Pluvial Lake Palomas, northwestern Chihuahua, Mexico

Reeves, Corwin C., Jr.

1969, pp. 143-154. https://doi.org/10.56577/FFC-20.143

in:

The Border Region, Chihuahua and the United States, Cordoba, D. A.; Wengerd, S. A.; Shomaker, J. W.; [eds.], New Mexico Geological Society 20th Annual Fall Field Conference Guidebook, 228 p. https://doi.org/10.56577/FFC-20

This page is intentionally left blank to maintain order of facing pages.

PLUVIAL LAKE PALOMAS NORTHWESTERN CHIHUAHUA MEXICO

By

C. C. REEVES, JR.

Department of Geosciences, Texas Technological College, Lubbock

ABSTRACT

Pluvial Lake Palomas, which once inundated approximately 3,000 square miles of northwestern Chihuahua, Mexico, during post-Kansan time, was confined mainly to Chihuahua by incisement of La Mesa by the Rio Grande. Measured sections and field traverses show the Camp Rice Formation continuous from La Mesa south into Chihuahua, but outcrops of older fluvial and lacustrine units are unknown. Evidence of Lake Palomas such as abandoned beaches, spits, wave-cut escarpments, multiple shorelines and lacustrine deposits, is widespread, the highest well-established Wisconsin level being about ± 4,018 feet.

Gravity profiles and regional geology indicate that the eastern part of the Lake Palomas basin is of tectonic origin, the deepest part being north of the Franklin bolson, but south of the International Border. Regional geology also indicates that the possibilities for discovery of commercial continental salines are especially promising in the lacustrine sections.

RESUMEN

El Lago Pluvial de Palomas, que una vez inundó aproximadamente 3,000 millas cuadradas del noroeste de Chihuahua, Mexico, durante la época post-Kansan, fue restrigido principalmente a Chihuahua de bido a la erosion de La Mesa por el Rio Grande. Secciones medidas y caminamientos muestran que la Forrnación Camp Rice, se continua desde La Mesa hacia el sur a Chihuahua, Pero se desconocen afloramientos de unidades fluviales y lacustres más antiguas. Testigos de la existencia del antiguo Lago de Palomas tales como playas abandonadas, bancos de arena, acantilados cortados por el oleaje, multiples lineas costeras y depósitos lacustres se encuentran ampliamente distribuidos, siendo el más alto de éstos el nivel Wisconsin, bien establecido a una altura de 4,018 pies.

Los perfiles gravimetricos y la geologia regional indican que la parte oriental de la cuenca del Lago de Palomas es de origen tectónico, la parte más profunda está al norte del bolson de Franklin e al sur del limite internacional. La geologia regional indica también que hay posibilidades de descubrir salinas continentales comerciales, que son especialmente prometedoras en secciones lacustres.

INTRODUCTION

Pluvial Lake Palomas was named and defined in the 16th Annual New Mexico Geological Society Guidebook (Reeves, 1965). Although the term "Lake Palomas" was used by Tamayo (1949) for a small basin along the Chihuahua-Durango border it is not to be confused with the term "pluvial Lake Palomas" which refers to a Pleistocene pluvial lake which once existed in northwestern Chihuahua.

LOCATION AND DESCRIPTION

The basin of pluvial Lake Palomas, located in the northwestern part of the Chihuahuan desert (Fig. 1), was named for the village of Palomas on the international border 35 miles south of Deming, New Mexico (Reeves, 1965). The Chihuahuan desert, located east of the high Sierra Madre Occidental plateau, extends for about 1,000 miles of Lat. 20° N., well into New Mexico and Texas. The basin of pluvial Lake Palomas extends from southeast of Villa Ahumada (30° 35' N., 106° 31' W.) northwestward to about 32° N., 107° 30' *W.;* however, there are innumerable other basins in the Chihuahuan desert and on the Sierra Madre south to Mexico City which contained lakes during pluvial times. For instance, in northern Mexico, Laguna del Cuervo northeast of Chihuahua City once covered nearly 600 square miles, and other smaller unnamed basins near Monclova, Torreon, and Santa Barbara exhibit paleolacustrine features.

EARLY TO MIDDLE PLEISTOCENE HISTORY

Early Pleistocene Lake Cabeza de Vaca (Strain, 1966) once extended throughout the bolsons surrounding El Paso, forming one large lake from the Hueco bolson on the east and north into the Tularosa basin, westward into the Mesilla bolson and south for at least 100 miles into Chihuahua. By late Kansan time filling of the bolsons, the rising mountains, and entrenchment of the Rio Grande in the Hueco bolson subdivided the basin of Cabeza de Vaca, forming isolated impondments.

Little is known of the subsurface deposits of Lake Cabeza de Vaca, although deep stratigraphic tests and irrigation wells have been drilled in several localities on both sides of the International Border. Pleistocene bolson deposits may not necessarily be correlative between Chihuahua and

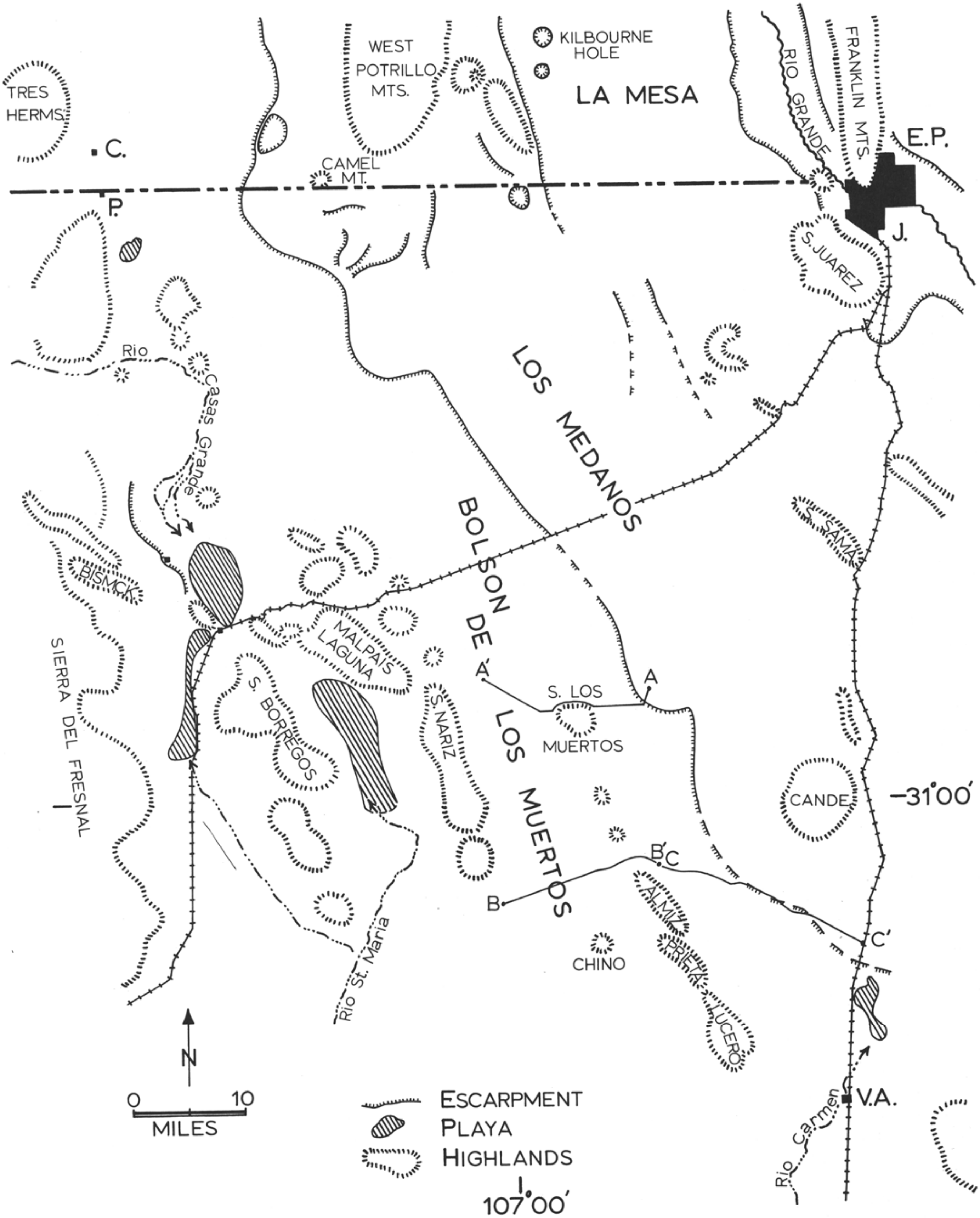

FIGURE 1.

