Summary Report for the El Paso, Texas, STATEMAP Project, 1996

by

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The El Paso STATEMAP project has focused on mapping the El Paso/Rio Grande Border Area in far west Texas. Geologic mapping is critical in this area because of the pressures of development, exploitation of natural resources, and degradation of the environment by increased industrialization. In addition, the North American Free Trade Agreement (NAFTA) is stimulating additional growth in this area. El Paso is growing rapidly northward along the flanks of the Franklin Mountains and eastward along the Rio Grande valley, the valley border margins, and the Hueco Bolson floor paralleling Interstate Highway 10 and U.S. Highway 62/184. Much of the land north of U.S. Highway 62/184 is Fort Bliss military land and, thus, unavailable for urbanization.

This third and final year of 1:24,000-scale geologic mapping of the El Paso, Texas, region resulted in the completion of 11 quadrangles (fig. 1). The completed Canutillo and Smeltertown quadrangles cover an area that extends westward from the west part of the Franklin Mountains to the Rio Grande. The Padre Canyon, TP Well, and Whiterock Hills quadrangles encompass the south edge and foothills of the Hueco Mountains and the northeast margins of the basin floor. The Isla, Tornillo, Fort Hancock NW, Acala, McNary, and Esperanza quadrangles contain the basin floor and Rio Grande valley and valley border.

This report summarizes the entire 29-quadrangle area mapped over the past 3 yr (fig. 1). Appendix A describes the stratigraphy of the mapped area in detail. Previously published geologic maps of the region, which are mostly of mountainous bedrock, have either highly generalized the areas or ignored the basins entirely. These maps are neither on accurate topographic base maps, nor are they at scales appropriate enough to impact developmental or remedial projects associated with the region's growing population. Published maps include a regional map of west Texas (Dietrich and others, 1968), a regional map of the Franklin

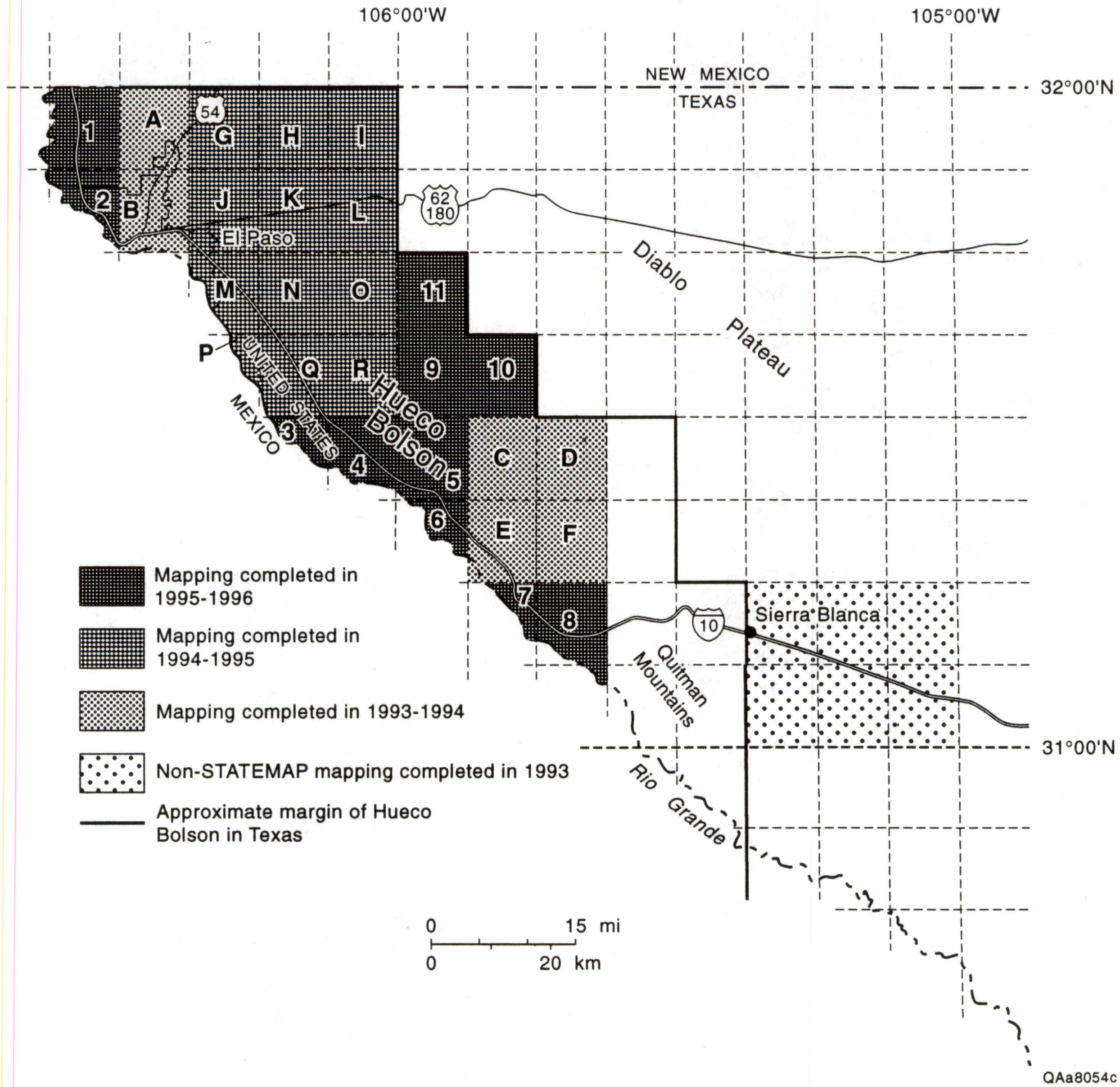

Figure 1. Diagram showing mapped areas. Numbers 1 through 11 and letters A through R correspond to quadrangle names listed in table 1.

Table 1. Names of 7.5-minute quadrangles completed for 1995–1996 mapping (1–11) and STATEMAP maps previously completed during 1993–1995. Map locations shown in figure 1.

