Notes on the geomorphology and late Cenozoic geology of northwestern Chihuahua

John W. Hawley

1969, pp. 131-142. https://doi.org/10.56577/FFC-20.131

in:

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

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

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

By

JOHN W. HAWLEY
U.S. Soil Conservation Service, University Park, N.M.

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 Ouaternary period on landscape evolution is also recognized.

RESUMEN

Sc expone la geomorfologia y la geologia del Cenozoico tardio de una area de 71,500 Km.' (27,600 millas cuadradas) del noroeste del Estado de Chihuahua y parte de los estados adyacentes de Sonora, Nuevo Mexico y Texas. Se pace mayor enfasis en la description de tres unidades fisiograficas principales: La Sierra Madre Occidental y dos subdiviciones de "Sierras y Cuencas." Se proponen nombres formales para estas subdiviciones. La unidad mas extensa en el norte y oriente de Chihuahua se caracteriza por amplios bolsones deserticos y sierras aisladas, lo cual aqui se designa como subdivición Bolson. La unidad de mayor relieve que la anterior se ha asignado como subdivision BabIcora-Bustillos, la cual ocupa una region transisional refiriéndose a caracteres geológicos, entre la unidad Bolson y la Sierra Madre. Los limites fisiográficos se seleccionaron basándose en estudios de compilaciones recientes de mapas topograficos Esc. 1:250,000 y algunos trabajos de campo. El control de la porción norte del area 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 regiOn frontieriza de los Estados de Nuevo Mexico y Chihuahua, han dado como resultado una elaboración considerable de los conceptos básicos del desarrollo evolutivo en la configuración del terreno durante el Cenozoico tardió.

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 Rio Grande (Rio Bravo) durante el Pleistoceno medio a tardio, parece toner aplicación al area en discusión de "Cuencas y Sierras."

También se reconoce la influencia de un cambio en el ciclo climatic°, durante el periodo 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 Soil Conservation Service. 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,

