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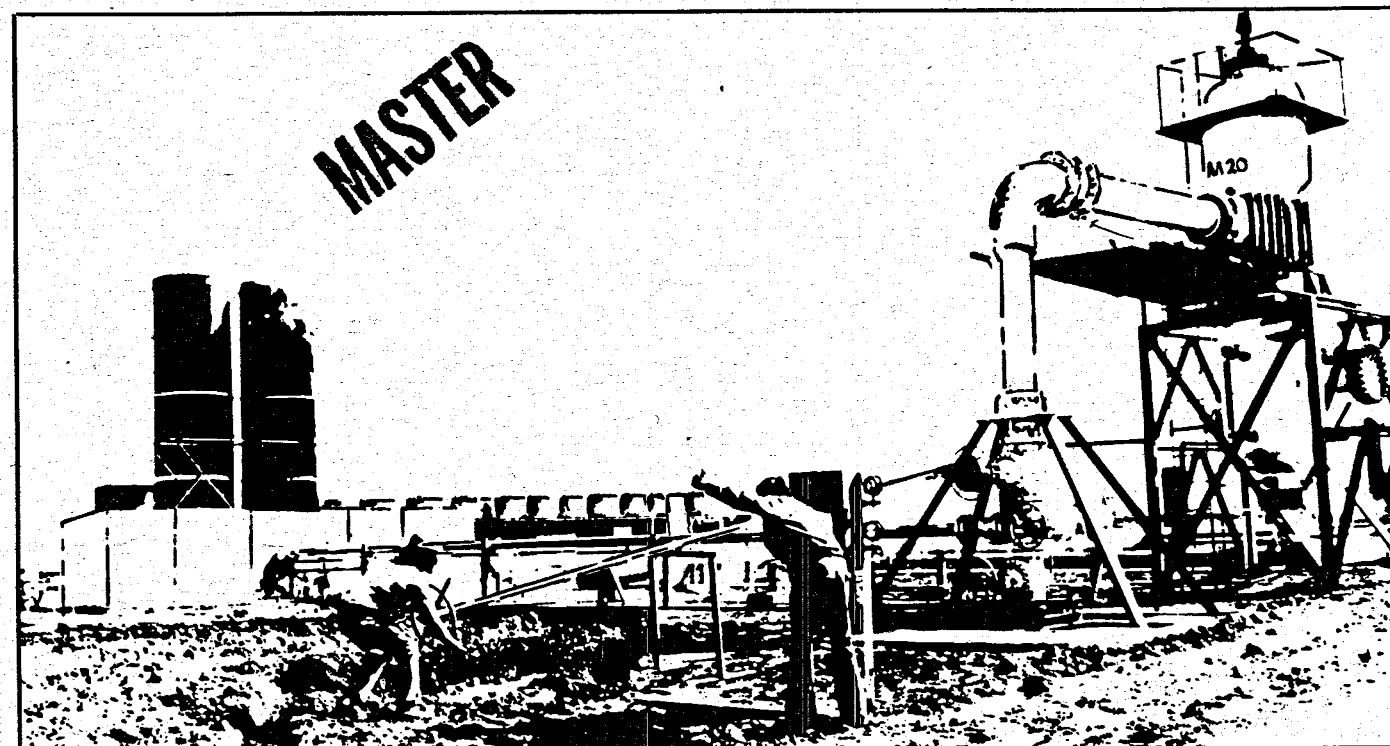