1995–1996 Mapping	1993–1995 Mapping
1. Canutillo	A. North Franklin Mountain
2. Smeltertown	B. El Paso
3. Isla	C. Cavett Lake
4. Tornillo	D. Diablo Canyon West
5. Fort Hancock NW	E. Fort Hancock
6. Acala	F. Campo Grande Mountain
7. McNary	G. Fort Bliss NE
8. Esperanza	H. Nations East Well
9. TP Well	I. Hueco Tanks
10. Whiterock Hills	J. Fort Bliss SE
11. Padre Canyon	K. Nations South Well
	L. Helms West Well
	M. Ysleta
	N. Clint NW
	O. Clint NE
	P. San Elizario
	Q. Clint
	R. Clint SE

Mountains (Richardson, 1909), a map of the northern Franklin Mountains (Harbour, 1972), maps of the Hueco Mountains (King and others, 1945) and southern Hueco Mountains (Beard, 1983), a map of the Campo Grande Fault area (Collins and Raney, 1990), and a map that partly coincides with the southeast study area near the Finlay Mountains, McNary, and Esperanza (Albritton and Smith, 1965). Other maps include numerous unpublished theses maps, an unpublished map of the southern Franklin Mountains by Lucia (1989), and page-sized maps at various scales in published reports such as Sayre and Livingston (1945), Strain (1966), Lovejoy (1971, 1975, 1976), Kufal (1977), Seager (1980), Henry and Gluck (1981), LeMone (1982, 1988), Machette (1987), Dyer (1989), and Stacy and others (1992). Unpublished theses maps of parts of the Franklin Mountains were done by McAnulty (1967), Dye (1970), Garcia (1970), Kadhi (1970), Thomson (1974), Thomann (1980), Figuers (1987), and Stacy (1991). Wise (1977) completed an unpublished thesis map of the Hueco Tanks area. Theses maps illustrating the occurrence of the Fort Hancock and Camp Rice basin-fill units within Arroyo Diablo and Madden Arroyo were done by Willingham (1980) and Riley (1984).

Previous studies of different stratigraphic aspects of the region are numerous, and some are cited below. Appendix A describes the stratigraphy of the mapped area in detail. Data on the bedrock stratigraphy was compiled from previous studies by Richardson (1909), King and others (1945), Albritton and Smith (1965), Harbour (1972), Thomann (1980), LeMone (1982, 1988), LeMone and Simpson (1982), Beard (1983), and Kelley and Matheny (1983). Data on the Pliocene to Pleistocene basin-fill units, the Fort Hancock and Camp Rice Formations, were compiled from Albritton and Smith (1965), Strain (1966, 1971), Cliett (1969) Willingham (1980), Stuart and Willingham (1980), Riley (1984), Vanderhill (1986), and Gustavson (1991). Description of the Pleistocene to Holocene surficial deposits is recent work by the authors. Mapping and description of the surficial deposits was greatly influenced by previous studies by Albritton and Smith (1965) of the southeast part of the Hueco Basin and studies by Gile and others (1981) of nearby southern New Mexico. We also benefited from (1) the many articles within the Permian Basin Section, Society of Economic Paleontologists and Mineralogists, Field

Conference Guidebook (Meader-Roberts, 1983) that describe different aspects of the geology of the southern Hueco Mountains and (2) the articles concerning the Franklin Mountains in the El Paso Geological Society Quinn Memorial Volume (LeMone and Lovejoy, 1976), West Texas Geological Society guidebooks (West Texas Geological Society, 1968, 1982), and a Permian Basin Section—SEPM—Guidebook (Candelaria and Reed, 1992).

Geologic Setting

The Hueco Bolson (fig. 2) is an extensional basin that may be the continuation of the Rio Grande Rift in Texas. Extension, which continues to the present, is thought to have begun 24 to 30 mya. Surrounding the basin are mountains and highlands in which Precambrian to Tertiary rocks are exposed. The basin is bounded on the east and northeast by the Diablo Plateau and the Malone and Quitman Mountains. The Diablo Plateau is underlain by nearly flatlying Cretaceous and older marine sedimentary rocks. Laramide-deformed Cretaceous and older rocks are present outside the map area in the Malone and Quitman Mountains and in the ranges in Mexico that lie southwest of the Rio Grande. Within the southeast part of the map area small, Laramide-deformed, Cretaceous bedrock hills that rise above the basin floor indicate that the leading edge of the Laramide thrust plate lies beneath the younger basin-fill deposits between the Laramide-deformed bedrock hills and the Diablo Plateau rim. The basin-fill sediments in outcrop are as old as the Pliocene, but they extend to depths of more than 2,500 m (>8,200 ft) in the subsurface, where they are of unknown age. The basin-fill sediments reflect the development of the Rio Grande, the international border between Texas and Mexico, and ancestral drainage systems that preceded the modern Rio Grande. Periods of stability and downcutting are recorded in the series of terraces and soils that are well exposed locally in the basin. The southwest portion of the Hueco Bolson lying in Mexico is not part of the STATEMAP project.