HISTORICAL REVIEW

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

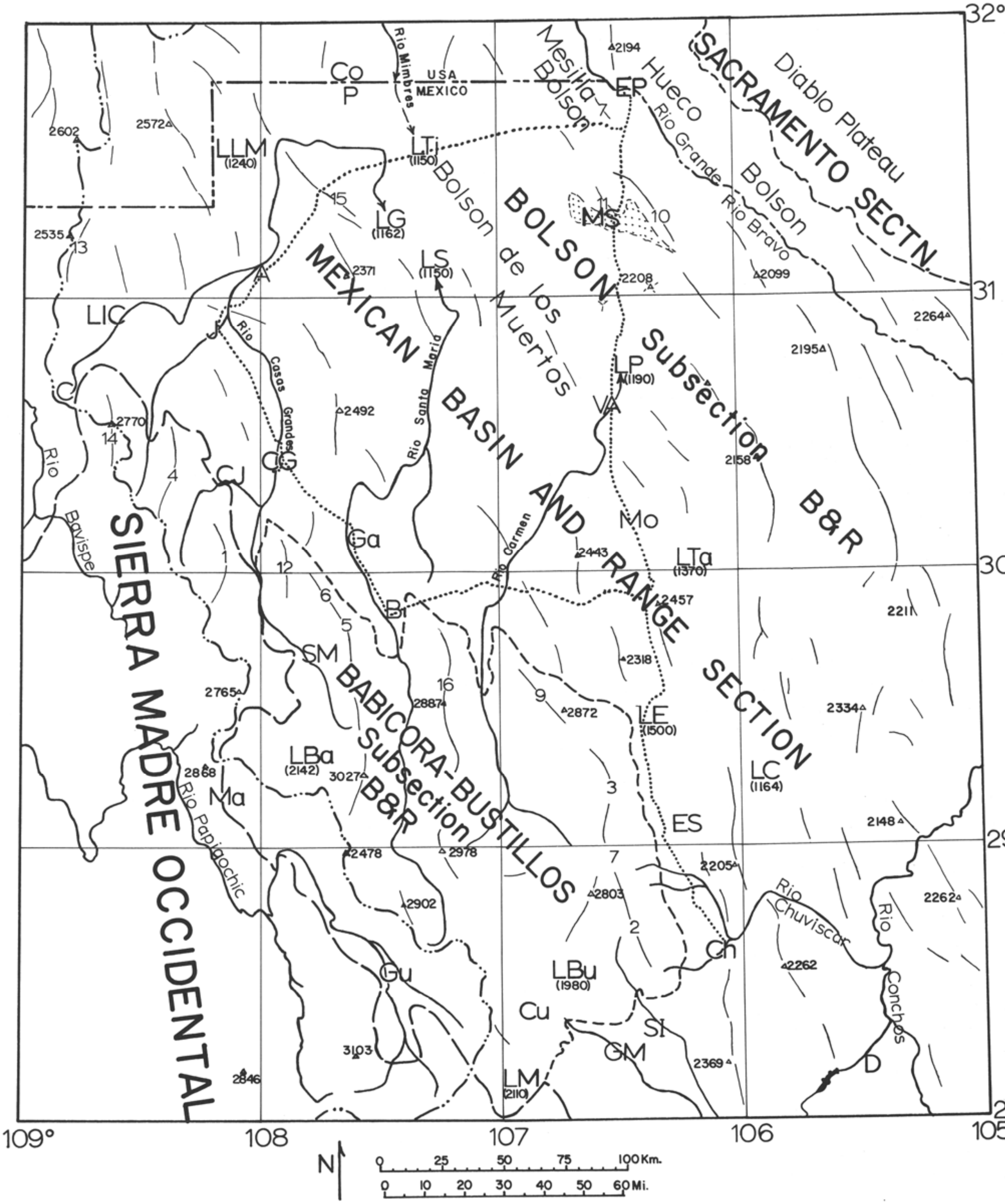

FIGURE 1. INDEX MAP—GEOMORPHIC FEATURES OF NORTHWESTERN CHIHUAHUA AND ADJACENT AREAS.
(Explanation on facing page)

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. 0. 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 geolo gists 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
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 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 Ouaternary 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. Blasquez (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 Hidraulicos (S.R.H.). Recent ground-water and land-resource investigations by the S.R.H. in parts of the Valle de Juarez and lower Rio Carmen, Encinillas and Rio Casas Grande 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 Hidraulicos, who have provided major assistance include Ing. G. Flores Mata, Director de Agrologia, and Ing. I. Sainz Ortiz, 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, Dominguez, Fuentes, and Amaya; and Sr. Oscar Munoz. 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; Ordonez, 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 (Ordónez, 1936, 1942; Almada, 1945; Ed. Porrua S.A., 1965). Ordónez (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.

Barrial. Spanish for a muddy spot (sometimes incorrectly spelled "barreal"). Ordonez (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. Ordonez 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 Tarnhumara 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 Juarez, Janos and Llano de Carretas (figure 1). Following the suggestions of Thayer (1916), Ordónez (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 (Km^2)	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 1:100,000 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 Campana 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) Abl 3 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 Hidraulicos. 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 pedologie 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 cpipedons 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 Dona 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 Juarez 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 dc Recursos Hidraulicos 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 Juarez 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.

BIBLIOGRAPHY

Albritton, C. C., Jr. and Smith, J. F., Jr. (1965) Geology of the Sierra Blanca area, Hudspeth County, Texas: U.S. Geol. Surv. Prof. Paper 479, 131 p.

Almada, F. R. (1945) Geografia del Estado de Chihuahua: Ruiz Sandoval S.A., Chihuahua, Chih.

Aristarain, L. F. (1961) Caliche deposits of New Mexico: Unpublished PhD dissertation, Harvard University.

Baker, C. L. (1928) Desert Range tectonics of Trans-Pecos Texas: Pan Amer. Geologist v.50, p. 341-372.

Baker, C. L. (1934) Major structural features of Trans-Pecos, Texas, Part 2 in Volume 2 of the Geology of Texas: Univ. Tex. Bull 3401, P. 137-214.

Blasquez, L. (1959) Hydrogeologia de las regiones deserticas de Mexico: Mex. Univ. Nac. Inst. Geologia Anales, tomo 15, 172 p.

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

Bryan, K. (1923) Erosion and sedimentation in the Papago Country, Arizona: U.S. Geol. Survey Bull. 730, p. 19-90.

Bryan, K. (1938) Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico. *(In* Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas) : National Resources Committee, Washington, Regional Planning, Part 6, p. 196-225.

Burrows, R. H. (1909-10) Geology of northern Mexico: Mining and Scientific Press, v. 99, no. 9 Whole No. 2562 (Aug. 28), p. 290-94; Whole No. 2563 (Sept. 4), p. 324-27. (Also Bol. Soc. Geol. Mexicana, v. 7, pt. 2 (1910) p. 85-103.

