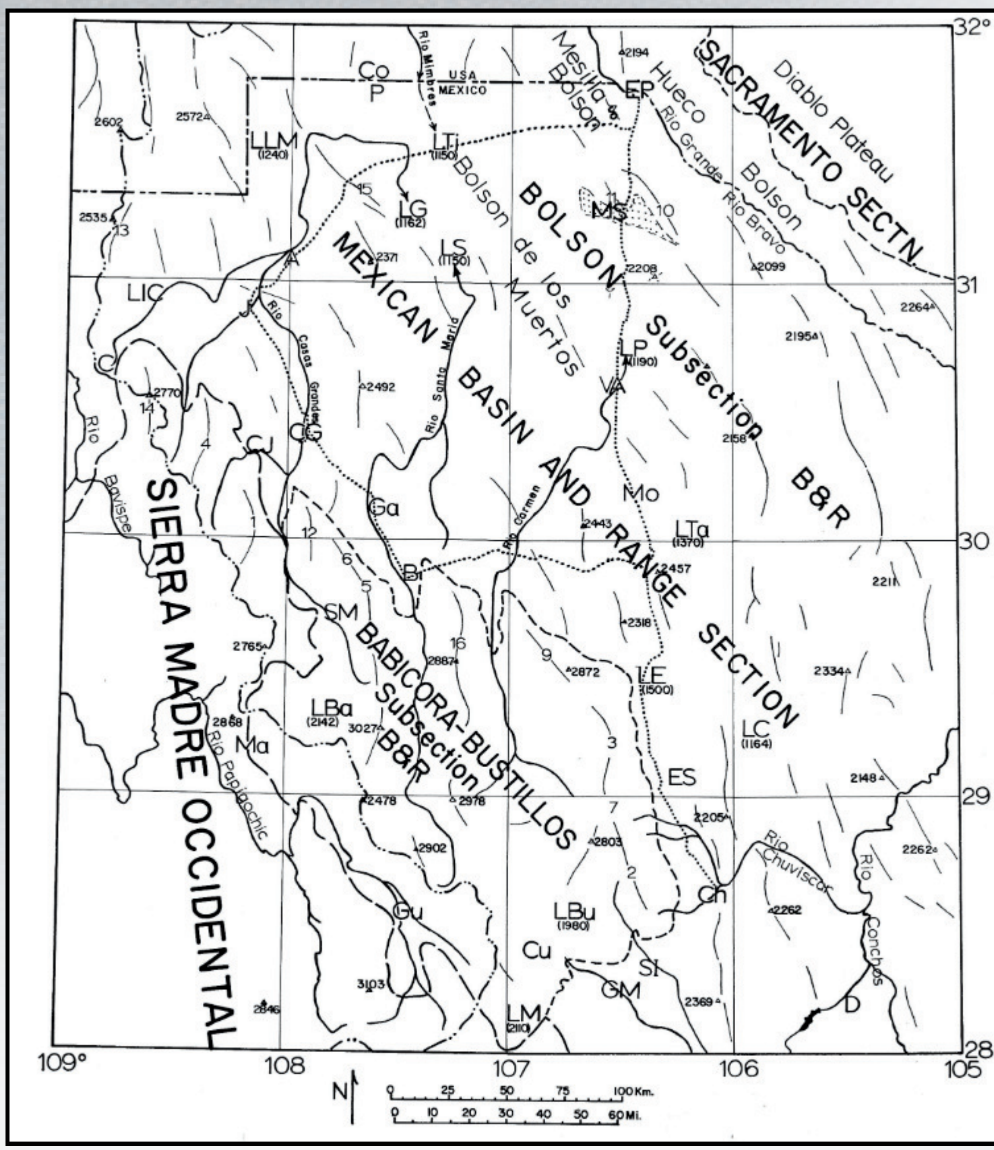
Hydrogeologic Framework of the Mesilla Basin Region of New Mexico, Texas, and Chihuahua (Mexico)—Advances in Conceptual and Digital-Model Development

Appendix D
Facsimile Reproductions of Selections from Published Work on the Cenozoic Geology, Hydrogeology, and Geomorphology of the New Mexico-Chihuahua Border Region

Compiled by

John W. Hawley



Index map—Geomorphic features of northwestern Chihuahua and adjacent areas (Hawley, J.W., 1969, Notes on the geomorphology and late Cenozoic geology of northwestern Chihuahua: New Mexico Geological Society Guidebook 20, p. 132).

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APPENDIX D[1]

FACSIMILE REPRODUCTIONS OF SELECTIONS FROM PUBLISHED WORK ON THE CENOZOIC GEOLOGY, HYDROGEOLOGY, AND GEOMORPHOLOGY OF THE NEW MEXICO-CHIHUAHUA BORDER REGION

John W. Hawley, Ph.D., Visiting Sr. Hydrogeologist,
New Mexico Water Resources Research Institute, NMSU
Emeritus Sr. Environmental Geologist, NM Bureau of Geology & Mineral Resources,
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[1]APPENDIX D *in* Hawley, J.W., Swanson, B.H., Walker, J.S., Glaze, S.H., and Ortega Klett, C.T., 2025, Hydrogeologic Framework of the Mesilla Basin Region of New Mexico, Texas, and Chihuahua (Mexico)—Advances in Conceptual and Digital Model Development: NM Water Resources Research Institute, NMSU, Technical Completion Report No. 363, 359 p., 8 Appendices.

Part D1. Selections from Introduction and First Day Road Log *from*: Córdoba, D.A., Wengerd, S.A., and Shomaker, J.W. (eds.), 1969, Guidebook of the Border Region: New Mexico Geological Society Guidebook 20, p. i., iv, v, and x; and Road Log Section, p. 1-8 (with permission from New Mexico Geological Society, Inc.).

Part D1.1. Facsimile Copies of Selections from the 1969 Annual Field Conference Guidebook of the New Mexico Geological Society, Inc.: Córdoba, D.A., Wengerd, S.A., and Shomaker, J.W. (eds.), 1969, Guidebook of the Border Region: New Mexico Geological Society Guidebook 20, 218 p. (reproduced with NMGS, Inc. permission).

Part D1.2. Author-Reprint of Article *in* Cordoba and others (1969), with Some *Errata* Corrections: Hawley, J.W., 1969b, Notes on the geomorphology and late Cenozoic geology of northwestern Chihuahua: New Mexico Geological Society Guidebook 20, p. 131-142 (with permission from New Mexico Geological Society, Inc.).

Part D2. Facsimile Copy of Selections from the 1975 Annual Field Conference Guidebook of the New Mexico Geological Society, Inc.): Hawley, J.W., 1975, Quaternary history of Doña Ana County region, south-central New Mexico, *in:* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society Guidebook 26, p. 139-150 (reproduced with NMGS, Inc. permission).

Part D3. Facsimile Copy of Selections from R.H. Schmidt, Jr., 1992, Chihuahua, tierra de contrastas geográficos: Geografía; *in* Márquez-Alameda, Arturo, Coordinador del volumen, Historía general de Chihuahua I—geología, geografía y arqueolgía: Universidad Autónoma de Ciudad Juárez y Gobierno del Estado Chihuahua, 307 p. – Cover, p. VI, 45, 47-51, and 61-64.

Part D1.

Selections from Introduction and First Day Road Log *from*:

Córdoba, D.A., Wengerd, S.A., and Shomaker, J.W. (eds.), 1969, Guidebook of the Border Region: New Mexico Geological Society Guidebook 20, p. i, iv, v, and x; and Road Log Section, p. 1-8 (with permission from New Mexico Geological Society, Inc.).

Road Log Addenda-Notes 1 to 5:

1. **Mile 27.8** "Sierra Mesquite" is named Sierra Sapello in current geological literature and this report (*cf.* Jiménez and Keller 2000, and Averill and Miller 2013).

2. **Mile 36.0** Most of the "basin area west of Sierra Mesquite [Sapello]" is now recognized as being part of the RGr "El Parabién Basin" of Jiménez and Keller (2000; Report **Figures 1-2** and **1-3,** and **Plate 2**).

3. **Mile 56.9** "STOP 2" is located on the La Laguna Bench at the southern end of the Malpais Basin (**MpB-LLBn**) near the southwestern corner of the Study Area (**Figs. 1-2** and **1-3**, and **Plates 2** and **3**). The site (elev. about 3,790 ft, 1,210 m) is about 5 mi (8 km) WNW of Rancho La Laguna, and overlooks to floor of northern Bolsón de los Muertos, which was episodically occupied by pluvial-Lake Palomas in the Late Pleistocene and Early Holocene (Reeves 1969, Hawley et al. 2000, Castiglia and Fawcett 2006). La Laguna section of the "Camel Mountain Escarpment" aligns with the southern part of the La Peña fault zone (**LPfz-Plate 2**). It is no longer recognized as a strand of the Camel Mountain fault zone of Reeves (1969; Seager 1995).

4. **Mile 56.9** Schematic depiction of Lake Palomas extent on **Figure 1-3**.

5. **Mile 66.1** Excellent aerial photographs of representative Lake Palomas shoreline features in Reeves (1969, Figs. 4, 6, and 7).

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GUIDEBOOK

of the

Border Region

EDITORS

Diego A. Córdoba
Sherman A. Wengerd
John Shomaker

NEW MEXICO GEOLOGICAL SOCIETY

TWENTIETH FIELD CONFERENCE — OCTOBER 23, 24, AND 25, 1969

PRESIDENT'S MESSAGE

On behalf of the Executive Committee and members of the New Mexico Geological Society, Inc., I welcome you to our Twentieth Annual Field Conference. The society is indeed honored and fortunate to be able to sponsor this tour in our neighboring State of Chihuahua.

Acknowledgment to the individuals and organizations who have contributed to the success of this field conference is made in the following messages and in the Guidebook texts. However, I would like to mention several people who have played particularly important roles in organizing this conference. First and foremost is William E. (Bill) King, our General Chairman. This tour of Northwestern Chihuahua has been Bill's labor of love for over two years. Without his pushing, prodding, words of encouragement, and just plain old hard work, this conference would not have been held.

Our editors, Diego Córdoba, Sherm Wengerd, and John Shomaker, have greatly assisted Bill in his task by compiling, and in part, creating, a guidebook that is as good as, and might even be better than, any of our previous guidebooks to the geology of New Mexico and adjacent areas.

The work of the Road Log Committee Chairmen, Roy Foster and Bob Weber, must also be especially acknowledged. The road logging for this conference involved some original geologic work, particularly in the volcanic range areas, in addition to compilation of a considerable amount of unpublished information furnished by our colleagues in various agencies of the Mexican Federal Government and the National and State Universities.

Finally, I want to acknowledge the contribution to the field conference that has been made by the West Texas Geological Society, and particularly by L. W. (Dan) Bridges. The 1964 field trip of that group to east-central Chihuahua (W.T.G.S. Publication No. 64-50) in a real sense "broke the ice" and provided an inspiration and a mark to equal or exceed in terms of field conference organization and guidebook preparation. The two field conference guidebooks in no way represent a duplication of geological society efforts, and should be companion volumes on the bookshelf of any person really interested in the great international Border Region.

The "President's Message" is usually a place where past actions of the New Mexico Geological Society, Inc. are reviewed, and plans and hopes for the future are expressed.

Our twenty field conference guidebooks and other publications represent the fruits of many past labors by many people. *The History of the New Mexico Geological Society*, by Stuart A. Northrop, which 1970 members of the Society received at the conference registration, gives all the details of what we have done or have attempted to do.

As for the future, I expect that twenty more excellent field conference guidebooks will be prepared in the next twenty years. In addition, I expect to see the completion of geologic road logging of all major and many lesser highways in the State of New Mexico within the next several years. The newly elected slate of officers of the Society, demonstrates that our organization is a dynamic one in terms of new faces and ideas. The long-time Society stalwarts are always here to give the needed continuity to our operations, but ours is an up-and-going group, as is our profession, and new wine is needed to keep old skins in shape.

John Hawley

SOME COMMENTS BY THE GENERAL CHAIRMEN

Whether it will become apparent or not in the next three days, this Field Conference has been in preparation for over two years. Many problems not common to field trips in the United States have had to be solved. The cooperation of the Instituto de Geología, Petróleos Mexicanos and Secretária de Recursos Hidráulicos, as well as the aid of many individual Mexicans, has been invaluable.

The Conference will be beneficial to geologists of both nations in the understanding of the geology of the Border Region. It is our hope also that many lasting friendships will be fostered.

May we ask each of you to do in México as the Mexicans do . . . relax. There will be malfunctions during the Conference, there is no doubt of that, but please accept these minor difficulties in good spirits. As a matter of fact, if you do not have a sense of humor, you probably should not be on this Conference. You will find the Mexican scientists a charming people who, while they do not necessarily have the same compelling and possibly idiotic sense of urgency as North Americans do, accomplish very sophisticated scientific work and organize their resources very efficiently.

If the coverage of some aspects of the geology is less than adequate, remember that Chihuahua is relatively virgin territory, and little is known about some parts of this beautiful region.

Finally, we will say that if we had the task of being General Chairmen of a Mexico field conference to do again, we would.

Bienvenidos á Chihuahua y feliz viaje!

Bill King
John Hawley

A CO-EDITOR'S LETTER FROM MEXICO

Sr. John W. Hawley
Presidente de la Sociedad
Geológica de Nuevo México
P r e s e n t e.

Estimado John:

Por fin hemos terminado la edición del vigésimo Libreto Guía de la Conferencia Anual de Campo. Creeme que la labor de editor en un trabajo de esta envergadura no es nada sencilla y en ocasiones es cansada, pero puede llegar a ser agradable, como en este caso, cuando se ha tenido una colaboración, tan amplia de toda la Mesa Directiva de la Sociedad Geológica de Nuevo México. Creo que la Sociedad puede, una vez más, estar orgullosa de la calidad de este libreto Guía, no sólo por los trabajos que contiene, sino por su presentación y principalmente por su significado.

Los geólogos mexicanos que hemos colaborado en la edición, preparación y en la presentación de trabajos geológicos en este Libreto Guía, estamos orgullosos de la labor realizada por la Sociedad Geológica de Nuevo México, al lograr la integración de una serie de estudios científicos en la zona fronteriza. Este esfuerzo debe servir como ejemplo para otras organizaciones, tanto mexicanas como norteamericanas.

Estoy seguro de que una vez más, nuestra Conferencia de Campo será un éxito.

Tu amigo,

Diego A. Córdoba
Co-Editor (México)

OBSERVATIONS BY A CO-EDITOR

Appropriately enough, this Guidebook for the 20th Field Conference is one of the most comprehensive yet published by the New Mexico Geological Society, and, although the articles cover a large segment of the Border Region of northern Mexico and the southwestern United States, the entire trip is in Chihuahua, our first conference entirely outside the United States! Always a large state filled with big enterprising people, Chihuahua has produced a great part of the mineral wealth of Mexico and has nurtured some of Mexico's most dedicated revolutionaries in that country's fight for freedom. The political stability and financial acumen of this fast-growing Republic allow one now to turn the coin around and call Mexico today a veritable "Colossus of the South."

Many authors, committee members, and field trip leaders have done the considerable amount of work represented by this Guidebook and the field conference. Errors there no doubt are, for production of such a Guide involving diverse authors from two different countries (including Texas!) is a long involved process. Nonetheless, and perhaps in misplaced apology, the editors have given authors almost completely free rein in presenting the results of their work. Editors are seldom well-enough versed in all facets of geology, hence care was exercised not to challenge their many diverse opinions or to "play" judge without having done all of the geological work. If some authors have taken what to you look like untenable positions in their papers, challenge them on the trip, *at the microphone*. I can assure you that some authors will challenge each other! Much discussion, vigorous defense, offensive sallies, downright arguments short of fisticuffs, and new observations are sought in this Conference, so let's have at it, with vigor!

Quién no se atrevé, no pasa el mar.

Sherman A. Wengerd
Co-Editor (United States)

FIELD TRIP LEADERS

The men who will lead this three-day field conference include: Roger Morrison, C. C. "Tex" Reeves, Co-chairman John Hawley, Co-editor Diego Córdoba, William Strain, Jorge Tovar, Robert Weber, Carlos Garcia-Gutierrez, David LeMone, Donald Webb, José Guerrero, Edward Berg, Harold James, Roy Foster, Luis Caire, Jerry Hoffer, Alejandro Solis, and your conference General Chairman, William King. There may well be others, among them such hecklers as Jim Wilson, Dan Bridges, Frank "Irish" Kottlowski, Santiago Reynolds, Sherm Wengerd, Zoltan de Cserna, Keith Young, Larry Werts, and Ron DeFord. You may see almost all of these names also as author, committeeman, road-logger, or editor; but this is not a closed corporation, and every conference participant who has observations to make will be handed the microphone upon request, volume turned up LOUD! The field trip leaders may even allow some of the officers of the New Mexico Geological Society to have a word or two. Last, possibly least, but never on purpose, if we've left any field trip leader out of the list, below is a prominant blank space designated specifically so that every conference participant who adds to the success of this trip can write his name in his own Guidebook!

SCHEDULE OF CONFERENCE

Wednesday, October 22 — *Registration Day*

9:00 A.M.-10:00 P.M. Registration in lobby of Camino Real Hotel, Juarez, Mexico. Early breakfast tomorrow is on you.

Thursday, October 23 — *First Day Field Trip*

7:30 A.M.-8:00 A.M. Caravan buses assemble at Camino Real Hotel, Juarez, Mexico. Departure time 8:00 a.m. (Sharp, it says here!) Late pre-registered arrivals check with Bill King.

Lunch, Stop 2, Camel Mountain Escarpment. (Who knows when? Or what?)

Barbecue at Motel El Ranchito, Casas Grandes, late p.m. (After the necessary pre-prandial dust-cutting refreshments.)

Friday, October 24 — *Second Day Field Trip*

7:30 A.M.-8:00 A.M. Caravan buses assemble at Motel El Ranchito, Casas Grandes; departure time 8:00 a.m. sharp, *after* an early breakfast.

Lunch stop somewhere between Buenaventura and Mina La Mojina around the middle of the day (maybe!)

Banquet, and cocktail hour or two, at 8:00 p.m. (or later), Hotel Fermont, Ciudad Chihuahua. Banquet speaker will be Ing. Guillermo P. Salas. "Big Bill," formerly Director of the Mexican Geological Institute, and that famous torero of the 1968 G.S.A. Convention in Mexico City, was General Chairman of that convention, and is now with Recursos Minerales Non-renovables.

Saturday, October 25 — *Third Day Field Trip*

7:30 A.M.-8:00 A.M. Board buses near Hotel Fermont ready to leave at or near 8:00 a.m. after breakfast at the hotel.

Lunch stop mile 143.2, placita at Villa Ahumada at high noon. A box lunch —just like yesterday—and the day before.

Late afternoon arrival at Camino Real, Ciudad Juarez, after a great exploratory tour of northern Mexico. Dinner on you and don't forget your car!

FIRST DAY

ROAD LOG FROM CIUDAD JUAREZ TO NUEVO CASAS GRANDES, VIA SIERRA DE JUAREZ, SIERRA BOCA GRANDE, ASCENCION, AND JANOS

October 23, 1969

DRIVING DISTANCE:
172.2 mi., 277 Km.

STARTING TIME:
8:00 A.M.

ASSEMBLY POINT:
Hotel Camino Real, Cd. Juarez, Chihuahua

SUMMARY

Much of the first day's route is across the broad bolson plains of northwestern Chihuahua. During this part of the trip we will learn much about the geologic history of these basins and their potentially important water supplies. The traverse is punctuated by a stop at the southern end of the Juarez Mountains to visit some Lower Cretaceous reefs and at the pass south of Sierra Boca Grande where Permian rocks are exposed. The remainder of the trip more or less follows the irrigated Rio Casas Grandes valley past exposures of Tertiary volcanics.

Cumulative Mileage (Kilometers to nearest tenth)

0.0 Camino Real, Ciudad Juarez. Proceed on Avenida Lopez Mateos.

0.4

0.4 (0.6) Centro Artesenal.

0.6

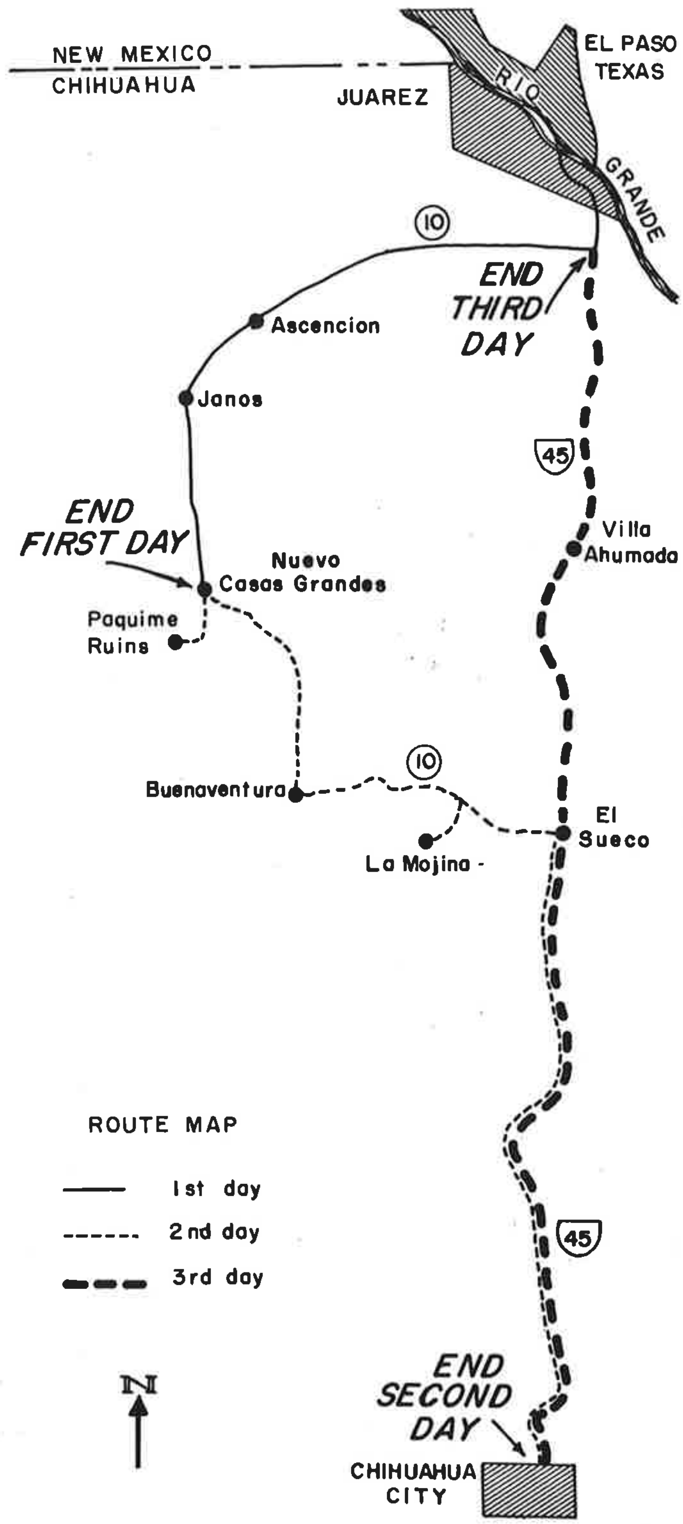
1.0 (1.6) Intersection with Calle "16 de Septiembre." TURN LEFT ONTO MEX. 45.

0.3

1.3 (2.1) Plaza Monumental bull ring on right. Olé.

0.8

2.1 (3.4) San Lorenzo section of Juarez. The route curves to the right and continues south across the Rio Grande (Rio Bravo del Norte) flood plain.



This segment of the river valley, the Valle de Juárez, is currently the site of an intensive ground-water investigation by the Mexican Federal-Secretaria de Recursos Hidráulicos. Test drilling indicates that the thickness of unconsolidated basin fill in the Juárez-Guadalupe-Bravo area is at least 1475 feet (450 meters). Over much of the valley floor a thin deposit (less than 100 feet, 30 m.) of late Quaternary alluvium overlies early Pleistocene (?) and older Santa Fe Group basin fill. Below the flood plain, the explored part of the Santa Fe Group consists of interstratified sand and clay with local zones of gravel. A basal gravel is usually present in the young valley-fill unit. (See Strain, and Metcalf, this guidebook) About 25 miles (40 km) southeast of this point, near Juárez y Reforma, artesian wells with flow capacities of up to 1000 g.p.m. are being constructed. The artesian pressure in an aquifer about 1000 ft. (300 m.) deep is as much as 38 p.s.i. at the flood plain surface and is known to increase in a southwesterly direction toward Sierra del Presidio. The water contains less than 1000 p.p.m. total dissolved solids. Water temperature is as high as 95° F (35° C). In contrast, the quality of the shallow ground water is commonly poor in the Valle de Juárez, as is some of the water encountered near the base of the explored basin-fill section.