Index map of northwestern Chihuahua showing the general area of pluvial Lake Palomas and the major physiographic and cultural features. Gravity traverses are lettered A-A′, B-B′, and C-C′. Columbus, New Mexico = C, Palomas, Mexico = P, El Paso, Texas = E.P., V. Ahumada, Mexico = V.A., Ciudad Juárez = J.

Texas and New Mexico, or even between the Hueco and Tularosa basins; however, early Pleistocene lacustrine deposits of Cabeza de Vaca should be distinguishable.

The deep test of the El Paso Water Utilities Board (Sec. 20, Blk. 80 Tsp. 1), at an elevation of 3,995 feet on the west flank of the Hueco bolson, revealed about ± 3,300 feet of lacustrine fill, the top of the lacustrine section being about 3,000 feet (personal communication, T. L. Cliett). (See Cliett, this guidebook) . The Corps of Engineers stratigraphic test well east of White Sands (Sec. 15-22S-5E), at an elevation of 3,950 feet, indicates over 5,971 feet of bolson fill (written communication, G. C. Doty), much of which appears correlative to the lacustrine section in the deep test well near El Paso.

Lee (1907), Burrows (1910), Bryan (1933), Kottlowski (1958), Strain (1965; 1966), Reeves (1965), and Hawley and Kottlowski (1969) agree that the ancient (Pliocene-middle Pleistocene) Rio Grande northwest of El Paso flowed south into Chihuahua through the Mesilla bolson, terminating in a gigantic lake or lakes. However, there has been some disagreement over establishment of the Rio Grande's present channel through El Paso canyon (Kottlowski, 1958; Strain, 1966) .

Strain (1966), on the basis of "mixed-rounded gravels" containing andesite and Soledad rhyolite in the Hueco trough along the east side of the Franklin Mountains and logs of wells in Fillmore pass north of El Paso (Knowles and Kennedy, 1956), believes the Rio Grande flowed through Fillmore pass and the Hueco bolson. The Mesilla and Hueco bolsons aggraded to a common level of about ± 4,200 feet in the Fillmore pass area, meandering or piracy causing diversion of the Rio Grande through Fillmore pass in early Kansan time (Strain, 1966) . The present course of the Rio Grande through El Paso canyon was supposedly caused by accelerated stream erosion through the fault escarpment on the east side of the Franklin Mountains and capture of the upper Rio Grande near the Organ Mountains late in Kansan time (Strain, 1966) . Geomorphic studies in the El Paso area, however, suggest a somewhat different series of events.

As the Rio Grande flowed into Chihuahua in Pliocene (?) and early Pleistocene time and the bolsons filled with debris, the terminal lake and associated Rio Grande delta area were consistently and inevitably forced northward. Volcanic action and faulting in the West Potrillo Mountains and along the Robledo fault tilted La Mesa to the east (Ruhe, 1967), thus as the bolson filled the Rio Grande was also slowly forced eastward. Studies by Ruhe (1962) indicate that Mesilla bolson, and Fillmore pass filled mainly by local wasting and not fluvial debris; however, unquestionable fluvial gravels are exposed in the Fillmore pass locality beneath the La Mesa surface. The question then is not "did or did not the Rio Grande run through Fillmore Pass," but "when and for how long?" The Rio Grande must have abandoned its course through Fillmore Pass and the Hueco bolson before entrenchment took place downstream in either the Hueco or Mesilla bolsons, or else the river must have changed from an aggrading to an erosional stream in a very few miles. It would have been highly improbable and geologically impossible, unless the Rio Grande had dissipated in the Hueco bolson after passing through Fillmore pass, for a pirate tributary stream to cut El Paso canyon, entrench the lower Mesilla Bolson, and behead the parent Rio Grande west of Fillmore pass if the Rio Grande had not first entrenched itself through the Hueco bolson and Fillmore pass.

Kottlowski (1958), Ruhe (1962: 1964), and Hawley and Gile (1966) suggest entrenchment of the Rio Grande from integration of the river system to the north; however, the absence of entrenchment in Fillmore pass and the Hueco trough illustrates that the Rio Grande abandoned the Fillmore pass channel before entrenchment took place in either bolson. Rather, I suspect that the ancient upstream Rio Grande flowed mainly into a terminal lake in Chihuahua until an increase in discharge caused by glacial runoff and pluvial conditions perhaps augmented by integration of upstream drainage, raised the lake level to create a higher local base level. This caused an increase in deposition and meandering, the situation indicated by the widespread "mixed-rounded gravels," which resulted in a distributary spill-over into the Hueco trough, the flow probably dissipating before reaching El Paso. Incisement of the Rio Grande on the Mesilla bolson occurred only after destruction of the temporary base level at El Paso canyon and not by a simple upstream increase in discharge.

Breakthrough of the ancient Rio Grande through El Paso canyon and into the Hueco bolson occurred after entrenchment had taken place through the Hueco bolson by the lower Rio Grande, entrenchment which was allowed only by prior elimination of the temporary base level (± 3,900 feet) at the Quitman Mountains. Before elimination of the Quitman Mountain base level and draining of Lake Cabeza de Vaca, the lower Rio Grande had a gradient of about 3 feet/mile and the upper Rio Grande flowing into Chihuahua probably had a gradient of about 1 to 2 feet/mile. As shown by vertebrates and volcanic ash (Strain, 1966), the Quitman Mountain base level was eliminated in early Kansan time, probably in response to the severe eustatic drop in sea level caused by the rapidly expanding continental ice sheets. Thus, incisement of the ancient Rio Grande through El Paso canyon and on La Mesa did not occur till later, a late Kansan-Yarmouth-Illinoian to late Illinoian date substantiated by vertebrate and invertebrate evidence (Strain, 1966: Metcalf, 1967).

The Cretaceous limestone and Tertiary andesite in the El Paso canyon area, rather than the incompetent bolson fill to the southwest, probably served as a barrier to headward erosion of small streams from the level of the Rio Grande in the Hueco bolson. By late Kansan time the northwestward migrating nickpoint associated with the lower Rio Grande had progressed from the Quitman Mountains through the Hueco bolson to the low spot near El Paso while the upper Rio Grande was still flowing at about the present La Mesa level into the western remnant of Lake Cabeza de Vaca with some distributary flow (Hawley and Kottlowski, 1969) through Fillmore pass. The combination of local tectonics, eastward tilting and the rising level of the terminal lake forced the Rio Grande closer and closer to the Franklin Mountains until the channel, perhaps due to an eastward meander (Kottlowski, 1958) was immediately west of Cerro de Muleros. What started the flow through El Paso Canyon is, of course, conjectural: perhaps the rising lake level, the meandering of the river, movement along local faults, or a fortuitous combination of any or all of these activities.

