfaunas in which Elphidium gunteri Cole is absent (Table 2); sediments between 2000 and 3000 m are assumed to be Pliocene in age. This tentative placement of the Pliocene/Pleistocene boundary in the eastern Cerro Prieto section is consistent with the estimated mid-Pleistocene (1 m.y.b.p.) shoaling of the Gulf of California-Imperial Valley marine connection based on lithofacies analysis of the Cerro Prieto sequence by Lyons and van de Kamp (1980). These correlations also allow the marine shale unit present at well depths of 750 to 1100 m in the western part of the Cerro Prieto field to be tentatively dated as mid-Pleistocene in age (Fig. 4).

Depositional Environments

Based on detailed lithofacies and seismic analysis, Lyons and van de Kamp (1980) conclude that the Cerro Prieto section represents a series of intertonguing alluvial, deltaic, and shallow marine units deposited along the margin of the Colorado River delta as it prograded southwestward across the Salton Trough during Plio-Pleistocene time. The presence of reworked Cretaceous foraminifera and *Inoceramus* prisms from the Colorado Plateau as well as *in situ* occurrences of brackish and marine ostracodes, oogonia of the fresh water algae *Chara*, and littoral and neritic species of benthic foraminifera (Table 2) all support this general interpretation, with the distribution of these microfossils allowing additional insights regarding the depositional environments represented in this sequence.

Ostracodes are present in varying abundance throughout the Cerro Prieto section to a depth of at least 1952 m with the unornamented nature of the shells indicating a brackish or shallow marine origin. Similar forms to those present in the Cerro Prieto sediments are common in the shallow marsh areas of the modern Salton Sea (Arnal, 1961) and lagoonal and deltaic environments of the Gulf of California (Bandy, 1963; Swain, Miller, and Mandelbaum, 1964) where individual species display specific environmental tolerances. Thus, further detailed study of ostracode assemblages in the Cerro Prieto samples is recommended. Samples M-5 (500-506 m), M-21 (185-191 m), M-39 (872-878 m), and NL-1 (1886.5-1895.5 m) contain ostracodes but no *in situ* foraminifera, suggesting these horizons represent fresh or brackish water sites of deposition based on modern trends of ostracode/foraminiferal ratios in modern paralic environments of coastal California and the Gulf of California (Bandy, 1963).

The presence of the fresh water algae Chara in sample M-39 (872-878 m) is further evidence of fresh or brackish water environments in this area.

The distribution of Plio-Pleistocene foraminifera in the Cerro Prieto section provides direct evidence of marine deposition in two portions of this sequence above 2000 m. Foraminifera indicative of littoral and neritic marine environments are present in five core samples (Table 2) with four samples including M-5 (706 m), M-5 (900 m), M-15 (700-706 m) and M-15 (1090-1095 m), located in a mid-Pleistocene shaly unit present in much of the Cerro Prieto sequence at depths between 700 and 1100 m (Fig. 4). This pattern of foraminiferal distribution indicates that this particular unit was likely deposited in a shallow marine environment possibly encompassing a transition from a marine lagoon to open continental shelf along the margin of the Colorado River delta. Elphidium articulatum s.l. (d'Orbigny) present in sample M-5 (706 m) is most common in marine lagoons of the modern Gulf of California (Bandy, 1961) indicating a similar environment for the ostracode-rich assemblage found at this horizon (Table 2). Alternately, the presence of Buliminella elegantissima (d'Orbigny), Epistominella bradyana (Cushman), and Nonionella sp. in sample M-15 (1090-1095 m) is indicative of an open neritic (continental shelf) marine environment with water depths in excess of 20 m based on the modern distribution of these species in the Gulf of California (Bandy, 1961; Phleger, 1964). Finally, the occurrence of planktic species of foraminifera including Globigerina sp. and Globigerinita uvula (Ehrenberg) in sample M-15 (700-706 m) confirms the presence of open marine water adjacent to this area during the waning phases of mid-Pleistocene marine deposition in this area. Although the number of specimens of foraminifera in these samples precludes meaningful quantitative analysis, the stratigraphic pattern of species distribution suggests that the mid-Pleistocene sand and shale unit present at depths of 700-1100 m represents a significant marine incursion induced by either a eustatic rise in sea level, a reduction in the rate of progradation of the Colorado River delta in this area or a major change in locus of deposition of the delta.