Information on the hydrogeology of basin and valley fill deposits used in this road log was kindly provided by Ings. Dominguez and Fuentes of the S.R.H. Staff, Chihuahua City, with permission of Ing. Carlos Carvajal, Chief.

0.6

2.7 (4.3) Intersection on left to Juarez dog track.

0.6

3.3 (5.3) Intersection with Mex. 2 to Porvenir. CONTINUE STRAIGHT AHEAD ON MEX. 45.

0.1

3.4 (5.5) Chihuahua State Police Headquarters on right.

1.0

4.4 (7.1) Hotel Villa Real on right.

0.6

5.0 (8.1) Sierra Juárez on right; Lower Cretaceous Albian limestone, sandstone, and shale. (see Córdoba, this guidebook).

1.0

6.0 (9.7) South edge of Rio Grande flood plain.

0.4

6.4 (10.3) Ascending onto series of terrace levels formed by cyclic entrenchment of the Rio Grande valley in late Pleistocene time. Rogélio's Hotel on left.

1.6

8.0 (12.9) Lechería Zaragoza (dairy) on right. Where's the grass?

1.3

9.3 (15.0) Juárez Municipal Airport on left. Sierra del Presidio at 10:00; Sierra de Samalayuca at 11:30. The bluffs on skyline from Sierra del Presidio to Juarez are capped by La Mesa surface and underlain by sandy sediments of the upper part of the Santa Fe Group. (Hawley et al., 1969, Fig. 1). Studies of vertebrate faunas by Strain (1966) indicate that most of the exposed basin-fill deposits in Hueco bolson are of early to middle Pleistocene age.

The airport is located on an intermediate basin-floor surface about 175-200 feet above the Rio Grande flood plain; 100 feet below

East front of Juárez Mountains from Juárez Airport, mile 9.3.

the level of the Hueco bolson floor north of the river valley; and 250 feet below the ancient La Mesa surface. Test drilling by the Secretaria de Recursos Hidráulicos for industrial park sites southwest of the airport shows that the basin fill is at least 940 feet (287 m) thick and consists mainly of fine-to-medium-grained sands. The water table in this area is at about the same elevation as the Rio Grande flood plain.

2.1

11.4 (18.4) Junction Mex. 45 and Mex. 10. TURN RIGHT ON MEX. 10.

0.4

11.8 (19.0) Railroad crossing. Franklin Mountains at 3:00.

0.9

12.7 20.4) Railroad crossing.

0.3

13.0 (20.9) Begin ascent to ancient basin surface at the western extremity of Hueco bolson (Hill, 1900). Caliche-cemented gravels exposed along side of road.

2.4

15.4 (24.8) TURN RIGHT onto dirt road for Stop 1. Route continues on piedmont-slope component of basin surface, probably equivalent to either the Jornado or Dona Ana surfaces of the northern Mesilla bolson area (Ruhe, 1967, Hawley and Kottlowski, 1969). These surfaces grade to the general La Mesa level and are of middle Pleistocene age. Surficial alluvial-fan gravels, derived from a large canyon extending into the southern Juarez Mountains, are cemented in a prominent caliche caprock zone. (Gile et al., 1965).

0.8

16.2 (26.1) Road on left at outcrop of Cretaceous limestones. Continue straight ahead.

0.1

16.3 (26.2) STOP 1. Walk north across large dissected fan to Cretacious reef exposures.

Stop 1 discussion by Ing. Diego Córdoba
Southwestern end of Sierra de Juarez:
We will be looking at the lower Cretaceous Cuchillo Formation (Aptian), made of:

a) *lower part:* brownish calcareous sandstone, gray limestone, biostromatic gray limestone, conglomeratic (chert fragments) gray limestone. Fossiliferous content: *Exogyra* sp. and *Cardium* sp.
b) *middle part:* reddish brown limestone, brown calcareous shale, gray shale. Fossiliferous content: *Exogyra* sp., *Ostrea* sp. and *Dufrenoya* sp.
c) *upper part:* dark gray limestone and pinkish calcareous sandstone (partially conglomeratic). Fossiliferous content: *Exogyra* sp. and *Ostrea* sp.

The Cuchillo is overlain by the Benigno Formation (Albian), made of:

a) *lower part:* gray shale, gray calcareous siltstone and shale. Fossiliferous content: *Trigonia* sp., *Ostrea* sp. and undetermined echinodermata.
b) *middle part:* thin-bedded gray limestone, with *Orbitolina texana.*
c) *upper part:* thick-bedded to massive, gray to brown limestone; containing *Caprina* sp. and *Toucasia* sp.

Following stop, retrace route to Mex. 10.

0.9

17.2 (27.7) Rejoin Mex. 10.

0.3

17.5 (28.2) ADUANA. Inspection station on right. STOP for immigration inspection. Have tourist permits ready.

0.2

17.7 (28.5) ADUANA. Inspection station on right. STOP for vehicle inspection. Have car permit ready.

1.3

19.0 (30.6) Granja Juanita on left. Sierra Mezquite (Lower Cretaceous strata, and Tertiary volcanics and intrusives) from 9:30 to 11:30. Sierra Juérez on right. Creosote bush is dominant vegetation in this part of the upland surface. Brand (1936) places this area in the creosote-yucca-mesquite association of the Chihuahuan desert region.

0.8

19.8 (31.9) Large gravel pit (surficial gravels cemented with caliche) on right is located on the southwestern piedmont slope of the Juárez Mountains. To the west the route crosses the southernmost part of the Mesilla bolson (Hill, 1900), an ancient intermontane basin extending south from Las Cruces, New Mexico, and bounded by the Organ-Franklin-Juárez mountain ranges on the east and the Sleeping Lady-Aden-Potrillo uplifts on the west. During long periods in the early and middle Pleistocene, parts of the bolson floor were occcupied by distributary channels of the ancestral Rio Grande, which entered this region from the Palomas and Jornado del Muerto basins of south-central New Mexico. At various times the ancient Rio

Grande discharged from the Mesilla bolson into the Hueco bolson and the extensive bolson plains of northwestern Chihuahua. The floors of these intermontane basins were the sites of a vast complex of perennial and ephemeral lakes that possibly coalesced into a single body of water during early Pleistocene pluvials. Strain (1966, and in this guidebook) has collectively designated these lakes as Lake Cabeza de Vaca in honor of Alvar Nuñez Cabeza de Vaca, the first European to visit this part of the New World in November 1535 (see Horgan 1954, v. 1).

2.3

22.1 Casita with water tower. Descend from the (35.6) piedmont slope to the broad floor of Mesilla bolson. The basin floor is continuous to the north with middle Pleistocene La Mesa surface (Ruhe, 1964, 1967; Hawley and Kottlowski, 1969).

1.0

23.1 Rancho. Caliche pits along the highway expose (37.2) soils with strong, partly indurated horizons of carbonate accumulation. Pedologic nomenclature used to describe this type of caliche includes the terms: petrocalcic, Ccam, and Km horizons. The "K" terminology has recently been proposed by Gile and others (1965) for master horizons of carbonate accumulation in soils of arid and semiarid regions. Such horizons are almost completely impregnated with secondary carbonate but are not necessarily indurated. (See Appendix to Table 2, Morrison, this guidebook).

The dominant processes of caliche genesis in this region appear to be pedologic (Hawley et al., 1968). Most caliche, as well as weaker zones of lime accumulation occur just below and parallel to older geomorphic surfaces, and they are primarily illuvial accumulations resulting from downward movement of carbonate from surface soil horizons. There is a direct correlation between geomorphic surface, age, and thickness and morphological complexity of associated caliche horizons if textural, mineralogic, topographic, and climatic factors of soil formulation are kept relatively constant. There is strong evidence for an eolian origin for much of the carbonate. (Gile, et al., 1966). Based on studies of hydraulic properties of basin fills and models of the geomorphic evolution of the Rio Grande valley and adjacent basins, present water-table configuration and hypothetical past configurations indicate that ground-water and capillary-fringe processes have not played an important role in caliche genesis in this area (Hawley et al., 1968; King et al., 1969).

Carbon 14 analyses of caliches in the Las Cruces (New Mexico) and Fort Hancock (Texas) areas indicate that the age of these horizons of carbonate accumulation generally increases with depth (Gile et al., 1966; Grossman et al., 1967; Rightmire, 1967), (Sigalove et al., 1961).

2.1

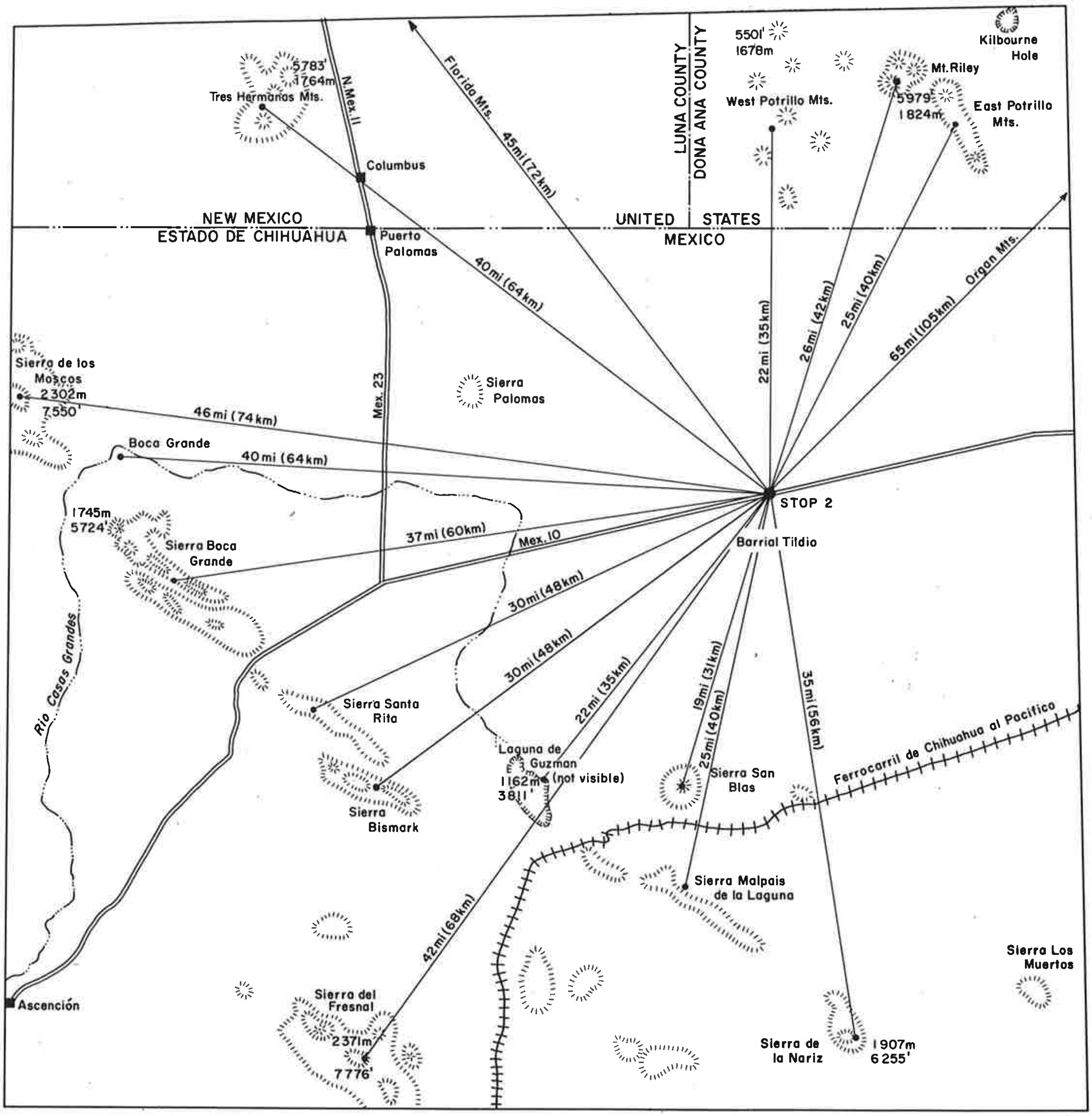
25.2 Mount Riley (Tertiary volcanics) and East (40.6) Potrillo Mountains (Lower Cretaceous strata) at 2:00.

2.6

27.8 Road to Rancho las Cuatas on left near north- (44.8) ern tip of Sierra Mezquite. Coppice-dune field (Melton, 1940; Gile, 1966).

Melton used the terms "coppice dune" and "shrub-coppice dune" to designate dunes associated with clump vegetation (coppice). Melton states that " . . . on the disappearance of the grasses and other effective sand binders with climatic change, overgrazing, etc., remaining clumps of shrubbery may trap a noticeable amount of sand; mesquite . . . grow vigorously on sand and is not readily killed by slow sand burial. Sand which falls within the bush may thus stay for a considerable time. If this process continues, a mound of sand eventually is built and held together by the coppice as well as local dune fields not stabilized by vegtation, . . ." Coppice-dune fields will be major features of the landscapes seen between stops 1 and 2 of the first day of the conference, and north of stop 2 on the third day.

From the north spur of Sierra Mezquite a northwest trending line runs to the southern tip of the East Potrillo Mountains. In general, this line marks the boundary between the Mesilla bolson and the huge closed-basin complex extending from southern Luna County, New Mexico to the Villa Ahumada area of northern Chihuahua. It has been variously called the "Great Northwest Chihuahua basin", "La Mesa", "Franklin bolson" and "Lake Palomas basin" (Brand, 1936, Sayre and Livingston, 1945, Reeves, 1965). In early through mid-Pleistocene time large areas of the basin floor were flooded and formed the western part of the Lake Cabeza de Vaca system (Strain, 1966, this guidebook). After initial en-



PANORAMIC INDEX
STOP 2

trenchment of the ancestral Rio Grande in the Hueco-Mesilla bolson area, in late-middle Pleistocene time, the major source of water for Lake Cabeza de Vaca was diverted to the Gulf of Mexico. Subsequently less extensive, but still very large lakes have periodically formed in the bolson area during late Pleistocene pluvials. These bodies of water, collectively designated Lake Palomas by Reeves (1965) represent episodes of coalescence of lakes fed by the Rios Casas Grandes, Santa Maria, Carmen and Mimbres.

3.7

31.5 (50.7) At 2:00, West Potrillo (colt) Mountains comprise a Quaternary basalt field. Descend low scarp (trend NNW-SSE) of probable tectonic origin, which extends an unknown distance to the south from the International Boundary.

4.5

36.0 (58.0) Caliche pit on north side of highway. Partly indurated caliche and underlying sands contain scattered rounded pebbles of mixed, generally silicieous composition. Rock types include rhyolite (welded tuff and trace of obsidian), granite, quartz, chert, and basalt. The gravel reflects the composition of bedrock and older basin-fill deposits north of the 32nd parallel, and is not from local sources. The lithology of surficial basin fill in this vicinity is identical to that of the Camp Rice Formation (Upper Santa Fe Group fluvial deposit) in the Mesilla Valley area and farther north. (Refer to paper by Strain in this Guidebook). Reconnaissance mapping along both sides of the International Boundary west of El Paso indicates that a southwestern extension of the main body of the Camp Rice Formation can be traced into the basin area west of Sierra Mezquite (King et al., 1969).

1.9

37.9 (61.0) End of pavement as of July 11, 1969. Yucca constitutes the dominant vegetation, accompanied by scattered small mesquite clusters.

1.6

39.5 (63.6) Rancho los Chontes to right.

1.4

40.9 (65.8) Curve.

2.9

43.8 (70.5) Crest of rise. Sierra de la Nariz (mountains of the nose) Lower Cretaceous strata and Tertiary volcanics at 9:00. The low scarp just ahead shows up faintly on photos taken from Apollo 9. (see Morrison, and Webb, this guidebook).

2.8

46.6 (75.0) Road crosses large depression (Blowout? Subsidence? What?).

4.4

51.0 (82.1) Descend hill. Florida Mountains at 2:30 (Precambrian, Paleozoic, Cretaceous, and Tertiary exposures). Sierra Boca Grande (Los Chinos) at 12:00 on distant skyline (Pennsylvanian, Permian and Cretaceous strata). Sierras Bismark and Santa Rita at 11:00.

5.9

56.9 (91.6) STOP 2 (LUNCH STOP—after geology!) on rim of "Camel Mountain escarpment" (Reeves, this Guidebook) and west edge of La Mesa surface. The escarpment at this point is about 150 feet (45 meters) high and overlooks Laguna Tildio (Brand, 1937), a playa (Bryan, 1923), or more correctly, a barrial (Ordoñez, 1936) in the northern part Bolson de Los Muertos. This stop offers a stunning panoramic view of the northern Chihuahuan Desert region (see diagram).

In the upper 50 feet of the escarpment face there are excellent exposures of ancient basin fill capped with a complex caliche zone. Underlying sediments consist primarily of horizontally- to cross-bedded sands, which are partly cemented by calcite. Silt and clay interbeds occur in the lower part of the section. The exposed sequence could represent an ancient fluvial-deltaic deposit, laid down at or near the mouth of the ancestral Mimbres River, where it emptied into a western extension of Lake Cabeza de Vaca.

The Camel Mountain escarpment extends south to southeast from the southeast corner of Luna County, New Mexico. It has generally been considered as a tectonic feature (Kottlowski, 1965; Reeves, this Guidebook). Reeves considers that at least the lower part of the scarp has been modified by wave action during deep stages of pluvial Lake Palomas in mid (?) to late Pleistocene time. Such lakes would have been very large bodies of water. A lake that reached even the base of the escarpment in this area (altitude 1200 meters, or 3937 feet) would have flooded about 2000 square miles, based on present topographic configuration, of the Los Muertos bolson floor. Such a lake would have extended about 100 miles from Arena, New Mexico (107° 25′ W., 31° 47′ N.) to Villa Ahumada, (106° 30′ W., 30° 40′ N),

Looking west across Laguna Tildio from crest of "Camel Mountain Escarpment," mile 56.9.

Contact of upper caliche zone with underlying silt and clay deltaic (?) interbeds, foot of "Camel Mountain Escarpment."

(3rd day, Stop 2) and would have had a maximum depth of over 160 feet (50 meters).

BACK TO BUSES AFTER A SHORT SIESTA!

1.1

58.0 (93.4) Route crosses floor of Laguna Tildio.

2.3

60.3 (97.1) Isolated hill at 9:30 exhibits apparent wave-cut cliffs. Refresqueria on right (warm "cokes" etc.).

62.8 (101.1) Road on right to Ejido Nuevo Cuauhtemoc. Two exploratory wells have recently been drilled for this Ejido by the Secretaria de Recursos Hidráulicos. The deeper of the two is located some miles southeast of this point and penetrated 1197 ft. (365 m.) of unconsolidated basin fill. The general section includes surficial gravel about 130 ft. (40 m.) thick, which overlies 984 ft. (300 m.) of clay. Water under artesian pressure is produced from a basal gravel zone (dominantly rhyolitic volcanics) between 1115 to 1197 ft. (340 to 365 m.), in depth. The piezometric surface is 39 ft. (12 m.) below ground surface. A sixteen-inch well developed in the deep aquifer zone produces up to 1110 gpm (70 l.p.s.) with a small amount of drawdown. The quality of the water is only fair (about 2400 ppm total dissolved solids); however, it is much better than the highly saline water developed from the surficial gravel zone. A second well, drilled at the Ejido, about 1 mile south of the highway, penetrated similar basin-fill materials to a depth of 115 ft. (340 m.), and again encountered water under artesian pressure that rose to within 72 ft. (22 m) of the ground surface. The quality of this water was slightly better (1800 ppm), but the well can produce only about 190 gpm (12 l.p.s.).

3.3

66.1 (106.4) Western edge of playa floor. Road ahead ascends a series of terrace levels (maximum elevation about 3800 feet, 1160 meters) suggestive of abandoned shorelines of pluvial lakes. Note thin, pervasive veneer of fine lag gravel. Apollo 9 photographs show two spit-like features about 3 and 6 miles (5 and 10 km) north of this point. (see Morrison, this guidebook). These features may be part of a large lake shoreline and deltaic deposits formed near the mouth of the ancestral Rio Casas Grandes at a time when it emptied into pluvial Lake Palomas (Reeves, 1965). Soils on stable surfaces in this area commonly have a well developed horizon of clay accumulation (argillic B horizon).

1.6

67.7 (109.0) Ejido "6th of January," a communal farm settlement, on left.

Isolated group of volcanic hills at 2:00 with Lower Cretaceous beds on the east. Ground water production in this area is limited to shallow aquifer zones. Deep basin-fill deposits have been tested to a depth of 1000 feet, but yield only saline water. This Ejido is supplied by a 10 ft. (3 m.) diameter well, which is about 40 ft. (12 m.) in depth. Fresh water (about 500 ppm) is produced from a gravel and sand zone between 7 to 12 meters in depth. Relatively fine-grained beds underlie and overlie this unit. The static water level here is about 20 ft. (6 m.) below the land surface.

1.8

69.5 (111.9) East edge of present slightly entrenched valley of Rio Casas Grandes. Route crosses river flood plain several miles southeast of Vado de Piedra.

0.3

69.8 (112.4) Culvert across Rio Casas Grandes distributary.

2.2

72.0 (115.9) Ranchitos north and south of highway. Colonia Vera Cruz to right. Fine-grained flood-plain deposits. Stock wells in the Colonia Vera Cruz area have penetrated as much as 300 ft. (90 m.) of basin fill, generally gravel and sand.

1.2

73.2 (117.9) Puente Vado. Drainageway southward into Laguna de Guzman ahead. This is the now obscure lower course of the Rio Casas Grandes. It heads in the Sierra Madre Occidental south of Casas Grandes, flows northward, turns eastward for 15 miles after leaving the Boca Grande canyon, then turns southward toward Laguna de Guzman. The river enters the barrial (playa) about 12 miles south of this point. The maximum recorded recent extent of Laguna de Guzman was about 16 miles by 5 to 7 miles wide (Brand, 1937). On May 26, 1969, no water was observed in the barrial.

0.2

73.4 (118.2) Ascend low escarpment, which marks the west edge of the Rio Casas Grandes valley and the area presumably flooded by pluvial Lake Palomas. Gravels exposed in the scarp may represent fluvio-deltaic deposits of the ancestral Rio Casas Grandes.

0.4

73.8 (118.8) Gravel pit on right. Cross-bedded gravel, locally capped by a sandy surface veneer, is exposed. Well-rounded clasts are mainly of rhyolite to andesite in the fine to coarse pebble size range. Gravel beds are locally impregnated with carbonate and stained with limonite.

1.9

75.7 (121.9) Crossing broad plain with gentle slope to east, possibly the surface of a large fan or delta built by the ancestral Rio Casas Grandes. Rounded pebble gravel veneers the surface.

2.9

78.6 (126.5) Trail to south leads to Laguna de Guzman and Rancho La Mota Nuevo, site of large travertine-capped spring terraces. These terraces may be associated with former spring activity (Hawley) or shoreline features as suggested by Reeves (1965).

2.5

81.1 (130.6) ADUANA. STOP FOR INSPECTION. Have vehicle permit ready. Junction on right with highway to Palomas. Cafe Lucero ahead on right. (burritos, cold cervesa, and local gossip available.)

1.7

82.8 (133.3) Restaurant El Desierto on right on toe of piedmont slope rising toward Sierra Boca Grande (Los Chinos); approaching edge of Bolson de Los Muertos.

1.1

83.9 (135.1) Isolated volcanic hills on left.

5.1

89.0 (143.3) Road on right to well site of Petroleos Mexicanos Pozo Los Chinos No. 1. Test spudded in Permian rocks on axis of south-plunging anticlinal fold.

1.6

90.6 (145.9) STOP 3 at pass between Sierra de la Boca (Sierra Boca Grande; Sierra de Los Chinos), and Sierra Santa Rita. Sierra Boca Grande, north of the road, consists of about 2400 ft.

Part D1.2.

Facsimile Copy of: Hawley, J.W., 1969b, Notes on the geomorphology and late Cenozoic geology of northwestern Chihuahua, *in* Córdoba, D.A., and others (eds.), Guidebook of the Border Region: New Mexico Geological Society Guidebook 20, New Mexico Geological Society Guidebook 20, p. 131-142 (with permission from New Mexico Geological Society, Inc.).

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NOTES ON THE GEOMORPHOLOGY AND LATE CENOZOIC GEOLOGY OF NORTHWESTERN CHIHUAHUA[1]

by
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ABSTRACT

The geomorphology and late Cenozoic geology of a 71,500 square kilometer (27,600 square mile) area of northwestern Chihuahua and adjacent parts of Sonora, New Mexico and Texas are discussed. Emphasis is on description of three major physiographic units: The Sierra Madre Occidental, and two subsections of Mexican Basin and Range section. Formal names are proposed for the latter two subdivisions. The larger unit is characterized by broad desert basins and isolated ranges of northern and eastern Chihuahua and is designated the Bolson Subsection. The higher unit, designated the Babicora-Bustillos subsection, occupies a region that is transitional, in terms of terrain and geologic features, between the Bolson unit and the Sierra Madre. Physiographic boundaries were selected on the basis of study of recently-compiled 1:250,000 scale topographic maps and some field work. Control in the northern part of the area was also provided by photos taken from Apollo and Gemini spacecraft.

