New Mexico Geological Society

Downloaded from: https://nmgs.nmt.edu/publications/guidebooks/26

Quaternary history of Doña Ana County region, south-central New Mexico

John W. Hawley

1975, pp. 139-150. https://doi.org/10.56577/FFC-26.139

in:

Las Cruces Country, Seager, W. R.; Clemons, R. E.; Callender, J. F.; [eds.], New Mexico Geological Society 26 th Annual Fall Field Conference Guidebook, 376 p. https://doi.org/10.56577/FFC-26

This is one of many related papers that were included in the 1975 NMGS Fall Field Conference Guidebook.

Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual Fall Field Conference that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

Free Downloads

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs*, *mini-papers*, and other selected content are available only in print for recent guidebooks.

Copyright Information

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.

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

QUATERNARY HISTORY OF DOŇA 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. 0. 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

1. Geologist, Soil Conservation Service, U.S. Department of Agriculture; on Intergovernmental Personnel Act assignment with New Mexico Bureau of Mines and Mineral Resources.

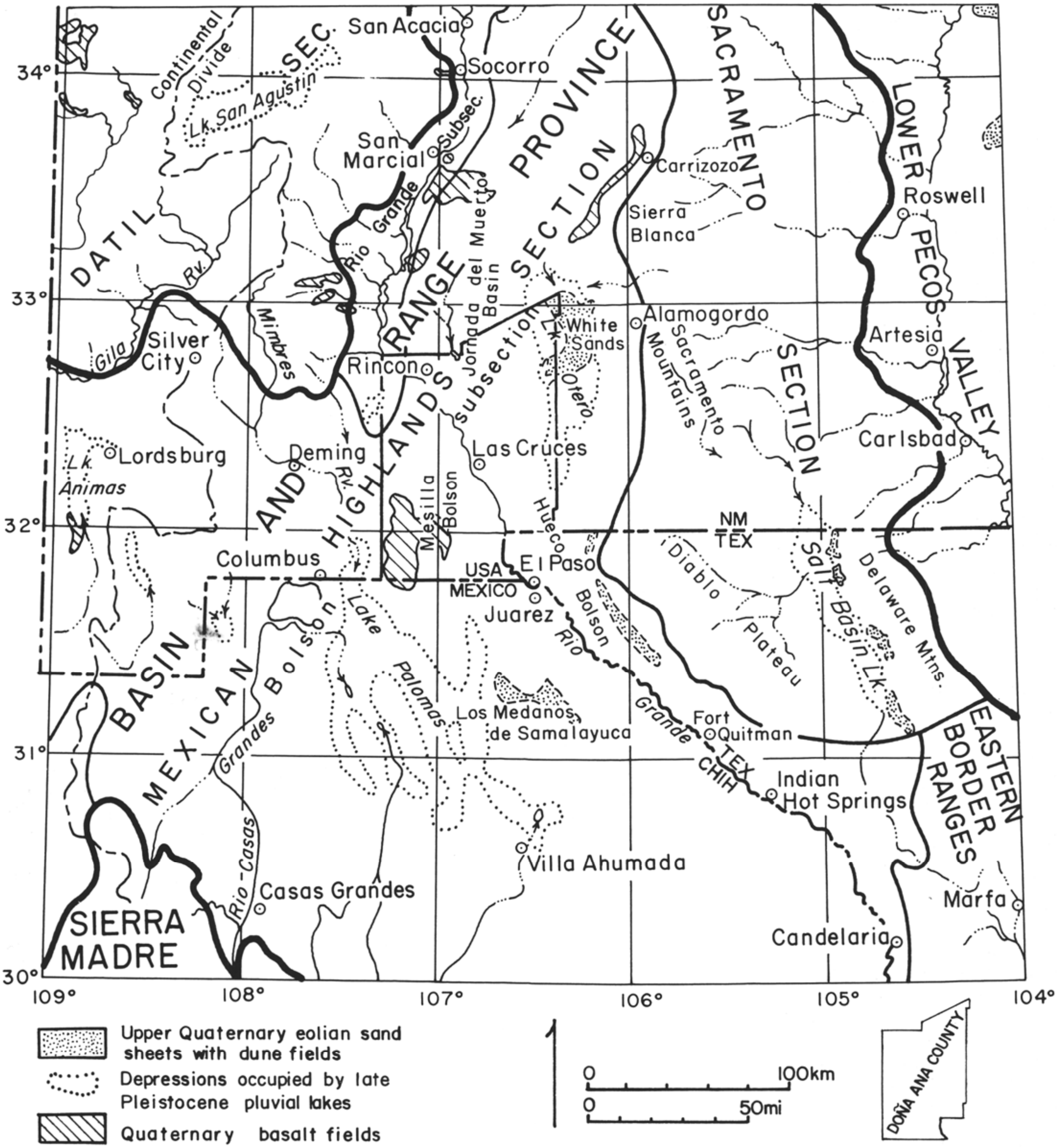

Figure 1. Physiographic subdivisions, major stream systems, pluvial lake basins, and dune and basalt fields in south-central New Mexico region.

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 0 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