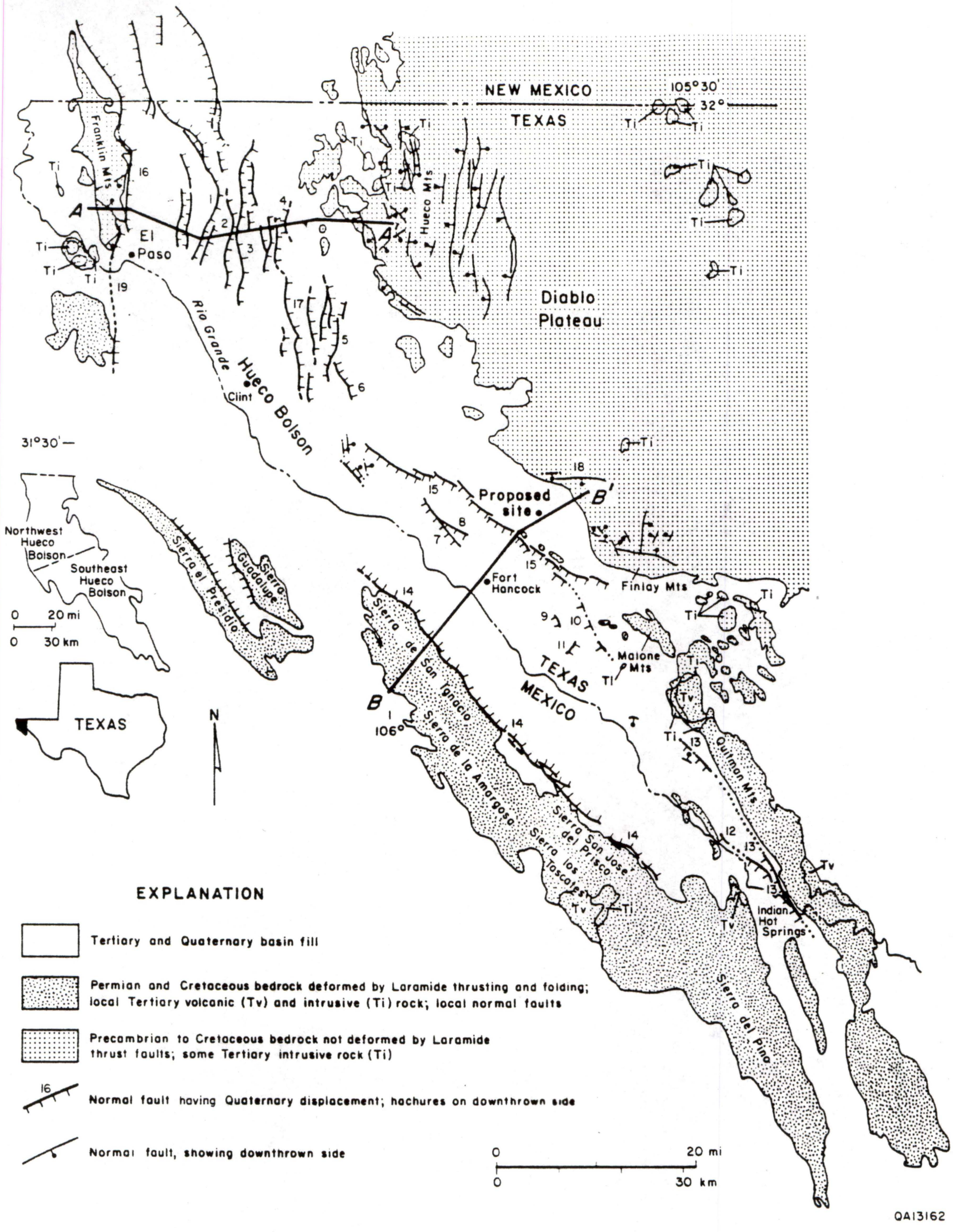

Figure 2. Geologic setting of the El Paso Study Area and the Hueco Bolson. Cross sections A–A′ and B–B′ and field stations at Quaternary faults refer to Collins and Raney (1991).

Franklin Mountains

The Franklin Mountains (relief as great as 820 m [2,700 ft]) bound the west edge of the northwest Hueco Bolson. El Paso lies at the south margin of the mountains, and urban growth is expanding rapidly northward along the flanks of the mountains. The mountain range is a west-dipping, tilted fault block that trends northerly. A relatively continuous stratigraphic section of Precambrian through Permian rocks that are locally intruded by Tertiary igneous rocks is present in the Franklin Mountains. Quaternary alluvial-fan deposits have built off the edge of the mountains into the Hueco basin to the east and into the Mesilla basin to the west. Tertiary to Quaternary basin-fill alluvial fan and fluvial deposits are not commonly well exposed along the east margins of the Franklin Mountains, although they are better exposed in arroyos at the west margin of the range that drain into the Rio Grande. The stratigraphy of the area is described in appendix A. Strata within the range are cut by faults that strike north, northeast, and northwest. These faults may predate the range-bounding faults that represent the latest episode of range uplift and tilting. The range is bounded on the east by a distinct, north-striking Quaternary fault, the East Franklin Mountains fault, which crosses the El Paso and North Franklin Mountain quadrangles. The fault cuts middle Pleistocene and upper Pleistocene deposits, the most recent surface rupture probably occurring during early Holocene time. Scarps commonly have compound-slope angles, and the steepest slope angles are between 13° and 23°. Multiple-rupture events have caused older Quaternary surfaces to be offset more than younger surfaces, and scarp heights generally range between 39 and 5.5 m [128 and 18 ft] because of the different ages of the faulted Quaternary surfaces along the fault trace.

Hueco Mountains

The east margins of the northwest Hueco Bolson are bounded by the Hueco Mountains (relief as great as 270 m [885 ft]) and its foothills. Only the west and south parts of the Hueco Mountains are within the map area. Similar to the Franklin Mountains, bedrock stratigraphy of the area records a long geologic history (appendix A). Precambrian granite locally crops out at the south margin of the mountains and foothills. Lower Ordovician–Upper Cambrian (?) Bliss sandstone is overlain by Lower Ordovician El Paso Group limestone, dolomitic limestone, and dolostone. Upper and Middle Ordovician Montoyo Group limestone and dolomitic limestone overlie the El Paso Group and are overlain by the Silurian Fusselman Dolomite. Devonian Percha Shale and Canutillo Formation bedded chert, limestone, and marl crop out locally. Mississippian Helms Formation and Rancheria Formation limestone, sandy limestone, and shale are well exposed. Pennsylvanian Magdalena Group limestone, marl, and shale overlie Mississippian deposits and are at angular unconformity with overlying Permian Hueco Group conglomerate, limestone, dolomitic limestone, marl, and shale. Tertiary intrusive rocks in the area, mostly syenite to monzonite of the Hueco Tanks region, were intruded about 35 mya as sills and dikes. Northwest-striking and north-striking normal faults cut bedrock. Broad, northwest-trending folds are expressed within the bedrock strata. Localized folding related to sill emplacement has also occurred. Limestone is actively being quarried for crushed stone and cement along the flanks of the Hueco Mountains. Alluvial fan and drainageway alluvium composes the piedmont deposits shed from the Hueco Mountains. Bedrock foothills surrounded by alluvium are common at the basin margin.