Studies of basin- and valley-fill geology and geomorphology in the New Mexico-Chihuahua border region since 1950 have resulted in considerable elaboration of basic concepts of the late Cenozoic landscape evolution developed notably by Hill, Lee, Baker, Bryan and P. B. King. The fundamental concept of mid- to late Tertiary and Quaternary development and filling of intermontane basins, followed by local establishment of the entrenched Rio Grande Valley system during mid- to late Pleistocene time, appears to be generally applicable to the Basin and Range area under discussion. The important influence of a cyclic climatic change during the Quaternary period on landscape evolution is also recognized.

RESUMEN

Se expone la geomorfología y la geología del Cenozoico tardío de una área de 71,500 Km^2 (27,600 millas cuadradas) del noroeste del Estado de Chihuahua y parte de los estados adyacentes de Sonora, Nuevo México y Texas. Se hace mayor énfasis en la descripción de tres unidades fisiográficas principales: La Sierra Madre Occidental y dos subdiviciones de "Sierras y Cuencas." Se proponen nombres formales para estas subdiviciones. La unidad más extensa en el norte y oriente de Chihuahua se caracteriza por amplios bolsones desérticos y sierras aisladas, lo cual aquí se designa como subdivición Bolson. La unidad de mayor relieve que la anterior se ha asignado como subdivisión Babícora-Bustillos, la cual ocupa una región transisional refiriéndose a caracteres geológicos, entre la unidad Bolson y la Sierra Madre. Los límites fisiográficos se seleccionaron basándose en estudios de compilaciones recientes de mapas topográficos Esc. 1:250,000 y algunos trabajos de campo. El control de la porción norte del área también fué apoyada por las naves espaciales Géminis y Apolo.

Desde 1950, los estudios geológicos y geomorfológicos realizados por Hill, Lee, Baker, Bryan y P. B. King, del relleno de los valles y cuencas en la región fronteriza de los Estados de Nuevo México y Chihuahua, han dado como resultado una elaboración considerable de los conceptos básicos del desarrollo evolutivo en la configuración del terreno durante el Cenozoico tardío.

Los conceptos fundamentales de desarrollo y relleno de las cuencas intermontanas, durante el terciario medio al tardió y Cuaternario, seguido por el establecimiento local del sistema protegido del Valle del Río Grande (Río Bravo) durante el Pleistoceno medio a tardío, parece tener aplicación al área en discusión de "Cuencas y Sierras."

También se reconoce la influencia de un cambio en el ciclo climático, durante el período cuaternario, en la configuración evolutiva del terreno.

INTRODUCTION

This paper is a preliminary statement on certain aspects of the geomorphology and late Cenozoic geology of northwestern Chihuahua and adjacent parts of Mexico and the United States in an area bounded by the 105th and 109th meridians and the 28th and 32nd parallels (figure 1). The ideas expressed are a joint product of a small amount of field work in northwestern Chihuahua, and a large amount of information gained from field work in adjacent parts of the United States, discussions with fellow workers, reviews of published literature, and study of topographic maps and space photographs.

1. Approved for publication by Director, Information Division, Soil Conservation Service.

HISTORICAL REVIEW

Chihuahua has attracted the attention of American geographers and geologists for over a century. In the middle

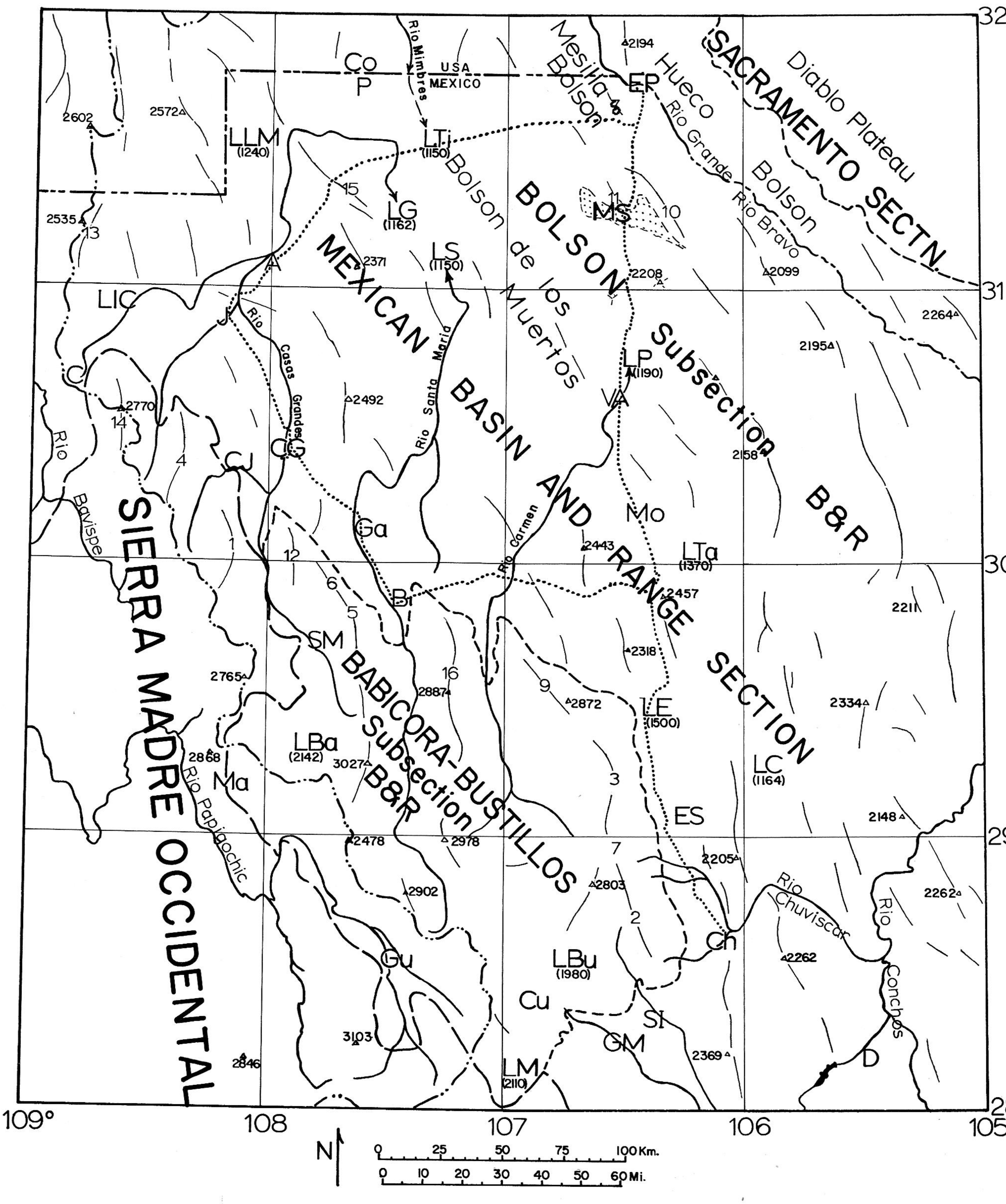

FIGURE 1. INDEX MAP—GEOMORPHIC FEATURES OF NORTHWESTERN CHIHUAHUA AND ADJACENT AREAS.
(Explanation on facing page)

of the 19th Century, during the era of territorial expansion, interest was directed toward location of transcontinental transportation routes and metallic mineral deposits (H. James, this guidebook; DeFord, 1964).

Encouragement of American involvement in exploitation of Mexico's mineral wealth by the Diaz regime lead to the first detailed reconnaissance studies of the region between 1885 and 1911. Early investigations which touched on important aspects of Cenozoic geology and geomorphology of Chihuahua, were made by R. T. Hill (1891, 1901, 1907), Hovey (1907), and Burrows (1909-10). Moreover, during the same general period, similar features in adjacent areas of the United States were being studied by Hill (1900), Lee (1907), Richardson (1909), N. H. Darton, (1916), and others.

Investigations in Trans-Pecos Texas, New Mexico, southeast Arizona and adjacent parts of northern Mexico in the two decades prior to World War II resulted in a series of classic papers that dealt in part with Cenozoic rocks and geomorphic features. Among these were publications by C. L. Baker (1928, 1934), D. D. Brand (1937), Kirk Bryan (1938), L. B. Kellum (1944), P. B. King (1935, 1947), R. E. King (1939), King and Adkins (1946), C. O. Sauer (1930) and Sayre and Livingstone (1946). Brand's monograph on the "Natural landscape of northwestern Chihuahua" (based on field work in 1929-31, 35-36) is the most comprehensive English language reference on the geomorphology of the area. It includes summary statements on previous work by Mexican, American, and European geologists and geographers, extensive descriptions of the biota, notes on the climate, and astute observations on the physical geography.

The present era of intensive studies of the late Tertiary and Quaternary geology of the New Mexico-Chihuahua border region was initiated in the early post-war years by Kottlowski (1953, 1958, 1960), Strain (1959) and Ruhe (1962, 1964). Ground-water investigations by the U.S. Geological Survey also continued to contribute information on basin-fill geology, particularly on subsurface lithofacies distribution and fill thickness (Conover, 1954; Knowles and Kennedy, 1958; and Leggat, Lowry and J. W. Hood, 1963).

In the past decade, interest in basin and valley fills and geomorphic surfaces has greatly increased. Strain (1966, 1969) has continued his studies on basin-fill stratigraphy and vertebrate paleontology in the Hueco and lower Mesilla Bolsons. Ruhe (1967) has presented a detailed synthesis of his three-year field investigations of surficial deposits, geomorphic surfaces and soils in the Las Cruces area. Kottlowski has continued as a guiding force in studies of the late Cenozoic, both as co-author of review papers (Kottlowski, et al, 1965) and as a source of support and encouragement for all other workers in his role as Assistant (and Acting) Director of the New Mexico Bureau of Mines and Mineral Resources. The papers in this guidebook by Cliett, Hoffer, Metcalf, Morrison, Reeves and Strain provide concrete evidence of the scope of late Cenozoic research in the border region.

EXPLANATION

Localities

A La Ascensión
B Buenaventura
C Carretas Pass
Ch Chihuahua City
Co Columbus, N. M.
Cu Cuauhtémoc
CG Nuevo Casas Grandes
CJ Colonia Juárez
D Delicias
EP El Paso-Juarez
ES El Sauz
Ga Galeana
Gu Guerro
GM Gran Morelos
J Janos
LlC Llano de Carretas
Ma Madera
Mo Moctezuma
MS Médanos de Samalayuca
P Las Palomas
SI Santa Isabel
SM San Miguel de Babicora
VA Villa Ahumada

Mountain Ranges

1 Sierra de La Breña
2 Sierra de La Calera
3 Sierra de La Compana
4 Sierra de Carcay
5 Sierra de La Catarina
6 Sierra del Cristo
7 Sierra Cumbres de Majalca
8 Sierra de Juárez
9 Sierra del Nido
10 Sierra del Presidio
11 Sierra de La Samalayuca
12 Sierra de San Joaquin
13 Sierra de San Luis
14 Sierra de San Pedro
15 Sierra de Santa Rita
16 Sierra de Las Tunas

Lake Plains
(elevation in meters)

LBa Laguna Babicora
LBu Laguna Bustillos
LC Laguna del Cuervo (de los Hormigas)
LE Laguna Encinillas
LG Laguna de Guzman
LM Laguna de Los Mexicanos
LLM Laguna de Los Moscos
LP Laguna de Los Patos
LS Laguna de Santa Maria
LTa Laguna Tarabillas
LTi Laguna Tildio

12 Ranges Designated in Figure 1 and Text

Other Ranges

2868 Elevations of Major Peaks in Meters

Tour Route

Continental Divide

Sierra Madre/Basin and Range Province Boundary

Basin and Range Section Boundaries

Current studies on the Cenozoic geology of the area have recently been reviewed in a "Border Stratigraphy Symposium" volume edited by Kottlowski and LeMone (1969). Papers in this volume by Hawley and Kottlowski, Hawley and others, Hoffer, LeMone and Johnson, and Strain (see bibliography) deal with a variety of subjects, including the stratigraphy and hydrogeology of late Cenozoic basin and valley fills, geomorphic history of the Rio Grande Valley and adjacent basins, ancient cienega deposits and Pleistocene vetebrate faunas in the Santa Fe Group, and Quaternary basalts of the La Mesa area.

In addition to the above, a number of other studies in the border region should be mentioned. Investigations of three Quaternary maare in the southern Mesilla Bolson area (Killbourne Hole, Hunt's Hole, and Potrillo Maar) have recently been completed by DeHon (1965), and Reeves and DeHon (1965). W. E. King and associates (1969) have just finished a comprehensive report on subsurface hydrogeologic conditions in Dona Ana County, New Mexico. Geophysical studies in the southern Hueco Bolson by R. E. Mattick (1967) and associates, in conjunction with U.S. Geological Survey ground-water investigations for the City of El Paso and Fort Bliss, have made important contributions to our knowledge of the thickness and consolidation of Santa Fe group basin-fill. The adjacent area of Trans-Pecos Texas and northeastern Chihuahua has also been the site of a number of important studies of Cenozoic geology in recent years, notably by University of Texas faculty members and their students (DeFord, 1964, this guidebook) and C. C. Albritton (Albritton and Smith, 1965). Of particular importance, in terms of the geomorphic evolution of the middle Rio Grande Valley, is work by Charles Groat (Univ. of Tex.) in the Presidio area.

Lustig (1968) has recently completed an "Inventory of Research on Geomorphology and Surface Hydrology of Desert Environments." This paper includes a good review of research in arid regions of Mexico. The most comprehensive Spanish language report on the geomorphology and hydrogeology of the area is by L. Blásquez (1959). For the major drainage basin units, he presents excellent summaries of the available information on physiography, extent of surficial basin-fill deposits, bedrock types, and hydrology (including climatic data, hydrologic budget analyses).

Paleoecologic and pedologic (soils) investigations have also been conducted during the past decade in connection with previously mentioned stratigraphic, hydrogeologic and geomorphic studies. The most important work in paleoecology has been the study by A. L. Metcalf (1967) on Pleistocene molluscan faunas of the Rio Grande Valley. Detailed studies on the distribution, genesis, and classification of desert soils in southern New Mexico by Gile and associates (see bibliography) represent a landmark in pedologic research, particularly in terms of the genesis and classification of horizons of carbonate and clay accumulation.

During the past 18 months, the writer has had the opportunity of participating in several studies of soil-geomorphic relationships and basin-fill geology in northwestern Chihuahua in cooperation with personnel of the Mexican Federal Secretaria de Recursos Hidráulicos (S.R.H.). Recent ground-water and land-resource investigations by the S.R.H. in parts of the Valle de Juárez and lower Rio Carmen, Encinillas and Rio Casas Grandes basins have resulted in the collection of a great amount of still-unpublished information (including both geologic and geophysical data) on the lithology and thickness of basin-fill deposits, as well as on the soils of those areas. Joint field-study tours and access to unpublished S.R.H. maps and subsurface data have been of immeasurable assistance in the preparation of this paper and the sections of the field conference road log dealing with basin-fill geology and geomorphology. Officials of the Secretaria de Recursos Hidráulicos, who have provided major assistance include Ing. G. Flores Mata, Director de Agrologia, and Ing. I. Sainz Ortíz, Director de Aquas Subterraneas, both in Mexico City; Ing. C. Carvajal Zarazua, Chief of the Chihuahua S.R.H. Office, and the following members of his staff: Ings. Martinez, Benitez, Dominquez, Fuentes, and Amaya; and Sr. Oscar Muñoz. Ing. Carlos Garcia, former Director, Comisión de Fomento Minero, Sucursal Chihuahua, and Professor Luis Lopez of the University of Chihuahua have also provided valuable assistance on a number of occasions.

REGIONAL GEOMORPHOLOGY

INTRODUCTION

The location of physiographic subdivisions and general topography of northwestern Chihuahua are shown on figure 1 and on the 1:1,000,000 scale aeronautical chart reproduced on the inside covers of this guidebook. Maps and photographs showing geomorphic features in the northern part of the region accompany guidebook papers by T. E. Cliett, J. Hoffer, R. B. Morrison, C. C. Reeves and W. S. Strain. Morrison's excellent paper illustrates the usefulness of space photography in studies of surficial geology, geomorphology and pedology. The space photos and new 1:250,000 scale topographic maps of northern Mexico (Army Map Service Series) represent a completely new set of tools available to students of the geology and geomorphology of this region. With these tools, description of the terrain can be done in a relatively sophisticated manner. Work on regional and local topographic analysis is in progress in conjunction with other geomorphic studies. The placement of physiographic-unit boundaries on figure 1 and the information given in table 1 are based on the preliminary results of these investigations.

A number of geographers and geologists have defined the general physiographic subdivisions of northern Mexico (Hill, 1901, 1907; Thayer, 1916; Ordóñez, 1936, 1942; Tamayo, 1962; Vivó, 1948; Raisz, 1964). However, Brand (1937) and Almada (1945) are the only workers who have dealt specifically with the State of Chihuahua. To quote Brand (p. 11):

> "Northern Chihuahua offers to view two geomorphic complexes: the Basin and Range landscape, in which a practically continuous flat, gently rolling, or sloping plain is broken by short, frequently parallel mountain

chains which rise above the basin floors like "islands out of a sea"; and the Sierra Madre Occidental, which is a great plateau of extrusives, having NNW-SSE narrow structural depressions between smooth-topped ridges, mesas, and minor plateaus, and segmented by the gorges of transverse, antecedent or headward-eroding streams flowing through deep gorges to the Pacific lowlands."

All workers have recognized these two basic subdivisions of the Chihuahua landscape. Moreover, there is general agreement on the formal use of the name "Sierra Madre Occidental" to designate the physiographic province that forms the mountainous backbone of this part of the continent.

Brand considered the intermontane basin region northeast of the Sierra Madre to be the southern extension of Mexican Highland section of the Basin and Range Province (using Fenneman's 1931 classification), and he designated it the "Mexican Basin and Range Section." This terminology is used in this paper, and it generally corresponds with Raisz's (1964) Basins and Ranges Province. However, some adjustments are made in Brand's placement of the Basin and Range-Sierra Madre boundary. The two leading works on the geography of Mexico (Tamayo, 1962; Vivó, 1948) use the term Altiplanicie (Mexicana) Septentrional (Northern Mexican High Plateau) to designate this physiographic unit. Other terms used in Mexico include: Mesa Central Septrentional (or Northern-Central Plateau), Llanuras Boreales, Altiplanicie Septentrional, Meseta Central del Norte, and Region de los Bolsones (Ordóñez, 1936, 1942; Almada, 1945; Ed. Porrua S.A., 1965). Ordóñez (1936, p. 1289), in agreement with Brand, states that this region is "really the southern extension of the Basin and Range Province of the southwestern United States in Arizona and New Mexico." Vivó (1948) on the other hand, relates the "altiplanicie" with the Great Plains physiographic province, and extends the Sierra Madre Occidental north to join the Southern Rocky Mountain province as an intermediate highland belt east of his Sonoran and Sinaloan plains unit.

To add to the profusion of names, Hill proposed two other terms: "the Mexican Basin Region of the Mexican Cordilleran (Plateau) Province (1901)" and the "Chihuahuan Desert Province (1907)." The first fits very nicely with, and obviously influenced, Brand's choice of physiographic terminology.

Finally, a number of workers have correctly recognized that structural features of the Sierra Madre Oriental fold and thrust-fault belt extend into Trans-Pecos region across eastern Chihuahua and that there are problems in applying the classic block-fault structural model as an explanation of basin and range development in at least part of the region. (Refer to Baker, 1928, 1934; King, 1935; Kelley and Silver, 1952; DeFord, 1964, this guidebook; Albritton and Smith, 1965; and de Cserna, this guidebook). Albritton and Smith (1965) use "Sierra Madre Oriental" to designate the physiographic province lying south of a line extending ESE from the southwestern foot of the Diablo Plateau toward Van Horn, Texas (generally following Fenneman's boundary line between the Mexican Highland and Sacramento sections of the B&R Province). To the writer, however, it does not seem desirable to use the term "Sierra Madre Oriental" to identify a physiographic unit that differs so markedly (in terms of terrain characteristics) from the main part of the Sierra Madre Oriental province (e.g. the closely packed system of high ranges in southern Coahuila and areas to the southeast). Current "Basin and Range" usage (Thornbury, 1965; Hunt, 1967) is certainly not restricted to areas where the relatively narrow Gilbert-Davis concept of Basin Range faulting dominates the structural picture, and the writer feels that he is justified in continued use of Brand's terminology.

TERMS USED IN LANDSCAPE DESCRIPTION IN THE CHIHUAHUA REGION.

Primarily due to R. T. Hill's classic studies, a number of terms of Spanish origin that describe major Basin and Range landscape features have been introduced into English-language geographic and geologic literature. Several of these terms are defined and discussed below, along with a number of other descriptive terms of non-Spanish origin.

Bajada. "The term *Bajada* literally means a gradual descent. I find it used upon the maps of New Mexico and applied to a gradually descending slope as distiguished from a more vertical escarpment. I take the liberty of proposing to limit the use of this term to extensive slopes of degradational and aggradational origin (Hill, 1896, p. 297)."

Comment: This definition generally corresponds with the definition of piedmont slope given below and to the manner in which "bajada" is commonly used by biologists (see Martin, 1963). However, most geologists use the term to describe the constructional part of a piedmont-slope surface (generally formed by coalescence of alluvial fans) as suggested in the following quote from Tolman (1909, p. 141-142): "Extending down from the rock surfaces surrounding the bolson are the flanking detrital slopes, built up by terrestrial deposition, the aggradational equivalent of the active erosion above. These slopes are the dominant features of the arid landscape. . . . The difficulty of preventing confusion between the detrital slopes and rock slopes of the mountains brought out the necessity of a new name for this feature (detrital slope), for which the Spanish word bajada has been selected, local usage almost exactly corresponding to the technical meaning suggested." The "Tolman" concept of "bajada" is used in this paper. Attention should also be drawn to the use of "bajada" is an equivalent of "hill" on Mexican highway signs. "steep downgrade"

Barrial. Spanish for a muddy spot (sometimes incorrectly spelled "barreal"). Ordóñez (1936, p. 1290) in reference to the landscape of the "north-central plateau of Mexico" states that: "the topographic elements of the (intermomtane) basin or 'bolson' are the mountain slope, the alluvial fans, the gentle alluvial plain (see Bolson Floor), and the silty bottom of the basin called the 'barrial', which is temporarily occupied by water immediately after the infrequent, but torrential rains." Ordóñez in the same paragraph also notes that "the 'barrial' (is) improperly called 'playa' by the American geologists and geographers."

Basin. A depressed area, which may be closed or open ended. Intermontane basin landscape elements are (1) piedmont slope and (2) basin floor. As used in this paper, "basin" is generally synonymous with "bolson".

Bolson. "The term 'bolson' derived from the Spanish word signifying a purse, is an apparently level valley, usually slightly depressed toward the center and enclosed by mountains usually without drainage outlet. These plains or 'basins' . . . are largely structural in origin. Bolsons are generally floored with loose, unconsolidated sediments derived from the higher peripheral region. Along the margins of these plains are talus hills and fans of bowlders, and other wash deposits brought down by mountain freshets. The sediments of some of the bolsons may be of lacustral origin (Hill, 1900, p. 8)."

According to Tolman (1909) the three main component parts of a bolson are: 1. The rock surface of surrounding mountains (in this paper limited to erosional footslope areas = pediments). 2. The bajada. 3. The playa (see Barrial). Tolman also designated bolsons with surface-water outlets "semibolsons".

Bolson (or Basin) Floor. The nearly level surface of varying width that forms the central part of a bolson (or basin). Alluvial (adobe-Bryan, 1923) and ephemeral-lake flats or plains are common basin-floor types.

Caliche. Derived from the Latin "calx" meaning lime. Most current definitions (Aristarain, 1962) limit the designation "caliche" to zones of calcium carbonate accumulation that occur within several feet of the surface of stable or slowly aggrading older landscapes in arid to subhumid regions. Nearly complete impregnation of the pre-existing parent sediment with carbonate is usually implied, with the secondary carbonate being (1) brought in from overlying soil horizons by downward percolating water (i.e., the process of illuviation) (2) formed in place by weathering, or (3) emplaced from below by capillary-fringe waters. Induration is usually not required, although partial cementation by the impregnating carbonate is commonly implied in most definitions. Varieties of caliche formed by a combination of processes (1) and (2), with (1) being most important, would qualify for the soil "K horizon" designation of Gile and others (1965, 1966); and Aristarain (1962) would limit the term "caliche" to illuvial accumulations of secondary carbonate.