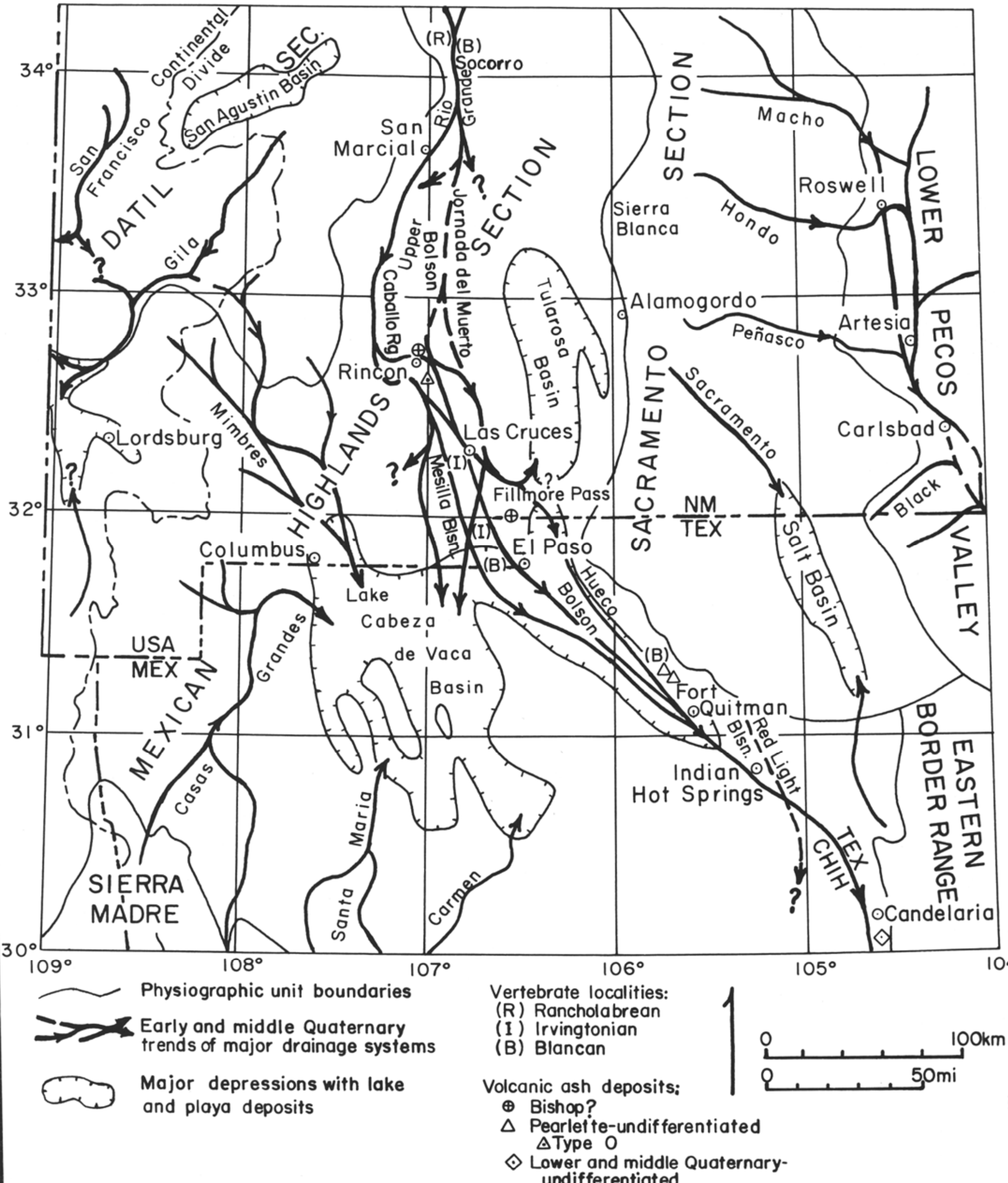

Figure 2. Early and middle Quaternary paleodrainage, undrained depressions, volcanic ash, and vertebrate faunal localities, and modern physiographic subdivisions in south-central New Mexico region.

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

1. *Akerston, W. A., (1970), Permian Basin Section, Soc. Econ. Paleontologists and Mineralogists (Midland, Tx.) Pub. 70-12, p. 82-87.*
2. *Albritton, C. C., Jr. and Bryan, K., (1939), Geol. Soc. America Bull., v. 50, p. 1423-1474.*
3. *Amer. Assoc. Petroleum Geologists, (1973), Geological Highway Map of Texas: AAPG (Tulsa) Map No. 7.*
4. *Anderson, J. E., (1968), Texas Univ. Bur. Econ. Geol. Quad. Map No. 36.*
5. *Bachman, G. O., (1974), U. S. Geol. Survey open file rept. 74-194, 81 p.*
6. *Bretz, J. H. and Horberg, L. H., (1949), Jour. Geology, v. 57, p. 477-490.*
7. *Bryan, K., (1938),* in *Rio Grande Joint Investigations in the upper Rio Grande basin: Nat'l. Res. Comm. (Washington, D. C.) Regional Planning, Pt. 6, p. 196-225.*
8. *Chapin, C. E., (1971), New Mex. Geological Soc. (Socorro) 22nd Field Conf. Guidebook, p. 191-201.*
9. *Dane, C. H. and Bachman, G. O., (1965), Geologic Map of New Mexico: U. S. Geol. Survey Map.*
10. *Groat, C. F., (1972), Texas Univ. Bur. Econ. Geol. Rpt. Inv. 76, 46 p.*
11. *Hawley, J. W., (1969), New Mex. Geol. Soc. (Socorro) 20th Field Conf. Guidebook, p. 131-142.*