Diablo Plateau Rim and Western Finlay Mountains

The southeast Hueco Bolson is bounded on the northeast by the Diablo Plateau (relief as great as ~200 m [~650 ft]) and Finlay Mountains (relief as great as 340 m [1,100 ft]). The map area includes the Diablo Plateau rim and the western Finlay Mountains. The Finlay Mountains consist of two broad structural domes having radiating dikes and sills. The domes probably formed as laccolithic intrusives. K-Ar ages of some Finlay Mountain intrusions range between about 46 and 50 m.y. (Matthews and Adams, 1986). Permian limestone and marl and Cretaceous limestone, marl, and sandstone of the Campagrande, Cox, and Finlay Formations (appendix A) dip as much as ~20° away from the central domal area. Cox and Finlay strata are also exposed along the Diablo Plateau rim. Outcrops of Campagrande strata locally occur along the plateau rim near the Hueco Mountains. A gentle monocline strikes northwestward along the plateau rim and basin margin. Strata along the monocline dip mostly ~5° to 7° southwestward. The monocline may have initially developed during the late Cretaceous–early Tertiary Laramide deformation that deformed strata of this region; the monocline was possibly reactivated during the younger Cenozoic extensional deformation, which resulted in the development of the Hueco Bolson. Alluvial fan and drainageway alluvium composes the piedmont deposits shed from the Finlay Mountains and Diablo Plateau.

Hueco Bolson Piedmont and Basin Floor

The piedmont area of the basin contains surficial deposits of alluvial fans and incised alluvial fans of the upper piedmont slope near the higher relief bedrock areas and surficial deposits of mostly coalesced–alluvial fans of the lower piedmont slope (appendix A). The older alluvial deposits contain a K soil horizon that is a 0.7- to 1.5-m-thick (2.3- to 5-ft-thick) stage IV to V calcrete. The K horizon suggests that these deposits are as old as middle Pleistocene. Calcic soils of younger alluvial deposits exhibit progressively decreased development (appendix A). The alluvial deposits overlie older basin-fill deposits of the Pliocene–middle Pleistocene Camp Rice Formation and the Pliocene Fort Hancock Formation (appendix A). Windblown sand commonly covers the piedmont alluvium.

The basin floor area mostly contains windblown sand deposits that overlie Pliocene–middle Pleistocene Camp Rice sand and gravel and lesser amounts of silt and clay and Fort Hancock lacustrine clay, bedded gypsum, and silt and lesser amounts of alluvial fan and fluvial gravel, sand, silt, and clay. Fort Hancock deposits represent lacustrine and associated deposition in a bolson setting. Camp Rice deposits represent a system of dominant fluvial and alluvial-fan deposition, along with some floodplain and minor lacustrine deposition. Lower Camp Rice deposits include reworked Fort Hancock sediments. Within the basin floor area, the top of the Camp Rice is capped by a well-developed stage IV–V pedogenic calcrete. Older alluvial-fan deposits at the basin margins may be nearly time equivalent to the uppermost Camp Rice deposits. Some coalesced-alluvial-fan deposits that are shed from the highlands across the piedmont may extend onto the basin floor area. Fluvial and lacustrine basin-fill deposits and deposits of piedmont alluvial fans and arroyo terraces are well exposed locally within the large arroyos that have incised into the basin floor and piedmont of the southeast part of the map area.

Windblown sand deposits that overlie basin-fill deposits appear mostly to be less than 2 to 3 m (<6 to 10 ft) thick, although at one abandoned sand quarry, the eolian sand was more than 8 m (>26 ft) thick. Coppice dunes, interdune sheet deposits, and deflation areas are common. At the east margin of the Hueco Bolson, local areas of active sand dunes and areas of partly vegetated, stabilized to partly stabilized dunes are present.

Within the northwest Hueco Bolson, the basin floor and piedmont contain a series of north-trending sand-covered scarps that may be fault related. In the southeast Hueco Bolson some northwest-trending sand-covered scarps and the uncovered, southeast scarp of the Campo Grande fault cut the basin floor and piedmont. The Campo Grande fault is the major graben-bounding Quaternary fault on the northeast side of the basin. This Quaternary fault displaces middle and early upper Pleistocene deposits as much as 10 m (32 ft) and 3 m (10 ft), respectively, although younger upper Pleistocene deposits are not displaced. This fault has scarps that are between 1.5 and 11.5 m (5 and 38 ft) high. Scarp slopes range between 4° and 17°.

Rio Grande Valley and Valley Border

The Rio Grande valley and valley border consist of the Rio Grande floodplain and remnant terraces that have been incised into the older basin-fill deposits (appendix A). The older basin-fill deposits, composing Fort Hancock and Camp Rice sediments, and the remnant terraces are commonly covered by windblown sand. Fan deposits at the mouths of arroyos and smaller drainageways that drain into the river valley also exist. Alluvium associated with the remnant terraces and fans along the valley border are thin. Observations of the calcic soil development and stratigraphic position of these deposits were used to subdivide the Quaternary valley border stratigraphy (appendix A). Alluvium of the Rio Grande floodplain is commonly cultivated where it is not urbanized. Sand and gravel quarries mining the relatively uncemented Camp Rice deposits and the caliche capping them are common along the valley border rim.

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APPENDIX A: EXPLANATION OF GEOLOGIC UNITS

Acala, El Paso, Campo Grande Mountain, Canutillo, Cavett Lake,
Clint, Clint NE, Clint NW, Clint SE, Diablo Canyon West, Esperanza,
Fort Bliss NE, Fort Bliss SE, Fort Hancock, Fort Hancock NW,
Helms West Well, Hueco Tanks, Isla, McNary, Nations East Well,
Nations South Well, North Franklin Mountain, Padre Canyon,
San Elizario, Smeltertown, TP Well, Tornillo, Whiterock Hills,
Ysleta, and Ysleta NW Quadrangles,
El Paso region, West Texas

QUATERNARY

Holocene–Late Pleistocene

Qws—Windblown sand. Coppice dunes, commonly 0.5 to 2.0 m (1.6 to 6.5 ft) high, and interdune sheet deposits; deflation areas common. May include local, undifferentiated areas of (1) active dunes **(Qwsd)**, (2) stabilized to partly stabilized dunes that are partly vegetated **(Qws2)**, and (3) local drainageway alluvium.

Qws2—Windblown sand area of partly vegetated, stabilized to partly stabilized dunes. Contains local areas of active sand dunes **(Qwsd).** Includes coppice dunes and interdune sheet deposits and deflation areas, similar to Qws areas; aerial photograph expression is more patchy/spotty than adjacent areas of Qws; commonly higher and more irregular topography than adjacent areas of Qws. May represent stabilized dune fields that formed at east side of Hueco Bolson and within the margins of the Rio Grande valley.