Conover, C. S. (1954) Ground-water conditions in the Rincon and Mesilla Valleys and adjacent areas in New Mexico: U.S. Geol. Survey Water Supply Paper 1230, 200 p.

Dane, C. H. and Bachman, G. a (1961) Preliminary geologic map of the southwestern part of New Mexico: U.S. Geol. Survey Misc. Geologic Investigations Map 1-334.

Darton, N. H. (1916) Geology and underground water of Luna County, New Mexico: U.S. Geol. Survey Bull. 618, 188 p.

DeFord, R. K. (1964) History of geologic exploration in Chihuahua *(In* Geology of Mina Plomosas—Placer de Guadalupe Area, Chihuahua, Mexico) : West Texas Geol. Soc. Publication No. 64-50, p. 116-129.

DeHon, R. A. (1965) Maare of La Mesa: New Mex. Geol. Soc. Guidebook of Southwestern New Mexico II, p. 204-209.

Dudal, R. (1968) Definitions of soil units for the Soil Map of the World: World Soil Resources Report 33, Land and Water Development Division, FAO/UNESCO, Rome.

Editorial Porrua, S. A. (1965) Diccionario Porrua de Historia, Biographic Y Geographia de Mexico (2nd ed.) : Los Talleres de Union Grafica S.A., Mex. D.F.

Fenneman, N. (1931) Physiography of the Western United States: McGraw-Hill Book Co., New York, 534 p.

Gile, L. H. (1961) A classification of ca horizons in the soils of a desert region, Dona Ana County, New Mexico: Soil Sci. Soc. Amer. Proc., v. 25, p. 52-61.

Gile, L. H. (1966) Coppice dunes and the Rotura soil: Soil Sci. Soc. Amer. Proc., v. 30, p. 657-660.

Gile, L. H. (1966) Cambic and certain noncambic horizons in desert soils of southern New Mexico: Soil Sci. Soc. Amer. Proc., v. 30, p. 773-781.

Gile, L. H. (1967) Soils of an ancient basin floor near Las Cruces, New Mexico: Soil Science, v. 103, p. 265-276.

Gile, L. H. and Grossman, R. B. (1968) Morphology of the argillic horizon in desert soils of southern New Mexico: Soil Science, v. 106, p. 6-15.

Gile, L. H., and Hawley, J. W. (1966) Periodic sedimentation and soil formation on an alluvial-fan piedmont in southern New Mexico: Soil Sci. Soc. Amer. Proc., v. 30, p. 261-268.

Gile, L. H. and Hawley, J. W. (1968) Age and comparative development of desert soils at the Gardner Spring Radiocarbon Site, New Mexico: Soil Sci. Soc. Amer. Proc., v. 32, no. 5, p. 709-719.

Gile, L. H., Peterson, F. F., and Grossman, R. B. (1965) The K horizon: A master soil horizon of carbonate accumulation: Soil Science, v. 99, p. 74-82.

Gile, L. H., Peterson, F. F., and Grossman, R. B. (1966) Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Hawley, J. W. and Kottlowski, F. E. (1969) Quaternary geology of the southcentral New Mexico Border region: *(In* Border Stratigraphy Symposium) New Mex. Inst. Min. & Tech., State Bur. Mines & Min. Res., Circular 104, p. 89-115.

Hawley, J. W., Kottlowski, F. E., Strain, W. S., Seager, W. R., King, W. E., and LeMone, D. V. (1969) The Santa Fe Group in the south-central New Mexico border region: Ibid. p. 52-76.

Hill, R. T. (1891) Preliminary notes on the topography and geology of northern Mexico and southwest Texas and New Mexico: Amer. Geologist, v. 8, no. 3, p. 133-141.

Hill, R. T. (1896) Descriptive topographic terms of Spanish America: National Geographic, v. 7, p. 291-302.

Hill, R. T. (1900) Physical geography of the Texas region: U.S. Geol. Survey, Topographic Folio No. 3.

Hill, R. T. (1901) Geographic and geologic features of Mexico: Engineering and Mining Jour., v. 72, no. 18, p. 561-564.

Hill, R. T. (1907) Characteristics of some Mexican mining regions: Engineering and Mining Jour. v. 84, no. 14, p. 631-636.

Hoffer, J. (1969a) The San Miguel lava flow, New Mexico: Geol. Soc. America Bull., v. 80, p. 1409-1414.