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ABSTRACT

To aid in a paleoenvironmental and age reconstruction of the Cerro Prieto reservoir system, we analyzed 59 samples of well cuttings for microfossils. The cuttings were obtained at depths from 351 to 3495 m in 14 geothermal wells in the Cerro Prieto field, Baja California, Mexico. We found foraminifera in 6 samples, ostracodes in 19 samples, and nannoplankton as coccoliths in 24 samples. Other groups, such as molluscs, insects, fish skeletal parts, and plant material were occasionally present. We cannot make detailed interpretations at this time because of poor preservation of samples. This is primarily due to causes: dissolution by geothermal fluids that reach 350°C, and the extensive mixing of filled Cretaceous forms (reworked from the Colorado Plateau region) with Tertiary species during drilling. Further studies of ostracodes and foraminifera from colder portions of the wells are needed. The abundant and well-preserved ostracodes indicate marine to brackish water environments that correspond, in part, to lagoonal or estuarine facies. The presence of the mid-Tertiary (15-m.y.-old) marine foraminifera, Cassigerinela chipolensis, in wells M-11 and M-38, 350 to 500 m deep, is perplexing. These are not laboratory contaminates and, as yet, have not been found in the drilling mud. If further studies confirm their presence at Cerro Prieto, established ideas about the opening of the Gulf of California and about Pacific Coast mid-Tertiary history will need to be rewritten.

INTRODUCTION

This study was intended to provide an examination of any microfossils present in subsurface samples from the Cerro Prieto geothermal field (Fig. 1), and to correlate the fossils to a general age range and paleoenvironment. Of the 55 wells at the field, 14 were selected to give a range of both exploration and production wells (see Fig. 2 for well locations). Some wells, such as Prian, were selected because of their cool water (100°C), compared with the fluids in the geothermal reservoirs (350°C). Well-cutting samples were collected from depths between 351 and 3495 m in the caprock units, the main reservoir, and the shale and siltstone interbeds.

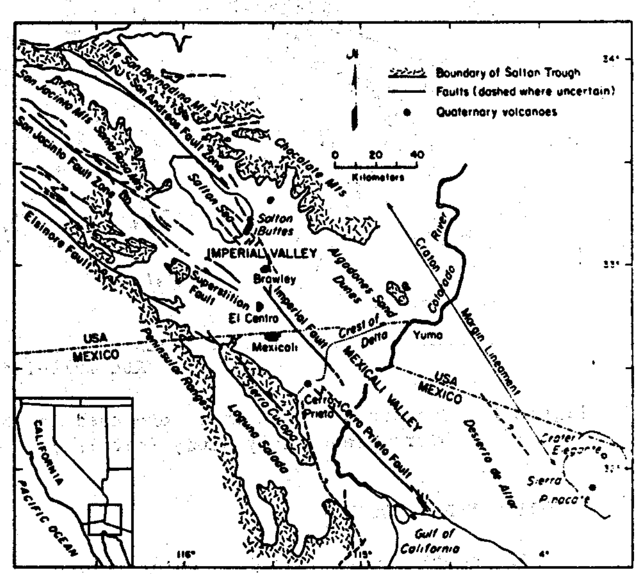

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Figure 1. Location map showing the Cerro Prieto geothermal field in the southern Salton Trough, Mexico.

In general, the geology at Cerro Prieto consists of a mixed deltaic environment (Fig. 3) in the southern Salton Trough (Puente C. and de la Peña L., 1979; Noble et al., 1977), similar to that of the East Mesa geothermal field 60 km to the north (Howard et al., 1979). However, Cerro Prieto appears to have had a greater marine influence from the Gulf of California than East Mesa does. Cerro Prieto is highly faulted with a major structural feature, the Cerro Prieto fault, bisecting the geothermal field (Vonder Haar and Puente C., 1979a,b).

Accepted laboratory methods used in micropaleontology were employed to assure that the samples were as uncontaminated as possible. We assumed initially that samples represented the sedimentary and stratigraphic level from which they were obtained in a given well. For those not familiar with microfossils, an excellent general overview is given by Haq and Boersma (1978).