Qwsd—Active sand dunes. Areas of active sand dunes that are as much as 3 m (10 ft) high having sparse to no vegetation. Active sand dune areas are located within larger areas of stabilized to partly stabilized dunes that are partly vegetated **(Qws2).**

Qac—Slope-wash alluvium and/or colluvium. Commonly covers basin-fill deposits (QTcr, Tfh) and younger, surficial, alluvial-fan deposits, (Qf1,2,3,4) along arroyos, piedmont, and Rio Grande valley border; covers bedrock and basin-fill deposits along the margins of mountains and Diablo Plateau.

Qarg—Alluvium of Rio Grande floodplain. Sand, silt, clay, and gravel; commonly cultivated; urbanized in and near El Paso; locally covered by undifferentiated windblown sand (Qws).

Qa—Undivided alluvium of drainageways, young fans (Qf4), and young arroyo terraces (Qt4). Sand, silt, gravel, and clay; gravel locally derived. Includes undifferentiated young deposits in relatively active settings and deposits in more stable settings that contain stage I to II BK horizons. Possibly includes local undifferentiated older alluvium and younger windblown sand. May overlie or be inset against older deposits.

Qavb—Undivided alluvium of drainageways, young fans, and young arroyo terraces located along the Rio Grande valley border. Sand, gravel, silt, and clay; includes locally derived and exotic gravel. Includes undifferentiated young deposits in relatively active settings and deposits in more stable settings that contain I to II BK horizons. May include local undifferentiated older terrace or fan alluvium, small outcrops of older QTcr or Tfh, and younger windblown sand. May overlie or be inset against older deposits.

Qf4—Alluvium of young fans. Sand, gravel, silt, and clay; gravel locally derived. Includes deposits that have stage I to II BK horizons. Possibly includes local, undifferentiated drainageway alluvium, older alluvium, and windblown sand. May overlie or be inset against older deposits. Commonly <1 m to several meters thick.

Qt4—Alluvium of young terraces along large arroyos. Sand, gravel, silt, and clay; gravel locally derived. Includes deposits that have stage I to II BK horizons. Locally may include more than one terrace having similar soil characteristics. May include local undifferentiated drainageway alluvium and windblown sand. Inset against older deposits.

Qt4rg—Alluvium of young terraces and fans along the Rio Grande valley border. Sand, gravel, silt, and clay; includes locally derived and exotic gravel. Includes deposits that have stage I to II BK horizons. Locally may include more than one terrace having similar soil characteristics. May overlie or be inset against older deposits.

Qf3-4—Undivided Qf3 and Qf4 alluvium.

Qt3-4—Undivided Qt3 and Qt4 alluvium.

Late Pleistocene Deposits

Qf3—Piedmont alluvium of alluvial fans, incised alluvial fans, and bajadas. Sand, gravel, silt, and clay; gravel locally derived. Commonly contains stage III BK horizon, <0.5 m (<1.6 ft) thick. Commonly <1 m to several meters thick. May overlie or be inset against older deposits. Locally covered by younger drainageway alluvium and windblown sand. May include small deposits of older alluvium cropping out along drainageways.

Qt3—Alluvium of terraces within large arroyos. Sand, gravel, silt, and clay; gravel locally derived. Commonly contains stage III BK horizon, <0.5 m (<1.6 ft) thick. Locally may include more than one terrace having similar soil characteristics. Inset against older deposits. Locally covered by younger drainageway alluvium and windblown sand.

Qt3rg—Alluvium of terraces and alluvial fans located along Rio Grande valley border. Sand, gravel, silt, and clay; includes locally derived and exotic gravel. Commonly contains stage III BK horizon, <0.5 m (<1.6 ft) thick. Locally may include more than one terrace having similar soil characteristics. May overlie or be inset against older deposits. Locally covered by undifferentiated younger drainageway alluvium and windblown sand.

Late Pleistocene to Middle Pleistocene

Qf2—Piedmont gravel and sand alluvium of alluvial fans, incised fans, and bajadas. Sand, gravel, silt, and clay; includes locally derived gravel. Commonly contains stage IV K horizon calcrete, 0.2 to 1.0 m (0.6 to 3.0 ft) thick. Commonly as much as several meters thick. May overlie or be inset against older deposits. Locally covered by undifferentiated younger alluvium and windblown sand.

Qt2—Alluvium of terraces along large arroyos. Sand, gravel, silt, and clay; gravel locally derived. Commonly contains stage IV K horizon calcrete, 0.2 to 1.0 m (0.6 to 3.0 ft) thick. Locally may include more than one terrace having similar soil characteristics. Inset against older deposits. Locally covered by undifferentiated younger alluvium and windblown sand.

Qtrg2—Alluvium of terraces and alluvial fans along Rio Grande valley border. Sand, gravel, silt, and clay. Includes locally derived gravel and exotic gravel. Commonly contains stage IV K horizon calcrete, 0.2 to 1.0 m (0.6 to 3.0 ft) thick. Locally may include more than one terrace having similar soil characteristics. May overlie or be inset against older deposits. Locally covered by undifferentiated younger alluvium and windblown sand.

Qf1-2—Undivided Qf1 and Qf2 alluvium.

Qf2-3—Undivided Qf2 and Qf3 alluvium.

Middle Pleistocene

Qf1—Alluvium of alluvial fans, bajadas, and alluvial plains. Sand, gravel, silt, and clay; gravel generally locally derived, local exotic gravel along Rio Grande valley border. Commonly contains stage IV to V K horizon calcrete, 0.7 to 1.5 m (2.3 to 5.0 ft) thick. Locally may be covered by younger alluvium and windblown sand. Northwest of Alamo arroyo along the Rio Grande Valley border, local Qf1 mostly not divided from upper QTcr, and only QTcr mapped. Southeast of Alamo arroyo, undivided Qf1+QTcr mapped. Surface of Qf1 approximately equivalent to Jornada I surface of Mesilla basin, southern New Mexico; locally may be equivalent to La Mesa surface if some Qf1 alluvial deposits are time-equivalent facies of Camp Rice fluvial deposits.

Pleistocene to Pliocene

QTl—Landslide deposits. Does not include probable Crazy Cat landslide (located west of south tip of Franklin Mountains, [Lovejoy, 1976]), which is mapped as bedrock units surrounded by alluvium.