The initial gradient of the upper Rio Grande through El Paso Canyon must have been at least the 18 feet/mile originally proposed by Kottlowski (1958). The river dropped, in about 10 miles, from ± 4,130 feet west of Cerro de Muleros where it was flowing on La Mesa to at least the level of the Hucco bolson east of El Paso (± 3,950 feet) *, but more probably into the canyon entrenched in the Hueco bolson by headward erosion of the lower Rio Grande. It was only this fortuitous association of an unusually steep gradient (which may have been as much as 40 to 50 feet/mile!), superposition of the channel near or on faults, and high pluvial and glacial runoffs with an unknown contribution from the backed up Chihuahuan lake, that allowed rapid incision of the Cretaceous and Tertiary rocks at El Paso canyon to the complimentary canyon level in the Hueco bolson. Had the Rio Grande ever entrenched itself into the Hueco trough and through Fillmore pass, with a base level controlled by the Quitman Mountain water gap, no tributary would have cut westward through El Paso canyon for headward erosion of tributaries in the soft bolson fill. Rather, if the Rio Grande had incised Fillmore pass and the Hueco trough, it would have thereafter been confined by the fault zone along the east flank of the Franklin Mountains and through Fillmore pass by the hard mountain flanks.

An absolute chronology for the Pleistocene bolson deposits in Chihuahua and the Mesilla bolson is conjectural although, from the previous discussion, the uppermost part of the section in Chihuahua and in the Mesilla bolson should be younger than that in the Hueco bolson. Sayre and Livingston (1945) could find no correlation between the Pliocene strata of the Hueco and Mesilla bolsons; however, Strain (1966) believes that once the Hueco and Mesilla bolsons aggraded to about ± 3,700 feet, their levels rose concurrently. Strain (1966) did not demonstrate continuity of the late Pleistocene deposits between the Hueco and Mesilla bolsons and thus he confined his Fort Hancock and Camp Rice Formations to the Hueco bolson; however, Camp Rice was extended into the Rio Grande valley upstream from El Paso by Hawley, et *al.* (1969) . (See also Strain, this guidebook).

In the Mesilla bolson the Tertiary-Quaternary fill is part of the Santa Fe Group but the youngest Pleistocene is of post-Santa Fe age (Hawley, et *al.,* 1969). The name Santa Fe Group is restricted to the " . . . Rio Grande watershed, to closed basins east of the Rio Grande, and to basins between the Rio Grande and the West Potrillo and Uvas-Goodsight Mountains" (Elston and Netelbeek, 1965), the basin fills west of the West Potrillo Mountains are correlative with parts of the Gila Conglomerate of Arizona. However, La Mesa geomorphic surface (Ruhe, 1967; Hawley and Kottlowski, 1969) is demonstrably continuous from east of the East Potrillo Mountains south for at least 50 miles into Chihuahua, southwest to the Camel Mountain escarpment, and thence west of the West Potrillo Mountains. Thus a large tongue of fluvial and lacustrine bolson-fill equivalent, in part, to the Santa Fe Formation and the Gila Conglomerate exists in northwestern Chihuahua. It may be advisable, at a later date, to propose, in a formal national publication either in Mexico or the United States, a new name such as "Camel Mountain Group." Camel Mountain is in an area of good exposures of some of these early to mid-Pleistocene bolson-fill deposits and is located at 31° 47' N, 107° 18' W in the United States. Informally, for ease of reference here, I should like to call the upper part of the section, "Palomas"** sediments, after the town of Las Palomas located in Mexico at 31° 45' N, and 107° 37' W, adjacent to the United States-Mexican border. This incompletely exposed section of upper fluvial and lacustrine sediments is equivalent to the Camp Rice Formation of the Mesilla and Hueco bolsons. (See Strain, this guidebook). The Pleistocene section exposed along La Mesa escarpment consists mainly of cross-bedded, incompetent, light yellow to gray and pinkish sands with gravels, and thin clay lenses in places. Hawley (written communication, 1969), who terms La Mesa outcrops in the Mesilla bolson the "MxR" unit or the "fluvial facies" of the Santa Fe Group, states that he and Strain " . . . have found no evidence that there is anything but Pleistocene deposits exposed in the La Mesa scarp," but that the clays thicken southward. The Chihuahuan section, in places, contains more clay than the La Mesa section but there are many areas where fluvial sediments predominate.

* No allowance has been made in this discussion for any Late Quaternary and possible Holocene changes in elevation.

The best exposures of the "Palomas" sediments in northwestern Chihuahua are along the Camel Mountain escarpment which starts north of Indian basin, about 6 miles northwest of Camel Mountain, New Mexico, and extends southeastward into Chihuahua for at least 55 miles (Fig. 2). Exposures exist southwest of Indian basin but the best outcrops are southeast of Camel Mountain or at places where the escarpment is not covered by sand. The following, presented as the type section of the "Palomas" sediments, was measured 5 miles southeast of the Ciudad Juarez-Ascensión road at about 31° 35' N., 107° 8' W., where access is provided by the dirt road leading south over the alkali flat.

SECTION OF "PALOMAS" SEDIMENTS, CAMEL MOUNTAIN GROUP, CHIHUAHUA, MEXICO

UNIT	FEET
12. Caliche, white (N9), hard to soft, nodular to laminated, arenaceous	10-20.0
11. Sand, yellowish gray (5/Y 7/2), fine-grained, indurated, calcareous	20.0
10. Clay, light brown (5YR 6/4) to grayish orange pink (5YR 7/2), vegetative debris, weathers rough, dense	3.0

** Name filed with Geologic Names Committee, April 18, 1969.

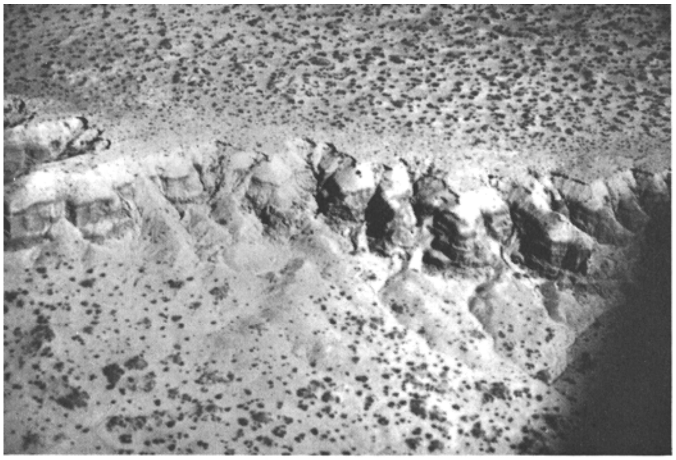

FIGURE 2.

Exposures of the Palomas Formation, Camel Mountain Group, along the Camel Mountain escarpment at approximately 31° 31′ N., 107° 13′ W. View east from low altitude.

9. Sand, yellowish gray (5Y 7/2), very fine-grained, angular medium-grained quartz and various heavy minerals, poorly exposed, upper part contains thin zones of yellowish gray (5Y 7/2) hard clay 15.0
8. Sand, grayish orange pink (5YR 7 /2) to pale yellowish brown (10YR 6/2), lentils of I/4-inch gravel, weathers blocky, more competent than underlying sands, some seams of clay 3.5-4.0
7. Sand, pale olive (10Y 6/2) to yellowish gray (5Y 7/2), finely laminated, incompetent, medium-grained, harder toward top, contains pale olive (10Y 6/2) clay galls up to 4 inches in diameter 7.0
6. Sand, very pale orange (10YR 8/2), medium-grained, angular, up to 50 per cent heavy minerals, thick-bedded, lentils 3/4 to 1/2-inch gravel, basal 1/2 to 1 inch stained yellow, incompetent, poorly exposed, gradational into overlying unit 8.0
5. Limestone, white (N9), nodular, no bedding apparent, discontinuous 0.1-0.2
4. Clay, lower 6 inches yellowish gray (5Y 7/2), grades upward to a grayish orange pink (5YR 7/2), calcareous, laminated, hard, weathers blocky, organic debris 3.0-4.0
3. Sand, very pale orange (10YR 8/2), weathers smooth, fine-grained at bottom becoming very fine grained at top, 20 per cent heavy minerals 8.0
2. Sand, pale yellowish brown (10YR 6/2), weathers orange (10YR 7/4) and blocky, fine-grained, grains angular to rounded, silty, calcareous, cavities filled with seed pods and mid-dens connected by soil-filled tunnels 4.0-5.0
1. Sand, grayish orange (10YR 7/4), light greenish in spots, mostly covered by talus, fine-grained, angular, 311 to 50 per cent heavy minerals, weathers blocky, vuggy, with small vugs to small caves, disintegrates readily when wet 20.0-30.0 Total Thickness 101.6-124.2