12. *Hawley, J. W. and Kottlowski, F. E., (1969), New Mex. Bur. Mines and Mineral Resource Circ. 104, p. 89-115.*
13. *Hawley, J. W., Kottlowski, F. E., Strain, W. S., Seager, W. R., King, W. E. and LeMone, D. V., (1969), ibid., p. 52-76.*
14. *Herrick, C. L., (1904), American Geologist, v. 34, p. 174-189.*
15. *Hill, R. T., (1900), U. S. Geol. Survey Topographic Folio No. 3.*
16. *Horberg, L., (1949), Jour. Geology, v. 57, p. 464-476.*
17. *Hunt, C. B., (1974), Natural regions of the United States and Canada: Freeman and Co., (San Francisco), 725 p.*
18. *Kelley, V. C., (1952), New Mex. Geol. Soc. (Socorro), 3rd Field Conf. Guidebook, p. 92-105.*
19. *Kelley, V. C., (1971), New Mex. Bur. Mines and Mineral Resources, Mem. 24, 75 p.*
20. *Kelley, V. C., (1972), New Mex. Bur. Mines and Mineral Resources, Bull. 98, 55 p.*
21. *King, P. B., (1937), U. S. Geol. Survey Prof. Paper 187, 148 p.*
22. *King, P. B., (1948), U. S. Geol. Survey Prof. Paper 215, 183 p.*
23. *King, W. E., Hawley, J. W., Taylor, A. M., and Wilson, R. P., (1971), New Mex. Bur. Mines and Mineral Resources, Hydrologic Rpt. 1, 64 p.*
24. *Kottlowski, F. E., Cooley, M. E., and Ruhe, R. V., (1965),* in *The Quaternary of the United States: Princeton Univ. Press (Princeton, N. J.), p. 287-298.*
25. *Lambert, P. W., (1968), Quaternary stratigraphy of the Albuquerque area (PhD Dissert.): Univ. New Mexico, 300 p.*
26. *Lovelace, A. D., (1972), Geology and aggregate resources, District II: New Mex. Highway Dept. Rpt., 120 p.*
