Summary Report for the El Paso, Texas, STATEMAP Project, 1995

by

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prepared for

United States Geological Survey
under Cooperative Agreement 1434-94-A-1254

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June 1995

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The El Paso STATEMAP project is 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 from increased industrialization. In addition, the North American Free Trade Agreement (NAFTA) is stimulating additional growth in this area. El Paso is rapidly growing northward along the flanks of the Franklin Mountains and eastward along the Rio Grande valley, valley border margins, and Hueco Bolson floor paralleling Interstate Highway 10 and U.S. Highway 62/180. Much of the area north of U.S. Highway 62/180 is military land of Fort Bliss and thus is not available for urbanization.

This second year of 1:24,000-scale geologic mapping of the El Paso, Texas, region resulted in the completion of twelve quadrangles (fig. 1). The completed Fort Bliss NE and Fort Bliss SE quadrangles are within part of the basin-floor area of the Hueco Bolson. The Nations East Well, Nations South Well, Hueco Tanks, Helms West Well, and Clint NE quadrangles encompass the eastern margin of the basin floor and the western edge and foothills of the Hueco Mountains. The Ysleta, San Elizario, Clint NW, Clint, and Clint SE quadrangles contain the basin floor, Rio Grande valley, and valley border. Our mapping during this year benefited greatly from previous studies concerning various geologic aspects of the region. Some of these studies include work by Richardson (1909), King and others (1945), Albritton and Smith (1965), Strain (1966), Cliett (1969), Wise (1977), Seager (1980), Gile and others (1981), Henry and Gluck (1981), Collins and Raney (1991), Gustavson (1991), and Monger (1993). We also benefited from the many articles within the Permian Basin Section SEPM Field Conference Guidebook (Meader-Roberts, 1983) that describes different aspects of the geology of the southern Hueco Mountains. Appendix A describes the stratigraphy of the mapped area in detail.

The basin-floor area of the Hueco Bolson contains windblown sand deposits that overlie middle Pleistocene–Pliocene Camp Rice sand and gravel and lesser amounts of silt and clay. Camp Rice deposition represents a system of predominantly fluvial and alluvial-fan deposition with some floodplain and minor lacustrine deposition. Within the basin-floor area, the top of the Camp Rice is capped by a well-developed stage IV–V pedogenic calcrete. Windblown sand deposits that overlie the Camp Rice Formation mostly appear to be <2 to 3 m thick (<6 to 10 ft), although at one abandoned sand quarry, the eolian sand was >8 m thick (>26 ft). Coppice dunes, interdune sheet deposits, and deflation areas are common. At the eastern margin of the Hueco Bolson, local areas of active sand dunes and areas of partly vegetated, stabilized to partially stabilized dunes are present. The basin floor contains a series of north-trending sand-covered scarps that may be fault related.

The Rio Grande valley and valley border consist of remnant terraces that have been incised into the Camp Rice Formation. Fan deposits at the mouths of arroyos and smaller drainageways that flow into the river valley also exist. Alluvium associated with the remnant terraces and fans along the valley border is thin. Observations of the calcic soil development and stratigraphic position of these deposits were used to subdivide the Quaternary valley border stratigraphy. Alluvium of the Rio Grande floodplain is commonly cultivated where it is not urbanized. Windblown sand deposits also occur within the valley border. Sand/gravel quarries mining the relatively uncemented Camp Rice deposits are common along the valley border rim.

San Felipe arroyo is a large arroyo that cuts about 10 km (6 mi) northward from the valley border into the basin-floor area. Arroyo terraces have been incised into the basin-fill deposits; in the upper parts of the arroyo, the clay-rich Pliocene Fort Hancock Formation crops out beneath the Camp Rice Formation. Fort Hancock deposits represent lacustrine and associated deposition in a bolson setting. Lower Camp Rice deposits include reworked Fort Hancock sediments.

At the eastern edge of the Hueco bolson, fan and drainage-way alluvium composes the piedmont deposits shed from the Hueco Mountains. Bedrock hills surrounded by alluvium are common at the basin margin. Bedrock stratigraphy of the area records a long geologic record (Appendix A). 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 are mostly syenite to monzonite of the Hueco Tanks region and 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.