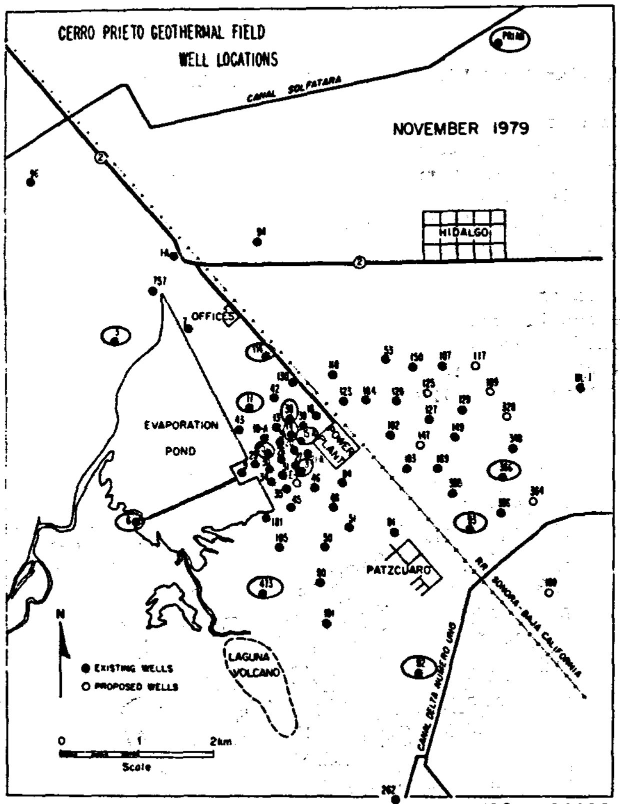

Figure 2. Geothermal wells that were used in the micropaleontology study (circled).

LABORATORY PROCEDURES

All samples were soaked in water before washing. Initial attempts to break down densified shale and slate samples by using kerosene proved futile, and that process was discarded. After soaking, samples that had not broken apart completely, particularly those with a high clay or silt fraction, were boiled for approximately 15 min on a hot plate. Except for those rock samples that were highly densified, all disaggregated well.

A small portion of the supernatant solution from each sample was removed before washing, placed in a large beaker, and dried; this portion was used to analyze calcareous nannofossils, which are typically smaller than 5 μm in diameter. The remainder of the sample was washed completely through a standard number 230 screen (opening 62 μm in diameter) to remove silt and clay-sized particles. The sand fraction was then drained through filter paper and dried.

When both portions of each of the samples were completely dry, one of two procedures was carried out:

1. Calcareous nannofossil procedure: A very small amount of the dried residue from the supernatant solution was scraped from the bottom of the beaker in which it was dried and placed on a 1-mm-thick glass microscope slide. Three or four drops of Caedax fixative (a synthetic Canada balsam) were placed on this sediment, covered by a cover glass, placed on a hot plate, and allowed to heat to boiling for several minutes. This procedure bonds the cover glass to the slide and fixes the sediment and its inclusions in place. Examination of these prepared slides was carried out by the use of a Zeiss petrographic transmitted light microscope, using both dry and oil-immersion lenses. Photographs of the calcareous nannofossils were taken with a similar microscope which has a camera attachment.

2. Larger calcareous microfossil procedure: After drying, each sample was sieved through a series of screens: number 18 (opening 1 mm), number 40 (opening 425 μm), number 80 (opening 180 μm), and number 140 (opening 105 μm). Each fraction of the sediment was examined in small amounts under the microscope (just enough to completely cover the bottom of a standard 45 square picking tray). The microscopes employed were an AO/Spencer biopetrographic light microscope and a Zeiss biopetrographic light stereomicroscope. Progressively smaller fractions were examined until the entire sample had been looked at and any fossils encountered removed by use of a number 0 picking brush. Fossils were placed in standard one-hole micropaleontologic faunal slides, where they were kept until identification.