The "Palomas" sediments thus comprise fine-grained, unevenly bedded sand, siltstone, mudstone and clay capped by a mature caliche profile. Much of the sand, which contains a high percentage of coarse heavy minerals, is frosted and has a limonitic stain or the greenish tint characteristic of lacustrine sediments deposited in a reducing environment. The siltstone, mudstone and clay tend to be bentonitic, light brown to greenish, and lenticular. Most of the beds are less than 10 feet thick and grade laterally, within a mile or two, into a different lithology. Unfortunately the lower boundary of the "Palomas" section is not exposed here, but this measured section represents the maximum exposed thickness I have found in northwestern Chihuahua. No fossils have yet been found in the "Palomas" sediments but middens and tunnels filled with seed pods are present in Unit 2, therefore vertebrate remains probably will be found after diligent search.

LATE PLEISTOCENE HISTORY

By early late-Pleistocene time, faults bounding many of the Late Cenozoic mountains had been rejuvenated, many of the bolsons had been filled with thousands of feet of alluvial and lacustrine debris, and the Rio Grande had assumed its present position. It is recognized of course that much of the basin filling also occurred in late Tertiary time. (Hawley et al. 1969). Thus, Lake Cabeza de Vaca had been destroyed and the basin of Lake Palomas created. The large playas presently in the old Lake Palomas basin, which frequently flood during wet years but which have never filled completely to form an integrated lake in Holocene time, are Laguna de Guzman north of Sierra Borregos, Laguna de Palomas south of Palomas, Laguna de Santa Maria south of Sierra de Malpais Laguna, and "El Barreal" which surrounds Sierra Los Muertos (Fig. 1) Laguna de Palomas and "El Barreal" occur along the axis of the floor of a large basin complex, termed Bolson de Los Muertos in this report, and in the field trip logs.

After deposition of the Camp Rice Formation and the "Palomas" sediments, the central part of the Lake Palomas basin west of the West Potrillo Mountains and north of Sierra Los Muertos was apparently "boxed in" by faulting (Fig. 1). It was in this low trough that the late Pleistocene levels of the northern part of pluvial Lake Palomas fluctuated as the lake expanded and contracted. Figure 3 illustrates the present extent of the major, easily recognized abandoned levels of pluvial Lake Palomas, Table 1 giving terminology and revisions necessitated by new control.

Theoretically the highest, oldest Pleistocene (late Kansan to late Illinoian?) lake level in northwestern Chihuahua should have been at about 4,100 feet (1,250 m) but indisputable evidence in the form of abandoned beaches, wave-cut terraces or lacustrine sediments has not yet been

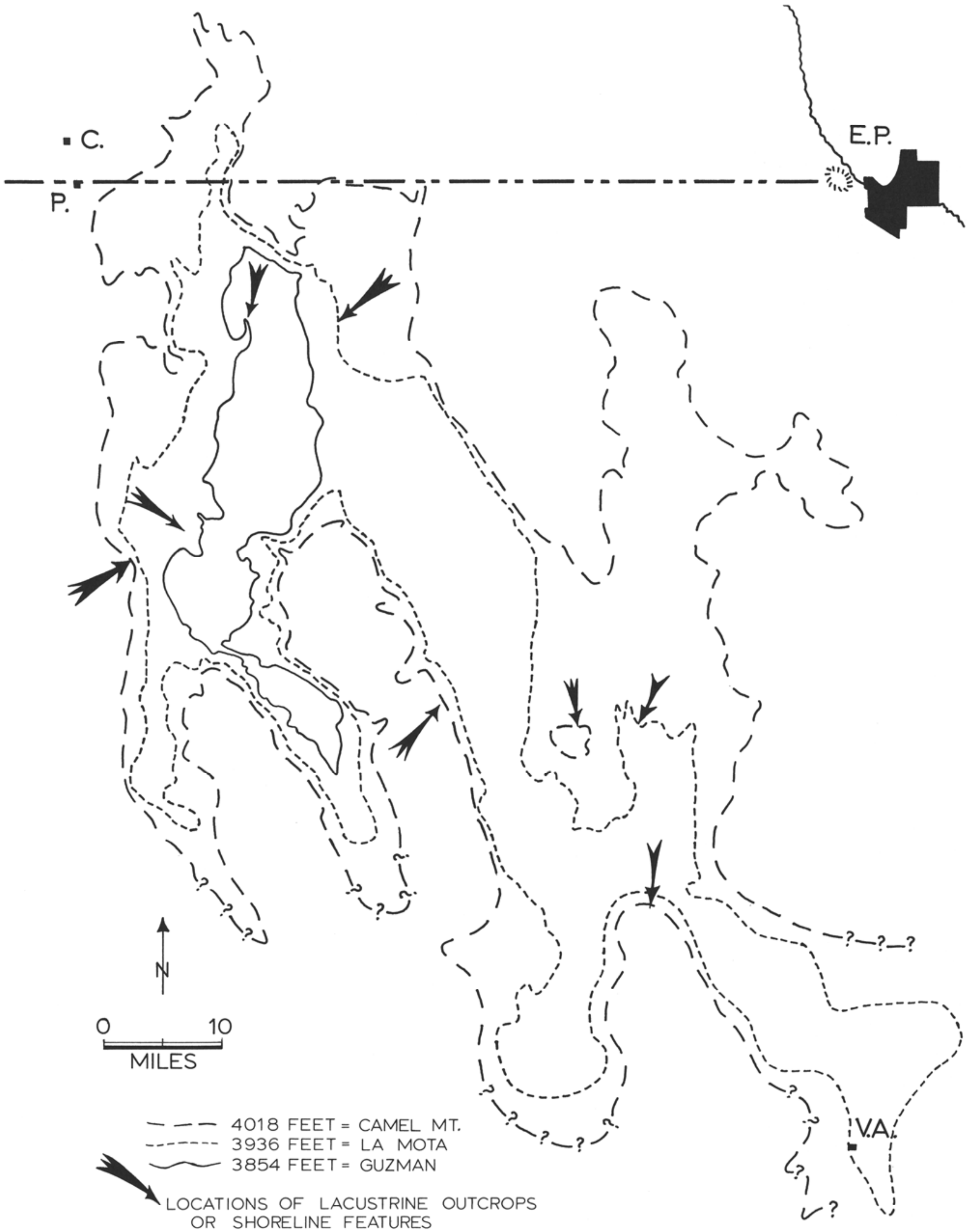

FIGURE 3.

The three main, easily recognizable late Pleistocene levels of pluvial Lake Palomas based on present contour lines. In places the contours have been adjusted for obvious recent changes.