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Appendix A: Explanation of Geologic Units

El Paso Region

Campo Grande Mountain, Cavett Lake, Clint, Clint NE, Clint NW, Clint SE, Diablo Canyon West, El Paso, Fort Bliss NE, Fort Bliss SE, Fort Hancock, Helms West Well, Hueco Tanks, Nations East Well, Nations South Well, North Franklin Mountain, San Elizario, and Ysleta quadrangles, Texas (1:24,000 scale)

QUATERNARY

Holocene–Late Pleistocene

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

Qws2—Windblown sand area of partly vegetated, stabilized to partially 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 eastern 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 high (10 ft), having sparse to no vegetation. Active sand dune areas are located within larger areas of stabilized to partially stabilized dunes that are partly vegetated **(Qws2).**

Qac—Slope-wash alluvium and/or colluvium. Commonly covers Santa Fe Group basin-fill deposits along arroyos 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—Undifferentiated 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–II BK horizons. Possibly includes local undifferentiated older alluvium and younger windblown sand. May overlie or be inset against older deposits.

Qavb—Undifferentiated 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 stage I–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–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 (3 ft) 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–II BK horizons. Locally may include more than one terrace with 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–II BK horizons. Locally may include more than one terrace with similar soil characteristics. May overlie or be inset against older deposits.

Qf3-4—Undifferentiated Qf3 and Qf4 alluvium.

Qt3-4—Undifferentiated 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 thick (<1.6 ft). Commonly <1 m (3 ft) 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 thick (<1.6 ft). Locally may include more than one terrace with 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 thick

(<1.6 ft). Locally may include more than one terrace with 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 thick (0.6 to 3.0 ft). 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 thick (0.6 to 3.0 ft). Locally may include more than one terrace with 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 thick (0.6 to 3.0 ft). Locally may include more than one terrace with similar soil characteristics. May overlie or be inset against older deposits. Locally covered by undifferentiated younger alluvium and windblown sand.

Qf1-2—Undifferentiated Qf1 and Qf2 alluvium.

Qf2-3—Undifferentiated 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–V K horizon calcrete, 0.7 to 1.5 m thick (2.3 to 5.0 ft). Locally may be covered by younger alluvium and windblown sand. Surface of Qf1 is 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.

Late Pleistocene to Pliocene

QTbf—Undivided Santa Fe Group basin-fill deposits. Includes gravel, sand, silt, and clay of the Fort Hancock Formation (Tfh) and Camp Rice Formation (QTcr) and younger piedmont, basin-floor, valley border, and alluvial-plain deposits.

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 thick (3.0 to 5.0 ft). Ash at top of unit assigned as 0.6-m.y.-old Lava Creek B ash (Izett, 1981; Izett and Wilcox, 1982; ash location is 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; ash locations are in Arroyo Diablo and Madden Arroyo and are shown on Campo Grande Mountain, Texas, quadrangle). Locally covered by younger alluvium and windblown sand. Camp Rice deposits along valley border may include high, undivided, middle Pleistocene Rio Grande terraces (approximately age equivalent to Qf1 deposits). Areas mapped as Camp Rice along valley border 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.

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 ~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 thick (~200 ft). In Diablo Plateau area, mostly limestone along rimrock of plateau; sandstone beds near base; ~53 to 61 m thick (~175 to 200 ft).

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. About 152 m thick (~500 ft) at Diablo Plateau; ~165 to 206 m thick (~540 to 675 ft) in Finlay Mountains; ~213 to 226 m thick (~700 to 740 ft) 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 is interbedded sandstone, fossiliferous limestone, siltstone, sandy shale, and limestone and chert conglomerate. About 114 m thick (~375 ft) in northwest Finlay Mountains; ~244 m thick (~800 ft) in southwest Finlay Mountains.

Franklin Mountains

TERTIARY

Ti—Undivided intrusive rocks. Includes Campus Andesite west of Crazy Cat Mountain; felsite dikes and sills unmapped.

CRETACEOUS

K—Undivided Cretaceous strata.

PERMIAN

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

PENNSYLVANIAN

Magdalena Group

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

IPmbc—Bishop Cap Formation. Shale and limestone. Composed primarily of poorly exposed shale with some thin resistant beds of limestone. About 194 m thick (~636 ft).

IPmb—Berino Formation. Limestone and shale. Composed primarily of alternating limestone and shale units ~0.6 to 6 m thick (~2 to 20 ft); 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).

IPml—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, and bryozoans; some petrified wood. About 85 m thick (~280 ft).

MISSISSIPPIAN

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

Mr—Rancheria Formation. Limestone, some siltstone and shale. Lower part is mostly cherty limestone with some siltstone and shale interbeds; ~40 m thick (130 ft); limestone beds as thick as 0.6 m (2 ft); siltstone and shale beds as thick as 2 m (7 ft). Middle part is black limestone; 8.5 to 12.8 m thick (28 to 42 ft); forms a light gray band in weathered hillsides. Upper part is limestone with siltstone and shale near the top; limestone is black, cherty, and sandy; ~61 to 70 m thick (~200 to 230 ft).