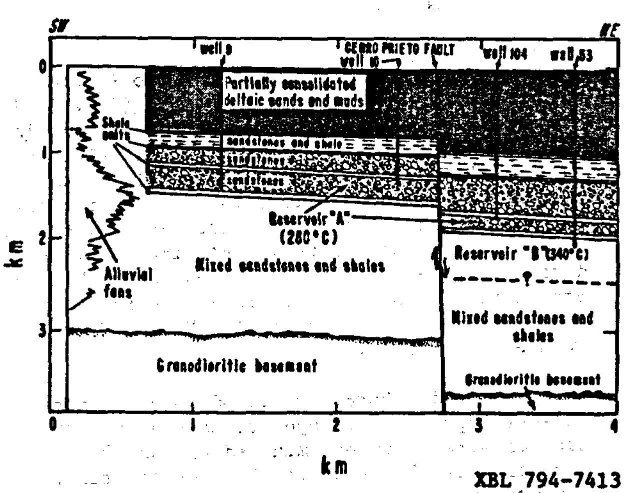

Figure 3. Simplified geologic section across the earliest developed portion of the Cerro Prieto geothermal field (from Vonder Haar and Puente C., 1979a).

MICROFAUNAL AND FLORAL ANALYSIS

Table 1 lists the microfossils encountered in various samples. Many of the samples were barren; these tended to be the samples composed mainly of the gray dense shale or slate material, although for 0473-567 m, (well 0-473, at 567-m depth), ostracodes were found imbedded in the shale. Ostracodes and calcareous nannoplankton (as coccoliths) were the most abundant fossil groups found; foraminifera were found in only 6 of the 59 samples examined. Other groups, such as molluscs,

TABLE 1. CHECKLIST BY GEOTHERMAL WELL AND SAMPLE DEPT OF MICROFOSSILS FROM CERRO PRIETO

Well	Sample depth (m)	Foram-inifer	Ostracodes	Nanno-fossils	Other
M3	839				
	2339			X	X
	2500			X	
M4	1200			X	
	1975			X	
M6	962		X		
	1245			X	
M8	964	X	X		
	906			X	
	1167			X	X
	1265				
M11	351	X	X	X	X
	470	X	X	X	X
	678		X		
	753		X	X	X
	879				
	882				
	912				
	921				
	1050				
	1161				
	1245				
	1365				
	1377				
M14	786		X	X	
	1041			X	
	1254				
M15	693	X	X	X	
	1008			X	
	1164			X	
M38	372	X	X		X
	480	X	X		
	718		X		
	864				
	961				
	969				
	1157				
	1239				
	1338				
	1479				
	1490				
M92	1998			X	
	2202			X	
	2446			X	
M93	1806			X	
	138		X	X	X
	606		X	X	
	996				
	1158				
	1680				
	1897				
0473	567		X	X	
	804				
	1062		X		
	1434			X	
Prian	3243		X		
	3495		X	X	
T366	2052				X
	2601				

insects, and fish skeletal parts, were found in small quantities. Some plant material was also encountered (see Table 2).

Foraminifera

Foraminifera are members of the phylum Protozoa, class Sarcodina, and are in essence amoebas that secrete elaborate calcareous shells ("tests"), or construct an agglutinated test by means of a secreted organic cement (Loeblich and Tappan, 1964). In the first analysis of the samples, only one or two foraminifera were found. Because several of the samples were very fine sands, which contained other calcareous microfossils and could be expected to contain foraminifera, this paucity was difficult to understand. Merriam and Bandy's (1965) study provided an explanation. Bandy described small (100 to 200 μm), perhaps juvenile (only one or two chambers), reworked Cretaceous specimens from the sandy sediments of the region. On reexamination of the sandy Cerro Prieto samples (particularly the fine fraction) under the highest power of the microscope (100 X), we observed very small foraminifera of similar size. Yellow-filled Cretaceous planktic foraminifera were found in samples M8-694 m, M11-470 m, and M38-372 m. Figures 4 and 5 show examples of this type of foraminifera. One Tertiary marine species, *Cassigerinella* sp. cf. *C. chipolensis* (Cushman and Ponton) (Fig. 6) was also identified in samples M11-351 m, M11-470 m, and M38-480 m. Other very small foraminifera, however, defied identification. We do not know whether they are Cretaceous or Tertiary, benthic or planktic (Douglas, 1979, oral commun.). Attempts at identification were made, but the extremely small size of the specimens makes positive identification impossible. Some of the individuals may be juveniles, a factor which complicates identification. Table 3 lists those foraminifera identified with an amount of certainty in the six foraminifer-containing samples (Figs. 4, 5, and 6).