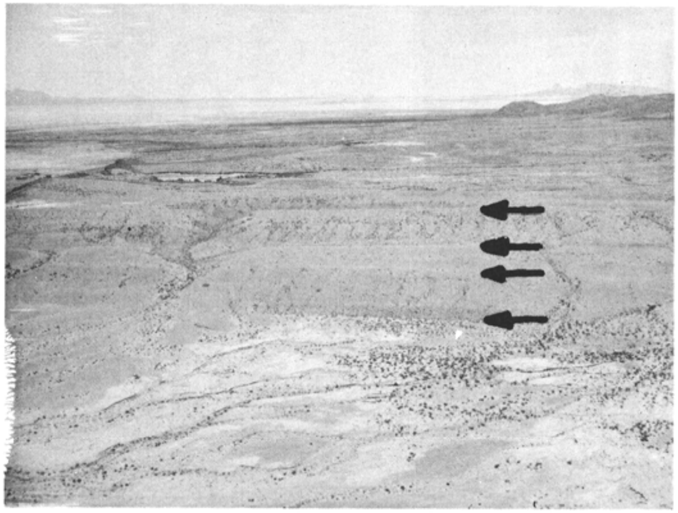

FIGURE 4.
Abandoned shoreline bars of the Camel Mountain level of pluvial Lake Palomas on the north end of Sierra Los Muertos, 31° 7′ N., 106° 55′ W. View to the south toward Salinas.

found. Escarpments at this level exist both northwest and about 7 miles west of Potrillo maar but exposed sediments are mainly sands.

TABLE 1.*

TERMINOLOGY 1965	ELEVATION FEET	TERMINOLOGY THIS PAPER	ELEVATION FEET	METERS
Guzman	4070	Camel Mt.	4018	1225
Santa Maria	4056	La Mota	3936	1200
Los Muertos	4030	Guzman	3854	1175
El Sancho	4010	—	—	—

* Revisions of shoreline terminology for pluvial Lake Palomas, Chihuahua, Mexico. Elevations for 1965 based on Paulin altimeter stations and airplane altimeter. Elevations for this report based on control from 1:250,000 sheet NH 13-1, Corps of Engineers.

The 4018-foot level, termed the Camel Mountain, is the most recent definitely discernable high level stand of pluvial Lake Palomas. The Camel Mountain level marks about the present base of the Camel Mountain escarpment. Wave-cut features of this level are well developed on the east side of Sierra Nariz, on the north end of Sierra Los Muertos (Fig. 4), and on Cerro de las Viboras.

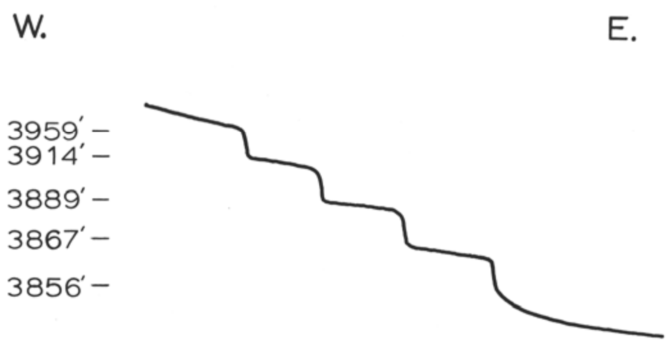

FIGURE 5.
Diagramatic cross-section of terraces at La Mota, Chihuahua. Terraces are cut into soft lacustrine sediments and capped by a travertine veneer.

The La Mota level, at approximately 3,936 feet, is named for Rancho La Mota on the northwest side of Laguna de Guzman and east of Sierra Bismark (Fig. 1). The terraced escarpment at La Mota (Fig. 5) is capped by a travertine veneer, the thinness of the travertine suggesting that the terraces pre-date spring action. The lacustrine origin of the La Mota terraces is also indicated by abandoned shoreline bars at the same level on the mountains southeast of Palomas, on the flanks of Sierra Nariz (Fig. 6), and in the Salinas area (Fig. 7). Outcrops of the lacustrine sediments into which the La Mota beaches are cut are rare and age of the older lacustrine section is unknown although the section at La Mota is similar to the section in front of the Camel Mountain escarpment. The section at La Mota consists of a lower coarse brown sand which grades upward into greenish to yellowish-brown lacustrine clays, the clays being reddish near the top of the escarpment. The following section, somewhat better exposed, was measured by the writer and R. A. DeHon at approximately 31° 20' N., 107° 31' W:

UNIT	FEET
5. Limestone, white, vuggy, nearshore deposit with incorporated beach pebbles, caliche forming on top	8.0
4. Sand, light brown, very fine-grained, grains subangular	2.0
3. Clay, yellowish green, fissile-bedded, widespread in area	5.5
2. Sand, pinkish gray, very fine-grained, angular to subangular	11.0
1. Shale, gray-green, fissile-bedded, bentonitic, blocky	5.5
Total Exposed Thickness	32.0

The Guzman level, named for the railroad stop of Guzman at approximately 31° 13' N., 107° 26' W. (Fig. 1), has an elevation of about 3,854 feet. Beach features are well developed about 6 miles east of Sierra Palomas and along the south side of Sierra Malpais de la Laguna and along the northeastern end of Guzman playa. At the Guzman level, Lake Palomas was about 50 miles long and 8 miles at its widest point. Although the Guzman level did not flood the Bolson de Los Muertos a remnant water mark shows that the Guzman level was high enough to flood the Santa Maria basin by a narrow waterway through the pass southeast of Guzman.

There are innumerable other lake levels that are not named, principally because wave-cut features or abandoned beaches are known from only a few localities. For instance, the profile 3 miles east of La Mota can be correlated with gravel beaches at the southeast side of Guzman playa but no correlative development is known elsewhere, and several water levels indicated by the bars on the northern side of Sierra Los Muertos (Fig. 4) also are not obvious elsewhere.

FIGURE 6.
Abandoned shoreline bars (arrows) of the La Mota level of pluvial Lake Palomas on the west side of the Bolson de Los Muertos, 31° 4′ N., 107° 5′ W., view to the south at 8,000 feet.

FIGURE 7.
Spit of La Mota level of pluvial Lake Palomas at Salinas, 30° 56′ N., 106° 47′ W. The gravel airstrip of the Salinas La Union salt producing facilities, with a storage warehouse to the right, occupies the straight part of the spit. Planes landing should avoid the low threshold at the south (left) end which may be muddy or eroded. Note the shoreline and another spit in the background. View is northwest.

To date there is little evidence for establishing an absolute chronology of the late Pleistocene shoreline features of pluvial Lake Palomas, but the highest recognizable level is probably post-late Kansan (Illinoian?). The only absolute date now available (27,150 1,060 years B.P.) is from a lacustrine carbonate in front of the Camel Mountain escarpment, and corresponds with beaches developed on the north side of Sierra Los Muertos (Fig. 4), the elevation of which indicate flooding of Guzman playa. Thus, the terraces at La Mota and the bars in the Guzman area are younger than those near the center of the Bolson de Los Muertos.

TECTONIC CONDITIONS

In the pluvial Lake Palomas basin area the northwest-southeast trending fault-block mountain ranges consist of some Paleozoic, but mainly Cretaceous, rocks which have southwest dip slopes where not disturbed by local folding and faulting. Vast areas are covered by igneous flows (mainly andesitic and basaltic) and associated pyroclastics, with sporadic Tertiary igneous intrusives like Cerro del Chino, Cerro Chile, and Sierra de la Candelaria north of Villa Ahumada forming the sharpest and highest peaks.

The basin of early Pleistocene Lake Cabeza de Vaca was undoubtedly structurally controlled by early Tertiary faulting, the spread of pluvial Lake Palomas being in great part due to filling of intermountain areas and integration of bolson areas. Depth of bolson fill in the pluvial Lake Palomas area exceeds 1,330 feet at Strauss, 3,750 feet in the Boles, Federal No. 1. Sec. 7, T 24 S, R 1 E, 18 miles north of Kilbourne Hole, and 4,363 feet on the west side of the Hueco bolson in Sec. 19, Blk. 60, Tsp. 1. Complete depth figures on the deep wells drilled in Chihuahua are not as yet available.