Prominent horizons of carbonate accumulation that qualify for the "K horizon" designation are often well developed in soils along the route of this field conference.

Pediment. That portion of the surface of degradation at the foot of a receding slope, which (a) is underlain by rocks of the upland and which is either bare or mantled by a layer of alluvium not exceeding in thickness the depth of stream scour during flood, (b) is essentially a surface of transportation, experiencing neither marked vertical downcutting nor excessive deposition, and (c) displays a longitudinal profile normally concave, but which may be convex at its head in later stages of development. The pediment may be found in regions of rising, stationary, or lowering base level (Howard, 1942).

Piedmont. Lying or formed at the base of mountains.

Piedmont Slope. "The piedmont slope consists of two parts, a lower part of aggradational origin, called a bajada, and an upper part which is really an eroded bedrock surface (pediment), although it is commonly veneered with alluvium (Thornbury, 1954, p. 284)." As mentioned previously, the piedmont slope is one of the two basic elements of the intermontane basin (bolson) landscape, the other being the basin floor. The (rock) pediment is locally a very important landform in northwest Chihuahua but it is not necessarily always present as a major element of the piedmont slope landscape.

Playa. "A Spanish word meaning literally shore or strand; a level or nearly level area that occupies the lowest part of a completely closed basin and that is covered by water at irrgular intervals, and for longer or shorter periods of time, forming a temporary lake (Bryan, 1923, p. 89)." (See "barrial".)

SIERRA MADRE OCCIDENTAL PROVINCE

In this paper the designation "Sierra Madre Occidental" is limited to an area that comprises a compact mass of high plateaus and ridges with intervening narrow, canyon-type valleys, or barrancas, south of the Llano de Carretas (latitude 30° 45′). In Chihuahua, it is called the Sierra Taruhumara and its eastern boundary is marked by the great escarpments that face (from south to north) the basins of Laguna de los Mexicanos, Guerrero, Madera, Laguna Babicora, San Miguel-Mata Ortiz, Piedras Verdes-Colonia Juárez, Janos and Llano de Carretas (figure 1). Following the suggestions of Thayer (1916), Ordóñez (1936) and Brand (1937), isolated ranges that extend north of the 31st parallel into southern New Mexico and Arizona are included in the Mexican Basin and Range section even though they maintain the general altitude of the Sierra Madre.

The province is capped by a thick sequence of Tertiary volcanics, dominantly rhyolite tuffs and welded tuffs but with significant amounts of volcanics of intermediate composition. Basalts are not abundant, and Tertiary intrusives and pre-Tertiary sedimentary rocks are only locally exposed (table 1, Ramirez and Acevedo, 1957). The summit area exhibits striking accordance of crestal elevations. The capping sheets of rhyolitic volcanics are locally faulted and folded, but generally show little evidence of diastrophic disturbance other than profound regional uplift and slight tilting. In the area north of the 28th parallel, the maximum elevations (2750 to 3103 meters, 9000 to 10,180 feet) occur in the easternmost part of the province. The elevation at the foot of the eastern escarpments ranges from 1500 meters (4915 feet) near Carretas to 2300 meters (7500 feet) near Laguna de los Mexicanos. In the area along the Sonora-Chihuahua border, no ridge or plateau summits rise above 2750 meters (9000 feet) and upland elevations are generally below 2450 meters (8000 feet).

The Continental Divide (figure 1) generally follows the eastern summit trend, but between Madera and Ciudad

TABLE 1. CHARACTERISTICS OF PHYSIOGRAPHIC UNITS IN NORTHWESTERN CHIHUAHUA AND ADJACENT AREAS
(107° to 109° W. Longitude, 28° to 32° N. Latitude)

PHYSIOGRAPHIC UNIT	SIERRA MADRE OCCIDENTAL	MEXICAN BASIN AND RANGE SECTION BOLSON SUBSECTION	BABICORA-BUSTILLOS
Total Area (Km²)	31,000	107,500	25,000
Area of Internal Drainage/Total Area (%)		70	29
Area of Ranges/Total Area (%)		19	37
Percentage of Ranges Composed of:			
Mainly carbonate sedimentary rocks	<0.2	35	<0.3
Mainly rhyolitic and andesitic volcanics	>99.6	61	>99.7
Mainly igneous intrusive rocks	<0.2	<2	
Mainly basalt (Quaternary?)		<3	
Percentage of Basin Areas in Active Dunes		>0.5	
Percentage of Basin Areas in Playas (Barrials)		2.5	<2
Percentage of Total Area Below 1220m. (4000 ft.)	9	15	0
Percentage of Total Area Above 1830m. (6000 ft.)	54	2.4	97.5
Percentage of Total Area Above 2440m. (8000 ft.)	5.5	<0.02	3.5
Highest Elevation in Meters (Feet)	3103(10,180)	2602(8532)	2978(9774)
Lowest Elevation			
Basin Floor		1150±(3770±)	1980±(6490±)
River Valley floor	550(1800)	850(2785)	1600(5250)
Range in Mean Annual Precipitation (mm)	<400->1100	<150->400	<300->600
Range in Mean Annual Temperature (°C)	<10-20	15-20	10-18
Range in Aridity Index ($I = \frac{P}{T+10}$)	15-50	<5->15	10-30

Cuauhtemoc it swings out to the western range of the Basin and Range province. The major rivers in this part of the Sierra Madre are the Rios Papigochic and Bavispe, which are tributary to the Aros-Yaqui system. The Yaqui enters the Gulf of California at a point less than 320 kilometers (200 miles) southwest of the highest point in its watershed (elevation 3103 meters, 10,180 feet). The barranca of the Rio Papigochic, while not as spectacular as the barrancas of the Urique (del Cobre) region south of Creel, has a local relief of over 1600 meters (5250 feet). The elevation of the barranca floor is about 550 meters (1800 feet) where it crosses the 109th meridian, or about 200 miles down a very sinuous valley from the high point of the watershed. In addition to rivers draining to the Pacific, the largest stream of the interior basin region, the Rio Casas Grandes, heads in the northernmost ranges of the Sierra Madre between Carretas Pass and San Miguel de Babicora (107° 45′ W, 29° 40′ N).

As has been previously recognized, the striking parallelism of the major stream valleys and intervening ridges and plateaus in the Sierra Madre Occidental reflects the NNW-SSE strike of regional structural trends. The origin of the transverse canyon segments connecting the longitudinal valleys has yet to be studied in detail. Use of genetic terms (such as "antecedent"; Brand, 1937) to describe parts of the drainage system is therefore not recommended.

Long-term climatic records for the northern Sierra Madre Occidental province are not available. In the early 1930's, Brand could find no information at all on the Sierra Tarahumara. However, on the basis of studies of plant communities and weather records from adjacent areas, he placed the upper Sierra Madre pine country in the Mesothermal savannah (Cw) category of the Koeppen climate classification system (Trewartha, 1954), with drier areas being placed in the hot steppe (BSh) category.

During the last decade, considerable new information on climate has been gathered from stations in the interior parts of the Sierra Madre; and precipitation, temperature and aridity index (deMartonne (1926) maps based on 1957-1965 data have recently been prepared by the Servicio Meteorological Nacional for the State of Chihuahua. This information is summarized in table 1.

Mexican Basin and Range Section

While it has the basic terrain attributes necessary for inclusion in the broad "Basin and Range concept" of Fenneman (1931), Thornbury (1965) and Hunt (1967), the Basin and Range section of northwestern Chihuahua does not fit neatly into a single category in terms of land-form parameters or geologic setting.

Brand (1937, p. 28) recognized that the "eastern margin (of the Sierra Madre) is actually an indefinite transition zone marking the change from limestone Basin and Range country to the plateau area of great effusives." He therefore selected "a compromise eastern limit," as much as to 40 miles east of the boundary line shown in figure 1, that bisected a group of large, high-level intermontane basins lying east of the Sierra front between the 28th and 30th parallels. The writer proposes that Brand's "difficulty" in fixing the Basin and Range—Sierra Madre Occidental boundary can be resolved by creating two subdivisions of the Mexican Basin and Range section: the Babicora-Bustillos and the Bolson subsections.

The major distinguishing geomorphic features of these subsections are listed in table 1. Areas of basins, ranges, playas, and dune fields have been determined from the 1:250,000 scale Army Map Service Topographic Sheets. Regional area-altitude measurements have been made on the 1:1,000,000 scale Aeronautical Chart (O.N.C. H-23, May 1968 edition) that incorporates current topographical data obtained from the A.M.S. surveys. Percentages of mountain areas primarily underlain by four general classes of bedrock units: (1) carbonate sedimentary rocks; (2) rhyolitic to andesitic volcanics; (3) intrusive rocks, and (4) basalt, were determined from the geologic maps of Chihuahua, western Texas and southwestern New Mexico (Ramirez and Acevedo, 1957; Texas Bur. Econ. Geol., 1968; Dane and Bachman, 1961) and unpublished maps showing the distribution of "Quaternary" basalt. Measurements were mechanically made with an MK area calculator. Where possible, basin and range distribution was checked by utilizing information from space photos (Gemni 4 and Apollo 9). Field observations were made in the areas of Laguna Guzman, southern Mesilla Bolson, Ascención-Los Moscos, Cuauhtemoc, Guerrero, El Sauz, Chihuahua-Aquiles Serdan, Delicia, and generally along the route of this field conference in cooperation with Leland Gile, officials of the Direccion de Agrologia (S.R.H.), Roger Morrison of the U.S. Geological Survey, and B. L. Allen, Texas Technological College.

The Babicora-Bustillos subsection receives its name from Lagunas Babicora and Bustillos, two ephemeral lakes, respectively in the northwest and southeast parts of the unit (figure 1). It can be distinguished from adjacent physiographic units in terms of elevation and size of basins and sierras, and bedrock composition of the ranges (table 1, figure 1). The subsection has an area of about 25,000 square kilometers (9700 square miles), and includes a group of high-level intermontane basins, and four major mountain chains, with peak altitudes locally exceeding the general summit elevation of the eastern Sierra Madre. In striking contrast to the Bolson subsection, where mountains "rise above the basin floors like islands out of the sea" (Brand, 1937), the mountains form almost continuous chains, and widespread coalescence of basin surfaces has not occurred. The bedrock composition of the ranges is similar to that of the Sierra Madre. The section of volcanics seen at Las Tunas Pass (stop 2, second day) is a good example of the type of bedrock sequence that is dominant in this region. The Babicora-Bustillos subsection also corresponds in part with the "Upland with Basins" Subdivision of the Sierra Madre Occidental suggested by Raisz (1964).

The nature and age of the structures controlling the positions of basins and ranges is apparently still a matter of some conjecture. Basin elevations are generally in the 1830 to 2290 meter (6000-7500 ft.) range. Basin surfaces commonly consist of constructional plains, with broad bajada, alluvial-flat and ephemeral lake-plain elements. Around the edges of the subsection, dissection of the older basin fill has been initiated by headwater tributaries of the Papigochic-Yaqui (Pacific), Satevo-Conchos (Atlantic), and Rio Casas Grandes-Santa Maria-Carmen (interior) systems. The northeastern to eastern boundary with the Bolson subsection is generally marked by the bases of frontal escarpments of the Sierra San Joaquin-del Cristo (Arco)-de la Catarina chain and the Sierras de las Tunas, del Nido, de la Campaña and de la Majalca. The southeastern subsection boundary is less distinct, being marked by the bases of mountains flanking the Chuviscar, Santa Isabel (General Trias) and Gran Morelos (Rio Satevo) basins on the northwest (figure 1).

The field conference tour route is entirely in the Bolson subsection of the Mexican Basin and Range country (except east of Buenaventura where it crosses the north end of Sierra de las Tunas), but tour participants can get a good view of the ranges bordering the Babicora-Bustillos subsection from Highways 10 and 45 between Galeana and Chihuahua City. The northeast ranges of the Sierra Madre can occasionally be seen from Highway 10 between Janos and Puerto Chocolate in Nuevo Casas Grandes area.

The Bolson subsection of the Mexican Basin and Range section comprises the great belt of coalescent desert basins (primarily with interior drainage) extending from southwestern New Mexico, partly across the western tip of Trans-Pecos Texas through Chihuahua, and on into the interior States of Mexico. Basin-floor elevations are generally in the 1190 to 1525 meter (3900 to 5000-foot) range and mountain peaks rarely exceed 2440 meters (8000 feet). Carbonate rocks (primarily Cretaceous limestones) dominate the bedrock terrane in the eastern and southern parts of the area, while Cenozoic volcanics are predominant in the west. Tertiary intrusive bodies are also locally present (table 1). Except for areas adjacent to valleys of the Rio Grande-Conchos and Rio Bavispe-Yaqui systems, and along several major fault zones, the (usually thick) bolson fills have undergone only a small amount of dissection. The structural mechanisms involved in formation of the present sierra and bolson topography are not yet clearly understood. However, a considerable amount of work on this problem is in progress (see papers by DeFord, and de Cserna in this guidebook).

The large Mesilla and Hueco Bolsons (named by Hill in 1900) occur on the northern part of the region, while the huge "Bolson de Gigantes" and "Bolson de Mapimi" basin complexes occupy the central part of the province between Chihuahua City and Torreón. El Bolson de Mapimi (mentioned by Hill in 1891) along with the Hueco (including the present Tularosa Basin), Mesilla and several other Trans-Pecos basins, served as models of Hill's (1900) concept. The tour routes between Sacramento and Sierra de Samalayuca (third day—stops 1 to 3), and between Sierra del Mesquite and the Sierra Santa Rita (first day—stops 1 to 3) cross several other classic bolsons. From south to north, these internally drained depressions comprise the basins of Laguna del Cuervo (105° 55′, 29° 15′), Laguna Encinillas (106° 20′, 29° 30′) and Laguna Tarabillas (106° 12′, 30° 2′) and Bolson de LosMuertos (Reeves, this guidebook).

The Bolson de Los Muertos extends 150 miles from the Florida Mountains (north of Columbus, New Mexico) to the vicinity of Moctezuma (106° 28′, 30° 11′) and ranges up to 50 miles in width. The "sinks" of Rio Carmen (Laguna Patos—106° 30′, 30° 45′) Rio Casas Grandes (Laguna Guzman—107° 30′, 31° 18′) and Rio Mimbres—Palomas Arroyo (Laguna Tildio—107° 20′, 31° 33′), and the "El Barrial—Salinas de Union" alkali flats occupy extensive areas of the bolson floor. The spectacular Medanos de Samalayuca dune field (refer to notes on stop 3, third day) is located on the east edge of the bolson. During pluvial episodes in early (?) to middle Pleistocene time, this large complex of coalescent basins was partly flooded by the western part of Lake Cabeza de Vaca (Strain, 1966, this guidebook; Hawley, et al., 1969), and the bolson periodically received large quantities of water and sediment from the ancestral Rio Grande. After initial incision of the present Mesilla-El Paso valley in late-middle Pleistocene time and diversion of the upper Rio Grande to the Gulf drainage system, a basin-floor area of at least 1700 square miles was still periodically flooded during late Pleistocene pluvials. The lake complex fed by the four existing rivers of the northern part of Bolson subsection, Rios Casas Grandes, Santa Maria, Carmen and Mimbres, has been designated Pluvial Lake Palomas by Reeves (1965, this guidebook).

Climate. Relatively good climatologic data are now available for the Basin and Range country of northwestern Chihuahua. The new precipitation, temperature, and aridity-index maps prepared by the National Meteorological Service for the 1957-65 period show the striking increase in aridity from SW to NE across the region discussed in this paper. The 16° mean annual isotherm, 300-350 mm mean annual isohyet and "15" aridity-index (semiarid—subhumid transition) contours closely parallel the western boundary of the Bolson subsection. The value ranges of these parameters in the two Basin and Range subsections are given in table 1.

The new map of arid lands of North America in *Deserts of the World* (McGinnies, et al., 1968) places the Chihuahuan Basin and Range country in the Meigs (1953) Ab13 and Sb13 categories (i.e., arid and semiarid, summer precipitation, coldest month 0-10°C, warmest month 20-30° C). Brand (1937, map 5) summarized the information available up to 1935, and subdivided the Basin and Range area into three climatic zones, using the Koeppen system. The Babicora-Bustillos subsection, as defined in this paper, is characterized by climates ranging from Mesothermal savannah (Cw—in western and higher elevation areas) to hot steppe (BSh—eastern basin area) according to Brand. The Babicora-Bustillos—Bolson subsection boundary (figure 1) falls very close to Brand's boundary between the BSh and hot desert (BWh) categories. The Bolson subsection is almost entirely in the latter category. Blásquez (1959) also summarized available climatic data and he classified climates at a number of weather stations in the two subsections according to both the Koeppen system and a "Lang (1920)-based" system. His general placement of climatic zones agrees relatively well with Brand's interpretation.

Considerable study is needed on the role of climatic (hydrologic and paleohydrologic) factors in landscape development in this desert and semidesert region. At present, much of the precipitation comes in the form of torrential summer storms (even in the high Sierra Madre); and the writer's preliminary observation is that running water appears to be the dominant (epigene) agent involved in terrain modification (with mass wastage and gravitative transfer playing a relatively minor role). Research is definitely needed on mechanisms of retreat of the bold escarpments that front so many of the ranges and plateaus in the area (with rock composition ranging from limestone to welded rhyolite tuff).

Soils. Discussion of soils of the Basin and Range subsections is beyond the scope of this paper. However, it should be noted that many of the soils and soil-landscape relationships described by Gile and his associates in southern New Mexico (see bibliography) have also been observed in the Bolson subsection in northwestern Chihuahua.

Soils maps of the State of Chihuahua (as well as other states and Mexico as a whole) on the Great Group classification level are being prepared by the Direccion de Agrologia, Jefatura de Irrigation y Control de Rios, Secretaria of Recursos Hidráulicos. Soils are being classified both according to the new United States system (Soil Survey Staff, 1960, 1967) and to the legend developed for the FAO/UNESCO Soil Map of the World (Dudal, 1968). S.R.H. officials in Mexico City and Chihuahua City can be consulted on the current status of this work.

Striking pedologic features seen in road cuts, borrow pits, and natural exposures along many segments of the tour route are the very strong (often indurated) horizons of carbonate accumulations so typical of desert soils of this region. In the areas south and west of the Bolson de Los Muertos, soils also commonly display textural B (argillic) horizons above the carbonate zone. The degree of soil development so often observed in exposures along the tour route reflects the great age (middle to late Pleistocene) of many of the geomorphic surfaces in that region.

Soils in the Babicora-Bustillos subsection reflect the increase in effective moisture observed in the eastern approaches of the Sierra Madre. Marked increase in thickness, darkness, and organic-carbon content of soil epipedons is usually evident, and argillic horizons are often very well developed. In contrast to the more desertic Bolson subsection, horizons of carbonate accumulation do not appear to be widespread pedogenic features.

COMMENTS ON LATE CENOZOIC GEOLOGIC HISTORY

Definitive statements of the late Cenozoic geology of northwestern Chihuahua obviously cannot be made at this time. Much more information is needed on (1) the mode of origin and time of formation of the present system of basins and ranges, (2) the thickness and lithologic character of the basin fill, (3) basic stratigraphy and paleontology, and (4) the evolution of the entrenched river valley systems that occupy peripheral parts of the region. As has previously been noted, this guidebook contains a number of contributions to the subject under discussion, both in the form of technical papers and information in the road logs.

The writer feels that it will be worthwile to review some basic ideas on the late Cenozoic history of the Jornada del Muerto, Mesilla and Hueco Bolson region of New Mexico and Texas. Many of the ideas expressed here are certainly not original and reflect information gained during the past years of close association with co-workers in the border region, notably Frank Kottlowski, W. S. Strain, Leland Gile, William Seager, A. L. Metcalf, W. E. King, R. B. Morrison and C. C. Reeves. Furthermore, many of the basic concepts of the geomorphic evolution of the region were first stated in papers by Hill, Lee, Baker, P. B. King, and Bryan.

The major rock-stratigraphic unit of late Cenozoic age in the border region near El Paso is the Santa Fe Group. This unit consists of a thick sequence of consolidated to unconsolidated sedimentary deposits, and some volcanic rocks, which partly fill intermontane basins adjacent to the valley of the Rio Grande. The lower limit of the Santa Fe Group in the border region is placed above volcanic, intrusive and associated sedimentary rocks of Oligocene to early (?) Miocene age, which are particularly well exposed northwest of Las Cruces, New Mexico. The upper limit of the Group is the surface of the youngest basin-fill deposits predating entrenchment of the present Rio Grande valley in middle Pleistocene time.

Regional mapping, studies of vertebrate faunas, volcanic ash correlation and potassium-argon dating of interbedded and overlapping basalts have established the general time correlation of the Santa Fe Group throughout New Mexico and westernmost Trans-Pecos Texas. Studies of lithologic variations in the basin fill, carried out in connection with investigations of basin geomorphology and basin-fill stratigraphy, demonstrate that environments of Santa Fe Group deposition included both closed and open intermontane basin systems. The former type, the classic bolson environment prevailed during early stages of basin filling (and exists in some areas to this day, e.g., Tularosa Basin and Bolson de Los Muertos). Later stages of basin filling were marked by coalescence of basin floors and development of a regional system of through drainage. Santa Fe deposition in the border region thus corresponds with Bryan's (1938) idealized concept of basin filling in the type Santa Fe region of central and northern New Mexico. The upper part of the Santa Fe Group, deposited in the early to middle Pleistocene time, has three basic facies, and a maximum thickness generally in the 300-500 foot range. A widespread sand and rounded gravel unit containing some rock types foreign to the local watersheds forms the uppermost deposit below the central basin floors in the southern Jornada del Muerto, Mesilla and southern Hueco Bolsons. It represents extension of the ancestral Rio Grande into the border region by early Pleistocene time. This unit is underlain by, and apparently intertongues to the south with, thick sections of fine-grained beds that are partly of lacustrine origin. Laterally towards adjacent uplands, the basin-floor deposits interfinger with piedmont-slope alluvium. The La Mesa, Jornada and Doña Ana geomorphic surfaces (Ruhe, 1964) and associated strong soils (Gile, 1967) cap the ancient basin fill sequence.

Cyclic entrenchment of the Rio Grande Valley was initiated after (1) development of the La Mesa basin-floor surface, (2) episodes of pedimentation and alluvial-fan deposition on adjacent piedmont slopes that resulted in formation of the Jornada surface, and (3) integration of the upper and lower (Pecos-Conchos?) segments of the ancestral Rio Grande. Subsequently at least three major cycles of river and tributary arroyo entrenchement (accompanied by episodes of partial reaggradation of valley floors) have taken place. Recognizing that some late Pleistocene faulting and warping of surfaces has locally occurred, levels of ancestral flood plain stability can generally be reconstructed at elevations of about 130 feet, and 70 feet above the present valley floor. Maximum entrenchment of the Rio Grande in latest Pleistocene time was about 80 feet below the present flood-plain surface.

Large physiographic features such as the intermontane basins and certain river-valley segments are considered to be of structural origin (with the major amount of displacement apparently taking place prior to the onset of the Quaternary Period). However, regional studies show that Rio Grande Valley-border surfaces can be correlated with similar stepped sequence in other segments of the river basin, indicating that cyclic climatic change has played a major role in Quaternary landscape development.

Aggradation of basin surfaces has continued in the broad areas still not integrated with the Rio Grande. Large lakes occupied the floors of several basins during late Pleistocene pluvials. Pleistocene volcanism has locally been an important factor in landscape evolution. The most prominent volcanic features are the large fields of lava and cinder cones, and maare in the La Mesa-Potrillo Mountain-Las Palomas area. Some structural deformation continued through the Pleistocene resulting with as much as 200 to 300 feet of local displacement of older (early to mid-Pleistocene) basin fill deposits, and relatively minor displacement inner valley fill and younger basin fill.

How the ideas just outlined will apply to the interior basin areas of Chihuahua, as well as to the upper Rio Conchos basin remains to be seen. The Santa Fe Group and its Gila-Mimbres basin analog, the Gila Conglomerate (Group) definitely extend for some distance into northern Chihuahua. The broad concept of early basin filling followed by partial (and periodic) dissection of ancient basin fills in areas where through drainage has developed seems to be valid. However, regional synchroneity of many events is not yet established. The age of the entrenched upper Conchos valley system certainly may not accord with the age of the Mesilla or Juárez Valleys. The answer to many questions will be provided by the detailed subsurface information on lithofacies distribution and bolson fill thickness now being obtained as part of the ground-water investigations of the Secretaria de Recursos Hidráulicos in a number of basins in northern Chihuahua. The upper 350 to 450 meters of bolson fills have already been explored in parts of the Valle de Juárez and Lower Rio Carmen and Rio Casas Grandes basins. Initial deep aquifer performance tests have demonstrated that this region has tremendous potential in terms of ground-water resource development. It follows that this region will also be a good one in which to pursue research on basin-fill stratigraphy and related aspects of late Cenozoic geology and geomorphology.