Hoffer, J. (1969b) Preliminary note on the Black Mountain basalts of the Potrillo field, south-central New Mexico (In Border Stratigraphy Symposium) : New Mex. Inst. Min. & Tech., State Bur. Mines & MM. Res. Circular 104, p. 116-121.

Hovey (1907) A geological reconnaissance in the Western Sierra Madre of the State of Chihuahua, Mexico: Amer. Museum of Natural History, Bull., v. 23, Art. 18, p. 401-442. (Includes geographic and geologic map of Chihuahua by R. T. Hill.)

Howard, A. D. (1942) Pediments and the pediment pass problem: Jour. Geomorphology, v. 5, p. 3-31, 95-136.

Hunt, C. B. (1967) Physiography of the United States: W. H. Freeman and Co., San Francisco, 480 p.

Kelley, V. C., and Silver, C. (1952) Geology of the Caballo Mountains: Univ. of New Mexico Publ. in Geology, no. 4, 286 p.

Kellum, L. B. (1944) Geologic history of northern Mexico and its bearing on petroleum exploration: Am. Assoc. Petrol. Geol. Bull., v. 28, p. 301-325.

King, P. B. (1935) Outline of structural development of Trans-Pecos Texas: Am. Assoc. Petrol, Geol. Bull., v. 19, p. 221-261.

King, P. B. (1947) Carta geologica de la parte septentrional de la Republicana Mexicana. Cartas Geologicas y Mineras de La Republicana Mexican no. 3, 24 p.

King, R. E. (1939) Geological reconnaissance in northern Sierra Madre Occidental of Mexico. Geol. Soc. of Amer.- Bull., v. 50, p. 1625-1722.

King, R. E. and Adkins, S. W. (1946) Geology of a part of the lower Conchos Valley, Chihuahua, Mexico: Geol. Soc. Amer. Bull., v. 57, p. 275-294.

King, W. E., Hawley, J. W. Taylor, Andrew, and Wilson, Richard (1969) Hydrogeology of the Rio Grande Valley and adjacent intermontane basins, Dona Ana County, New Mexico: Water Resources Research Institute, Research Report 6, New Mex. State Univ.

Knowles, D. B. and Kennedy, R. A. (1958) Ground-water resources of the Hueco Bolson, northeast of El Paso, Texas: U.S. Geol. Surv. Water-Supply Paper 1426, 186 p.

Kottlowski, F. E. (1953) Tertiary-Quaternary sediments of the Rio Grande Valley in southern New Mexico: New Mexico Geol. Soc. Guidebook of Southwestern New Mexico, p. 144-148: Road Log, Las Cruces to Caballo, Ibid, p. 30-41.

Kottlowski, F. E. (1958) Geologic history of the Rio Grande near El Paso: West Texas Geol. Soc. Guidebook, Field Trip, Franklin and Hueco Mountains, Texas, p. 46-54.

Kottlowski, F. E. (1960) Reconnaissance geologic map of Las Cruces 30-minute quadrangle: New Mex. Bur. of Mines and Min. Res., Geologic Map 14.

Kottlowski, F. E., Cooley, M. E., and Rube, R. V. (1965) Quaternary geology of the Southwest *(In* The Quaternary of the United States) : Princeton Univ. Press, p. 287-298.

Kottlowski, F. E., and LeMone, D. (1969) Border Stratigraphy

Symposium: New Mex. Inst. Min. & Tech., State Bur. Mines & Min. Res. Circular 104.

Lang, W. (1920) Verwitterung and Bodenbildung als Einfuehrung *in* de Bodenkunde: Stuttgart.

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

Leggat, E. R., Lowry, M. E., and Hood, J. W. (1963) Ground-water resources of the lower Mesilla Valley, Texas and New Mexico: U.S. Geol. Survey Water-Supply Paper 1669AA, 49 p.

LeMone, D. V. and Johnson, R. R. (1969) Neogene flora from the Rincon Hills, Dona Ana County, New Mexico: New Mex. Inst. Min. & Tech., State Bur. Mines & Min. Res., Circular 104, p. 77-88.

Lustig, L. K. (1968) Inventory of research on geomorphology and hydrology of desert environments *(In* Deserts of the World) : University of Arizona Press, Tucson, p. 95-286.

Martin, P. S. (1963) The last 10,000 years: University of Arizona Press, Tucson, p. 1.

Martonne, E. de (1926) Areisme et indices d'aridite; Academie des Sciences, Paris, Compte Rendus 182, p. 1395-1398.

Mattick, R. E. (1967) A seismic and gravity profile across the Hueco Bolson, Texas: U.S. Geol. Surv. Prof. Paper 575D, p. D85-91.