Calcareous nannoplankton

Coccoliths are the skeletal remains of members of the algal class Haptophyceae. Table 1 lists samples that contained coccoliths. Readily identified species were taken from samples Prian-3495 m, M6-1245 m, and 0473-1434 m. Most of the samples contained reworked Cretaceous species, such as *Watznaueria barneseae* Perch-Nielson, but a few Tertiary nannofossils, such as discoasters and sphenoliths, were observed (Table 4).

Ostracodes

Ostracodes belong to the phylum Arthropoda, class Crustacea, and are small shrimp-like organisms that secrete a bivalved shell known as a carapace. This carapace is the part of the animal that can become fossilized. Ostracodes molt several times during their lives, and these stages or "instars" are also preserved in the geologic

TABLE 2. COMPLETE LISTING OF SHELL FRAGMENTS AND OTHER ORGANIC REMAINS IN THE CERRO PRIETO GEOTHERMAL WELL SAMPLES STUDIED

Well	Depth (m)	Fossils found*	Well	Depth (m)	Fossils found*
M3	839	B	M38	372	O, F, S
	2339	N, I		480	O, F
	2500	N		718	O
				864	B
M4	1200	N		961	O
	1975	N		969	O
				1157-	
M6	962	O		1490	B
	1245	N			
			M92	1998	N
M8	964	O, F		2202	N
	906	N		2446	N
	1167	N, I			
	1265	B	M93	1806	N
M11	351	S, G, O, N, F	M114	138	G, P, O, N
	470	S, G, O, N, F		606	O, N
	678	O		996	B
	753	O, N		1158	B
	879-			1680	B
	1377	B		1897	N
M14	786	O, N	0473	567	N, O
	1041	N		804	B
	1254	B		1062	O
				1434	N
M15	693	O, N, F			
	1008	N	Prian	3243	O
	1164	B		3495	O, N
M25	486	O	T366	2052	I
	1041	O, N, I		2601	B
	1242	N, I			

Key: B = barren; F = foraminifera; G = gastropod; I = insect parts; N = nannofossils; O = ostracods; P = pelcypod; S = shell fragments

record through fossilization of the various carapaces (Pokorny, 1978). Many complicated criteria are used to identify individual species, including the type of hinge that articulates the two valves, muscle attachment scars, and valve margin structures.

Many of the samples from the Cerro Prieto area contained ostracode valves or fragments (Tables 1 and 2). The specimens have smooth, thin shells, with no strong ornamentation, which indicates that they are from a low-energy marine or brackish water environment. The pores, margins, and inner surfaces of the valves are well-preserved, which indicates that they are not very old; in fact, the ostracodes encountered in the samples, although not identified as to genus or species, appear to be of Holocene age (McRaney, 1979, oral commun.).

INTERPRETATION OF DATA

Several problems present themselves in the samples from the Cerro Prieto area; the most obvious are the apparent contamination during drilling and hydrothermal alteration.

The first problem is typified by the presence of ostracodes at all levels in the wells. Although their presence in shallow samples (such as M38-372 m, M38-480m, M11-138 m) is certainly expected and reasonable, in deep samples (M38-969 m, Prian-3243 m, and Prian-3495 m) ostracodes indicate far too much downward displacement to be explained by natural reworking of the sediments. This phenomenon can also be observed in the calcareous nannofossils, when shallow samples (M11-470 m) contain Cretaceous specimens, and deep samples Tertiary forms (0473-1434 m). Because nannofossils are extremely small, they are, of course, easily transported and reworked; the degree of displacement in these samples, however, appears to be introduced by mud recirculating during drilling operations. Very great care was taken in laboratory preparation in order to prevent contamination during that procedure.