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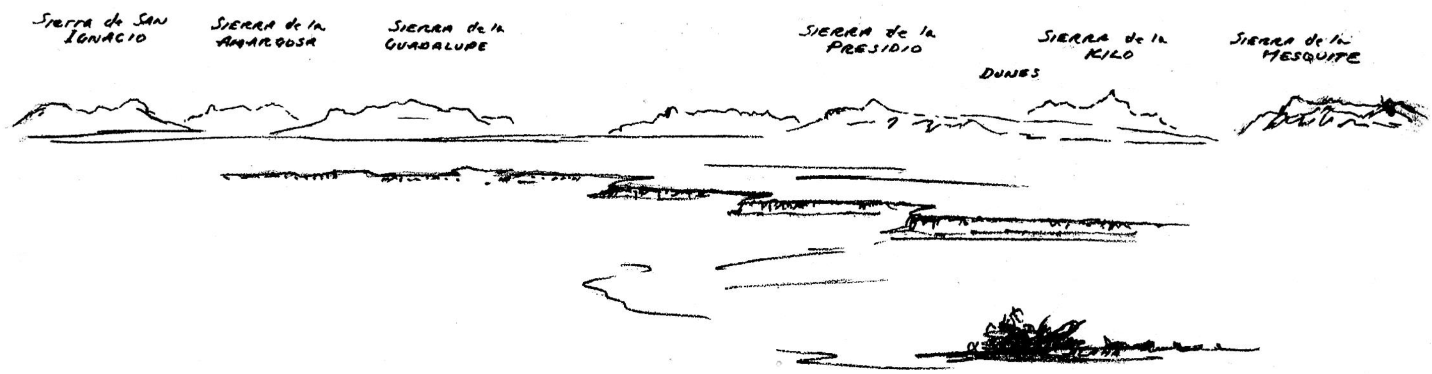

Part D2.

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QUATERNARY HISTORY OF DOÑA ANA COUNTY REGION, SOUTH-CENTRAL NEW MEXICO

by

JOHN W. HAWLEY[1]

INTRODUCTION

The region discussed in this paper comprises south-central New Mexico and adjacent parts of Trans-Pecos Texas and Chihuahua, Mexico (Fig. 1). Emphasis is on Quaternary events and alluvial deposits in the Dona Ana County area of the Mexican Highlands section, Basin and Range province. Many of the local features mentioned herein are described in the road-log section of this guidebook, particularly at Day 2 and 3 tour stops. Aspects of Quaternary research in the area are also discussed in companion guidebook papers by Dick-Peddie, Hawley, Hoffer, Fox, Stone and Brown, and King and Hawley.

This paper is an outgrowth of cooperative studies of late Cenozoic and environmental geology by the New Mexico Bureau of Mines and Mineral Resources, U.S. Soil Conservation Service, New Mexico State University, University of Texas at El Paso, and U.S. Geological Survey. Many persons have been involved in this work. In particular, contributions by G. O. Bachman, R. E. Clemons, L. H. Gile, J. M. Hoffer, C. B. Hunt, W. E. King, F. E. Kottlowski, A. L. Metcalf, W. R. Seager and W. S. Strain are gratefully acknowledged.

GEOMORPHIC SETTING

Regional geomorphic subdivisions as well as the location of major land forms, stream systems, pluvial lake basins, eolian deposits, and basalt fields are shown on Figure 1. General concepts of physiographic units are based on early work of Fenneman (1931), and later studies by Brand (1937), King (1937), Thornbury (1965), Hawley (1969), and Hunt (1974). Subdivision of the Mexican Highland section into Bolson and Rio Grande subsections, and some adjustments in section and province boundaries reflect current geomorphic investigations by the author utilizing ERTS and Skylab satellite imagery. Major features of Basin and Range province subdivisions are described in Table 1.

Hydrographic features on Figure 1 include major stream systems (e.g. Rio Grande, Gila, Mimbres, Casas Grandes) and closed depressions of intermontane basins (bolsons). The latter were occupied by perennial lakes during glacial-pluvial intervals of the late Pleistocene and are now sites of many ephemeral (playa) lakes. Figure 2 shows the position of major drainage systems and closed basins of early to middle Quaternary age. Sites are shown where vertebrate faunas and volcanic ash deposits have been described and used in stratigraphic correlation.

The Quaternary history of this part of North America has been characterized by continued tectonic deformation and volcanic activity. The location and gross form of intermontane basins and major stream valleys shown on Figures 1 and 2 are controlled by deep-seated process. Epeirogenic uplift has affected the entire region (King, 1965); and effects of volcanism and Basin and Range faulting are particularly pronounced along the structural depression occupied by the Rio Grande (Fig. 1; Chapin and Seager, Woodward and others, this guidebook). Total displacements of lower Pleistocene and upper Pliocene beds along high-angle faults and monoclinal folds may locally exceed 300 ft (90 m). Significant fault displacement (usually $<$30 ft, 9 m) of upper Quaternary units has occurred; however, scarps produced by historic earthquakes have not been reported (Sanford and others, 1972).

While tectonism has been a major factor influencing erosion and deposition on a regional scale, cyclic change in climate, represented by Quaternary glaciations and interglaciations (pluvial-interpluvial cycles), has been the primary factor controlling depositional processes in individual basins and river-valley segments. Most deposits in this warm, arid and semiarid region record a succession of landscape instability intervals with alternating times of surface stability and soil formation. They reflect cyclic shifts in nature of hydrologic regimes and related vegetation changes. Waxing parts of glaciations (pluvial subcycles) corresponded with episodes of increased river discharge, entrenchment of major valleys, and flooding of pluvial lake basins. However, large areas of piedmont and valley-border slopes were stable during full glacials because of increased effectiveness of vegetative cover. Aridity increased during the transition from glaciations to interglaciations. This resulted in decreased vegetative cover, and widespread erosion and sedimentation on piedmont slopes and valley borders during occasional storm-runoff events. Concurrent decrease in river discharge also caused aggradation of valley bottoms and encroachment of arroyo-mouth fans onto flood plains. Deflation and eolian deposition also affected large areas during early parts of interglaciations, particularly in and near river valleys and depressions with desiccating lakes. Paleosols that developed throughout the region, largely during intervals of surface stability, are prominent as both relict and buried features. This topic will be further discussed in sections covering late Quaternary deposits in the Rio Grande Valley and adjacent bolsons.

QUATERNARY EVENTS AND DEPOSITS

Introduction

Major advances over the past decade in tephrochronology, radiometric dating, magnetic polarity stratigraphy, vertebrate paleontology, soil-geomorphology, and detailed field investigations have contributed significantly to the understanding of Quaternary history in the Southwest. Advances in tephrochronology and magnetic polarity stratigraphy probably have had the most impact. Studies of rhyolitic eruptive centers at Yellowstone National Park, Long Valley, California (Bishop Tuff), and the Jemez Mountains, New Mexico (Bandelier Tuff), and dating of ash falls from these centers at many vertebrate fauna localities, demonstrate that certain revisions in Quaternary chronology and stratigraphic correlation are in

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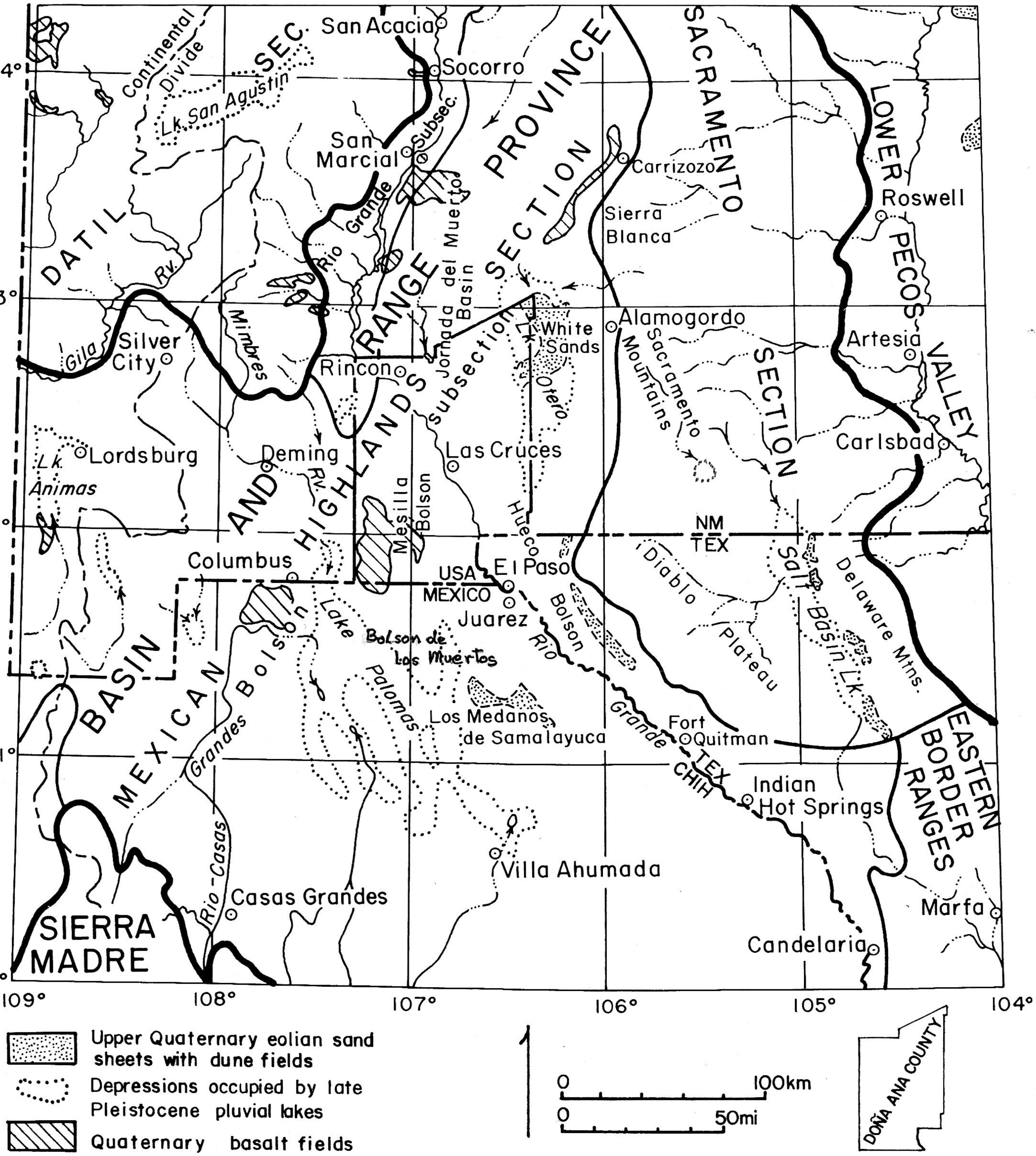

Figure 1. Physiographic subdivisions, major stream systems, pluvial lake basins, and dune and basalt fields in south-central New Mexico region.

order (Christiansen and Blank, 1972; Izett and others, 1970, 1972; Naeser and others, 1973; Doell and others, 1968; Smith and Bailey, 1968). For example, the concept of a single Pearlette ash fall of late Kansan age, rather than three ash-fall units from Yellowstone sources of 2 m.y., 1.2 m.y., and 0.6 m.y. age (respectively types B, S, and O Pearlette; Izett and others, 1972), was still almost universally accepted in 1965 (Hibbard and others, 1965). Revisions in stratigraphic concepts are further supported by magnetic polarity stratigraphy of dated volcanic events in New Mexico (Doell and others, 1968), and

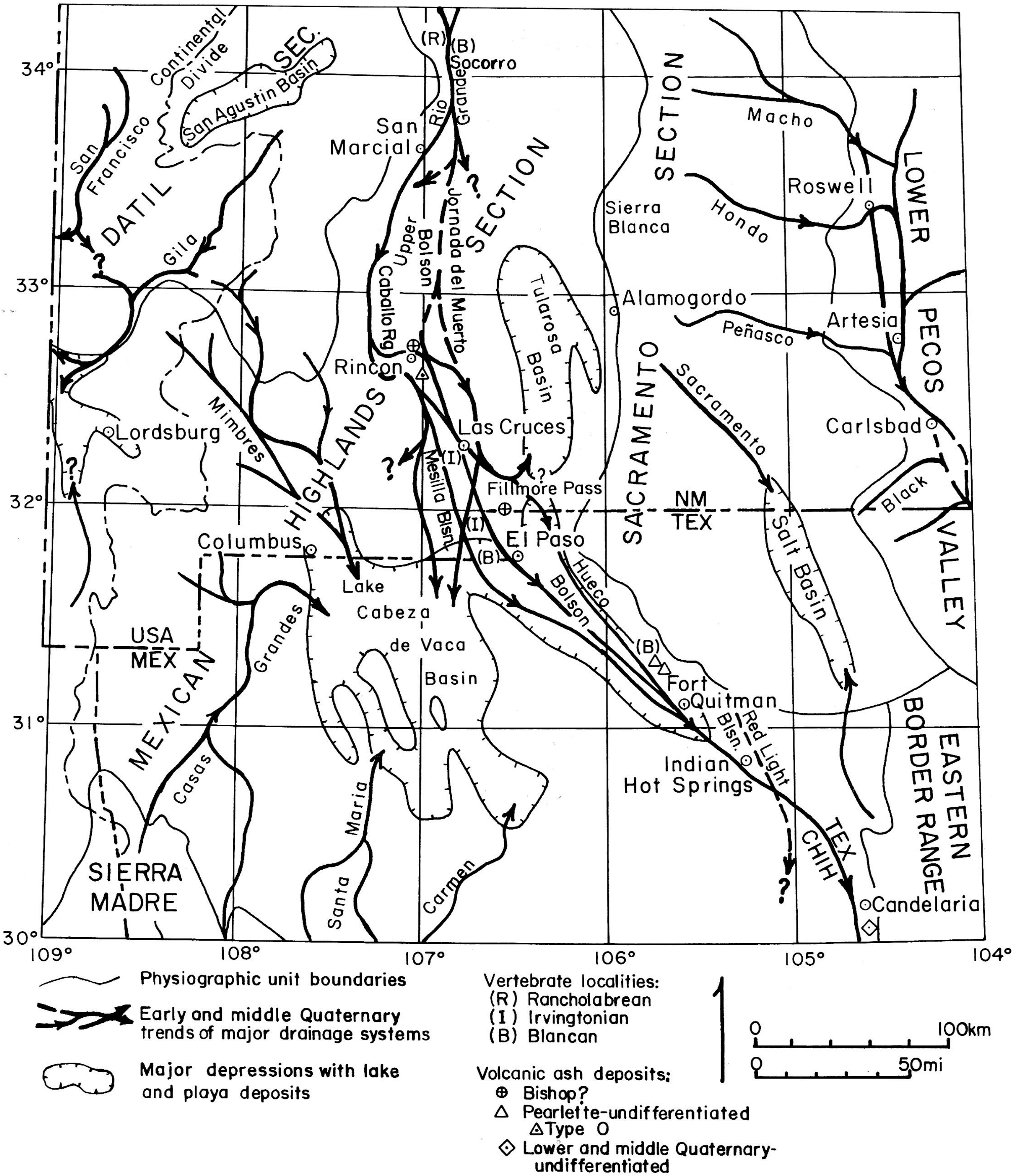

Figure 2. Early and middle Quaternary paleodrainage, undrained depressions, volcanic ash, and vertebrate faunal localities, and modern physiographic subdivisions in south-central New Mexico region.

ash-bearing vertebrate localities in southeastern Arizona (Johnson and others, 1975), New Mexico (Reynolds and Larsen, 1972) and west Texas (Izett and others, 1972).

Table 2 is a chart showing representative Quaternary events and deposits in the Rio Grande Valley and adjacent bolsons in southern New Mexico and Trans-Pecos Texas (columns G to

TABLE 1. CHARACTERISTICS OF BASIN AND RANGE PROVINCE SUBDIVISIONS IN SOUTH-CENTRAL NEW MEXICO REGION

Province	Section	Subsection	Characteristic Features
	Datil		*Volcanic upland with basins; dominated by high tablelands, with scattered fault-block ranges and basins, and deep canyons. Welded rhyolitic tuffs (mid-Tertiary) are the major upland former; with pre-Tertiary rocks locally forming highlands (9). Section is transition between Colorado Plateau and Basin and Range Provinces (17).* *Special Features: Continental Divide (elev. range 2025-3050m, 6650-10,000 ft.); extensive Quaternary basalts in lowland areas; San Agustin Plains, a large closed basin (min elev. 2067m, 6780 ft.) was the site of pluvial Lake San Agustin (24, 27, 30).*
Basin and Range	Mexican Highlands	Rio Grande	*Narrow structural depression, partly occupied by the valley of the Rio Grande, between the Datil section and the Bolson subsection of the Mexican Highlands. The river flows from north to south through an alternating series of broad and narrow valley segments that coincide with an en echelon series of structural basins each separated by uplifts of more resistant, Miocene and older rocks (7, 8, 18). The valley for the most part is incised in intermontane basin fill and associated volcanics of Late Cenozoic age. From the Albuquerque-Belen Basin south, Pliocene to mid-Pleistocene (Upper Santa Fe Grp.) deposits form the bulk of the exposed basin fill (13, 25). A stepped-sequence of valley-border surfaces, graded to successively lower levels of river incision, is inset below relict basin-fill and piedmont-erosion surfaces of early to mid-Pleistocene age (12).* *Special Features: Rio Grande flood plain gradient between San Acacia (1420m, 4660 ft.) and Rincon (1231m, 4040 ft.) is about 0.0009 (4.7 ft/mi). Flood discharge in excess of 1,418* m^2/s *(50,000 cfs) was measured at San Acacia on 9/23/29 (39). Average discharge of San Marcial (40) at the head of Elephant Butte Reservoir is 39* m^3/s *(1,371 cfs) or 121,388 ha-m/yr (992,600 ac-ft/yr).*
		Bolson	*Large area of southwestern New Mexico, extending into Texas, Chihuahua and Arizona, characterized by broad intermontane basins with internal drainage (=bolsons) and scattered fault-block ranges that occupy about one-fifth of the area (11). Type region of the bolson land form (15, 37). Mountains formed mainly of pre-Tertiary carbonate and clastic rocks, with local Tertiary volcanic sequences and plutonic bodies, and Precambrian igneous and metamorphic terranes (3, 9, 36, 38). Quaternary bolson fill, rarely more than 100m (330 ft.) thick, overlies late Tertiary bolson deposits (lower Santa Fe and Gila Group equivalents) that locally exceed 1000m (3300 ft.) in thickness (1, 10, 13, 23, 34, 35). Major basin-fill facies are: 1) piedmont alluvium, including fan deposits and erosion-surface veneers; b) basin-floor sediments, including fine-grained alluvium and lake and playa deposits; c) fluvial sand and gravel of ancient river systems; and d) eolian sand.* *The Rio Grande crosses the southeastern part of the area in a valley entrenched about 100m (300-400 ft.) below remnants of mid-Pleistocene bolson plains. As in the Rio Grande subsection to the north the flood plain is flanked by a stepped-sequence of valley-border surfaces. The Gila River crosses the northwest part of the area in a similar setting (29).* *Special Features: The continental divide (min. elev. 1359m, 4460 ft.) shown on Figure 1 is arbitrarily located along highest drainage divides in a complex of closed basins west of the Rio Grande. The highest peak in the area is Organ Needle (elev. 2747m, 9012 ft.). Rio Grande flood plain elevation ranges from about 1231 (4040 ft.) at Rincon to 853m (2800 ft.) at Candelaria 400 km (250 mi) downstream. Intermontain basins contain numerous closed depressions, some occupied by perennial lakes during Pleistocene glacial-pluvial intervals (12, 24). The largest Late Pleistocene lakes, ranging from hundreds to thousands of square kilometers in surface area, include Lake Animas west of Lordsburg (33), Lake Otero in the Tularosa Basin (14, 24), and Lake Palomas in north-central Chihuahua (31). Major dune fields, White Sands (28) and Los Medanos de Samalayuca (11), have formed on the lee sides of the latter two lake plains. Quaternary basalt fields are locally extensive (9).*
	Sacramento		*Broad, rolling upland plains, cuesta-form mountains with west-facing escarpments, and widely scattered structural basins. Highlands are primarily underlain by Paleozoic carbonate and gypsiferous-clastic rocks that have a gentle eastward dip disrupted by local flexures. The mid-Tertiary Sierra Blanca volcanic and plutonic complex (max. elev. 3658m, 12,002 ft.) forms the highest part of the section (3, 9, 19, 20, 26, 36). Salt Basin (min. elev. 1095m, 3590 ft.) a large graben complex between the Guadalupe-Delaware uplift and the Diablo Plateau contains thick late-Cenozoic bolson fill (22).* *Special Features: Lacustrine and eolian deposits in Salt Basin are associated with Late Quaternary intervals of pluvial lake formation and desication (22). Late Pleistocene glacial moraines (min. elev. 3050m, 10,000 ft.) have been identified on the north slope of Sierra Blanca (32). High-level remnants of ancient stream deposits (ancestral lower Pecos system) are locally present (5, 6, 16, 19, 20, 26).*
	Eastern Border Ranges		*Volcanic upland with basins (21). High tablelands and tilted fault-block ranges, including some uplands formed on Cretaceous limestone as well as Tertiary acid to intermediate volcanics; extends south through the Big Bend region into Mexico (3, 41). The area includes the Davis Mountain volcanic center (4) and exhumed features of the Late Paleozoic Quachita System in the Marathon region (21). Alluvial fills in basins and valleys are areally extensive (2, 3) but are probably thin except in basin areas northwest of Marfa.*

Table 1. Characteristics of Basin and Range province subdivisions in south-central New Mexico region.

Table 1 continued. References

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K). The chart is a "state of the art effort" presented to stimulate further thought on Quaternary stratigraphy and geomorphic processes in the region. Many of the stratigraphic and geomorphic units shown in this table are informal units, and most of the stratigraphic names are not formally approved by the U.S. Geological Survey. Reference columns in Table 2 show: A, an age scale based on radiometric dating; B, Quaternary and late Tertiary epochs; C, interglaciations and glaciations (pluvial subcycles), based on deposits in the region and a model of worldwide glacial cycles; D, provincial (land-mammal) ages; E, magnetic polarity epochs, and subdivisions of a late Quaternary alluvial chronology; and F, a representative basin- and valley-fill sequence in southeast Arizona where detailed information is available on magnetic polarity stratigraphy, vertebrate faunas, and radiometric ages. Brief explanations of individual reference columns follow:

Column C in its upper part shows a sequence of inferred world-wide interglacial-glacial cycles, termed "glacial cycles" by Fairbridge (1972). Each complete interglacial-glacial oscillation is here assumed to have a period of about 115,000 years, the approximate length of the last cycle, which culminated in Wisconsinan time (Broecker and Van Donk, 1970; Cooke, 1973; Suggate, 1974). The "glacial cycle" concept is discussed by Fairbridge, Hays and Perruzza, Matthews, and Mörner in the volume on "the present interglacial" edited by Kukla and others (1972). Relatively short and intense interglacials (IG) and full glacials (PG), respectively modeled after the Holocene and the preceding glacial maximum (late Wisconsinan), marked the earliest and latest parts of a complete cycle. The Holocene comprises the first part of the present "glacial cycle." Placement of terms "Wisconsinan" and "Kansan" on column C suggests that these are the only units of the "classic" Midwest glacial succession that can be used with any precision in Southwest stratigraphy.