27. *Martin, P. S., and Mehringer, P. J., Jr., (1965),* in *The Quaternary of the United States: Princeton Univ. Press, (Princeton, N. J.), p. 433-451.*
28. *McKee, E. D., and Moiola, R. J., (1975), U. S. Geol. Survey Jour. Research, v. 3, p. 59-66.*
29. *Morrison, R. B., (1965), U. S. Geol. Survey Misc. Geol Investigations Map, I-442.*
30. *Powers, W. E., (1939), Jour. Geomorphology, v. 2, p. 345-356.*
31. *Reeves, C. C., Jr., (1969), New Mex. Geol. Soc. (Socorro) 20th Field Conf. Guidebook, p. 143-154.*
32. *Richmond, G. M., (1963), U. S. Geol. Survey Prof. Paper, 450E, p. 121-125.*
33. *Schwennesen, A. T., (1918), U. S. Geol. Survey, Water-Supply Paper 422, 152 p.*
34. *Seager, W. R., and Hawley, J. W., (1973), New Mex. Bur. Mines and Mineral Resources, Bull. 101, 42 p.*
35. *Strain, W. S., (1966), Texas Memorial Museum (Austin) Bull. 10, 55 p.*
36. *Texas Bur. Economic Geology, (1968), Geologic Atlas of Texas, Van Horn-El Paso Sheet.*
37. *Tight, W. G., (1905), American Geologist, v. 36, p. 271-284.*
38. *Twiss, P. C., (1970), West Texas Geol. Soc. (Midland) Pub. 71-59, p. 139-155.*
39. *Water Resources Div., (1965), U. S. Geol. Survey Water-Supply Paper 1682, p. 418-419.*
40. *Water Resources Div., (1970), U. S. Geol. Survey Water-Supply Paper 1923, p. 545-685.*
41. *West Texas Geol. Soc., (1972), Geology of the Big Bend Area, Texas: WTGS (Midland) Pub. 72-59, 248 p.*