McGinnies, W. G., Goldman, B. J. and Paylor, P. (1968) Deserts of the World, an appraisal of research into their physical and biological environments: Univ. Arizona Press, Tucson, 788 p.

Meigs, P. (1953) World distribution of arid and semi-arid homoclimates *(In* Reviews of Research on Arid Zone Hydrology) : UNESCO (Paris) Arid Zone Programme 1, p. 203-209.

Metcalf, A. L. (1967) Late Quaternary mollusks of the Rio Grande Valley, Caballo Dam, New Mexico to El Paso, Texas: The Univ. of Texas at El Paso, Science Series No. 1, Texas Western Press, 62 p.

Ordonez, E. (1936) Physiographic provinces of Mexico: Amer. Assoc. Pet. Geologists Bull., v. 20, no. 10, p. 1277-1307.

Ordonez, E. (1942) Las provincial fisiograficas de Mexico: Revista geografiia de Instituto Panamericano geografia e Historia, v. 1, nos. 2 & 3.

Raisz, E. (1964) Land forms of Mexico (2nd ed.) : Geography Branch, Office of Naval Research, Cambridge, Mass.

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

Reeves, C. C. Jr. (1965) Pluvial Lake Palomas, northwestern Chihuahua and Pleistocene geologic history of south-central New Mexico: N. Mex. Geol. Soc. Guidebook, Sixteenth annual field conference, Southwestern New Mexico II, p. 199-203.

Reeves, C. C., Jr. and DeHon, R. R. (1965) Geology of Potrillo Maar, New Mexico and northern Chihuahua, Mexico: Am. Jour. Sci., v. 263, p. 401-409.

Richardson, G. B. (1909) Description of the El Paso District: U.S. Geol. Survey Geol. Atlas, Folio No. 166.

Ruhe, R. V. (1962) Age of the Rio Grande Valley in southern New Mexico: Jour. Geol., v. 70, p. 151-167.

Ruhe, R. V. (1964) Landscape morphology and alluvial deposits in southern New Mexico: Assoc. Am. Geog. Annuals, v. 54, p. 147-159.

Ruhe, R. V. (1967) Geomorphic surfaces and surficial deposits in southern New Mexico: N. Mex. Inst. Min. & Tech., State Bur. of Mines & Min. Res., Mem. 18.

Sauer, C. 0. (1930) Basin and range forms in the Chiricahua area: Univ. of California Publ. Geography, no. 3, p. 339-414.

Soil Survey Staff (1960) Soil Classification: A comprehensive system, 7th Approximation: Soil Cons. Svc., Washington, D.C., 265 p.

Soil Survey Staff (1967) Supplement to soil classification system (7th Approximation) : Soil Cons. Svc., Washington, D.C., 207 p.

Strain, W. S. (1959) Blancan mammalian fauna from Rio Grande Valley, Hudspeth County, Texas: Geol. Soc. Amer. Bull., v. 70, p. 375-378,

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

Strain, W. S. (1969) Late Cenozoic strata of the El Paso area (Border Stratigraphy Symposium) : New Mex. Inst. Min. & Tech., State Bur. Mines & Min. Res. Circular 104, p. 122-123.

Tamayo, J. L. (1962a) Geografia General de Mexico, v. I to IV (and ed.) : Talleres Graficos de la Nacion, Tolsa 9, Mexico, D. F.

Tamayo, J. L. (1962b) Atlas Geografico General de Mexico: Mexico, D. F.

Texas Bureau of Economic Geology (1968) Geologic Atlas of Texas, Van Horn-El Paso Sheet (1:250,000) : Austin, Texas.

Thayer, W. N. (1916) The physiography of Mexico: Jour. Geology, v. 25, p. 61-94.

Thornbury, W. D. (1954) Principles of geomorphology: John Wiley & Sons, Inc., New York, p. 284 (Also see 1968 edition.)

Thornbury, W. D. (1965) Regional geomorphology of the United States; John Wiley & Sons, Inc., New York, p. 471-505.

Tolman, C. F. (1909) Erosion and deposition in the southern Arizona bolson region: Jour. Geology, v. 17, p. 136-163.

Trewartha, G. T. (1954) An introduction to climate (3rd ed.) : McGraw-Hill Book Co., Inc., New York, 402 p.

Vivó, J. A. (1948) Geografia de Mexico: Fondo de Cultura Economica (see also 1958-4th edition).