Column D shows tentative placement of provincial (land-mammal) age boundaries for the Blancan (Wood and others, 1941), Irvingtonian and Rancholabrean (Savage, 1951) ages. Current status of provincial age dating is discussed in some detail by Berggren and Van Couvering (1974), Evernden and Evernden (1970), Hibbard and Dalquest (1973), Johnson and others (1975), and Savage and Curtis (1970). Blancan faunas were formerly considered by some to be as young as early

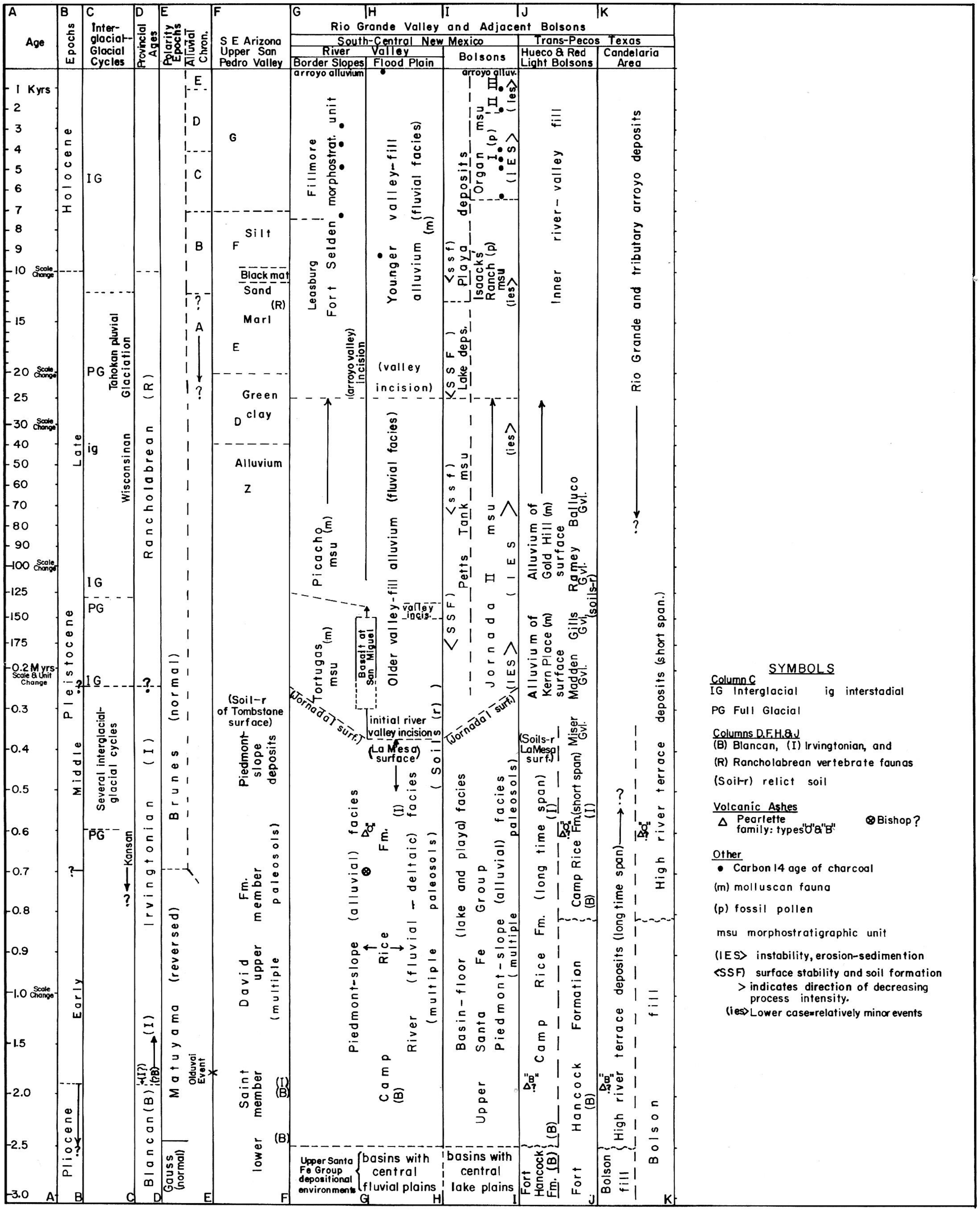

Table 2. Chart showing Quaternary deposits and events in south-central New Mexico region.

Kansan (Hibbard and others, 1965; Strain, 1966, 1970). The Blancan-Irvingtonian boundary is now placed by a number of workers near the beginning of the Quaternary Period and possibly before the onset of continental glaciation (Berggren and Van Couvering, 1974, Boellstorff, 1973, Evernden and Evernden, 1970; Johnson and others, 1975).

Column E shows position of magnetic-polarity epochs (Dalrymple, 1972) and subdivisions (Depositions A to E) of the late Quaternary alluvial chronology developed by Haynes (1968a, 1970) for the southwestern United States.

Column F. The upper San Pedro Valley of Arizona, about 100 mi (160 km) west of Lordsburg (Fig. 1), is a very important reference area for late Cenozoic stratigraphy. Contrasting magnetic polarity zones in the Saint David Formation of Gray (1967), the basal unit of a Pliocene-Pleistocene basin-fill sequence, have recently been described and dated by Johnson and others (1975). The Saint David Formation contains two important land mammal assemblages, the early Blancan Benson Fauna and the late Blancan-Irvingtonian Curtis Ranch Fauna. Overlying basin and valley fills have been described in detail by Gray (1967) and Haynes (1968b). Placement of valley-fill units Z and D to F of Haynes is based on information in the regional correlation chart of Birkeland and others (1971).

EVENTS AND DEPOSITS IN DONA ANA COUNTY REGION

Late Pliocene to Middle Pleistocene History

Columns G to K of Table 2 relate to parts of the Mexican Highlands, Rio Grande and Bolson subsections (Table 1) in and near the Field Conference area. Quaternary basin fill representing the culmination of Santa Fe Group deposition is shown on the lower parts of the columns. The upper Santa Fe beds comprise a south to southeast-trending fluvial-deltaic-lacustrine or playa sequence, with intertonguing piedmont-slope alluvium, that extends from central New Mexico to the bolson plains of western Trans-Pecos Texas and northern Chihuahua (Hawley and others, 1969, p. 62-64).

Ancestral Rio Grande deposits (fluvial facies herein) that make up the bulk of the upper Santa Fe Group in south-central New Mexico can be traced nearly continuously along the river valley from Socorro to south of Las Cruces. Piedmont facies, however, are discontinuous and cannot be physically traced from one basin to another. Major ancestral river trends are shown on Figure 2. Recent work by Belcher (1975) indicates that the river also temporarily occupied one or more channels in the Jornada del Muerto Basin east of the Fra Cristobal and Caballo Mountains during upper Santa Fe deposition.

The major Quaternary unit in terms of extent, thickness and age span is the Camp Rice Formation of Strain (1966). It is the youngest subdivision of the Santa Fe Group (Strain, 1969; Seager and others, 1971). The upper part of the formation locally contains fossil vertebrates of Irvingtonian age (*Equus, Mammuthus, Cuvieronius*; Hawley and others, 1969), type O Pearlette ash (Reynolds and Larsen, 1972), and possible Bishop ash (columns G and H). Strain (1966; column J) has described a Blancan fauna and possible type B Pearlette ash in the lower part of the formation in its type area southeast of El Paso (Fig. 2). Representative Camp Rice sections have also been described and the formation has been extensively mapped near Rincon (Figs. 1 and 2; Seager and others, 1971, 1975; Seager and Hawley, 1973). The base of the formation is extensively exposed in parts of Rincon and Sierra Alta (7½′) quadrangles (Seager and Hawley, 1973; Seager and others, 1975) and elsewhere in northwest Dona Ana County. In that area Camp Rice beds rest on a widespread erosion surface cut both on lower Santa Fe basin fill and on older rocks of flanking uplifts.

Two possible time spans for Camp Rice deposition are shown in the lower part of Table 2, column L. Presence of late Blancan vertebrates (*Nannippus* and *Plesippus*) below lenses of a Pearlette-family ash in the lower part of the formation originally led Strain (1966) to correlate the Camp Rice with deposits on the Great Plains with similar fauna and ash then considered to be of Kansan age (Hibbard and others, 1965). This correlation is potentially untenable because (a) the ash lenses may be type B rather than type O Pearlette, and (b) the Blancan fauna contains forms that were probably extinct well before the onset of the Kansan glaciation (see discussion of Table 2 reference columns).

The major facies of the Camp Rice is fluvial sand and gravel deposited by the ancestral Rio Grande during times when the river terminated in, or flowed through bolsons southwest and southeast of El Paso. The broad (diagrammatic) pattern of river distributaries in the Dona Ana County area shown on Figure 2 indicates the broad zone where fluvial beds constitute most of the formation. To the south in Chihuahua, and probably also in the Tularosa and Hueco bolsons, these deposits grade to fine-grained, dominantly lacustrine units with gypsiferous evaporites (Hawley, 1969; Hawley and others, 1969). The latter deposits include the Fort Hancock Formation of Strain (1966; Table 2, column J).

Piedmont-slope deposits, which intertongue with and overlap the fluvial facies, also make up an important part of the Camp Rice section. These fan, coalescent fan, pediment-veneer, and colluvial deposits constitute a major part of the formation only in areas adjacent to larger mountain masses.

In areas unaffected by post-Santa Fe valley incision or bolson aggradation, original depositional surfaces of Camp Rice basin fill are extensively preserved as relict forms with strongly developed soils that commonly have indurated horizons of carbonate accumulation. Major surface components are in the La Mesa (basin-floor) and Jornada I (piedmont-slope) geomorphic surfaces of middle Pleistocene age (Gile and others, 1970). The La Mesa surface is the broad constructional plain built by distributaries of the ancestral Rio Grande in the Jornada del Muerto, Mesilla, and Hueco Bolsons (Fig. 2) The bulk of the Jornada I surface was constructed by piedmont drainage systems graded to the ancient fluvial plain.

Initial river valley entrenchment and termination of Camp Rice deposition in the Dona Ana County area occurred in middle Pleistocene time. The triggering event is presumed to have been the integration of ancestral upper and lower Rio Grande systems in or southeast of the El Paso area (Hawley and Kottlowski, 1969; Strain, 1966, 1970).

The critical area for solving problems related to development of through-flowing drainage to the Gulf of Mexico is located in the Rio Grande canyon and valley reach between Indian Hot Springs at the south end of Hueco Bolson and Candelaria at the north end of Presidio Bolson (Fig. 2; Akerston, 1970; Jones and Reaser, 1970). Groat (1972, p. 31-32; Table 2, column K) described rhyolitic ash lenses, probably derived from a single air fall, in high terrace deposits along the river valley near Candelaria. The author examined these deposits in March, 1975, and is currently studying sampled units. Composition of the terrace gravel show that integration with an axial river in the Hueco Bolson area had occurred before ash deposition. Work to date indicates that the ash is derived from an eruptive event in the western United States between 2 and 0.6 m.y. ago and possibly belongs to the Pearlette family (Table 2 reference columns). Column K therefore also shows long and short time spans for early river terrace deposits based on the assumption that the ash could be either type B or type O Pearlette.

The author now speculates that the ancestral Rio Grande originally developed in Pliocene time, possibly much earlier than 2 m.y. ago. An early river channel in Fillmore Pass (Fig. 2, 25 mi north of El Paso between the Franklin and Organ Mountains) definitely connected the Mesilla and Hueco Bolsons as noted by Strain (1966, 1970). The early river system possibly continued southeast through Hueco Bolson and the downstream canyon and valley area into Presidio Bolson. It could even have joined an ancestral Rio Conchos (heading in southwest Chihuahua) near Presidio, Texas and flowed through the Big Bend country to the Gulf of Mexico. Subsequent uplift and west tilting of the Organ-Franklin chain of fault-block mountains diverted the river to the south into the Mesilla Bolson segment of Strain's (1966, 1970) Lake Cabeza de Vaca basin (Figs. 1 and 2). Termination of widespread basin filling (Camp Rice deposition) in late middle Pleistocene was caused by extension of the Rio Grande through the mountain gap at El Paso, possibly by lake overflow, rapid integration with lower river valley segments, and initial cutting of the present valley system upstream from El Paso.

Late Quaternary History of the River Valley in Dona Ana County

Late Quaternary events and deposits in the river valley area of Dona Ana County have been described in considerable detail by Hawley (1965), Metcalf (1967), Ruhe (1967), Hawley and Kottlowski (1969), Gile and others (1970), Seager and Hawley (1973), and Seager and others (1975). Evolution of the river and arroyo valley system, now deeply incised below remnants of the Jornada I and La Mesa geomorphic surfaces, was characterized by several major episodes of valley cutting each followed by intervals of partial backfilling and near steadystate conditions. Evidence of these geomorphic events is preserved in the Rio Grande Valley, as well as in valleys of arroyo tributaries, in the form of a stepped sequence of graded valley-border surfaces of both constructional and erosional origin (e.g., terraces, fans, valley-side slopes, and structural benches).

Two facies subdivisions of the valley-fill alluvium are recognized, one associated with Rio Grande activity (fluvial facies) and the other a product of tributary arroyo systems. These units are analogs of the Camp Rice fluvial and piedmont facies, but are limited to narrow strips inset below remnants of the blanket-like upper Santa Fe deposits. Valley fills are generally non-indurated except in thin surficial zones of soil-carbonate accumulation in some late Pleistocene deposits. Trace amounts of fossil molluscs and proboscidian remains have been recovered from various valley-fill units.

Seager and Hawley (1973) and Seager and others (1975) have developed informal rock-stratigraphic terminology, "older and younger valley-fill alluviums" (Table 2, upper column H), for general (1:24,000 and smaller scale) mapping of the valley-fill complex. Individual fills associated with major intervals of valley aggradation usually cannot be separated on a lithologic basis, particularly in the detailed mapping required for soil-geomorphic or paleoecologic investigations. Deposits (fan, terrace, erosion-surface veneers) are best differentiated on the basis of relative placement in topographic sequences and original form of constructional surfaces. Therefore, the *morphostratigraphic unit* category, proposed by Frye and Willman (1962), has been used as the fundamental mapping unit for detailed studies in the Dona Ana County area. Formal names of morphostratigraphic units (e.g., Tortugas, Picacho, Fort Selden) were originally used to designate members of the geomorphic-surface sequence flanking the Rio Grande flood-plain or forming basin floors and piedmont slopes of bolsons. Fills associated with constructional phases of these surfaces comprise the morphostratigraphic mapping units (designated by msu on Table 2, columns G and I). Following earlier proposals by Ruhe (1962) and Metcalf (1967), Hawley and Kottlowski (1969) and Gile and others (1970) formally defined the morphostratigraphic units shown on Table 2 and described representative sections and map areas.

Older valley-fill alluvium includes deposits associated with at least two late Pleistocene episodes of valley entrenchment and partial backfilling that preceded development of present flood-plain and arroyo-valley topography. Ancestral flood-plain positions, forming local base levels to which tributary streams were graded, ranged from about 200 ft (60 m) above to near the present level of the river valley floor. Morphostratigraphic components of the older valley-fill, the Tortugas and Picacho units of Hawley and Kottlowski (1969), represent aggradational intervals culminating in relatively long periods of base-level stability at elevations, respectively, about 115 to 150 ft (34-45 m) and 70 to 90 ft (21-27 m) above the present flood plain. Both the Tortugas and Picacho units locally approach 100 ft (30 m) in thickness, but they are generally thinner than 25 ft (8 m).

The early cycles of valley entrenchment and aggradation are not precisely dated; however, they are known to be older than the last major (pre-Fort Selden) episode of Rio Grande entrenchment that occurred in late Wisconsinan time, apparently during the early part of the 25,000 to 10,000 years B.P. interval. The oldest Tortugas deposits are known to be older than a valley-basalt flow near San Miguel dated at about 180,000 years B.P. (Hoffer, 1971; Lifshitz-Roffman, 1971) and significantly younger than the type O Pearlette ash unit described by Seager and others (1975) in a Camp Rice section in Selden Canyon (Table 2, columns G-H). Current work by the author indicates that the bulk of the Tortugas unit was deposited during the first part of the interglacial-glacial cycle preceding the Wisconsinan cycle (Table 2, column C, 245,000-130,000 year interval). However, the Tortugas may include still older deposits.

Most of the Picacho unit probably was deposited during the last interglacial (IG) and the waning part of the preceding full glacial (PG). This interval is tentatively considered to have started between 130,000 and 140,000 years ago (Table 2, column C). Well-developed soils with some morphological features formed under conditions significantly more moist than the present are preserved in deposits of many Picacho surface remnants. These pedogenic features started forming during a relatively long interval of surface stability prior to late Wisconsinan valley entrenchment (Gile and others, 1970).

Younger valley-fill alluvium is associated with the last major interval of valley incision and partial backfilling. On the basis of C^{14} dating of charcoal in younger valley fill (Hawley and Kottlowski, 1969), deep valley entrenchment below a late-Picacho base level and initial backfilling occurred in late Wisconsinan time prior to 10,000 years B.P. River entrenchment during this period was of regional extent and probably occurred throughout the river valley from the Albuquerque-Belen Basin at least as far south as the southern Hueco Bolson (Davie and Spiegel, 1967; Hawley, 1965). In the Las Cruces area the basal river erosion surface is from 65 to 80 ft (20-24 m) below and slightly wider than the present river flood plain. Slow aggradation to near-graded conditions have characterized the Rio Grande regime throughout the Holocene. During the past 7,500 years fans at the mouths of tributary arroyo valleys have encroached on the river flood plain, and the upper one-half to one-third of the axial river facies has been deposited.

Morphostratigraphic subdivisions of the younger valley fill, in order of decreasing age, include the Leasburg, Fillmore, and historic arroyo subunits of the Fort Selden valley-border unit. River flood-plain and channel facies are undifferentiated in present mapping. Arroyo-fan and terrace deposits of the Fillmore subunit make up the bulk of the valley-border surface alluvium and contain C-14-dated charcoal ranging in age from about 7,300 to 2,600 years B.P. (Gile and others, 1970). Archeological studies of pueblo sites on parts of the Fillmore geomorphic surface indicate that most of the Fillmore subunit was deposited by 1,000 A.D. (Gile and others, 1969).

Historic river activity prior to closure of the Elephant Butte Dam and canalization of the main river channel (U.S. Reclamation Service, 1914) involved lateral shifting of the meander belt and reworking of upper valley-fill deposits in channel zones during major floods. Toes of Fillmore and arroyo fans were occasionally removed when impinged upon by the laterally shifting channel thus initiating local arroyo incision. The present arroyo system is entrenched from about 5 ft (1.5 m) to as much as 40 ft (12 m) below Fillmore fan surfaces along the inner valley border.

The younger river valley fill in Dona Ana County and the buried erosion surface on which it rests clearly record a sequence of climate-controlled events that occurred at least twice earlier in the late Pleistocene (i.e., Tortugas and Picacho "cycles").

Late Quaternary History of El Paso Valley

Late Quaternary surfaces and deposits near El Paso were described by Kottlowski (1958). His La Mesa, Kern Place, Gold Hill, and low-terrace sequence of valley-border surfaces and associated fills (Table 2, column J) are correlative with the La Mesa, Tortugas, Picacho, and Fort Selden sequence just described. Kottlowski (1958) also suggested that river valley evolution was characterized by climate-controlled degradation and aggradation cycles with glaciations being times of major valley cutting. Molluscan faunas in valley fill units near El Paso have also been described by Metcalf (1969). Albritton and Smith (1965) mapped a similar valley-fill sequence in the lower Hueco Bolson and proposed formal rock-stratigraphic names for thin alluvial deposits capping valley-border erosion surfaces near Fort Quitman (Fig. 1). These units comprise the Miser to Balluco Gravel sequence shown on column J.

Discussion—a Scheme of Regional River Activity

The depositional history of the Tortugas, Picacho, and Fort Selden morphostratigraphic units (and their downstream correlatives) just discussed is in general agreement with Metcalf's (1967, 1969) observations that (a) fossil molluscan faunas in basal river facies of the Tortugas and Picacho units indicated cooler pluvial regimes with significant depression of life zones relative to present positions, and (b) upper parts of a given depositional sequence were mainly arroyo-mouth fan deposits with faunal assemblages indicative of warm-dry conditions like the present. Events in the history of Rio Grande Valley evolution also fit well in Schumm's (1965, p. 790-792) "scheme of river activity" for the semiarid, continental-interior midsection of a river system heading in glaciated mountains. According to this scheme, fluvial processes would go through the following cyclic sequence: late interglacial-stability, early glacial and full glacial-erosion, late glacial and early interglacial-deposition, and interglacial-stability.

Late Quaternary History of Bolson Areas

Much of late Quaternary time in internally-drained basin areas of the Bolson subsection was characterized by long intervals of general landscape stability and soil formation (SSF, Table 2, column I). These intervals were separated by several episodes of surface instability with widespread erosion and sedimentation (IES, column I) on piedmont slopes and adjacent basin floors. The main difference between bolson and river-valley areas is that basin-floor depressions were sites of lakes or aggrading alluvial plains during full glacial times, while the inner Rio Grande valley was being deepened. Bolson fills that overlie Santa Fe Group deposits and older bedrock units are relatively thin, with aggregate thicknesses rarely exceeding 25 ft (8 m). The main type of deposit is a piedmont fan and drainageway-fill facies commonly associated with up-and-down-slope migrating systems of discontinuous gullies and larger channels.

The major post-Camp Rice deposit mapped in the Jornada del Muerto Basin is the late Pleistocene Jornada II morphostratigraphic unit of Gile and others (1970). It comprises piedmont-slope alluvium associated with constructional parts of the Jornada II geomorphic surface. Near the mountains this surface (Gile and Hawley, 1968) is primarily an erosional feature, cut in Camp Rice and older formations that is inset below Jornada I pediments and fan remnants. Constructional phases occur predominantly on broad and relatively smooth, middle and lower piedmont slopes. In the latter setting Jornada II deposits are thin (generally <10 ft, 3 m) sheet-like units with local basal-channel zones (Gile and Hawley, 1966, sediment *b*). On the more undulating to deeply-dissected slopes near mountain fronts, the Jornada II unit includes valley alluvium and colluvial facies. Along piedmont-toeslope zones the unit grades to basin-floor alluvium and possible playa-lake deposits of the Petts Tank morphostratigraphic unit (Table 2, column I).

The bulk of the Jornada II morphostratigraphic unit is tentatively correlated with the Picacho and Tortugas units. The upper depositional surface appears to be mainly a Picacho correlative. The unit is locally buried by late Wisconsinan and Holocene deposits and it bears soils morphologically like those on the Picacho unit. However, datable materials other than soil-carbonates have not yet been recovered from Jornada II deposits. C^{14} activities of secondary carbonates in both Picacho and Jornada II soils range back to about 28,000 years B.P. (Gile and others, 1970).

The Isaacks' Ranch and Organ morphostratigraphic units shown on the upper part of column I are bolson-fill analogs of Fort Selden subunits in the valley-fill sequence. Charcoal recovered from the Organ unit (Gile and Hawley, 1968) shows that it was being deposited on piedmont slopes at essentially the same time as deposition of Fillmore fans along the river valley border.

The Isaacks' Ranch unit (sediment *c* of Gile and Hawley, 1966) typically comprises fills of broad drainageways and discontinuous gullies crossing the Jornada II surface. It locally spreads out at the mouths of ancient gully systems as thin fan deposits that form slight rises on middle to lower piedmont slopes (Gile and others, 1970; Hawley, 1972). Isaacks' Ranch deposits are locally overlapped by the Organ unit, and they are tentatively correlated with the Leasburg subunit of the valley-border sequence.

The Organ morphostratigraphic unit (Hawley and Kottlowski, 1969) comprises locally extensive piedmont fan and valley deposits of Holocene age that are similar in character to Picacho and Isaacks' Ranch units. Gile and Hawley (1968) have divided the Organ into 3 subunits (I-III) at the Gardner Spring radiocarbon site in the NASA-Apollo test area near Stop 5-Day 1 of the Field Conference. C^{14} dating of charcoal in a piedmont valley-fill sequence documents at least 3 depositional episodes between 6,500 and 1,000 years B.P. (Gile and Hawley, 1968; Hawley and Kottlowski, 1969). These episodes correlate with depositions C and D of the Southwest alluvial chronology developed by Haynes (1968a; Table 2, column E). Major Organ deposition appears to have occurred between 6,500 and 3,900 years ago. Pollen distribution in the main body of the Organ unit at the Gardner Spring site has been described by Freeman (1972). Pollen counts indicate that vegetation communities during Organ deposition varied somewhat, but not greatly, from present regional vegetation patterns. However, Freeman did note a shift from dominant shrub to dominant grass cover in the 5,000 to $<4{,}500 >2{,}200$ yr. B.P. interval that possibly indicates a significant change from relatively dry to moist climate in middle to late Holocene time.

A number of ephemeral lake plains occupy basin floors in the region. Small fresh-water playas, such as Isaacks' Lake in the southern Jornada del Muerto, are hundreds of feet (about 100 m) above regional water tables and are flooded every few years after summer storm-runoff events. Evidence that perennial lakes formed in the southern Jornada during late Pleistocene pluvials has yet to be found. Lake Lucero, located at the southwest edge of White Sands (Fig. 1), is one of the largest playa-lake plains in the region and occasionally contains bodies of water up to 9 mi^2 (25 km^2) in area. Relict shorelines and evaporite deposits of Lake Lucero's Wisconsinan predecessor, Lake Otero (Fig. 1, Table 1), indicate that the latter's area reached several hundred square miles during at least one glacial-pluvial substage. Reeves (1969) has described relict shoreline features and deposits of pluvial Lake Palomas that flooded a large area of northwest Chihuahua in the late Pleistocene (Fig. 1, Table 2). Numerous saline playa depressions now dot the floor of the Lake Palomas depression (Hawley, 1969).

SUMMARY

Quaternary stratigraphic and geomorphic units in the Dona Ana County region record a complex series of events involving tectonism, volcanism, climatic change, and a variety of epigene geomorphic processes in a physiographic setting characterized by high topographic relief and a warm-dry climate. Alluvial and lacustrine deposits of early to middle Pleistocene age are particularly extensive and thick in intermontane basins flanking the Rio Grande Valley. Late Quaternary alluvium is extensive but thin in areas other than the inner valley of the Rio Grande. Widespread eolian deposits include large dune complexes on the east side of pluvial lake plains throughout the region. Pleistocene basalts are also locally extensive.