Mlc—Las Cruces Formation. Limestone. Evenly bedded; beds ~0.3 to 0.6 m thick (~1 to 2 ft); mostly chert free; weathers white to light gray and commonly forms distinct band at the base of ledgy cliffs. About 15 to 27.5 m thick (~50 ft to 90 ft).

DEVONIAN

Dpc—Undivided Canutillo Formation and Percha Shale. Limestone, shale, marl, and some siltstone. Canutillo limestone, shale, marl, and siltstone, ~41 m thick (~135 ft), is overlain by 12-m-thick (40-ft) Percha black shale. Lower part of Canutillo is shale, limestone, and dolomite breccia (derived from Fusselman Dolomite) overlain by interlensed chert and marl. Chert lenses 0.15 to 0.6 m thick (0.5 to 2 ft). Upper part of Canutillo is 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 the 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. About 152 to 183 m thick (~500 to 600 ft).

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 is massive, gray dolostone. Aleman is dark gray dolostone commonly interlayered with chert lenses and nodules. Cutter is ~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; 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, 1982, 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(?)

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

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 thick [35 to 90 ft]).

p€l—Lanoria Quartzite. Quartzite, sandstone, siltstone, and shale. Three members include (1) **lower Lanoria (p€ll)**, 320 m thick (1,050 ft); fine-grained quartzite, sandstone, siltstone, and shale; commonly forms slopes; (2) **middle Lanoria (p€lm)**, 183 to 243 m thick (600 to 800 ft); medium-grained quartzite, crossbedded; commonly forms cliffs; (3) **upper Lanoria (p€lu)**, 168 to 213 m thick (550 to 700 ft); fine-grained quartzite, sandstone, siltstone, and 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; formation ~335 m (~1,100 ft) thick; base not exposed.

Hueco Mountains

TERTIARY

Ti—Undivided intrusive rocks. Includes syenite to monzonite rocks of Hueco Tanks area; small sills and dikes unmapped.

PERMIAN

Ph—Hueco Group, undivided. Limestone, dolomitic limestone, marl, siltstone, and 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, chert-pebble conglomerate, mudstone, and marl; 0 to ~30 m thick (~100 ft). **Phl—lower Hueco Group/Hueco Canyon Formation.** Limestone and dolomitic limestone, medium- to thick-bedded; cherty; fossiliferous; ~90 to ~150 m thick (~300 to ~500 ft) (as thick as 200 m [650 ft] outside map area). **Phm—middle Hueco Group/Cerro Alto Formation.** Limestone, dolomitic limestone, marl and shale interbeds; fossiliferous; ~75 to ~110 m thick (~250 to ~350 ft) (as thick as 137 m [450 ft] outside map area). **Phu—upper Hueco Group/Alacran Mountain Formation.** Limestone, medium- to thick-bedded; mudstone, includes 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 thick [~500 to ~900 ft] outside map area).

PENNSYLVANIAN

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

MISSISSIPPIAN

Mh—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 thick as 170 m (550 ft). Rancheria Formation (lower unit) is cherty limestone and sandy limestone, contains Meramec fossils, and is as thick as 45 m (150 ft). Helms Formation (upper unit) is sandy limestone and shale, contains Chester fossils, and is as thick as 120 m (400 ft).

DEVONIAN

Dpc—Devonian Percha Shale and Canutillo Formation, undivided. Shale, bedded chert, marl, and limestone. As thick as 50 m (170 ft) (as thick as 75 m [240 ft] outside of map area). Canutillo Formation (lower unit) is composed of ≤30 m (≤100 ft) of bedded chert with marl and limestone interbeds; outcrops are generally poor. Percha Shale is a ≤30-m-thick (≤100-ft) 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 thick (~600 ft).

UPPER AND MIDDLE ORDOVICIAN

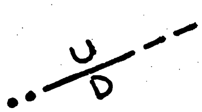
Om—Montoya Group. Limestone, dolomitic limestone, and dolostone. Karst breccia; local fossils. Montoya Group includes undivided lower, 30-m-thick (100-ft) Upham Formation; middle, 50-m-thick (160-ft) Aleman Formation; and upper, 45-m-thick (155-ft) Cutter Formation. Upham is massive, gray and brown dolostone,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

LOWER ORDOVICAN

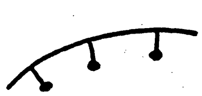
Oe—El Paso Group. Limestone, dolomitic limestone, dolostone, sandy limestone and dolostone, and dolomitic sandstone. Massive to thin-bedded; some crossbeds and cross-laminations; some chert; karst breccia; ~415 m thick (~1,370 ft).