There are so few foraminifera present in the samples that it is difficult to draw conclusions

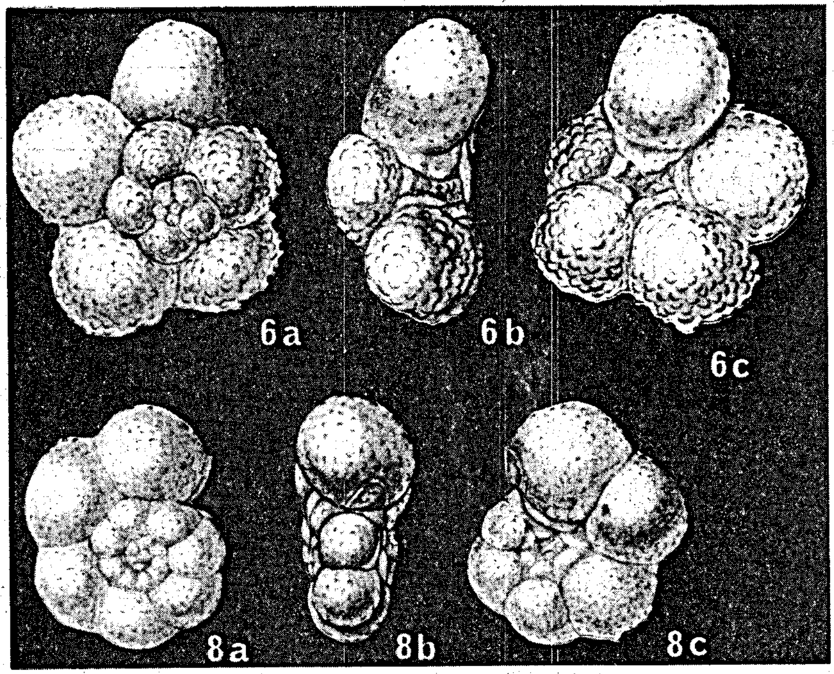

Figure 4. Hedbergella holmdelensis (from Sliter, 1968). A reworked Cretaceous foraminifer from the Colorado Plateau found in the deltaic sediments of well M-11. Actual size of each foraminifer is 0.15 mm.