Sandstone units underlying the marine unit discussed above yielded only one sample containing in situ benthic foraminifera, indicating the major portion of these sediments were deposited in brackish or non-marine deltaic/estuarine environments. However, the common presence of Elphidium gunteri Cole in sample M-93 (1944-1952 m) along with rare ostracodes indicates this horizon represents the site of littoral marine deposition in water of subtropical to tropical temperature based on the living distribution of this species (Phleger, 1960). The fact that many of the specimens of Elphidium gunteri Cole display abnormal tests also suggests a nearby source of fresh or brackish water (Arnal, 1961) and an estuarine environment of deposition. Foraminifera were not found in samples deeper than 1952 m but lithofacies analysis (Lyons and van de Kamp, 1980) indicate Pliocene(?) sediments below this depth likely represent non-marine and occasional littoral or estuarine delta front environments.

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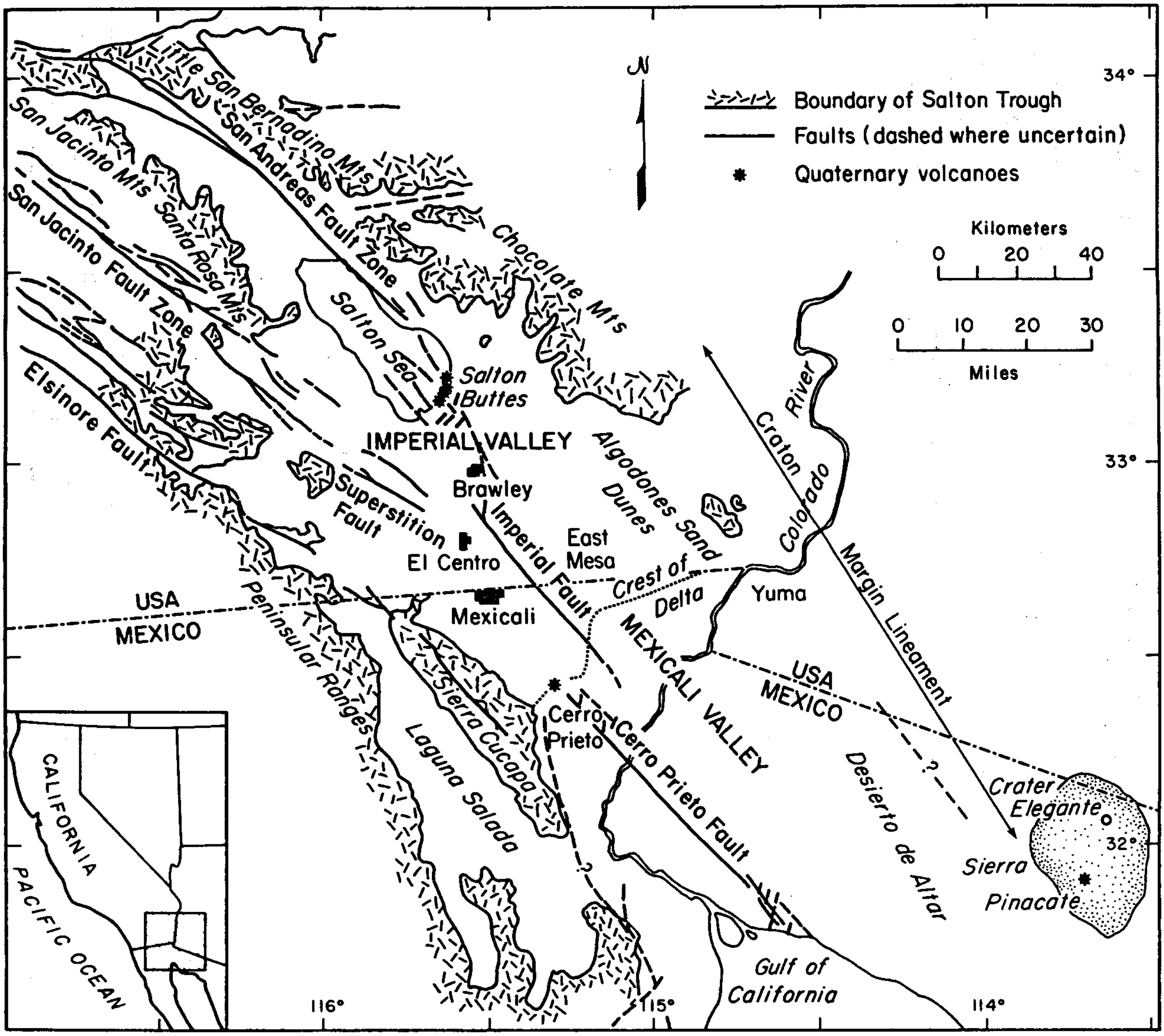
TABLE 1. GENERAL OCCURRENCE OF MICROFOSSILS IN CORE SAMPLES EXAMINED FROM CERRO PRIETO GEOTHERMAL WELLS, BAJA CALIFORNIA, MEXICO