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-ammal) 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 stratigaphy, vertebrate faunas, and radiometric ages. Brief explanaions 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 oscillaion is here assumed to have a period of about 115,000 years, he 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 Morner 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 formally considered by some to be as young as early

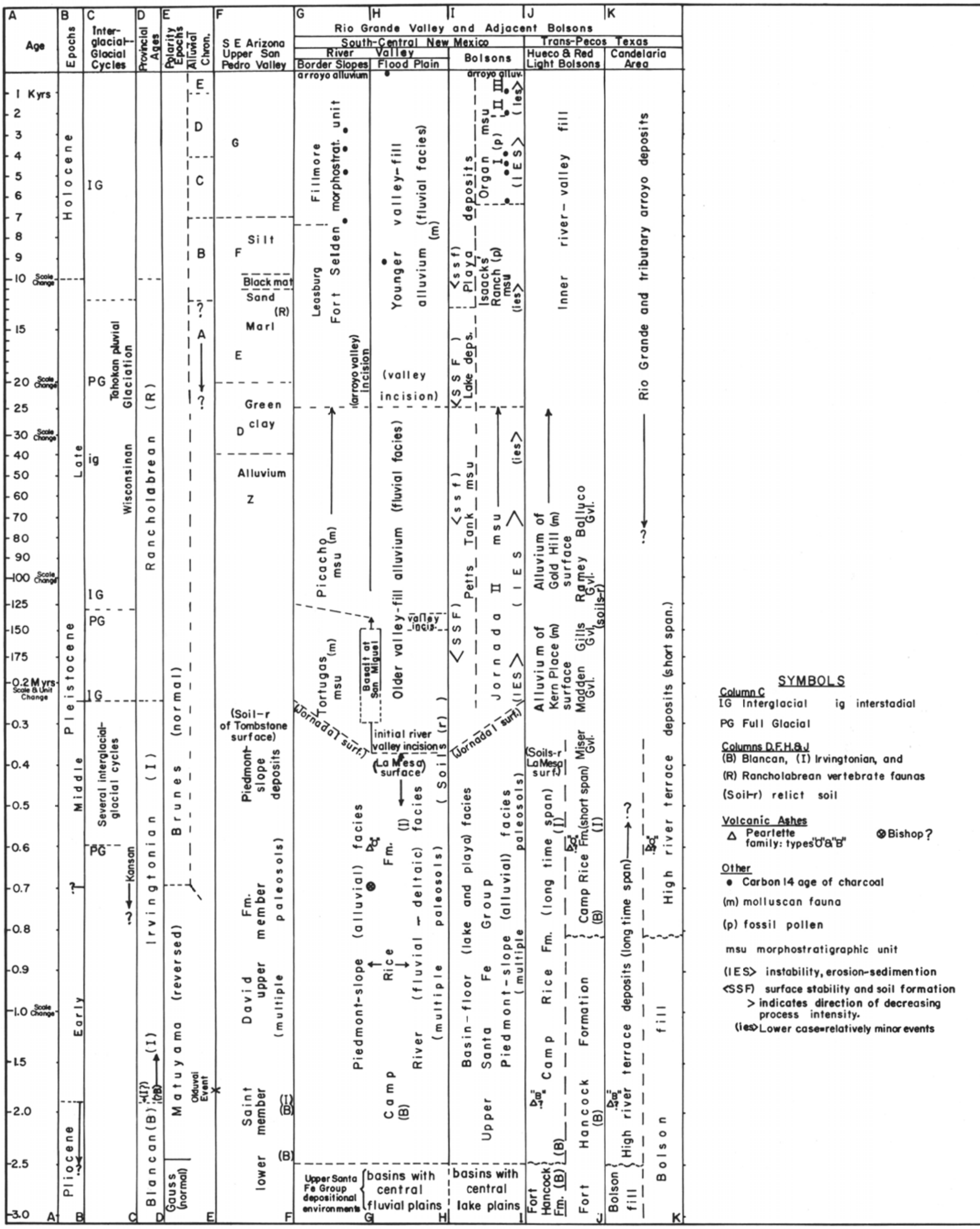

Table 2. Chart showing Quaternary deposits and events in south-central New Mexico region.

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 3. 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 ristobal 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 0 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 (71/2') 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 0 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 0 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 larger 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 0 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' 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 river system heading in glaciated mountains. According to this scheme, fluvial processes would go through the following cycle 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 formations (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 (late-phase Jornada of 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 base-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 2), 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.

REFERENCES

Akerston, W. A., 1970, Interpretation of sediments and vetebrate fossils in fill of Red Light Bolson, southeastern Hudspeth County, Texas, *in* Geology of the southern Quitman Mountain area, Trans-Pecos Texas: Midland, Texas, Permian Basin Section, Soc. Econ. Paleontologists and Mineralogists Guidebook, Publ. 70-12, p. 82-87.

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

Belcher, R. C., 1975, The geomorphic evolution of the Rio Grande (M.S. thesis): Waco, Texas, Baylor University, 210 p.

Berggren, W. A., and Van Couvering, J. A., 1974, The late Neogene; biostratigraphy, geochronology, and paleoclimatology of the last 15 million years in marine and continental sequences: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 16, nos. 1 & 2, 216 p.

Birkeland, P. W., Crandell, D. R., Richmond, G. M., 1971, Status of correlation of Quaternary stratigraphic units in the western conterminous United States: Quaternary Research, v. 1, p. 208-227.