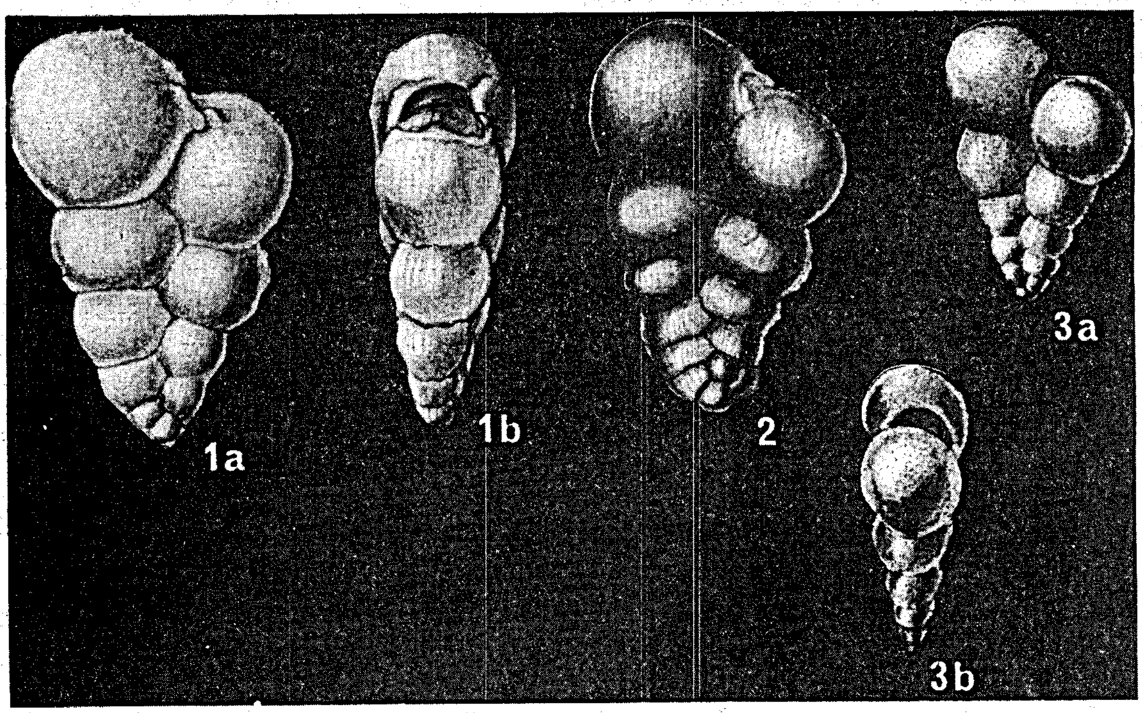

Figure 5. Heterohelix globulosa (from Sliter, 1968). A reworked Cretaceous foraminifer from the Colorado Plateau found in well M-8. Actual size of each foraminifer is approximately 0.25 mm.

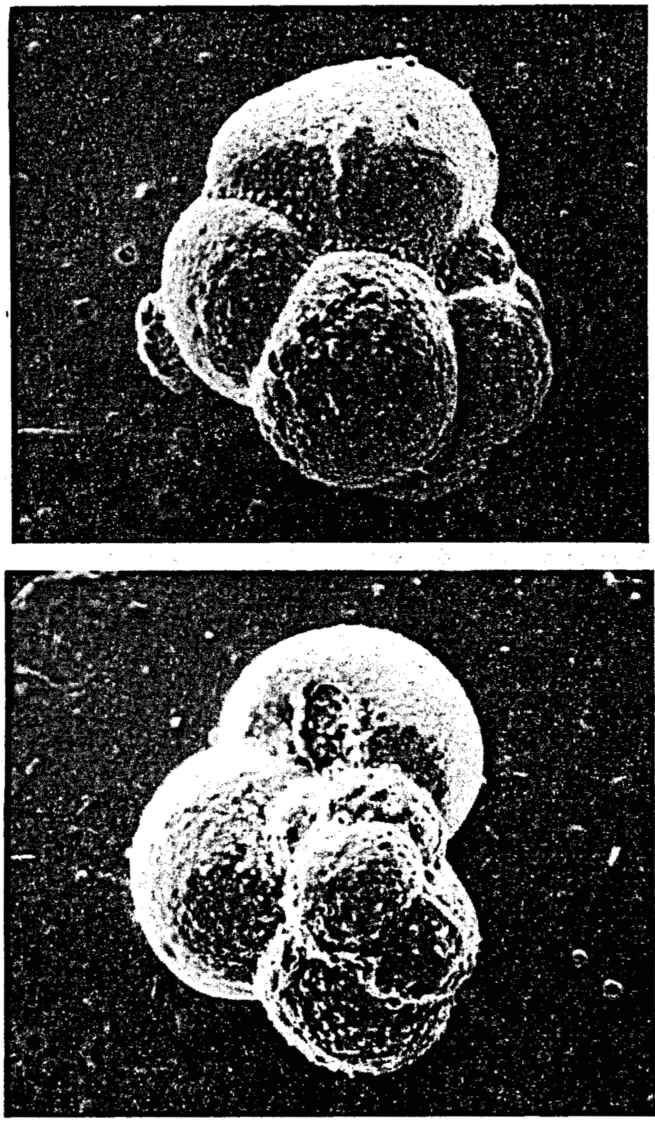

Figure 6. Two views of the Tertiary foraminifer Cassigerinella chipolensis (Stainforth et al., 1975) found in the Cerro Prieto well cuttings. These scanning electron microphotographs were provided by J. L. Lamb, EXXON Production Research, Houston, Texas. Actual size of the foraminifers is 1.0 mm.