WELL	Sample Depth m	Foraminifera	Ostracodes	Algae	Other
E-2	1732-1736				
M-3	2206				
M-5	500-506	X	X		X
	706	X	X		
	900	X	X		
	1100-1106				
M-6	700-704				
	866-872				X
	1907-1913				
M-9	818-824				X
M-11	700-705				
	1099-1104				
M-13	847-853				
M-15	704-706	X	X		
	1090-1095	X			
	1239-1244				
M-20	911-916	X			X
M-21	185-191	X	X		
M-26	1270-1275				X
M-38	1213-1217				
M-39	872-878		X	X	X
M-93	1565-1573				
	1944-1952	X	X		
M-94	2416-2421				
M-96	1977-1985				
M-123	1949				X
M-129	1600-1610				
	1800-1809				
M-149	1889-1897				
NL-1	1886.5-1895.5		X		

TABLE 2. SPECIFIC OCCURRENCE OF MICROFOSSILS IN CERRO PRIETO GEOTHERMAL WELLS, BAJA CALIFORNIA, MEXICO

SAMPLES MICROFOSSILS	M-5 500-506 m	M-5 706 m	M-5 900 m	M-6 866-872 m	M-9 818-824 m	M-15 700-706 m	M-15 1090-1095 m	M-20 911-916 m	M-21 185-191 m	M-26 1270-1275 m	M-39 872-878 m	M-93 1944-1952 m	M-123 1949 m	NL-1 1886.5-1895.5 m
BENTHIC FORAMINIFERA														
Buliminiella elegantissima (d'Orbigny)							X							
Elphidium articulatum s.l. (d'Orbigny)		X				X								
Elphidium gunteri Cole												X		
Elphidium translucens Natland			X											
Epistominella bradyana (Cushman)							X							
*Gavelinella sp.									X					
Nonionella sp.							X							
PLANKTIC FORAMINIFERA														
*Hedbergella spp.								X	X					
*Heterohelix globosa (Ehrenberg)	X													
Globigerina spp. (juveniles)						X		X						
Globigerinita uvula (Ehrenberg)						X								
OSTRACODES	X	X	X			X			X		X	X		X
MOLLUSKS														
Pelecypod fragments	X			X	X								X	
Inoceramus prisms	X				X			X			X			
FISH BONES										X				
ALGAE														
Chara oogonia											X			
MISCELLANEOUS														
Arenaceous tubes	X													

*Reworked Cretaceous species from Colorado Plateau area



XBL 801-6718

Figure 1. Location of the Cerro Prieto geothermal field and the Salton Trough (from Lyons and van de Kamp, 1980).