Depositional processes were primarily controlled by tectonism and cyclic changes in climate represented by interglacial-glacial cycles. Times when climatic and associated vegetative-cover regimes were conducive to widespread erosion and sedimentation alternated with long intervals when large areas were essentially stable. The latter were usually cooler and moister parts of climatic cycles. Strong soils that formed primarily during stable intervals are prominent as both relict and buried features.

Representative stratigraphic units at several localities in the Rio Grande Valley and nearby bolson areas are described and tentatively correlated. Correlations are based on vertebrate fossils, tephrochronology, radiometric dating, inferred paleoecologic conditions, and relative position in geomorphic sequences. Basin deposits of the upper Santa Fe Group contain fossils of Blancan and Irvingtonian provincial ages as well as Pearlette family ash from one or more eruptions of volcanic centers at Yellowstone, Wyoming. Post Santa Fe units record at least 3 major cycles of entrenchment and partial backfilling of the river valley in late Quaternary time, and contemporaneous aggradation of internally-drained bolson areas.

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Part D3.

Facsimile Copy of Selections from R.H. Schmidt, Jr., 1992, Chihuahua, tierra de contrastas geográficos: Geografía; *in* Márquez-Alameda, Arturo, Coordinador del volumen, Historía general de Chihuahua I—geología, geografía y arqueolgía: Universidad Autónoma de Ciudad Juárez y Gobierno del Estado Chihuahua, 307 p. – Cover, p. VI, 45, 47-51, and 61-64.

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Historia General de Chihuahua I

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Chihuahua, tierra de contrastes geográficos*

*Robert Schmidt***

Chihuahua es el estado más grande y uno de los más ricos de la República Mexicana. Sus 247 mil kilómetros cuadrados cubren aproximadamente 6° de latitud y otros 6° de longitud (25° 35' a 31° 47' N y 103° 12' a 109° 07' W) lo cual equivale al 13 por ciento del territorio nacional, con una área mayor que la antigua República Federal Alemana. Sonora ocupa el segundo lugar por sus dimensiones y tan sólo representa las tres cuartas partes de la superficie de Chihuahua.

La entidad limita con Sonora y Sinaloa al oeste, con Durango al sur, con Coahuila y Texas al este y con Nuevo México al norte. Está dividida en 67 municipios, de los que Villa Ahumada y Camargo son los más extensos, y ocupan 13 por ciento de su territorio.

El actual estado de Chihuahua anteriormente fue parte de una provincia mucho mayor, la de la Nueva Vizcaya. El primer asentamiento español empezó con el establecimiento de un centro minero en Santa Bárbara, a principios de 1560. Santa Bárbara, localizada en la parte sur-central de Chihuahua, sirvió como residencia del gobernador de Nueva Vizcaya, provincia que incluía los actuales estados de Chihuahua, Durango y parte de Sinaloa y Coahuila. A lo largo de las principales rutas comerciales de esa época fueron estableciéndose asentamientos aislados, en el trayecto de la cuenca del Río Bravo (Río Grande) y hasta Santa Fe, Nuevo México. Las órdenes jesuita y franciscana establecieron misiones en Chihuahua poco después de 1600. El trabajo relativamente reciente de Swann proporciona una excelente descripción del desarrollo geo-histórico de la Nueva Vizcaya.[1]

Chihuahua obtuvo la categoría de estado en 1824. Los españoles se asentaron primero en aquellas áreas ricas en recursos minerales y más tarde vieron las áreas favorables para la agricultura. Luego fueron establecidos los lugares estratégicos como Ciudad Juárez y Janos, a lo largo de los caminos y rutas.

Los dos centros urbanos más grandes son Ciudad Juárez y la ciudad de Chihuahua. El primero fue establecido en 1659, cuando se fundó la misión de Nuestra Señora de Guadalupe. En 1888 fue nombrado oficialmente Ciudad Juárez en honor al presidente Benito Juárez, quien se había refugiado en este lugar en dos ocasiones.

La ciudad de Chihuahua, de la que se deriva el nombre del estado, fue fundada en la Junta de los ríos Chuvíscar y Sacramento, poco después de que se iniciaron las operaciones mineras cerca de Santa Eulalia (Aquiles Serdán) en 1702.

No hay un significado universalmente aceptado de la palabra Chihuahua; entre otras, se ha planteado la probabilidad de que sea una palabra híbrida de las lenguas náhuatl y tarahumara, que se refiere

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[1] Michael M. Swann, *Tierra Adentro: Settlement and society in colonial Durango,* Westview Press, Dellplain Latin American Studies 10, Boulder, 1982.

al "lugar de las dos aguas", o a un área seca arenosa (por ejemplo donde los ríos Chuvíscar y Sacramento se unen).

Una rica herencia histórica y su diversidad física son palabras clave en la descripción de este estado.[2] Actividades importantes de personalidades históricas bien conocidas como Benito Juárez, Francisco Villa y Luis Terrazas fueron realizadas aquí.

El número más grande de mormones, menonitas y tarahumaras de la nación se concentra aquí. Muchos de los paisajes naturales importantes del país también pertenecen a esta entidad; la barranca del Cobre de la Sierra Madre Occidental, Majalca, la cascada de Basaseachi y los médanos de Samalayuca. Además, Chihuahua presta su nombre al desierto más grande de México.

I. Geomorfología

La superficie del territorio chihuahuense puede dividirse en dos provincias fisiográficas mayores:

— La Sierra Madre Occidental.
— Las cuencas y sierras del Desierto de Chihuahua.

Para una descripción mejor de la zona de transición entre ambas provincias se hace necesaria una subdivisión fisiográfica al oriente de la Sierra Madre Occidental; esta subdivisión es objeto de una descripción aparte.

I.1. La Sierra Madre Occidental

La Sierra Madre es parte de una larga cordillera montañosa que está orientada hacia el noroeste, con una anchura promedio de casi 115 kilómetros y una extensión de cerca de 1,200 kilómetros, que va desde Arizona, Estados Unidos, hasta el estado de Nayarit, en México. Los 560 km. de la sierra en el estado de Chihuahua tienen una altitud promedio de 2 mil 275 metros, en tanto que la parte del sur mantiene una diferencia de 300 a 600 metros mayor que la del norte.

El punto más alto es el cerro Mohinora, que se localiza a 20 kilómetros de Guadalupe y Calvo, con coordenadas geográficas de 25° 28' N y 107° 03' W. El Mohinora tiene una altitud de 3 mil 250 metros, mientras que el segundo pico más alto del estado, probablemente el cerro de las Iglesias, alcanza los 3 mil 100 metros. Este último se localiza entre los ríos Verde y Turuachi, aproximadamente a 6.5 kilómetros al noroeste del poblado La Catedral, que se ubica en el camino principal que une las poblaciones de Guadalupe y Calvo con Hidalgo del Parral, con coordenadas de 26° 16' N y 106° 37' W.

El punto más bajo en la entidad se encuentra en la confluencia de los ríos Septentrión y Chínipas, en los límites con Sinaloa. La altitud río arriba del poblado Palo Dulce, Sinaloa, y cerca del puente del ferrocarril Chihuahua-Pacífico, es de 220 metros (27° 40' N y 108° 24' W).

El desarrollo de la Sierra Madre Occidental se inició entre los periodos Cretácico Tardío y Terciario Temprano (de 80 a 40 millones de años antes del presente (en adelante maap), cuando la actividad volcánica formó grandes capas de cenizas y lavas que cubrieron las rocas plegadas del Cretácico Temprano (135 a 100 maap) y aun otras más antiguas.

La secuencia volcánica principal se puede dividir en una Serie Volcánica Inferior (SVI), o temprana, y la Serie Volcánica Superior (SVS) o Tardía, según Clark y De la fuente.[3] La Serie Inferior consiste en derrames andesíticos y riolíticos, tobas y brechas de hasta 1,000 metros de espesor; la Serie Volcánica Superior es del Terciario Medio (Oligoceno de 37 a 19 maap) está formada por tobas ignimbritas, lavas riolíticas, cenizas y vitrófidos con un espesor mayor a los 1,000 metros.

Las principales rocas huéspedes, donde se aloja la mayoría de los depósitos minerales de la sierra, son calizas del Cretácico Temprano y rocas andesíticas del Terciario Temprano. Los antiguos distritos mineros como Batopilas y Ocampo (antes distrito de Rayón) fincaron su riqueza en los depósitos de vetas de fisura de la serie Volcánica Inferior.[4] Es por eso que la gran riqueza de oro y plata producida en Chihuahua, que han documentado amplia-

[2] Así lo han descrito en su libro Robert H. Lister y Florence C. Lister, *Storehouse of Storms*, University of New Mexico Press, Albuquerque, 1966.

[3] K.F. Clark y F.E. De la Fuente, "Distribution of Mineralization in Time and Space in Chihuahua, Mexico", en *Mineral Deposita*, vol. 13, Berlín, 1978, pp. 27-49.

[4] E. Wisser, "The epithermal precious metal province of northwest Mexico", en *Nevada Bur. Mines*, reporte 13, 1966.

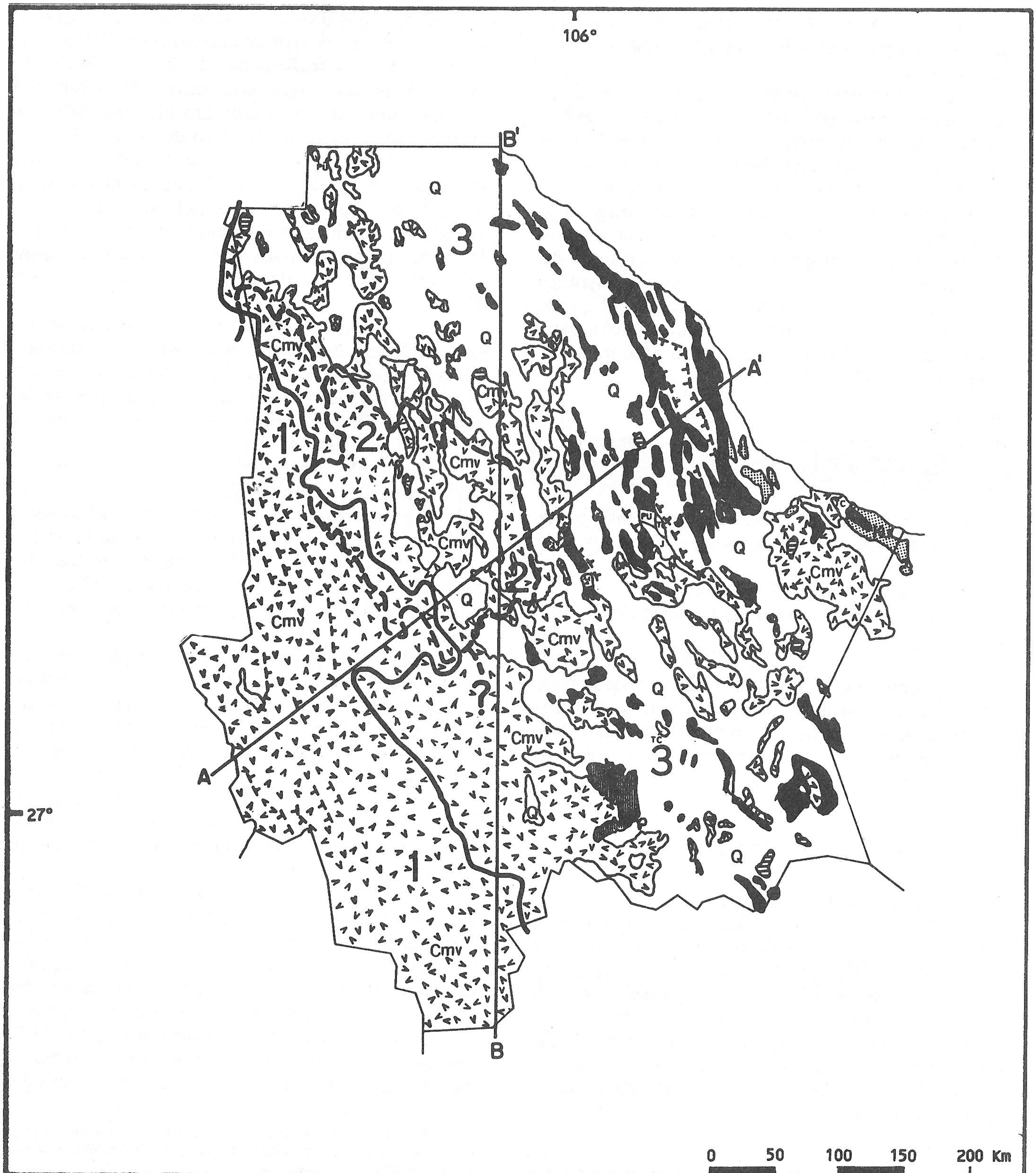

ILUSTRACIÓN 2

Schmidt R.H. 1973. (Adaptado).

GEOLOGÍA, PROVINCIAS FISIOGRÁFICAS Y CORTES TRANSVERSALES

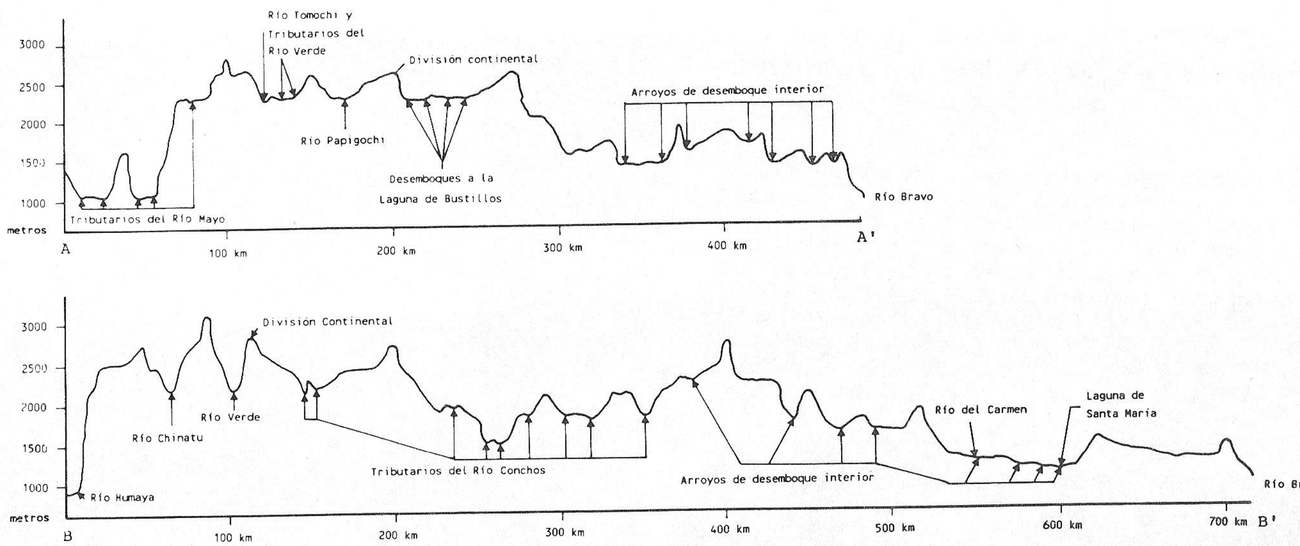

ILUSTRACIÓN 3

Fuente: *ONC. H-23, Escala 1:1000,000,* 8ª ed. (1969).

PERFILES TOPOGRÁFICOS

(Exageración vertical de cuarenta veces)

mente Southworth y Grigss, por lo general está asociada con las profundas barrancas del suroeste chihuahuense.[5]

Durante el Terciario Medio, cuando la sierra tarahumara empezó a tomar su forma actual, hubo levantamientos y hundimientos extensivos acompañados por la intrusión de grandes masas de roca plutónica. En esta meseta volcánica elevada que formaba la Sierra Madre Occidental, los materiales menos resistentes fueron erosionados y cortados a manera de profundos cañones con el avance del agua de los ríos. La evidencia disponible indica que las fallas solamente han tenido un efecto menor sobre el control de los sistemas de drenaje. Muchos de estos incipientes cañones se caracterizan por una serie de resaltes horizontales en las pendientes, que en ocasiones parecen verdaderos escalones, estos resaltes o mesetas escalonadas son resultados de flujos intercalados riolíticos y otras rocas resistentes de la secuencia volcánica. Entre los tipos de roca que coronan la Sierra Madre encontramos sobre todo toba riolítica, ignimbrita y andesita. Aunque están presentes las rocas volcánicas de composición intermedia, los basaltos no son abundantes.

En el oeste, la planicie costera tiene una anchura de aproximadamente 80 kilómetros a partir del golfo de California; en su porción más septentrional alcanza hasta 125 kilómetros. Esta planicie pasa gradualmente a una angosta región de talud con elevaciones de entre los 150 y 600 metros, la cual culmina en los escarpes y cantiles de las partes altas de la sierra. El abrupto escarpe de la Sierra Madre, desde las planicies costeras al oeste y especialmente al suroeste, forma una barrera muy significativa tanto para el hombre como para los vientos húmedos.

La única carretera pavimentada que cruza la sierra, al norte de la federal número 40, es la recién terminada carretera federal número dos, que en el extremo norte del país une a Janos con Agua Prieta. Es posible que se concluya otra vía muy importante que va hacia el oeste y que parte de la ciudad de Chihuahua, cruza la sierra vía Basaseachi y Yécora para conectar con Hermosillo y Ciudad Obregón, en Sonora. Otra carretera de importancia rumbo a la planicie costera de Sinaloa está por terminarse al suroeste de Parral, actualmente pavimentada hasta un poco después de El Vergel. Pasa cerca de Guadalupe y Calvo y sale del estado a la altura de los Frailes, para continuar a Badiraguato, en Sinaloa, a 100 kilómetros al norte de Culiacán.

La Sierra Madre no presenta una cresta clásica o línea de parteaguas. Los vientos prevalecientes vienen del oeste y con ellos las lluvias. Como resultado de la drástica erosión, los ríos que fluyen al Pacífico han podido cortar y atrapar las cuencas

[5] Jorge Griggs, *Mines of Chihuahua,* Chihuahua, 1907.

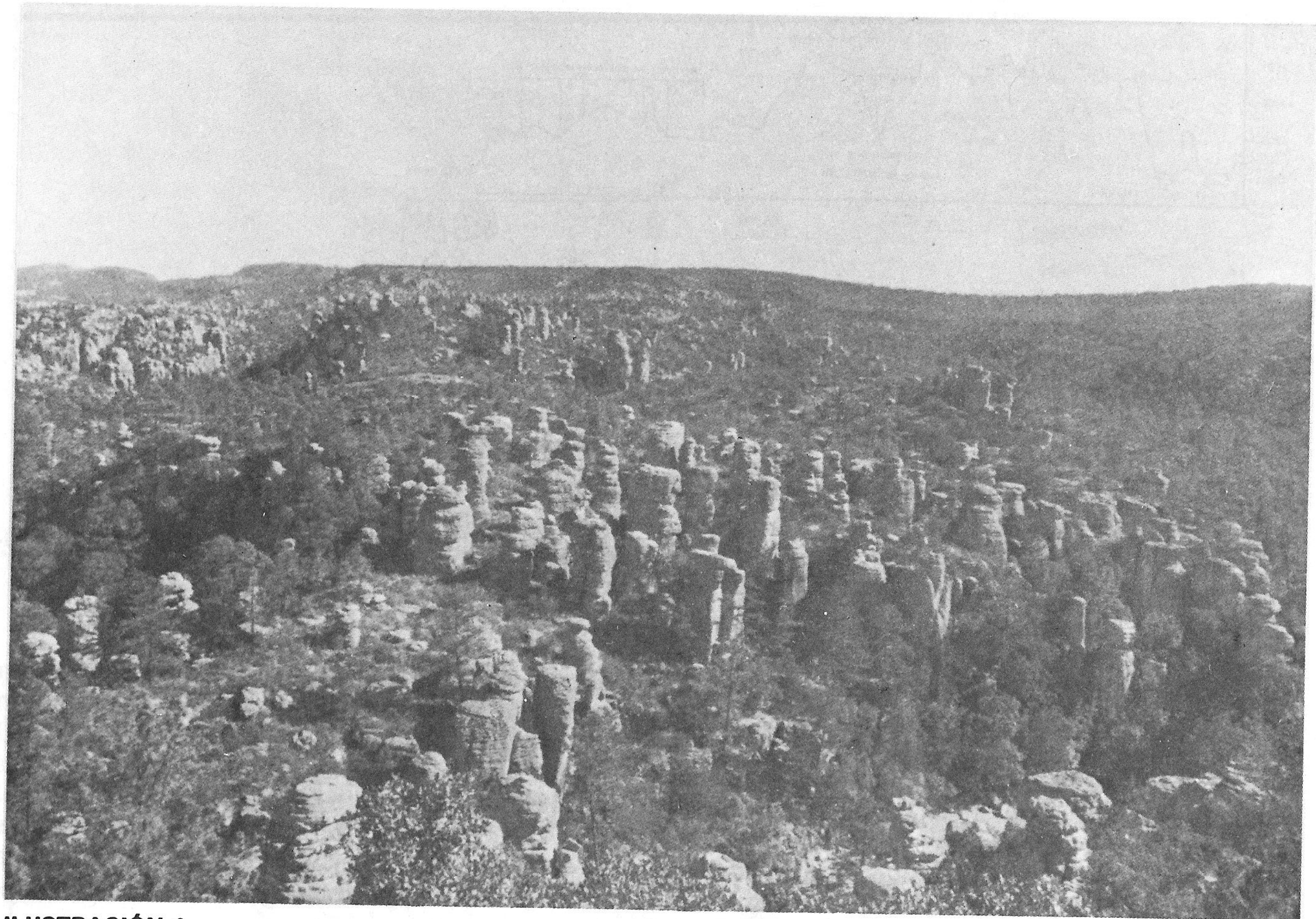

ILUSTRACIÓN 4

Vista de uno de los paisajes naturales de la porción chihuahuense de la Sierra Madre Occidental.

endorreicas que existen en el norte de México, hasta cerca del límite oriental de la Sierra Madre. Un complejo e interdigitado patrón de drenaje resultante, hace difícil trazar la línea de parteaguas que separa las tierras bajas a ambos lados de la sierra.

Esta masa montañosa que se extiende hacia el sur de Durango es la característica orográfica y el parteaguas más importante de todo el país; las aguas de la sierra fluyen hacia los golfos de California y México y hacia las cuencas endorreicas. Entre la sierra y los golfos se encuentran muchos de los distritos de irrigación más grandes y valiosos.

El río Conchos, que fluye hacia el este, es el mayor sistema fluvial en Chihuahua, tanto por su extensión como por su caudal. Este río nace cerca de San Juanito, en la serranía, y su cuenca cubre un área que se aproxima a un tercio del área total del estado —77 mil 090 km^2—. El 18 por ciento del agua total que fluye en el Bravo del Norte —río Grande— es una aportación del Conchos.[6] Cabe señalar que el Complejo Conchos-Bravo es el único sistema de drenaje que cruza por completo la región árida de México.

En general, los profundos cañones son resultado del corte provocado por los ríos jóvenes muy erosivos, además de la erección de montañas, en este caso de tipo volcánico. Los arroyos y ríos se hacen más atrincherados hacia el oeste y al sur, formando un paisaje profundamente cortado y dramático. Como resultado general se puede apreciar una línea del horizonte relativamente plana, formada por superficies remanentes entre las corrientes.

[6] Según se establece en el texto de Jorge L. Tamayo en colaboración con Robert C. West, "The hydrography of Middle America", en *Handbook of Middle American Indians,* vol. 1, Natural environment and early cultures, University of Texas Press, Austin, 1964.

A consecuencia de los procesos erosionales y la estructura geológica, la meseta volcánica elevada y relativamente plana formada en la sierra se puede dividir en cuatro subunidades o subprovincias:

a. Las sierras y valles del norte.
b. Las sierras con cuencas del este.
c. La gran altiplanicie o mesa alta del sur.
d. Las barrancas o tierra de cañones.

La distribución de estas unidades coincide más o menos con los grupos representados en la Carta Fisiográfica y son modificaciones a los trabajos de Brand, King, Raisz y Hawley.[7]

[7] Carta Fisiográfica publicada por la Secretaría de Programación y Presupuesto, en *Atlas Nacional del Medio Físico,* escala 1:1'000'000 México, 1981; Donald D. Brand, "The natural landscape of northwestern Chihuahua", en *The University of New Mexico Bulletin,* Geological Series, vol. 5, núm. 2, Albuquerque, 1937; R.E. King, "Geological reconnaissance in northern Sierra Madre Occidental of Mexico", en *Geological Society of America Bulletin,* vol. 50, 1939, pp. 1625-1722; E. Raisz, *Landforms of Mexico,* office of naval Res., Geography Branch, Cambridge, 2a.ed., 1964 y John W. Hawley, "Notes on the geomorphology and late Cenozoic geology of northwestern Chihuahua", en *Guidebook of the border region,* New Mexico Geological Society, 20th Field Conference, Diego A. Cordoba *et. al.,* (eds.), New Mexico, 1969.