Middle Pleistocene to Pliocene

QTcr—Camp Rice Formation. Sand and gravel; lesser amounts of silt and clay. Represents fluvial, alluvial-fan, floodplain, and minor lacustrine deposition. Constructive depositional surface commonly contains stage V K horizon calcrete, 1.0 to 1.5 m (3.0 to 5.0 ft) thick. Ash at top of unit assigned as 0.6-m.y.-old Lava Creek B ash (Izett, 1981; Izett and Wilcox, 1982; location in El Paso, Texas). Ash in lower part of unit assigned as 2.1-m.y.-old Huckleberry Ridge ash (Izett, 1981; Izett and Wilcox, 1982; locations in Arroyo Diablo and Madden Arroyo, Campo Grande Mountain, Texas Quadrangle). Locally covered by younger alluvium and windblown sand. Upper Camp Rice deposits along valley border may include local, high, undivided, middle Pleistocene Rio Grande terrace deposits (approximately equal in age to Qf1 deposits) that are incised into older QTcr and undivided local middle Pleistocene piedmont fan alluvium (Qf1) that overlies older QTcr. Northwest of Alamo arroyo, **c** indicates calcic soil of upper Camp Rice or unmapped local terrace and fan alluvium (unmapped QF1). Areas mapped as Camp Rice along valley border slopes include small, undivided deposits of younger terrace, fan, and drainageway alluvium. Depositional surface of QTcr equivalent to La Mesa surface of Mesilla basin, southern New Mexico.

Qf1 + QTcr—Undivided Qf1 and QTcr.

Pliocene

Tfh—Fort Hancock Formation. Lacustrine clay, bedded gypsum (southeastern Hueco Bolson), and silt; alluvial-fan gravel, sand, silt, and clay; minor fluvial deposits. Blancan vertebrate fossils. Locally covered by younger alluvium and windblown sand.

Finlay Mountains and Diablo Plateau

TERTIARY

Ti—Undifferentiated intrusive igneous rocks. Dikes and sills of andesite porphyry, hornblende andesite porphyry, and latite porphyry in Finlay Mountains. Many small dikes and sills not shown. K-Ar ages of some Finlay Mountain intrusions range between about 46 and 50 m.y. (Matthews and Adams, 1986).

LOWER CRETACEOUS

Kf—Finlay Formation. Limestone, marl, shale, and sandstone. Gray; abundant marine microfossils and macrofossils. In Finlay Mountains, mostly medium and thin beds and nodular; some thick and massive beds; thin sandstone beds near base; ~61 m (~200 ft) thick. In Diablo Plateau area, mostly limestone along rimrock of plateau; sandstone beds near base; ~53 to 61 m (~175 to 200 ft) thick.

Kcx—Cox Sandstone. Quartz sandstone, conglomerate, limestone, and shale. Mostly quartz sandstone; fine to medium grained, thin to thick bedded, crossbedded, and rippled. Contains silicified wood; some silicified branches and logs several feet long. Fossiliferous limestone common in upper half of unit. Various shades of brown, gray, orange, and pink; ~152 m (~500 ft) thick at Diablo Plateau; ~165 to 206 m (~540 to 675 ft) thick in Finlay Mountains; ~213 to 226 m (~700 to 740 ft) thick at Campo Grande Mountain.

Kb—Bluff Mesa Formation. Limestone and sandstone; some limestone conglomerate and sandy shale. Locally crops out in hills northwest of Campo Grande Mountain on upper Laramide thrust plate of area; basinward facies approximately equivalent to Campagrande Formation (Kca).

Kca—Campagrande Formation. Limestone, marl, conglomerate, sandstone, siltstone, and shale. Interbedded limestone and marl in upper 61 to 76 m (200 to 250 ft); thin to thick beds;

gray. Lower part interbedded sandstone, fossiliferous limestone, siltstone, sandy shale, and limestone and chert conglomerate; ~114 m (~375 ft) thick in northwest Finlay Mountains; ~244 m (~800 ft) thick in southwest Finlay Mountains.

PERMIAN

Pl—Limestone, Leonard Series.

Pm—Marl and limestone, Leonard Series.

Franklin Mountains

TERTIARY

Ti—Undivided intrusive rocks. Includes Campus Andesite west of Crazy Cat Mountain and other andesite intrusions west of mountains; felsite dikes and sills unmapped in mountain range. K-Ar age of Campus Andesite intrusion ~48 m.y. (Hoffer, 1970; Henry and others, 1986).

CRETACEOUS

K—Undivided Cretaceous strata. Mostly limestone and marl.

PERMIAN

Ph—Hueco Group. Limestone, dolomitic limestone to dolostone, siltstone, shale; thin to thick bedded; generally light gray; ~670 m (~2,200 ft) thick.

PENNSYLVANIAN

Magdalena Group

lPmps—Panther Seep Formation. Argillaceous limestone, gypsum beds, silty shale, chert-pebble conglomerate. Conglomerate marks base of unit; gypsum beds 2 to 12 m (6.5 to 39 ft) thick; generally forms gentle slopes; ~360 m (~1,180 ft) thick.

lPmbc—Bishop Cap Formation. Shale, limestone. Composed primarily of poorly exposed shale along with some thin, resistant beds of limestone; ~194 m (~636 ft) thick.

lPmb—Berino Formation. Limestone, shale. Composed primarily of alternating limestone and shale units ~0.6 to 6 m (~2 to 20 ft) thick; shale dominates base of unit; ~21 m (~70 ft) of massive, resistant limestone at top of unit. Common fossils include mollusks, brachiopods, corals, bryozoans, and fusulinids. Total thickness ~137 m (~448 ft).

lPml—La Tuna Formation. Limestone. Cherty; massive limestone beds at base; shale interbeds increase upward and unit more thinly bedded upward. Resistant to weathering; forms cliffs. Common fossils include silicified corals, brachiopods, crinoids, mollusks, bryozoans; some petrified wood; ~85 m (~280 ft) thick.

MISSISSIPPIAN

Mh—Helms Formation. Shale, some limestone. Shale calcareous and gray. Limestone locally oolitic; contains traces of quartz sand; commonly <0.3 m (<1 ft) thick. Limestone interbeds as thick as 1 m (3 ft) more common in upper part of unit. Fossils include brachiopods, gastropods, ostracodes, crinoids, and bryozoans; ~46 to 70 m (~150 to 230 ft) thick; thins northward.