Birkeland, P. W., and Shroba, R. R., 1974, The status of Quaternary soil-forming intervals in the western United States, *in* Quaternary Environments: Toronto, York Univ. Geographical Monograph 5, p. 241-275.

Boellstorff, John, 1973, Fission-track ages of Pleistocene volcanic ash deposits in the central plains, U.S.A.: Isochron/West, No. 8, p. 39-43.

Brand, D. B., 1937, The natural landscape of northwestern Chihuahua: Univ. New Mex. Bull. Geol. Ser., v. 5, 74 p.

Broecker, W. S., and van Donk, J., 1970, Insolation changes, ice volumes, and the O^{18} recorded in deep sea cores: Rev. Geophysics and Space Phys., v. 8, p. 169-189.

Bryan, Kirk, 1938, Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico, *in* Rio Grande Joint Investigations in the upper Rio Grande basin in Colorado, New

Mexico, and Texas: Washington, D.C., Nat. Res. Comm., Regional Planning, Pt. 6, p. 196-225.

Christiansen, R. L., and Blank, H. R. Jr., 1972, Volcanic stratigraphy of the Quaternary rhyolite plateau in Yellowstone National Park: U.S. Geol. Survey Prof. Paper 729-B, 18 p.

Cooke, H. B. S., 1973, Pleistocene chronology: Long or short: Quaternary Res., v. 3, p. 206-220.

Dalrymple, G. B., 1972, Potassium-argon dating of geomagnetic reversals and North American glaciations, *in* Calibration of homininoid evolution, recent advances in isotopic and other dating methods applicable to the origin of man: New York Wenner-Gran Foundation for Anthropological Research, p. 107-134.

Davie, William Jr. and Spiegel, Zane, 1967, Geology and water resources of Las Animas Creek and vicinity, Sierra County, New Mexico: Santa Fe, New Mexico State Engr., Hydrographic Survey Rept., 44 p.

Doell, R. R., Dalrymple, G. B., Smith, R. L., and Bailey, R. A., 1968, Paleomagnetism, potassium-argon ages, and geology of rhyolites and associated rocks of the Valles Caldera, New Mexico, *in* Studies in Volcanology-a memoir in honor of Howell Williams: Geol. Soc. America Mem. 116, p. 211-248.

Evernden, J. F., and Evernden, R. K. S., 1970, The Cenozoic time scale, *in* Radiometric Dating and Paleontologic Zonation: Geol. Soc. America Spec. Paper 124, p. 71-90.

Fairbridge, R. W., 1972, Climatology of a glacial cycle: Quaternary Res., v. 2, p. 283-302.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., 534 p.

Freeman, C. E., 1972, Pollen study of some Holocene alluvial deposits in Dona Ana County, southern New Mexico: Texas Jour. Sci., v. 24, p. 203-220.

Frye, J. C., and Willman, H. B., 1962, Morphostratigraphic units in Pleistocene stratigraphy: Am. Assoc. Petroleum Geol. Bull., v. 46, p. 112-113.

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., Grossman, R. B., and Hawley, J. W., 1969, Effects of landscape dissection on soils near University Park, New Mexico: Soil Science, v. 108, p. 273-282.

Gile, L. H., Hawley, J. W., and Grossman, R. B., 1970, Distribution and genesis of soils and geomorphic surfaces in a desert region of southern New Mexico: Guidebook, Soil Sci. Soc. Amer. Soil-Geomorphology Field Conf., Las Cruces, NMSU Agronomy Dept., 156 p.

Gray, R. S., 1967, Petrography of the upper Cenozoic non-marine sediments in the San Pedro Valley, Arizona: Jour. Sed. Pet., v. 37, p. 774-789.

Groat, C. G., 1972, Presidio Bolson, Trans-Pecos Texas and adjacent Mexico: geology of a desert basin aquifer system: Texas Bur. Econ. Geology Rept. Inv. 76.