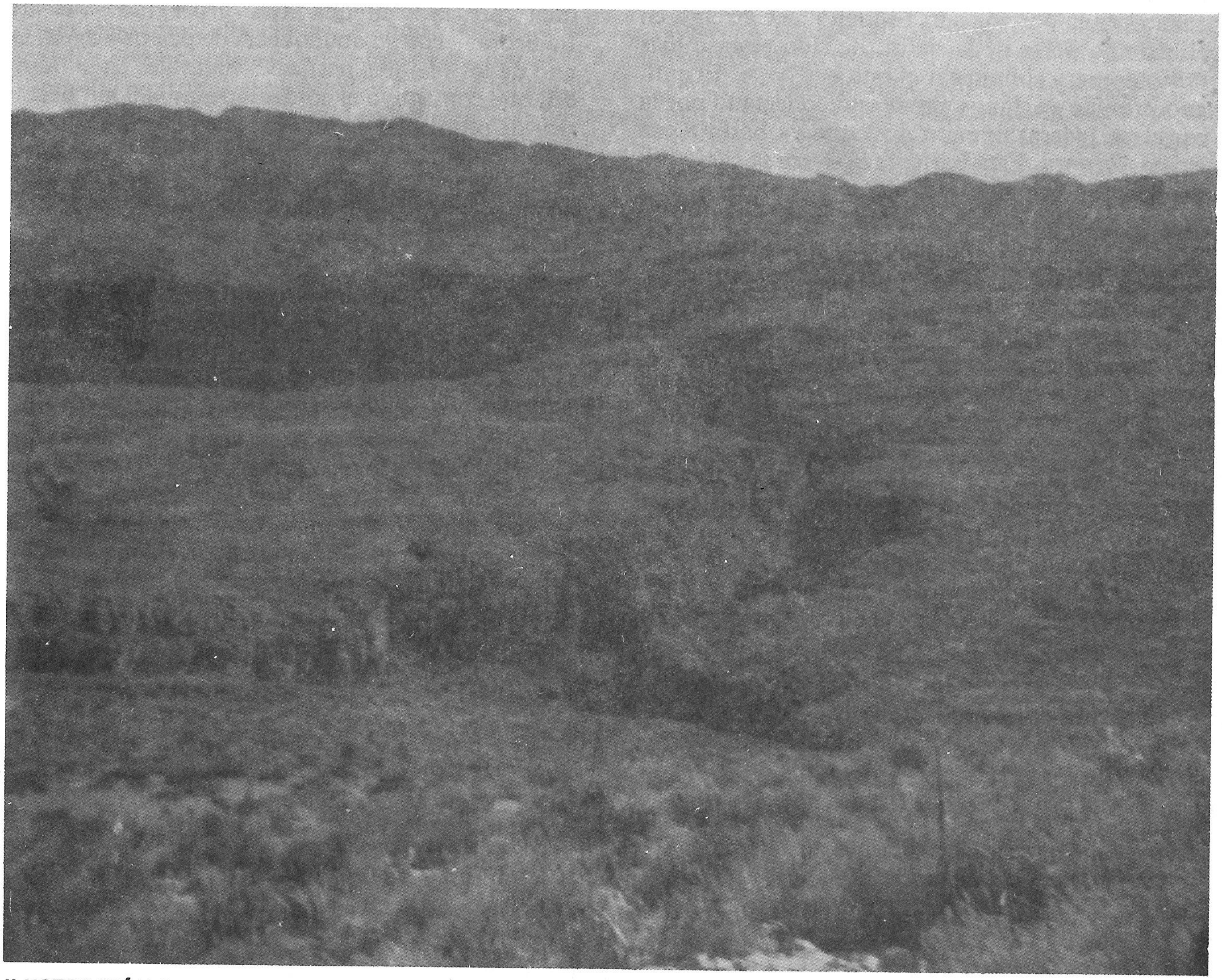

ILUSTRACIÓN 5

Sierra Madre Occidental. Mesetas escalonadas y efectos erosivos del agua de los ríos.

II. Sierras y cuencas

Las cuencas y sierras de Chihuahua forman parte de una provincia fisiográfica mayor. Se extiende desde el oeste y sur de Arizona, cruza el oeste de Nuevo México hasta incluir una porción de Texas; hacia el sur se expande incluyendo una buena parte de México. Las formas superficiales que genera esta provincia de cuencas y sierras están caracterizadas por la unión de los bolsones parcialmente rellenos, enmarcados por sierras orientadas hacia el nor-noroeste. La variación de alturas de los pisos de las cuencas está entre los 1,200 y 1,500 metros. Por lo común, las montañas son aquellas áreas con alturas superiores a 1,800 metros. La composición geológica de las sierras forma una amplia zona de transición entre las rocas sedimentarias plegadas del Cretácico (125 a 100 maap) falladas y cabalgadas en los lados oriental y sur, y las rocas ígneas del Terciario (65 a 20 maap) que se asocian con la Sierra Madre Occidental en el oeste. Muchas de las sierras aisladas están constituidas de rocas carbonatadas, en especial calizas cretácicas intensamente plegadas y acompañadas de pequeñas fallas de cabalgamientos.[30]

[30] Z. DeCserna, "Mexico-geotectonics and Mineral Deposit", en *Tectonics and Mineral Resources of Southwestern North America,* L.A. Woodward y S.A. Northrop (eds.), New Mexico Geological Society, Special Publication 6, 1976, pp. 18-25.

TABLA I

BARRANCAS MAYORES EN LA SIERRA DE CHIHUAHUA

BARRANCA	PROFUNDIDADES DEL CAÑON	ALTITUD (m)		DISTANCIA LINEAL (km)		DIFERENCIA DE ALTURA ENTRE PROMONTORIOS
		RIO	PROMONTORIO	DEL RIO AL PROMONTORIO MAS ALTO	ENTRE PROMONTORIOS AL PUNTO MAS PROFUNDO	
Río Urique						
10 km al sur de Urique	1,870	500	2,370	6.5	13.0	40
Urique	1,760	600	2,300	4.0		
Divisadero	1,300	1,000	2,300	6.0		
Río Verde						
C. de Guerachi	1,830	700	2,528	5.0	17.5	225
San Rafael	1,655	800	2,455	5.0		
C. de Sinforosa	1,400	1,000	2,400	4.0		
Río Batopilas						
10 km río arriba de Batopilas	1,800	700	2,498	4.5	16.0	130
La Bufa	1,300	900	2,167	2.5	8.0	55
Río Candameña						
Candameña	1,640	900	2,540	5.0	14.0	180
Río Septentrión						
Santo Niño y F. Ch. P.	1,600	400	1,998	4.5	7.0	160
Río Oteros						
27°44'y 108°17'	1,520	700	2,220	5.0	11.5	200
27°44'y 108°17'	1,300	700	2,000	2.5	6.5	0
Río Mayo						
28° y 108°40'	1,680	500	2,180	6.5	11.0	380
Río Guaynopa						
Punto Magnífico	1,140	1,500	2,640	3.5	9.0	240
Río Colorado, Az.						
Gran Cañón/ Punto Hopi	1,425	730	2,155	3.5	7.0	20

Otras sierras son las clásicas montañas de fallamiento en bloque. La mayoría de las montañas en este grupo son pilares o bloques basculados o rotados, producidos cuando los sedimentos fueron levantados en forma dispareja a lo largo de fallas más o menos paralelas.

Con base en escasas evidencias, muchos de los bolsones parecen ser profundas fosas —por ejemplo de 2 mil 750 metros— o depresiones estructurales; son bloques caídos a lo largo de fallas paralelas y limitados por pilares o bloques levantados. Estas cuencas fueron parcialmente rellenadas con sedimentos de facies fluviales de edad reciente sobrepuestas en los depósitos lacustres pleistocénicos.[31] El material de los abanicos aluviales sepultados y los sedimentos eólicos también se encuentran presentes.[32] Las superficies de las cuencas se caracterizan por ser planicies levemente onduladas o con suaves pendientes aluviales. En su texto, Hawley nos presenta una descripción y excelentes definiciones relacionadas con las superficies geomorfológicas del área.[33]

Entre los bolsones y las sierras montañosas, las cuales "se levantan por encima de los pisos de las cuencas como las islas sobre el nivel del mar", encontramos el talud aluvial.[34] Este talud intermedio se constituye de dos partes: un piedemonte —piamonte— y una bajada.

Lo que conocemos como piedemonte es una superficie de roca sobre la cual se transporta el material erosionado. Se forma al pie de un talud de montaña en retroceso; es decir, que se encuentra en proceso de erosión activa y con frecuencia se cubre por una delgada capa de hasta 25 metros de aluvión. La bajada o porción más baja del talud —parte distal del mismo—, consiste en gruesos depósitos de material erosionado y acarreado de las partes altas de la montaña.

Por su forma y composición, la totalidad del talud desde la boca del cañón hasta la base, recibe el nombre de abanico aluvial. Aunque la palabra en español "bajada" literalmente significa declive o talud, en general es definida como la unión o coalescencia de abanicos aluviales unidos. Es posible que el término delantal aluvial sea una mejor alternativa, pero éste no es muy conocido. El señalamiento de carretera mexicano "bajada" no es un intento para educar al grueso del público como geomorfólogo, sino que se refiere a una pendiente pronunciada.

Típicamente, en la base del talud aluvial encontramos una superficie plana casi siempre referida como una superficie desértica, que gradúa a una playa —barrial—. Por playa entendemos comúnmente una zona nivelada que ocupa la parte más baja de una cuenca cerrada y que a intervalos irregulares se cubre por el agua.

También, las playas —barriales— que merecen nombrarse son medianamente grandes en tamaño, por lo general mayores a los 600 metros y hasta los 900 metros en diámetro. Playa, en un sentido estricto, se deriva de la palabra española que significa costa arenosa, mientras que barrial se refiere al área que al recibir la lluvia se vuelve lodo pegajoso. La referencia de playa como una línea costera alrededor de un cuerpo de agua efímero ha sido construida para incluir la totalidad del lecho del lago —es decir, también incluye al barrial—.

Hawley señala que la palabra española "barrial", la cual significa lugar lodoso, representa más acertadamente las formas superficiales del terreno.[35] Ordóñez ha señalado que los geólogos y geógrafos estadunidenses, de forma poco apropiada, han llamado playa al barrial.[36]

Tal parece que el término "playa" está tan arraigado en la literatura, en especial la escrita en inglés, que barrial, en ocasiones escrito *barreal,* nunca alcanzará el lugar adecuado dentro de la literatura en español.

Las cuencas con drenaje interior —o cuencas endorreicas— ocupan casi la mitad de la superficie de Chihuahua. Las playas de los lagos, los lagos secos y los lagos o lagunas ocupan las partes más bajas de estos bolsones. Un "cociente de inundación" ayudaría a clarificar el uso de las diferentes palabras y términos que se usan para describir estas condiciones superficiales temporales.

A partir de algunas investigaciones, se ha sugerido que el término playa sea utilizado si la depresión permanece seca más de dos terceras partes del año.

[31] R.E. Mattick, "A seismic and gravity profile across the Hueco Bolsón", en *US geol. Surv. Prof. Paper 575D,* 1967.
[32] Tom Cliett, "Groundivater occurrence of the El Paso area and its related geology" en *Guidebook of the border region...*, ver Córdoba, *et. al.* (eds.), 1969.
[33] John W. Hawley, "Notes on the geomorphology..., 1969.
[34] Donald D. Brand, "The natural landscape..., 1937.
[35] John W. Hawley, "Notes on the geomorphology..., 1969.
[36] E. Ordóñez, "Physiographic provinces of Mexico", en *American Association of Petroleum Geologist Bulletin,* vol. 20, núm. 10, 1936.

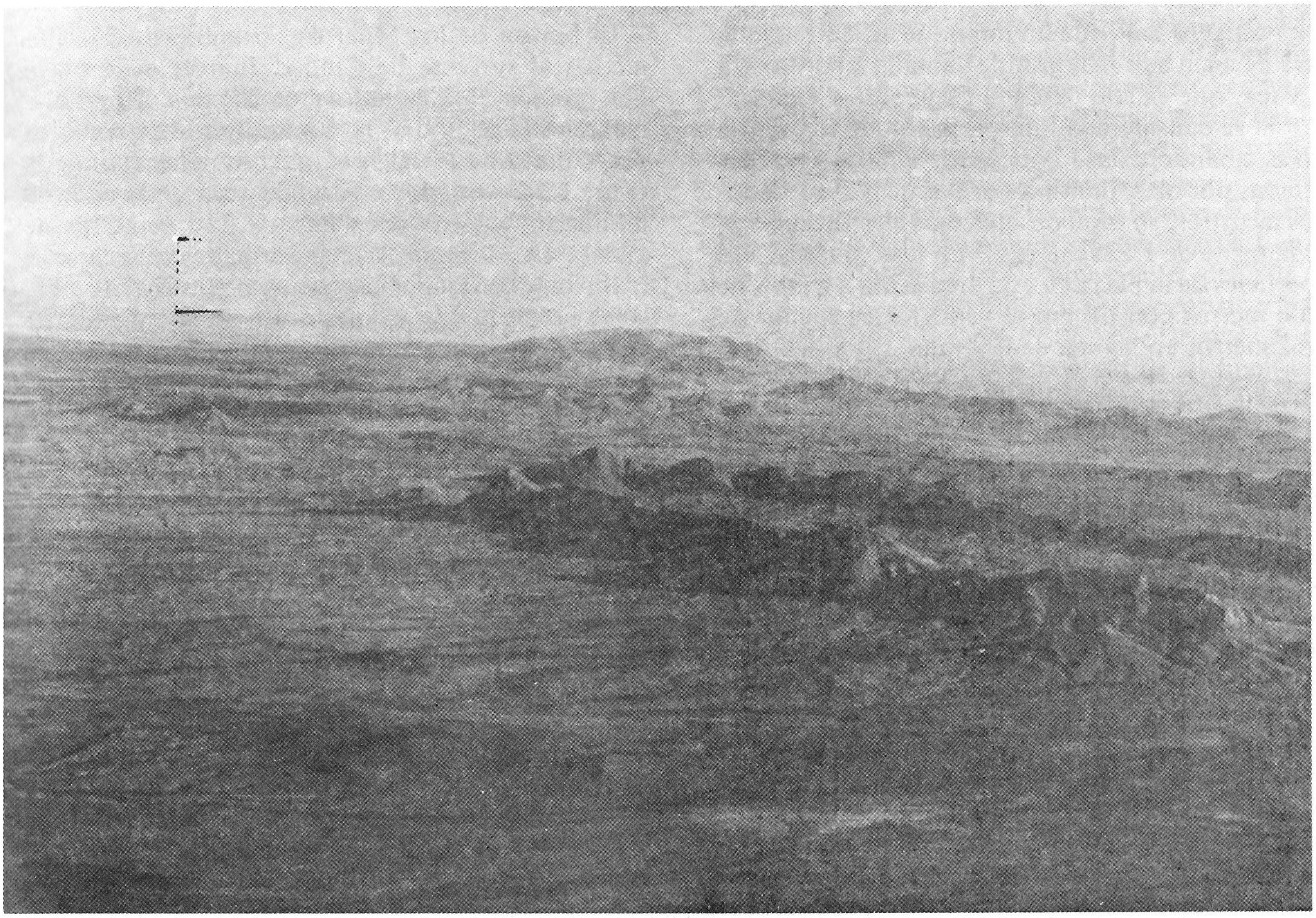

ILUSTRACIÓN 10

Región de los bolsones y planicies aluviales onduladas.

Cuando el agua temporalmente cubre la superficie de la playa, el término playa de lago es apropiado. Si la depresión contiene agua durante dos terceras partes del año, debe llamarse lago o laguna. Si el lago está temporalmente seco, se define como un lago seco. La terminología que se debe aplicar al tercio intermedio restante —considerando el cociente de inundación— depende del uso local y el punto de vista del observador. Las presas y represas han sido construidas río arriba o en casi todos los ríos que alguna vez inundaron en forma directa las lagunas de Chihuahua. Ahora, sólo los canales y asequias de irrigación y las tormentas ocasionales hacen su camino dentro de estas cuencas endorreicas.

II.1. Los bolsones

La zona más grande de planicies cubiertas con aguas efímeras se ubica en el norte, desde el piamonte de la sierra en dirección al oriente, hasta cerca de 15 kilómetros del río Bravo. Las cuencas endorreicas más grandes son el bolsón de los Muertos, el área del río Casas Grandes y laguna de Guzmán, el del río Santa María y la laguna Santa María, además del río del Carmen y la laguna de Patos. Este complejo de lagos es un remanente del antiguo lago pluvial de Palomas.[37] El lago Palomas, que inunda

[37] C. C. Reeves, "Pluvial lake Palomas, northwestern Chihuahua and pleistocene geologic history of south-central New Mexico", en *New Mexico Geological Society Guidebook,* Sixteenth Annual Field Conference, Southwestern New Mexico, 1965.

casi 7 mil 770 km^2, fue un estanque aislado de una masa de agua aun más grande llamada lago Cabeza de Vaca, que existió desde el Pleistoceno Temprano.[38] Si se considera la interpretación de Reeves de playas abandonadas, bancos de arena, escarpes cortadas por olas, múltiples orillas de playa y depósitos lacustres, su nivel de agua más alto fue aproximadamente de 1,225 metros.[39] En la actualidad, las superficies de la playa en esta área están a menos de 1,200 metros con un punto topográfico menor de 1,162 metros en laguna de Guzmán.

[38] William S. Strain, "Late cenozoic bolson integration in the Chihuahua tectonic belt", en *The geologic framework of the Chihuahua tectonic belt,* Seewald y Sundeen, (eds.), West Texas Geological Society, 1970.

[39] C. C. Reeves, "Pluvial lake Palomas..., 1965, y "Pluvial lake Palomas, northwestern Chihuahua, México en *Guidebook of the border region...,* ver Córdoba, *et al.* (eds.), 1969.

El bolsón de los Muertos, a menos de 75 kilómetros al suroeste de Ciudad Juárez, es la playa más grande en el estado y en México. Probablemente es la segunda playa más grande en América del Norte. La superficie actual de la playa contigua cubre 1,245 km^2, su longitud de norte a sur es de 69 kilómetros y tiene poco más de 24 kilómetros de ancho. Las enormes grietas formadas al secarse el lodo, también llamadas grietas de desecación, llegan a ser de hasta tres metros de ancho; algunas de estas grietas se encuentran en la parte noroeste de la playa.

Las dimensiones totales del bolsón son de aproximadamente 240 kilómetros de largo y 80 de ancho.[40]

[40] John W. Hawley, "Notes on the geomorphology...

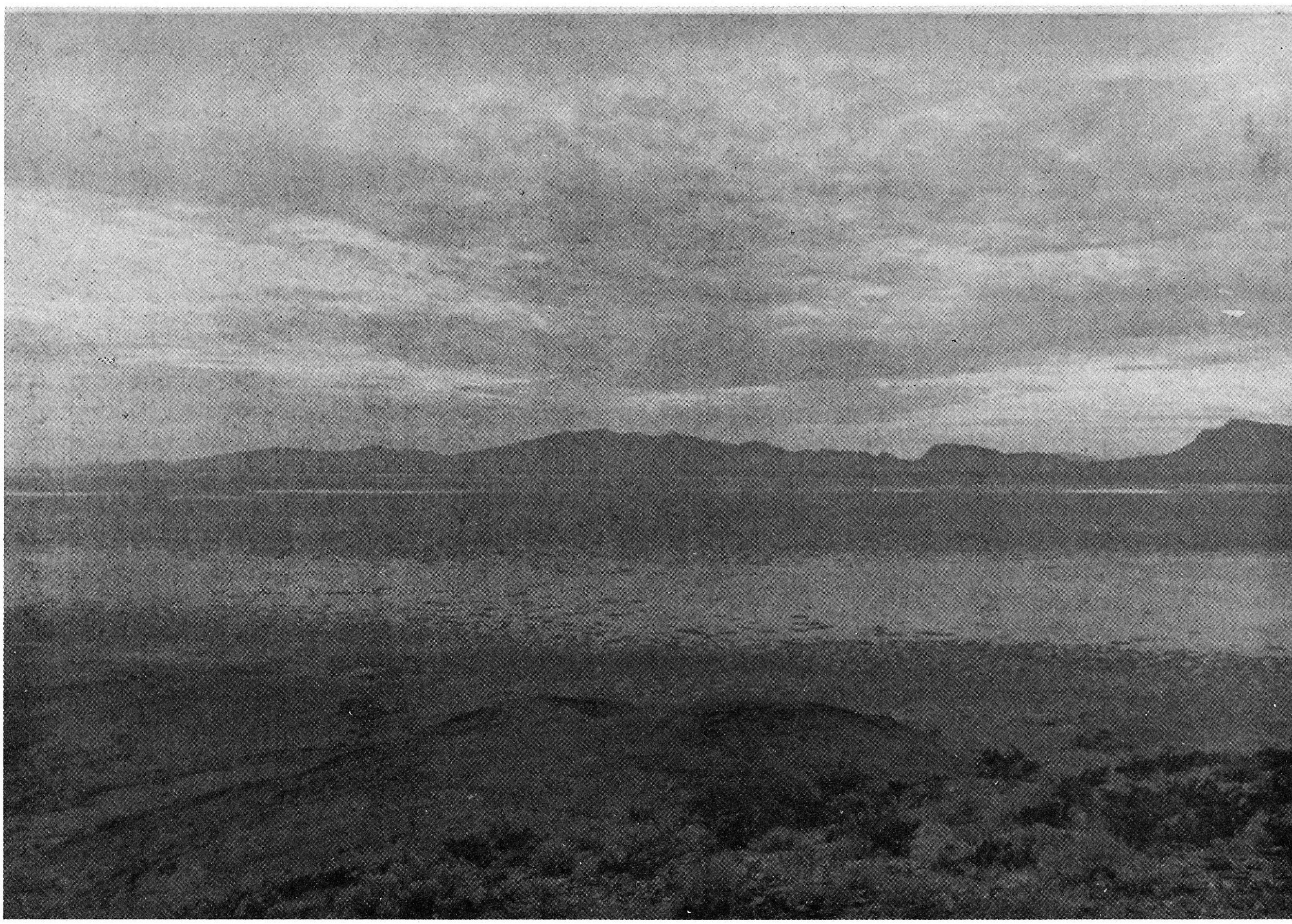

ILUSTRACIÓN 11

Cuencas endorreicas. Paleolaguna y zona de playa.

Part D4.

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Topic/Subtopic Categories, with Alphanumeric Cross-Reference Codes (Appendix B)

A. Bibliographies, Dictionaries, Glossaries, Biographies, Reviews, and News Items
- A1. Bibliographies, Dictionaries, and Glossaries
- A2. Biographies and Reviews
- A3. News Items

B. Time: Geologic, Prehistoric, and Historic
- B1. Geologic and Prehistoric Time
- B2. Prehistoric Perspective: US Southwest and Northern Mexico
- B3. Historic Perspective: US Southwest and Northern Mexico

C. Environmental, Physiographic, and Geologic Setting
- C1. Climatic, Hydrographic, Ecologic, and Paleoenvironmental Setting
- C2. Geologic and Geomorphic Setting
  - C2a. Geologic and Geomorphic Setting: Pre-1990
  - C2b. Geologic and Geomorphic Setting: Post-1989
- C3. Soil-Geomorphic Relationships and Soil Surveys
- C4. Geophysical/Geochemical Data and Interpretations

D. Basic Hydrogeologic Concepts
- D1. Conceptual Models, Definitions, and Regional Overviews
- D2. Groundwater-Flow Systems, Including Recharge

E. GIS/Remote Sensing and GW-Resource Management/Planning
- E1. GIS/Remote Sensing
- E2. Resource Management/Planning
  - E2a. Desalination
  - E2b. Recharge and Recovery
  - E2c. Groundwater-Quality Projection and Waste Management
- E3. Legal and Environmental Issues and Constraints

F. Transboundary Regional Hydrogeology and Geohydrology
- F1. Binational
- F2. USA
- F3. México

G. Early Documents on Mesilla Basin Regional Aquifer Systems (1858-1970)
- G1. 1858 to 1935
- G2. 1935 to 1970

H. Contemporary Documents on Mesilla Basin Regional Aquifer Systems
- H1. Hydrogeology
- H2. Hydrochemistry
- H3. Flow Models

I. Paleohydrology: Ancestral Fluvial and Pluvial Lake Systems
- I1. Regional Overviews
- I2. Transboundary Region Paleohydrologic Systems
- I3. Evolution of the Rio Grande Fluvial System

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