LOWER ORDOVICIAN—UPPER CAMBRIAN(?)

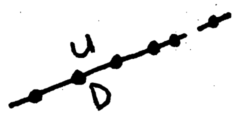
OCb—Bliss Sandstone. Quartz-rich sandstone and siltstone. Fine- to coarse-grained; medium- to thick-bedded; crossbedded and cross-laminated; glauconitic; weathers reddish brown; as thick as 110 m (325 ft).



Normal fault. U = upthrown, D = downthrown.



Known low-angle normal fault. Bar on footwall block.



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

Strike and dip of beds.

Monocline.

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

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

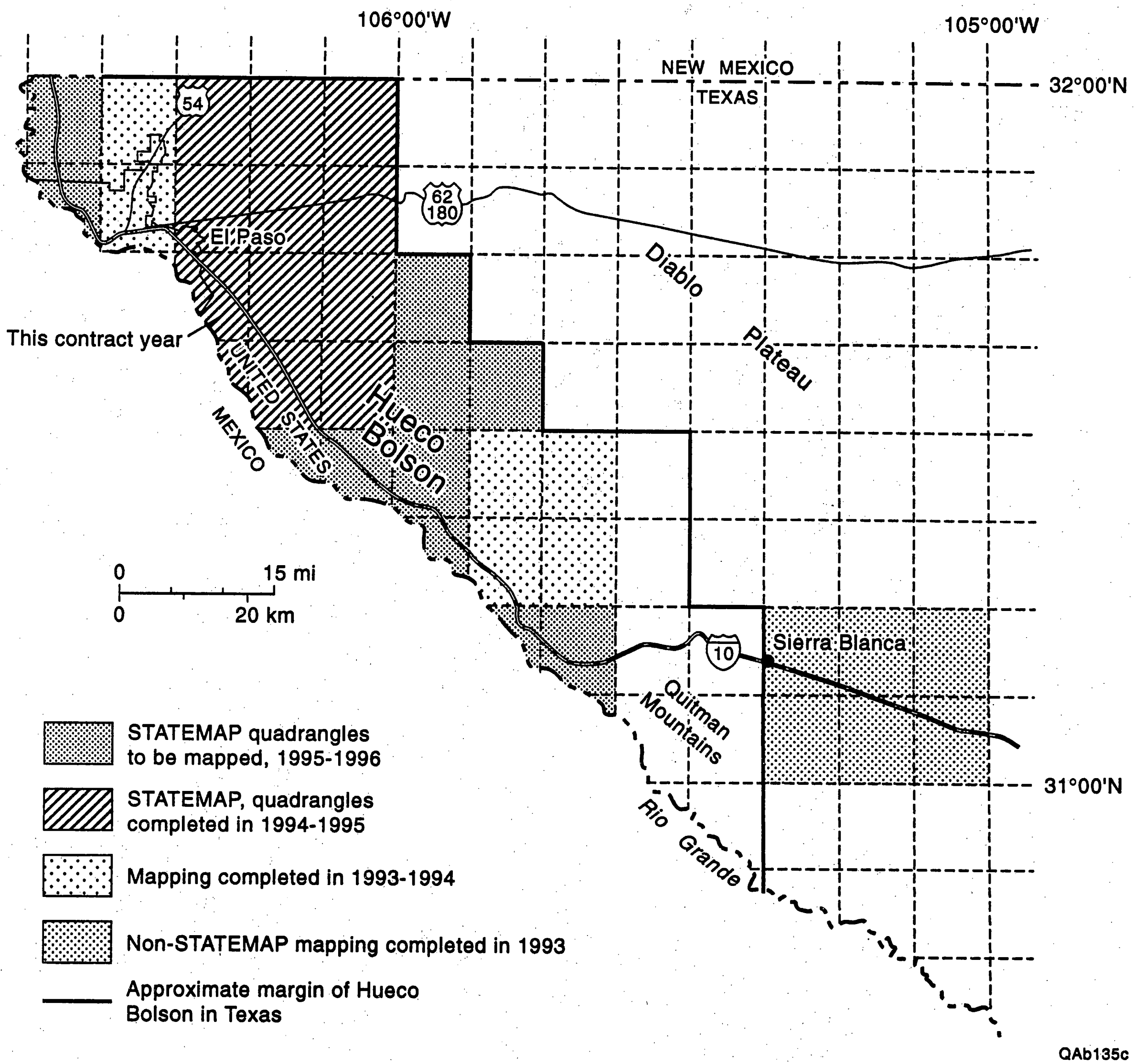


Figure 1. Diagram showing mapped areas.