Mrl—Undivided Rancheria and Las Cruces Formations. Rancheria Formation; limestone, some siltstone and shale. Lower part mostly cherty limestone, along with some siltstone and shale interbeds; ~40 m (~130 ft) thick; limestone beds as thick as 0.6 m (2 ft); siltstone and shale beds as thick as 2 m (7 ft). Middle part black limestone; 8.5 to 12.8 m (28 to 42 ft) thick; forms light-gray band in weathered hillsides. Upper part limestone containing siltstone and shale near the top; limestone black, cherty, and sandy; ~61 to 70 m (~200 to 230 ft) thick. Las Cruces Formation; limestone. Evenly bedded; beds ~0.3 to 0.6 m (~1 to 2 ft) thick; mostly chert free; weathers white to light gray and commonly forms distinct band at the base of ledgy cliffs; ~15 to 27.5 m (~50 ft to 90 ft) thick.

DEVONIAN

Dpc—Undivided Canutillo Formation and Percha Shale. Limestone, shale, marl, and some siltstone. Canutillo limestone, shale, marl, and siltstone, ~41 m (~135 ft) thick, overlain by 12-m-thick (40-ft) Percha black shale. Lower part of Canutillo shale, limestone, and dolomite breccia (derived from Fusselman Dolomite) overlain by interlensed chert and marl. Chert lenses 0.15 to 0.6 m (0.5 to 2 ft) thick. Upper part of Canutillo calcareous dark-gray shale interbedded with thinner (<0.3-m-thick [<1-ft]) beds of dark-gray marl and limestone. Local evidence that some lower Canutillo strata were deposited in sinkholes or channels in underlying Fusselman Dolomite.

SILURIAN

Sf—Fusselman Dolomite. Dolostone, some limestone. Mostly light-gray to tan dolostone; some gray limestone patches surrounded by dolomite/dolostone in upper part of unit; minor chert; karst breccia. Resistant to weathering; forms massive cliffs. Fossils include brachiopods, corals, and gastropods; ~152 to 183 m (~500 to 600 ft) thick.

UPPER AND MIDDLE ORDOVICIAN

Om—Montoya Group. Dolostone, some limestone, marl, and shale. Includes undivided lower, 30.5-m-thick (100-ft) Upham Dolomite, middle, 46-m-thick (150-ft) Aleman Formation, and upper, 39.5- to 50-m-thick (130- to 165-ft) Cutter Formation. Upham massive, gray dolostone.

Aleman dark-gray dolostone commonly interlayered with chert lenses and nodules. Cutter ~9 m (~30 ft) of nodular marl, dolostone, limestone, and shale overlain by cliff-forming, 0.6- to 1.8-m-thick (2- to 6-ft), evenly bedded, light-gray dolostone. Karst breccia common. Fossils include brachiopods, corals, and gastropods and abundant dolomitized fossil debris.

LOWER ORDOVICIAN

Oe—El Paso Group. Limestone, dolostone, sandy dolostone, and some dolomitic sandstone. Massive to thin bedded; some crossbeds and cross-laminations; some chert; karst breccia. Several published subdivisions of these cyclic, shelfal carbonate strata exist. Seven formations (LeMone, 1968, 1988) include, from base to top: (1) 26 to 49 m (85 to 160 ft) of Sierrite sandy dolostone, (2) ~33 m (~110 ft) of Cooks dolomite, (3) ~88 m (~290 ft) of Victorio Hills limestone and dolostone, (4) 21 to 27.5 m (70 to 90 ft) of José sandy, crossbedded dolostone, massive dolostone, and dolomitic sandstone, (5) 173 to 210 m (570 to 690 ft) of McKelligon Canyon limestone and dolostone (upper 7.6 m [25 ft]), (6) ~88 m (~290 ft) of Scenic Drive dolomitic sandstone (base), sandy dolostone and dolostone (lower 18 to 30.5 m [60 to 100 ft]), and limestone (upper part), and (7) ~12 m (~40 ft) of Florida Mountains limestone. Common fossils include snails, brachiopods, trilobites, and conodonts.

LOWER ORDOVICIAN – UPPER CAMBRIAN (?)

O€b—Bliss Sandstone. Quartz-rich sandstone, quartzite, and siltstone. Fine to medium grained; medium to thick bedded; laminated and cross-laminated; glauconitic in upper half; weathers dark reddish-brown. Sparse fossils include brachiopods, gastropods, rare trilobites; some trace fossils. As thick as 76 m (250 ft); locally absent.

PRECAMBRIAN

p€g—Undivided porphyritic granite, biotite granite, biotite-hornblende granite, riebeckite granite, and associated pegmatite, aplite, and basalt (p€b) dikes. Includes granites of Red Bluff Granite complex. Granite commonly medium to coarse grained, massive, and pink to red. Intrudes all other Precambrian rocks. May include local, undifferentiated rhyolite (pCr).

p€r—Undivided Thunderbird Group. (1) Rhyolitic ignimbrites and porphyritic rhyolite dikes (upper Tom Mays Park Formation; as thick as 168 m [550 ft]); (2) porphyritic trachyte, tuffaceous sandstone and conglomerate, and ignimbrite (middle Smugglers Pass Formation; as thick as 140 m [460 ft]); and (3) rhyolite-cemented conglomerate of cobble- to pebble-sized quartzite, siltstone, shale, chert, ignimbrite, and trachyte (lower Coronado Hills Formation; 11 to 27 m [35 to 90 ft] thick).

p€l—Lanoria Quartzite. Quartzite, sandstone, siltstone, and shale. Three members include (1) **lower Lanoria (p€ll);** 320 m (1,050 ft) thick; fine-grained quartzite, sandstone, siltstone, and shale; commonly forms slopes; (2) **middle Lanoria (p€lm)**; 183 to 243 m (600 to 800 ft) thick; medium-grained quartzite, crossbedded; commonly forms cliffs; (3) **upper Lanoria (p€lu)**; 168 to 213 m (550 to 700 ft) thick; fine-grained quartzite, sandstone, siltstone, shale; thin bedded; commonly forms slopes.

p€mc—Undivided Mundy Breccia and Castner Limestone. Mundy Breccia: randomly oriented, black basalt boulders, angular to slightly rounded, in matrix of dark-gray mudstone; as thick as 76 m (250 ft). Castner Limestone: limestone, hornfels, conglomerate, dolomite, and diabase; mostly limestone, slightly metamorphosed, some chert lenses, thin bedded, containing metamorphic minerals that include serpentine, tremolite, and garnet; numerous thin beds of hornfels in upper third of unit, very fine grained, laminated; some conglomerate in upper third of unit; dolostone in basal part of unit; local algal structures; diabase sills near base and middle, dark greenish gray, thin to thick, constituting about one-third of unit; thickness of formation ~335 m (~1,100 ft); base not exposed.