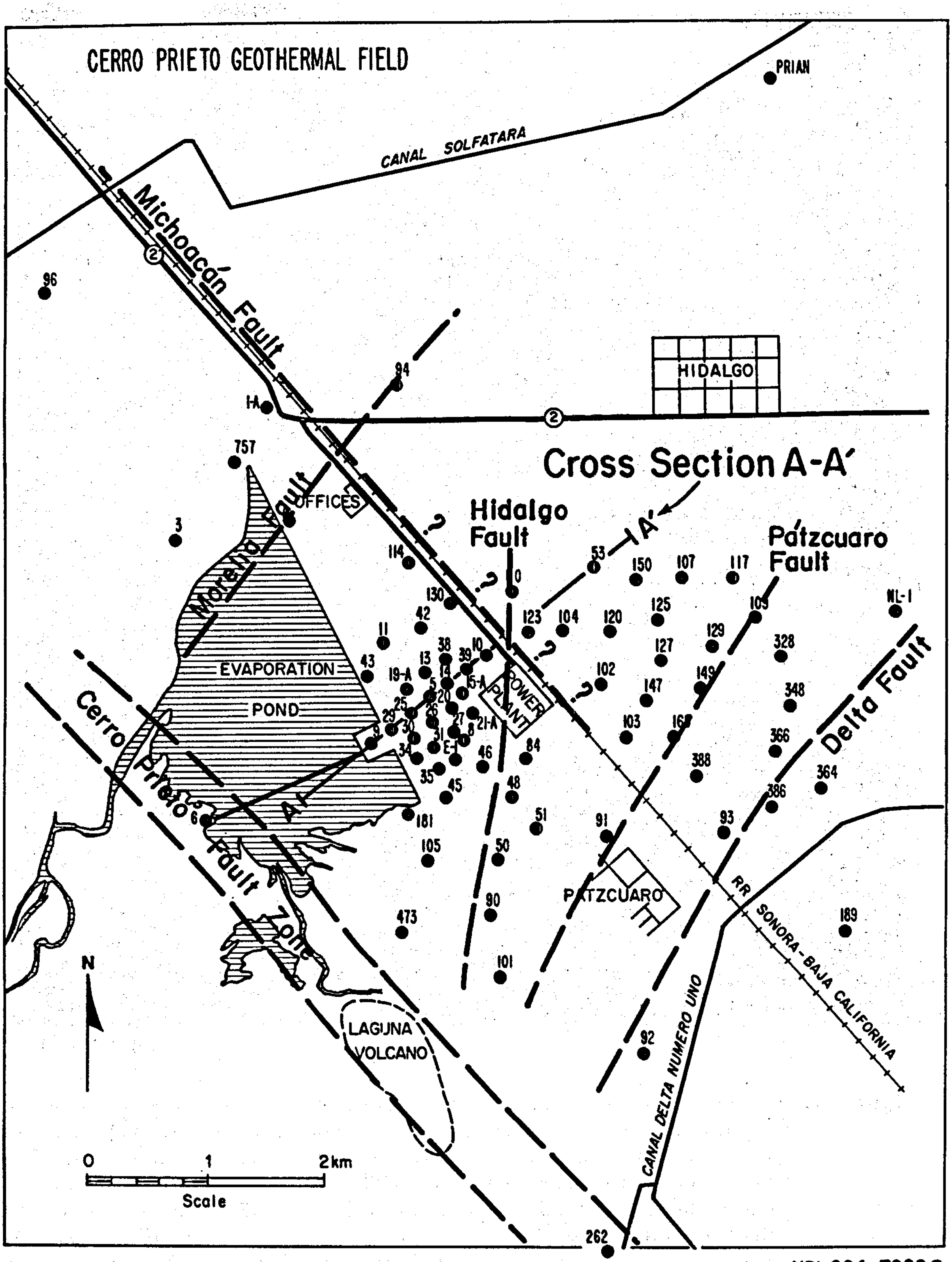