from them. The systematic ambiguity of the very small specimens limits them as an aid to identifying either the age or paleoenvironment of the Cerro Prieto field, and prevents us from making a judgment in either regard. The fact that the small specimens are all of similar size indicates that they were transported and winnowed into position. The three or four benthic foraminifera we found are badly preserved, and we cannot form a hypothesis about their paleoenvironment. Our inability to identify the small individuals also prevents us from assigning an age to the samples.

TABLE 3. FORAMINIFERA IDENTIFIED WITH CERTAINTY IN THE CERRO PRIETO WELL SAMPLES

Well	Depth (m)	Foraminifera Found
M11	351	Cassigerinella sp. cf. C. chipolensis (Cushman and Ponton)
M11	470	C. sp. cf. C. chipolensis Hedbergella sp. cf. H. holmdelensis (Olsson)
M8	694	Heterohelix globulosa (Ehrenberg) possible benthic form
M15	693	Possible Cretaceous globigerine form
M38	372	Hedbergella sp. cf. H. monmouthensis (Olsson)
M38	480	C. sp. cf. C. chipolensis Globigerina Possible Tertiary turborotalids

References used as aids in identification include Loeblich and Tappan (1964), Sliter (1968), and Stainforth, et al., (1975).

The ostracodes are, therefore, perhaps the best indicators of environmental conditions in the area, since they are abundant and well preserved. As noted above, their shell morphology is typical of ostracodes from marine or brackish water environments; it is not unreasonable to propose that they may indicate lagoonal or estuarine conditions.

TABLE 4. NANOPLANKTON OBSERVED IN CERRO PRIETO WELL CUTTINGS.

Well	Depth (m)	Nannoplankton Found
M6	1245	Zygodiscus diplogrammus Gartner Lithraphadites carniolensis Delfandre Tranolithus sp. Watznaueria barneseae Perch-Neilsen Vagalapilla sp. Eifellithus turriseifelli Deflandre E. eximius Perch-Nielsen
M11	470	Nannoconus multicadus Deflandre and Deflandre-Rignaud W. barneseae
M92	2466	Micula sp. cf. M. staurophora
0473	1434	Discoaster sp. cf. D. deflandrei Bramlette and Riedel base of sphenolith
Prian	3495	W. barneseae

References used as aids in identification include Bramlette and Sullivan (1961) and Hill (1976)

Colorado River sediments of the northern Gulf of California were largely deposited during a post-Pleistocene sea-level rise. The area is now largely nondepositional, and the sediments left in the northern gulf region are relict sediments (van Andel, 1964). Merriam and Bandy (1965) classified samples taken from near the Cerro Prieto area as "recent delta" sediments. Reworked Cretaceous foraminifera found in the samples probably are derived from the highly fossiliferous Upper Cretaceous Mancos shale of the Colorado Plateau, through which the Colorado River flows (Merriam and Bandy, 1965).

Mid-Tertiary marine Cassigerinella chipolensis in wells M-38 and M-11 at depths of 350 to 500 m may be of major geologic importance. These foraminifera are not laboratory contaminants and, as yet, have not been located in samples of the drilling mud or in the mud pits next to the wells. There are no known outcrops or subsurface units in the Salton Trough from which this microfossil could have been reworked. Their age (approximately 15 m.y.) is much in excess of any reported samples from the Salton Trough and Gulf of California. Further studies of Cerro Prieto well cuttings should be undertaken to search for a suite of specimens. If the presence of Cassigerinella chipolensis is confirmed, it will affect current theories about the opening of the Gulf of California and about Pacific coast mid-Tertiary history.

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