Hawley, J. W., 1965, Geomorphic surfaces along the Rio Grande Valley from El Paso, Texas to Caballo Reservoir, New Mexico, *in* Southwestern New Mexico II: New Mex. Geol. Soc. Guidebook 16, p. 188-198.

----, 1969, Notes on the geomorphology and late Cenozoic geology of northwestern Chihuahua, *in* The Border Region: New Mex. Geol. Soc. Guidebook 20, p. 131-142.

----, 1972, Geologic-geomorphic mapping to serve soil-resource development: Ankeny, Iowa, Soil Conservation Soc. America, 27th Ann. Meeting Proc., p. 24-30.

-------, and Kottlowski, F. E., 1969, Quaternary geology of the south-central New Mexico border region, *in* Border Stratigraphy Symposium: New Mex. Bur. Mines and Min. Res. Circ. 104, p. 89-115.

, 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, *in* Border Stratigraphy Symposium: New Mex. Bur. Mines and Min. Res. Circ. 104, p. 52-76.

Haynes, C. V. Jr., 1968a, Geochronology of late Quaternary alluvium, *in* Means of Correlation of Quaternary Succession: I NQUA VII Congress Proc., v. 8, Salt Lake City, University of Utah Press, p. 591-631.

– 1968b, Preliminary report on the late Quaternary geology of the San Pedro Valley, Arizona: Tucson, Arizona Geol. Soc., Southern Ariz. Guidebook III, p. 79-96.

Hibbard, C. W., and Dalquest, W. W., 1973, *Proneofiber,* a new genus of vole (Cricetidae: Rodentia) from the Pleistocene Seymour Formation of Texas, and its evolutionary and stratigraphic significance: Quaternary Res., v. 3, p. 269-274.

Hibbard, C. W., Ray, D. E., Savage, D. E., Taylor, D. W., and Guilday, J. E., 1965, Quaternary mammals of North America, *in* The Quaternary of the United States: Princeton, N.J., Princeton Univ. Press, p. 509-525.

Hoffer, J. M., 1971, Mineralogy and petrology of the Santo Tomas-Black Mountain basalt field, Potrillo volcanics, south-central New Mexico: Geol. Soc. America Bull., v. 82, p. 603-612.

Hunt, C. B., 1974, Natural regions of the United States and Canada: San Francisco, Freeman and Co., 725 p.

Izett, G. A., and Wilcox, R. E., Powers, H. A., and Desborough, G. A., 1970, The Bishop ash bed, a Pleistocene marker bed in the western United States: Quaternary Res., v. 1, p. 121-132.

Izett, G. A., Wilcox, R. E., and Borchardt, G. A., 1972, Correlation of a volcanic ash bed in Pleistocene deposits near Mount Blanco, Texas, with the Guaje Pumice Bed of the Jemez Mountains, New Mexico: Quaternary Res., v. 2, p. 554-578.

Johnson, N. M., Opdyke, N. P., and Lindsay, E. H., 1975, Magnetic polarity stratigraphy of Pliocene-Pleistocene terrestrial deposits and vertebrate faunas, San Pedro Valley, Arizona: Geol. Soc. America Bull., v. 86, p. 5-12.

Jones, B. R., and Reaser, D. F., 1970, Geology of southern Quitman Mountains, Hudspeth County, Texas: Texas Univ. Bur. Econ. Geol. Quad. Map No. 39, with text.

King, P. B., 1937, Geology of the Marathon region, Texas: U.S. Geol. Survey Prof. Paper 215, 183 p.

Kottlowski, F. E., 1958, Geologic history of the Rio Grande near El Paso, *in* Franklin and Hueco Mtns., Texas: West Texas Geol. Soc. Guidebook, p. 46-54.

Kukla, G. J., Matthews, R. K., and Mitchell, J. M., eds., 1972, The present interglacial: how and when will it end?: Quaternary Res., v. 2, p. 261-445.

Lifshitz-Roffman, Haia, 1971, Natural and experimental weathering of basalts (Ph.D. dissert.): Socorro, New Mexico Inst. Mining and Technology, 123 p.