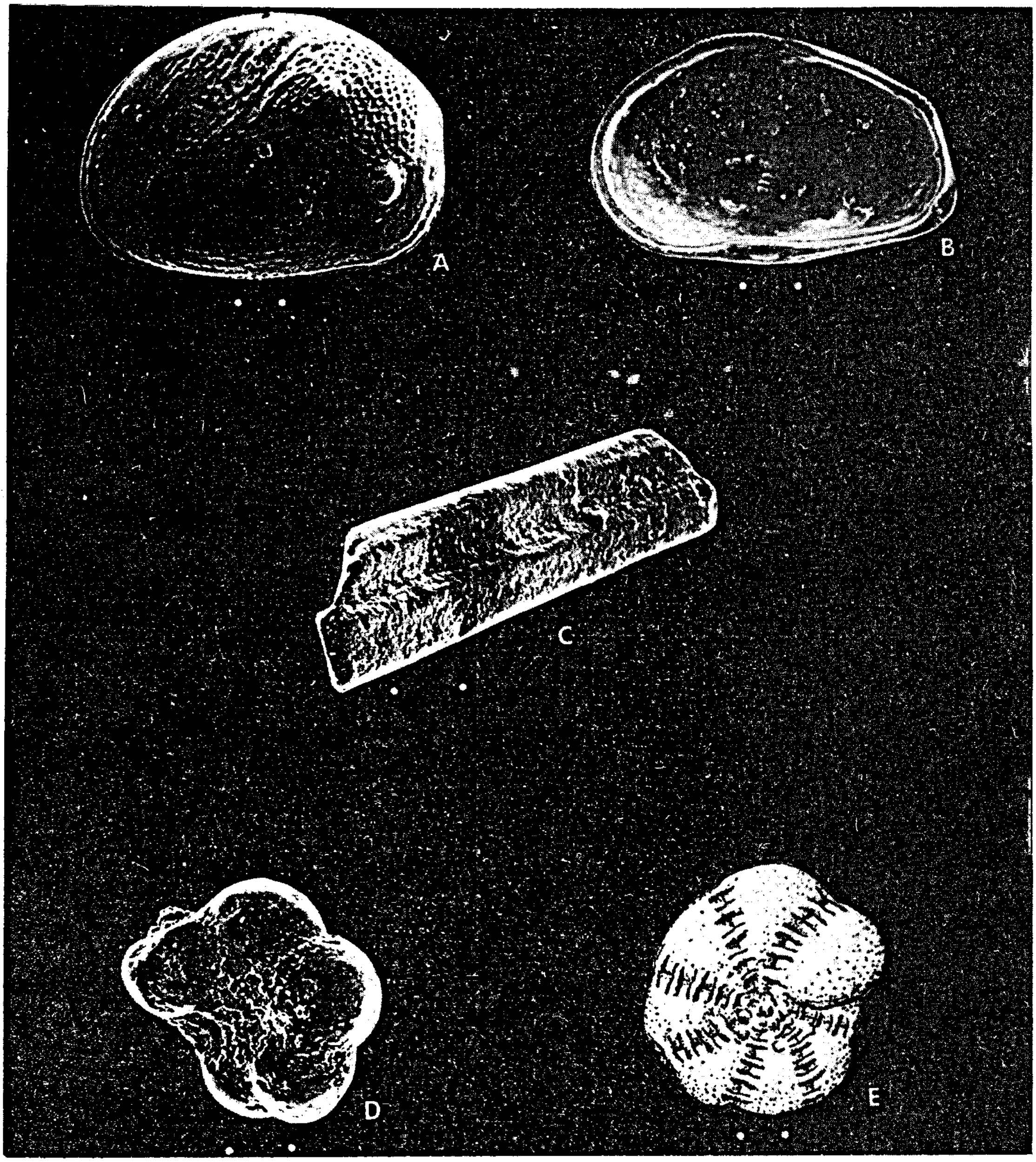