Hueco Mountains

TERTIARY

Ti—Undivided intrusive rocks. Includes syenite to monzonite rocks of Hueco Tanks area; small sills and dikes unmapped. K-Ar ages of Hueco Tanks and some nearby intrusions range between 33 and 35 m.y. (Wise, 1977; Henry and others, 1986).

PERMIAN

Ph—Hueco Group, undivided. Limestone, dolomitic limestone, marl, siltstone, shale; fossiliferous; cherty; lower part may comprise chert and limestone clasts in limestone matrix, mudstone, and marl. Generally light gray to dark gray; maximum thickness 455 m (1,500 ft). Lower contact with Magdalena Group is angular unconformity. Four units separately mapped (from base to top): **Php—Powwow Conglomerate.** Limestone and chert-pebble conglomerate, mudstone, and marl; 0 to ~30 m (0 to ~100 ft) thick. **Phl—lower Hueco Group/Hueco Canyon Formation.** Limestone and dolomitic limestone, medium to thick bedded; cherty; fossiliferous; ~90 to ~150 m (~300 to ~500 ft) thick (as much as 200 m [650 ft] thick outside map area). **Phm—middle Hueco Group/Cerro Alto Formation.** Limestone, dolomitic limestone, marl, and shale interbeds; fossiliferous; ~75 to ~110 m [~250 to ~350 ft] thick (as much as 137 m [450 ft] thick outside map area). **Phu—upper Hueco Group/Alacran Mountain Formation.** Limestone, medium to thick bedded; mudstone, including reddish-brown mudstone and cherty, medium-bedded limestone interval, Deer Mountain Red Shale; fossiliferous; minor thickness crops out in map area (~150 to ~275 m [~500 to ~900 ft] thick outside map area)

PENNSYLVANIAN

lPm—Magdalena Group, undivided. Limestone, marl, shale. Massive to medium beds; fossiliferous; cherty; ~400 m (~1,300 ft) thick. Upper contact with Hueco Group is angular unconformity. Three units separately mapped (from base to top): **lPml—lower Magdalena Group.** Limestone. Thick to medium bedded; cherty; fossiliferous, coral common, crinoids, mollusks, brachiopods, fusulinids; ~150 m (~500 ft) thick. **lPmm—middle Magdalena Group.** Marl, shale, and limestone. Fossiliferous; fusulinids, coral, algae; ~90 m (~300 ft) thick. **lPmu—upper Magdalena Group.** Limestone, marl. Massive to medium beds; cherty; local reef complex; fossiliferous, fusilinids, pelecypods, coral, crinoid fragments; as much as 140 m (450 ft) thick.

MISSISSIPPIAN

Mhr—Helms Formation and Rancheria Formation, undivided. Limestone, sandy limestone, and shale. Undivided unit grades upward from limestone and cherty limestone to sandy limestone and shale. Locally fossiliferous. As much as 170 m (550 ft) thick. Rancheria Formation (lower unit), cherty limestone and sandy limestone, contains Meramec fossils; as much as 45 m (150 ft) thick. Helms Formation (upper unit) sandy limestone and shale, contains Chester fossils; as much as 120 m (400 ft) thick.

DEVONIAN

Dpc—Devonian Percha Shale and Canutillo Formation, undivided. Shale, bedded chert, marl, and limestone. As much as 50 m (170 ft) thick (as much as 75 m [240 ft] thick outside of map area) Canutillo Formation (lower unit) composed of ≤30 m (≤100 ft) of bedded chert, along with marl and limestone interbeds; outcrops generally poor. Percha shale ≤30 m (≤100 ft) thick shale unit that rarely crops out owing to weathering.

SILURIAN

Sf—Fusselman Dolomite. Dolostone, dolomitic limestone, and limestone. Light gray; cherty interval in lower part; karst breccia; local fossils; ~180 m (~600 ft) thick.

UPPER AND MIDDLE ORDOVICIAN

Om—Montoya Group. Limestone, dolomitic limestone and dolostone. Karst breccia; local fossils. Montoya Group includes undivided lower 30-m-thick (100-ft) Upham Formation, middle 50-m-thick (160-ft) Aleman Formation, and upper 45-m-thick (155-ft) Cutter Formation. Upham massive, gray and brown dolostone, dolomitic limestone, and limestone. Aleman mostly limestone and cherty limestone; dark gray to tan. Cutter mostly white to light-gray dolostone and dolomitic limestone.

LOWER ORDOVICAN

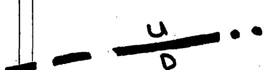
Oe—El Paso Group. Limestone, dolomitic limestone, dolostone, sandy limestone and dolostone, and dolomitic sandstone. Massive to thin bedded; some crossbeds and cross-laminations; some chert; karst breccia; ~415 m (1,370 ft) thick.

LOWER ORDOVICIAN — UPPER CAMBRIAN (?)

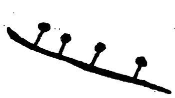
OЄb—Bliss Sandstone. Quartz-rich sandstone and siltstone. Fine to coarse grained; medium to thick bedded; crossbedded and cross-laminated; glauconitic; weathers reddish-brown; as much as 110 m (325 ft) thick.

PRECAMBRIAN

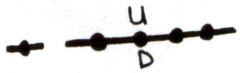
pЄg—Granite and associated intrusive rocks.



Normal fault. U = upthrown, D = downthrown.



Known lower angle normal fault. Bar on footwall block.

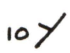


Sand-covered scarp. Possible normal fault scarp covered by windblown sand. U = upthrown, D = downthrown.

Reverse fault. Teeth on upthrown side.

Covered thrust fault. T indicates upper plate. Marks approximate edge of Laramide thrusting.

Fissure



Strike and dip of beds.

Monocline.

Ash; assigned as 2.1-m.y.-old Huckleberry Ridge ash by Izett (1981) and Izett and Wilcox (1982).