Wells drilled by Skelly Oil Company (No. 1-C, Sec. 19, T 28 S, R 5 W) and Sunray-DX (Federal "R" No. 1, Sec. 27, T 28 S, R 5 W) were spotted east of the Camel Mountain escarpment near Indian basin. (See Kottlowski et *al.*, in this guidebook). Both wells showed about 660 feet of sands and clays before going into volcanics (written communication, F. Kottlowski and log of Sunray-DX well); however, there was no correlation with the section drilled by the water well on the flat east of Indian basin even though that water well went below the elevation of the volcanics in the oil tests. Kottlowski (personal communication) also advises that gravity and magnetic maps of the area show a fault with the east side upthrown, thus the Camel Mountain escarpment is in part due to Pleistocene faulting, the scarp having been accentuated by wave erosion at the La Mota lake levels.

Evidence of Quaternary faulting is common along the west flank of the Hueco bolson (Apollo 502 photo No. 1447) and on La Mesa from Las Cruces south to the East Potrillo Mountains. In the Lake Palomas basin several northwest-southeast trending faults which cut the "Palomas" sediments and Late Quaternary sands are seen on the Apollo photographs.

The northernmost part of the Lake Palomas basin exhibits several tectonically controlled features. For instance, Kilbourne and Hunts holes "maare" occur along the Fitzgerald fault which joins the Robledo fault at the southeast end of the East Potrillo Mountains and follows the eastern front of those mountains. The extension of the Fitzgerald-Robledo faults to the south into Chihuahua is called the Potrillo fault. The Potrillo fault continues to the southeast into Chihuahua for at least 15 and perhaps up to 40 miles, the trace marked by en echelon fracture zones on the Apollo

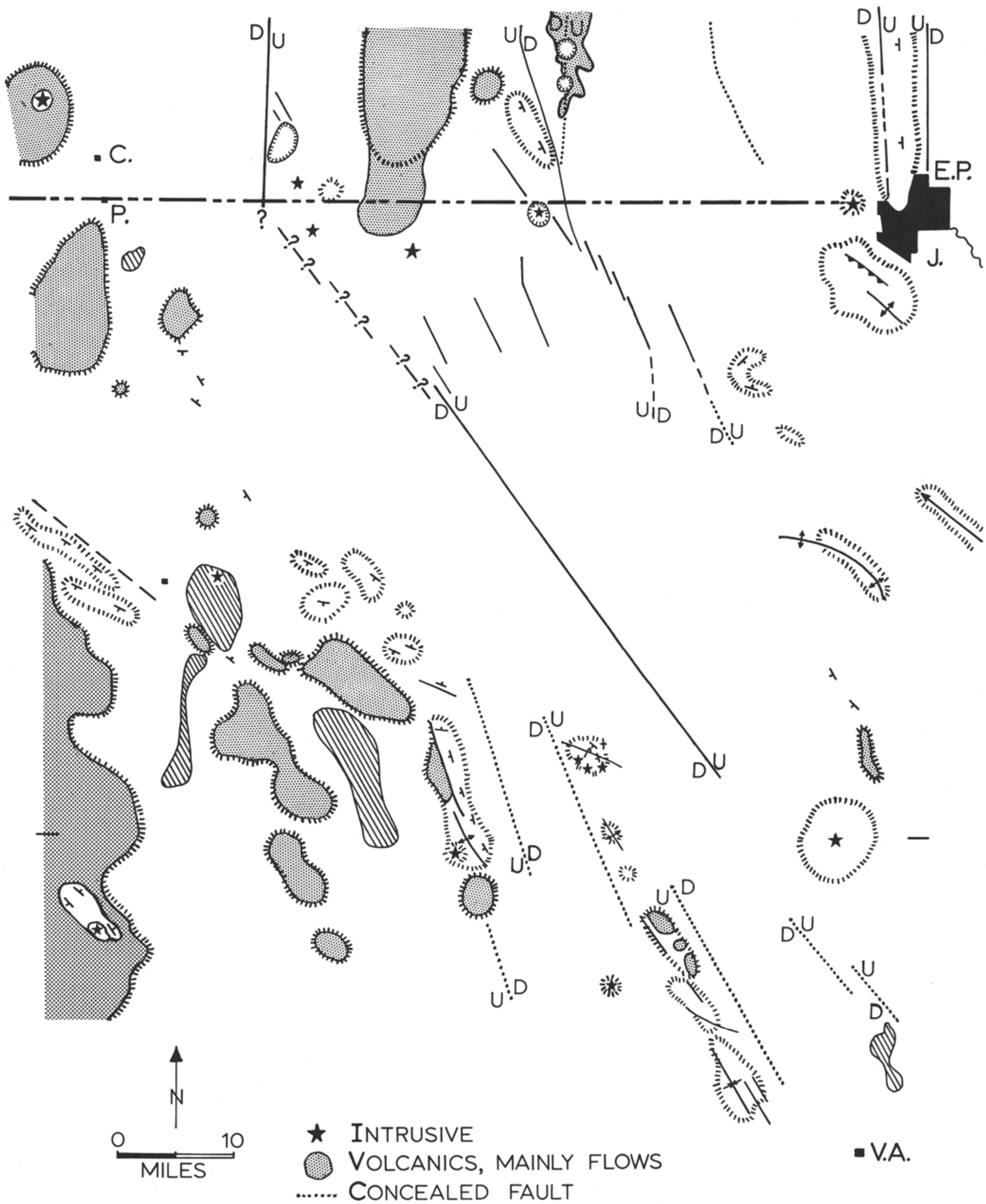

FIGURE 8.
Tectonic map of pluvial Lake Palomas basin area based on Apollo 502 orbital photos, aerial photographs, aerial reconnaissance by light airplane, field study, and reports by Diaz and Navarro (1964) and Ramirez and Acevedo (1957).

photographs. However, to the northwest, the en echelon pattern seems to also lead the fault zone west of the East Potrillo Mountains by way of the Potrillo maar. To the southeast the Potrillo fault may extend to the Sierra de Samalayuca although the easternmost northwest-trending fault "scarp" disappears about 2 miles north of the Ciudad Juárez-Ascension road. Because the dip on the easternmost fault is down to the west and the dip on the other fault of the Potrillo en echelon zone is up to the west, a graben is formed. Could this graben (marked by the northward-trending depression shown by the 1,225 m contour on the El Paso 1:250,000 sheet or on the 1:1,000,000 World Aeronautical Chart ONC-H-23) represent the southern continuation of the Rio Grande depression which is thought to abut against the Sierra de las Uvas (Kottlowski, 1958)?

The faults south of the Potrillo Mountain area (Fig. 8), as well as those on La Mesa, have formed by recent movement along older, deep-seated fractures, the trends of which match regmatic (strike-slip, wrench, or transcurrent) fracture directions known elsewhere in this part of the North American continent. (Badgley, 1965). In Chihuahua the northwest-southeast trend is the more obvious, the northeast-southwest and north-south trends being much weaker. Age of last major movement on the Robledo fault around Las Cruces is about late Pleistocene to pre-9,500 years B.P., with minor movements having occurred in the last few thousand years (Ruhe, 1967) . However, the Potrillo fault zone shows traces of alignment across the shifting sands of the Chihuahuan desert; thus it may be active at the present time.

In 1967 three gravity surveys were completed across parts of the Bolson de Los Muertos (Fig. 1) . The first, about 15 miles long, extended from Rancho El Sancho (A) on the east side of the present playa to Sierra los Muertos and then west to the San Blas road intersection (A') on the west side of the playa. The second, about 11 miles long, extended from Rancho La Piedra at the south end of Sierra de la Nariz (B) east to Salinas (B'). The third, about 18 miles long, extended from Salinas (C) to the Juárez highway (C'). The instrument was a Lacoste-Romberg with a constant of 0.0837 mg/div. Heat was provided throughout the survey by batteries hooked into the field vehicle's electrical system.

Figure 9 illustrates the corrected Bouguer anomalies calculated from the stations, spacing ranging from one to three miles. No corrections were made for latitude,* temperature drift, nearby mountain masses, or tides. Elevation control was taken from the El Paso 1:250,000 NH 13-1 sheet. Bolson fill minima can be quickly computed, of course, by using a density of about 2.65 gm/cm^3 in the Bouguer correction formula, although this is not generally recommended in light of bolson fill density variations as determined by Cabaniss (1965).