Metcalf, A. L., 1967, Late Quaternary mollusks of the Rio Grande Valley; Caballo Dam, New Mexico, to El Paso, Texas: El Paso, Texas Western Press, Scientific Ser. No. 1, El Paso, 62 p.

----, 1969, Quaternary surfaces, sediments, and mollusks: southern Mesilla Valley, New Mexico and Texas, *in* The Border Region: New Mex. Geol. Soc. Guidebook 20, p. 158-164.

Naeser, C. W., Izett, G. A., and Wilcox, R. E., 1973, Zircon fission-track ages of Pearlette family ash beds in Meade County, Kansas: Geology, v. 1, no. 4, p. 187-189.

Reeves, C. C. Jr., 1969, Pluvial Lake Palomas, northwestern Chihuahua, Mexico, *in* The Border Region: New Mex. Geol. Soc. Guidebook 20, p. 143-154.

Reynolds, R. L., and Larsen, E. E., 1972, Paleomagnetism of Pearlette-like air-fall ash in the midwestern and western United States: a means of correlating Pleistocene deposits: Geol. Soc. America Abs. with Programs (Rocky Mountain Sec.), v. 4, no. 6, p. 405.

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

----, 1967, Geomorphic surfaces and surficial deposits in southern New Mexico: New Mex. Bur. Mines and Min. Res. Mem. 18, 65 p.

Sanford, A. R., Budding, A. J., Hoffman, J. P., Alptekin, 0. S., Rush, C. A., and Toppozada, T. R., 1972, Seismicity of the Rio Grande rift in New Mexico: New Mex. Bur. Mines and Min. Res. Circ. 120, 19 p.

Savage, D. E., 1951, Late Cenozoic vertebrates of the San Francisco Bay region: California Univ. Pubs. Geol. Sci., v. 28, p. 215-314.

----, and Curtis, G. H., 1970, The Villafranchian Stage-age and its radiometric dating, *in* Radiometric Dating and Paleontologic Zonation: Geol. Soc. America Spec. Paper 124, p. 207-231.

Schumm, S. A., 1965, Quaternary paleohydrology: *in* The Quaternary of the United States: Princeton, N.J., Princeton Univ. Press, p. 783-794.

Seager, W. R., and Hawley, J. W., 1973, Geology of Rincon quadrangle, New Mexico: New Mex. Bur. Mines and Min. Res. Bull. 101, 42 p.

----, Clemons, R. E., and Hawley, J. W., 1975, Geology of Sierra Alta quadrangle, New Mexico: New Mex. Bur. Mines and Min. Res. Bull. 102, 56 p.

----, Hawley, J. W., and Clemons, R. E., 1971, Geology of San Diego

Mountain area, Dona Ana County, New Mexico: New Mex. Bur. Mines and Min. Res. Bull. 97, 38 p.

Smith, R. L., and Bailey, R. A., 1968, Resurgent cauldrons, *in* Studies in Volcanology—a memoir in honor of Howell Williams: Geol. Soc. America Mem. 116, p. 613-662.

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

----, 1969, Late Cenozoic strata of the El Paso area, *in* Border Stratigraphy Symposium: New Mex. Bur. Mines and Min. Res. Circ. 104, p. 122-123.

----, 1970, Late Cenozoic bolson integration in the Chihuahua tectonic belt, *in* The Geologic Framework of the Chihuahua Tectonic Belt: West Texas Geol. Soc. Pub. 71-59, p. 167-173.

Suggate, R. P., 1974, When did the last interglacial end?: Quaternary Res., v. 4, p. 246-252.

Thornbury, W. D., 1965, Regional geomorphology of the United States: New York, John Wiley and Sons, Inc., 609 p.

U.S. Reclamation Service, 1914, Maps of Mesilla Valley showing various known river channels, Rio Grande Project, New Mexico-Texas: U.S. Dept. of Interior, Bur. of Reclamation.

Wood, H. E., Chaney, R. W., Clark, J., Colbert, E. J., Jepsen, G. L., Reeside, J. B. Jr., and Stock, C., 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, p. 1-48.