Figure 2. Location of geothermal wells and faults in the Cerro Prieto area, and location of schematic cross section A-A' illustrated on Figure 4.



XBB 821-493

Figure 3. Representative microfossils recovered from Plio-Pleistocene sediments of the Cerro Prieto geothermal field, Baja California, Mexico. A. SEM exterior view of ostracode shell from 706 m in well M-5. B. SEM view of interior of ostracode shell from 706 m in well M-5. C. SEM view of reworked Cretaceous Inoceramus prism from 818-824 m in well M-9. D. SEM view of reworked partial internal mold of the Cretaceous planktic foraminifer Hedbergella. E. Line drawing of a replaced specimen of the benthic foraminifer Elphidium gunteri Cole from 1944-1952 m in well M-93. Note that the distance between the two dots beneath each view represents 100 microns.

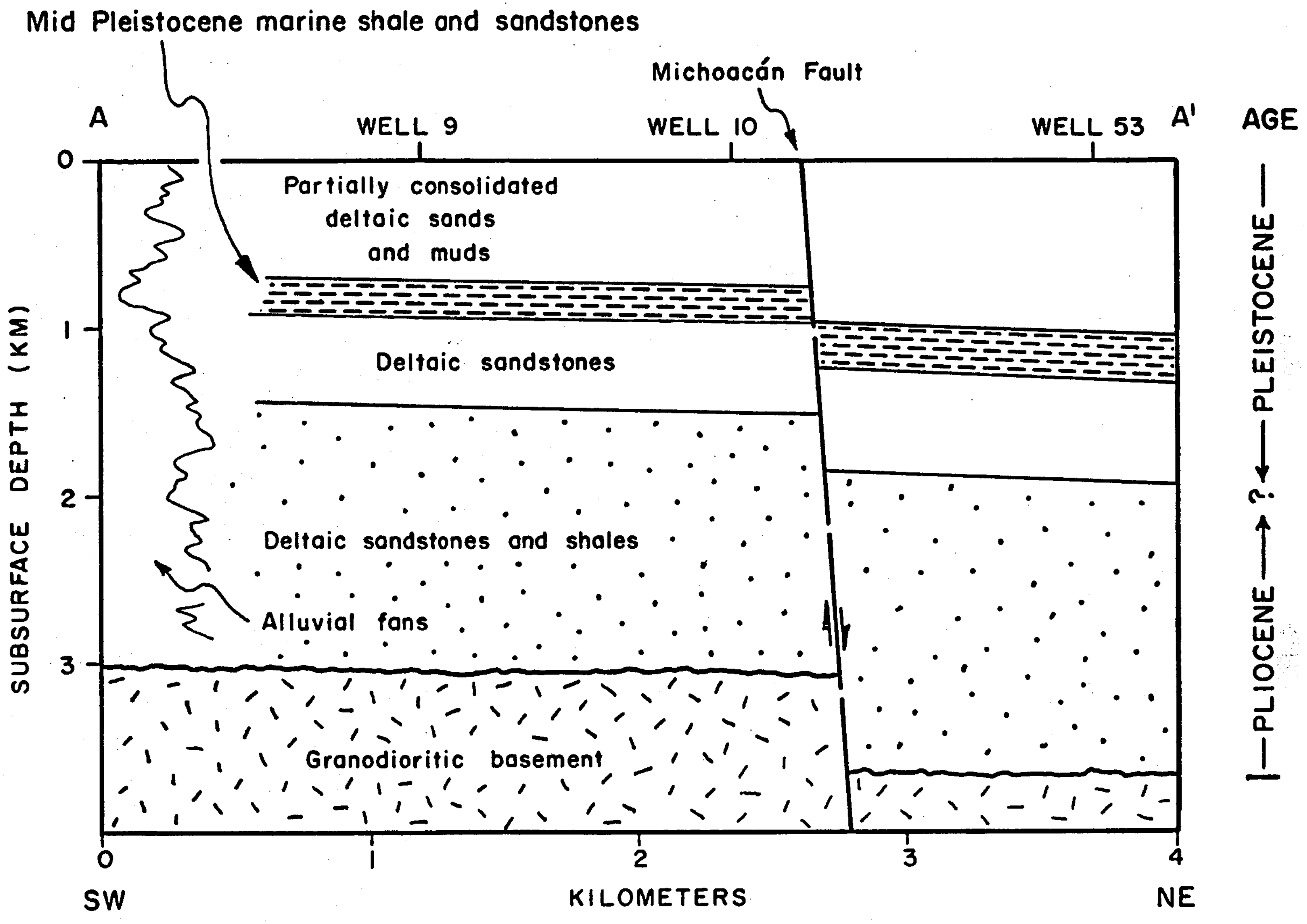


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Figure 4. Schematic cross section through the Cerro Prieto geothermal field, Baja California, Mexico. Tentative position of the Pliocene/Pleistocene boundary is based upon analysis of foraminifera as discussed in text. Position of cross section shown on Fig. 2; figure modified from Vonder Haar and Howard (1979).