Profile A-A' across the mid-part of the Bolson de Los Muertos shows the deepest part of the bolson close to the mountains on the west side. This was expected because of the high east-facing front of the Sierra de la Nariz, the steep

* Maximum latitude change was only about 06'.

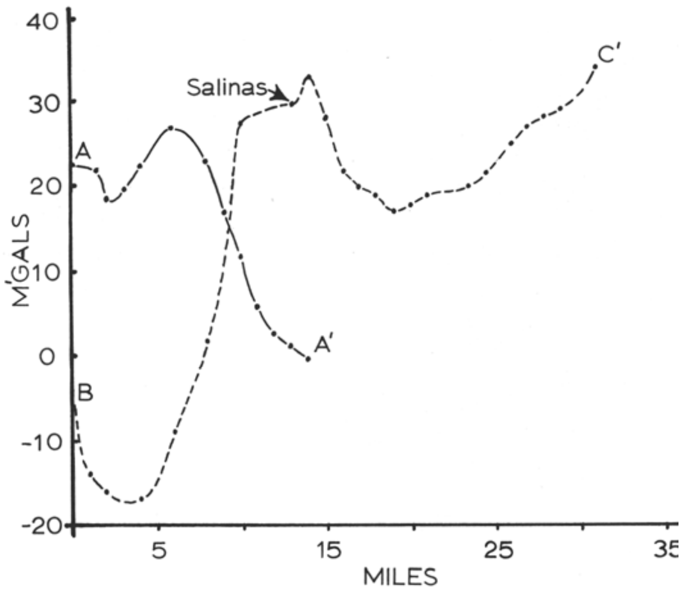

FIGURE 9.

Gravity profiles across parts of the Bolson de Los Muertos, Chihuahua, Mexico. See Figure 1 for locations of the traverses.

gradient of the profile of 5 m'gals/mile west of Muertos indicating a near-vertical fault.

A few miles to the south, profile B-B' from Rancho Piedra to Salinas, suggests a similar structure. The bolson splits at Salinas, a long narrow playa extending southeast along the east side of the Sierra Almirez-Prieta-Lucero ranges toward Villa Ahumada and another but larger playa extending due south to Rancho Nuevo. Profile B-B' crosses most of the western part of the bolson, the 5 m'gal difference between point A' and B showing that the deepest part of the bolson west of Muertos is probably somewhat west of point A'. The steep 7 m'gal/mile gradient of traverse B-B' indicates a near-vertical fault west of Rancho Ojo de Monte which is about 2 miles south of Cerro Almirez and 3 miles west of Salinas.

Profile C-C', which extends from Salinas to the Juárez highway, indicates the bolson on the east side of Muertos deepens to the south toward Villa Ahumada. The thinness of the fill between Rancho Sancho and Muertos, shown by the eastern part of profile A-A', is emphasized by a small Edwards rudistid reef poking through the fill immediately west of Sancho (Fig. 10); however; profile C-C' shows that a fault probably exists along the east side of the Sierra Almirez-Prieta-Lucero range, passing east of Salinas. If this fault maintains a northwest trend it must also pass west of Muertos, thus the steep gradient west of Muertos may be caused by a step-like fault zone. Comparison of the eastern part of profile A-A' with the western part of profile C-C' indicates, however, that this fault passes west rather than east of Muertos, unless the throw decreases to the north.

The several "bumps" in the C-C' profile may indicate small faults or bedrock noses; however, the sharp increase

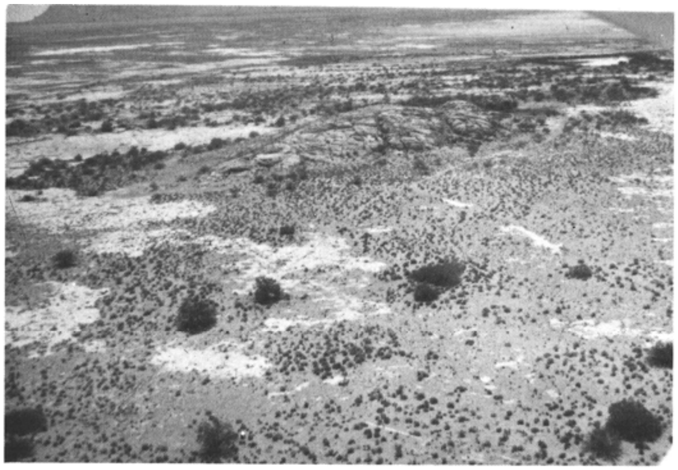

FIGURE 10.

Cretaceous (Edwards?) rudistid reef projecting through lacustrine sediments in pluvial Lake Palomas basin at Rancho El Sancho. View to the southeast. 31° 10′ N., 106° 41′ W.

in gradient near the highway and southeast of Sierra de la Candelaria is indicative of fault control. This fault zone is apparently the southeast continuation of the Camel Mountain escarpment fault trending northwest towards Indian basin (Fig. 1).

The boundary between the bolson fill and the surrounding igneous or sedimentary rocks in northwestern Chihuahua is probably sharp but lack of subsurface data precludes knowledge of density changes with depth. Cabaniss (1965), by plotting depth of bolson fill against residual gravity and using a density contrast between bolson fill and bedrock, was able to correlate calculated gravity (and thus thickness of bolson fill) with drill hole data. Becaus a 45 m'gal anomaly is generally indicative of about 10,000 feet of bolson fill (personal communication, G. H. Cabaniss), the density contrast between the fill and the bedrock in Chihuahua must be about 0.35. The calculated gravity anomalies, compared to Cabaniss' chart, indicate about 7000 feet of bolson fill west of Sierra Los Muertos, 13,000 feet west of Salinas, and 3500 feet east of Salinas. Thus, from known bolson-fill figures on La Mesa, the basin of Cabeza de Vaca-Lake Palomas, deepens to the south, which might be another indication of the extent of the Rio Grande tectonic depression.* Additional conclusions from these gravity data will be forthcoming when put into the computer program developed by Cabaniss at Air Force Cambridge Research Laboratories. The reader will note that these conclusions differ from the general statement in the abstract prepared prior to availability of these data.

HOLOCENE HISTORY AND ECONOMIC DEVELOPMENT

The basin of pluvial Lake Palomas, during Holocene time, was subjected mainly to severe and persistent deflation with only intermittent shallow flooding. This created the sand-covered areas and the broad flat playas we see today. The extensive Medanos de Samalayuca, parts of which probably formed during earlier Pleistocene time, continued to accumulate during the last ± 10,000 years by deflation of fine-grained lacustrine debris from the Bolson de Los Muertos. The sand dunes covering the Camp Rice Formation on La Mesa and the Camel Mountain sediments south of the East Potrillo Mountains, represent deflated debris from the lacustrine flat to the west of the Camel Mountain escarpment. Vegetated dune alignments (coppice dunes) and longitudinal dune swales indicate that older prevailing winds blew N. 80° E., although local areas such as those northeast of Laguna Palomas suggest that winds of the last few thousand years blew N. 60° E. Some older dunes also indicate a more easterly blowing wind and some terraces and bars suggest strong winds from the east. The beachs and bars on the north side of Sierra Los Muertos may be indicative of north winds or of nothing more than the 60-mile fetch across the ancient lake surface.

* Late data change; abstract written earlier.

Little economic development has occurred in the basin of pluvial Lake Palomas. The area is presently too dry and many of the soils too immature and alkaline for crops. The long dry canal which once carried stock water from the Palomas springs into the northern part of the Bolson de Los Muertos is now a mute testament to the falling water level.

Because the basin of pluvial Lake Palomas has always been closed, surrounded by volcanics, and was the terminal reservoir for at least three large rivers, it satisfies several of the requisites listed by Smith (1966) for accumulation of continental salines. The high, abandoned shorelines show that evaporation of vast quantities of water took place and the bordering volcanics and stream influents from these terraces have undoubtedly supplied the salts.

Salines la Union S. A., with general offices in Villa Ahumada, has been producing sodium sulfate for several years at Salinas (Fig. 11) about 27 miles northwest of Villa Ahumada. Production is from confined brines of 13° Beaumé which rise to nearly the playa surface, are concen-

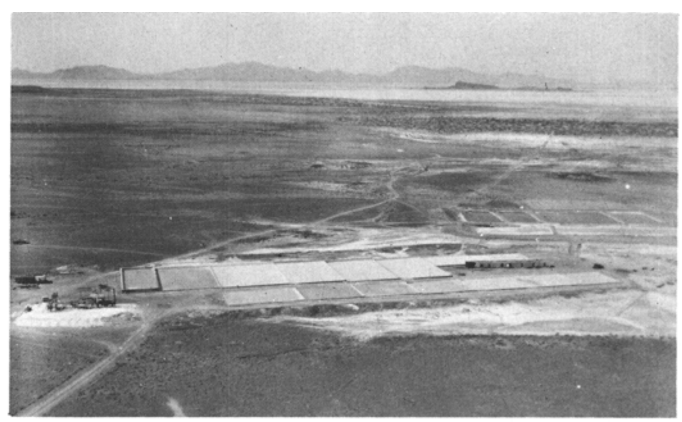

FIGURE 11.

The sodium sulfate producing facilities of the Salinas La Union at Salinas, Chihuahua. View to the west toward Rancho Piedra. Photo courtesy of R. G. Ponsford, Jr.

trated by evaporation, and then pumped to concrete evaporation pits. The brine is then pumped, after additional concentration by solar evaporation, over an ammonia cooler which causes precipitation of the sodium sulfate. Production of several tens of thousands of tons per month is easily attained (personal communication, R. G. Ponsford, Jr.) .

Extent of the Salinas sodium sulfate deposit is not known; however, waters in other areas show high concentrations of various ions necessary for other salt deposits. Because of the resemblance of the basin of pluvial Lake Palomas to Searles Lake, California, one may suggest that exploration for continental salines will be highly successful in certain areas of the basin.

ACKNOWLEDGMENTS

The writer is indebted to Ing. G. P. Salas for loaning aerial photographs and preliminary topographic and geologic maps during the early phases of this study and also for the invitation to conduct the gravity surveys across the Bolson de Los Muertos. Although the responsibility for the gravity data and resulting computations rests with the writer, the introduction to these methods was graciously directed by D. H. Shurbet and J. Dowling of the Seismological Observatory at Texas Technological College.

Informal discussions, reviews, and visitations by various members of the New Mexico Geological Society working in southern New Mexico are also gratefully acknowledged. Many thanks are due R. G. Ponsford, Jr., for his courtesies in the Salinas area.

REFERENCES CITED

Badgley, P. C., 1965, Structural and Tectonic Principles: Harper and Row, New York, 521 p.

Blasquez, L., 1959, Hydrogeologia de las regiones desierticas de Mexico: Mex. Unit. Nac. Inst. Geologia Anales, tomo 15, 172 p.

Brand, D. D., 1937, The natural landscape of northwestern Chihuahua: Univ. New Mexico Press, Albuquerque, 74 p.

Bryan, K., 1938, Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico: *in* Rio Grande Joint Invcs. in Upper Rio Grande Basin in Colorado, New Mexico, and Texas: Nat Resour. Comm., Washington Regional Planning, pt. 6, p. 197-225.

Burrows, R. H., 1910, Geology of northern Mexico: Bol. de la Soc. Geol. Mexico, v. 7, p. 88-89.

Diaz, T. and A. Navarro, 1964, Litologia y correlation estratigrafica del Paleozoico superior en la region de Palomas, Chihuahua, Mexico: Asso. Mex. Geol. Petroleros Bull., v. 16, p. 107-120.

Cabaniss, G. H., 1965, Geophysical studies of playa basins: *in* Geology, Mineralogy, and Hydrology of U.S. Playas, J. T. Neal ed., Air Force Camb. Resch. Lab. Terr. Sciences Lab. Pro. 8623, 176 p.

Elston, W. E. and T. A. Netelbeek, 1965, Road log from Mimbres Valley to Silver City: 16th Ann. Guidebook, New Mexico Geological Society, p. 36.

Hawley, J. W. and F. Kottlowski, 1969, Quaternary geology of the south-central New Mexico border region, in Kottlowski and LeMone (editors) Border Stratigraphy Symposium: New Mexico Bureau Mines and Mineral Resources Circular 104.

Hawley, J. W., Kottlowski, F. E., Strain, W. S., Seager, W. R., King, W. E., and LeMone, D. V., 1969. The Santa Fe Group in the south-central New Mexico border region. Ibid.

Hawley, J. W. and L. H. Gile, 1966, Landscape evolution and soil genesis in the Rio Grande region, southern New Mexico: 1 1 th Ann. Guidebook, Rocky Mt. Section, Friends of the Pleistocene, 74p.

Knowles, D. B. and R. A. Kennedy, 1956, Ground-water resources of the Hueco bolson, northeast of El Paso, Texas: Texas Water Eng. Bull. 5615, 265 p.

Kottlowski, F. E., 1958, Geologic history of the Rio Grande near El Paso: *in* Guidebook of Franklin and Hueco Mountains, Texas: West Texas Geol. Soc. 1958 Fall Field Trip, 91 p.

Lee, W. T., 1907, Water resources of the Rio Grande valley in New Mexico: U.S. Geol. Survey Water Supply Paper 188, 59 p.

Metcalf, A. L., 1967, Late Quaternary mollusks of the Rio Grande Valley, Caballo Dam, New Mexico to El Paso, Texas: Univ. Texas at El Paso Sci. Series I, Texas Western Press.

Morrison, R. B. and J. C. Frye, 1965, Correlation of the middle and late Quaternary successions of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), southern Great Plains and eastern midwest areas: Nevada Bureau Mines Rept. 9, 45 p.

Ramirez, J. C. and F. Acevedo, 1957, Notas sobre la geologia de Chihuahua: Assoc. Mex. Geol. Petroleros Bull. v. 9, p. 583-770.

Reeves, C. C., Jr., 1969, Origin, classification, and geologic history of caliche on the southern High Plains, Texas: *in* preparation.

, 1965, Pluvial Lake Palomas, northwestern Chihuahua, Mexico and Pleistocene geologic history of south-central New Mexico: 16th Ann. Guidebook, New Mexico Geol. Society, p. 199-203.

Ruhe, R. V., 1967, Geomorphic surfaces and surficial deposits in southern New Mexico: New Mexico Bureau Mines Mem. 18, 66 p.

, 1964, Landscape morphology and alluvial deposits in southern New Mexico: Annls. Amer. Geographers, v. 54, p. 147-159.

, 1962, Age of the Rio Grande Valley in southern New Mexico: Jour. Geology, v. 70, p. 151-167.

Sayre, A. N. and P. Livingston, 1945, Ground-water resources of the El Paso area, Texas: U.S. Geol. Survey Water Supply Paper 919, 190p.

Smith, G. I., 1966, Geology of Searles Lake-a guide to prospecting for buried continental salines: in Second Symposium on Salt, Northern Ohio Geol. Soc., Cleveland, Ohio, p. 167-180.

Strain, W. S., 1966, Blancan mammalian fauna and Pleistocene formations, Hudspeth County, Texas: Texas Mem. Museum Bull. 10, Austin, Texas, 55 p.

, 1965, Early Pleistocene history of southern part of Mesilla Bolson: *in* 16th Ann. Guidebook, New Mexico Geol. Society, p. 243.

Tamayo, J. L., 1949, Interior watersheds: *in* Geografia General de Mexico, Talleres Gráficos de la Nación, Tolsa 9, Mexico City, D.F.