National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Big Bend National Park

Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory Digital Geologic Data for Big Bend National Park

bibe_geology.pdf

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Geologic Resources Inventory Map Document for Big Bend National Park

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Geologic Resources Inventory Map Document

Big Bend National Park, Texas

Document to Accompany Digital Geologic-GIS Data

bibe_geology.pdf

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This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Big Bend National Park, Texas (BIBE).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

For information about the status of GRI digital geologic-GIS data for a park contact:

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Natural Resource Information Reference Search Application: http://nrinfo.nps.gov/Reference.mvc/Search. To find GRI data for a specific park or

parks select the appropriate park(s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Big Bend National Park, Texas (BIBE) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qal - Alluvium). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the Geologic Unit Information (UNIT) table included with the GRI geology-GIS data.

Geologic Map Units

Quaternary

Qaw - Active tributary wash and river deposits (latest Holocene)
Qe - Eolian sand (Holocene)
Qyw1 - Younger of the young axial deposits (Holocene)
Qyw2 - Older of the young axial river deposits (late Pleistocene to Holocene)
Qya - Young alluvial deposits, undivided (late Pleistocene to Holocene)
Qya1 - Younger of the young alluvial deposits (Holocene)
Qya2 - Older of the young alluvial deposits (late Pleistocene to Holocene)
Qrf - Rock fall deposits (Holocene and late Pleistocene)
Qc - Colluvium and colluvial-fan deposits (Holocene and Pleistocene)
Qls - Landslide deposits (Holocene and Pleistocene)
Qs - Spring deposits (Holocene and Pleistocene)
QTu - Quaternary to Tertiary deposits, undivided (Miocene to Holocene)
Qiw - Intermediate axial river deposits, undivided (late and middle Pleistocene)
Qiw1 - Youngest intermediate axial river deposits (late Pleistocene)
Qiw2 - Older intermediate axial river deposits (middle to late Pleistocene)
Qiw3 - Oldest intermediate axial river deposits (middle Pleistocene)
Qia - Intermediate alluvial deposits, undivided (late and middle Pleistocene)
Qia1 - Younger of the intermediate alluvial deposits (middle to late Pleistocene)
Qia2 - Older of the intermediate alluvial deposits (middle Pleistocene)
Qow - Old axial river deposits (early? to middle Pleistocene)
Qoa - Old alluvial deposits, undivided (early? to middle Pleistocene)
QTa - Very old alluvium (early Pleistocene and Pliocene)

Tertiary

Ta - Basin-fill deposits (Miocene)
Tgs - Gravity slide blocks (Miocene?)
Tv - Volcanic rocks, undivided (Oligocene)
Tirc - Intrusive complex at Rattlesnake Mountain (Oligocene)
Tfb - Basaltic flow (Oligocene)
Tbr - Burro Mesa Formation, Rhyolite member (Oligocene)
Tbw - Burro Mesa Formation, Wasp Spring member (Oligocene)
Tbi - Burro Mesa Formation, intrusive rocks, undivided (Oligocene)
Tt - Trachytic lava, undivided (Oligocene)
Tqd - Sierra Quemada ring dike (Oligocene)
Tqi - Sierra Quemada intrusive rocks, undivided (Oligocene)
Tqv - Sierra Quemada vent breccia (Oligocene)
Tdm - Dominguez Mountain mafic lava flows (Oligocene)
Tdd - Dominguez Mountain dike swarm (Oligocene)
Tdi - Dominguez Mountain intrusive rocks, undivided (Oligocene)

Tse - South Rim Formation, Emory Peak rhyolite member (Oligocene)
Tsb - South Rim Formation, Boot Rock member (Oligocene)
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Ti - Intrusive rocks, undivided (Eocene to Oligocene)
Tir - Rhyolitic and other felsic composition intrusive rocks, undivided (Eocene to Oligocene)
Tia - Andesitic and other intermediate composition intrusive rocks, undivided (Eocene to Oligocene)
Tib - Basaltic and other mafic composition intrusive rocks, undivided (Eocene to Oligocene)
Tcy - Chisos Formation, younger part, undivided (Oligocene and Eocene)
Tctm - Chisos Formation, Tule Mountain Trachyandesite Member (Oligocene)
Tcbm - Chisos Formation, Bee Mountain Basalt Member (Oligocene)
Tcme - Chisos Formation, Mule Ear Spring Tuff Member (Oligocene)
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Tcrt - Chisos Formation, rhyolite tuff unit (Eocene)
Tx - Christmas Mountains related volcanic rocks (Eocene)
Tc - Canoe Formation (Eocene)
Thh - Hannold Hill Formation (Eocene)
TKbp - Black Peaks Formation (Upper Cretaceous to Paleocene)

Cretaceous

Kj - Javelina Formation (Upper Cretaceous)
Ka - Aguja Formation (Upper Cretaceous)
Kp - Pen Formation (Upper Cretaceous)
Kb - Boquillas Formation, undivided (Upper Cretaceous)
Kbs - Boquillas Formation, San Vicente Member (Upper Cretaceous)
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Ktm - Telephone Canyon Formation and Maxon Sandstone, undivided (Lower Cretaceous)
Kgr - Glen Rose Limestone (Lower Cretaceous)

Paleozoic

PMt - Tesnus Formation (Lower Pennsylvanian and Upper Mississippian)
PZu - Paleozoic rocks, undivided (Ordovician through Lower Pennsylvanian)
MOu - Mississippian to Ordovician rocks, undivided (Ordovician to Mississippian)

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Qaw - Active tributary wash and river deposits (latest Holocene)

Unconsolidated gravel, sand, and silt deposited in active channels and flood plains of larger creeks and the Rio Grande. Light gray, light brownish gray, grayish brown, pale brown or very pale brown. In washes, deposits typically poorly to moderately sorted and poorly to moderately bedded. Cobble- and small boulder-size clasts common. Clasts subangular to subrounded, locally rounded. Braided channels and bar-and-swale topography common. Along the Rio Grande, deposits moderately to well sorted and moderately to well bedded, with subrounded to well-rounded clasts. Flood-plain deposits made up mostly of fine-grained sediment. Meander scroll topography common. Near Cottonwood Campground (west of Castolon), flood-plain deposits dating to within the last 17 years are at least 3.5 m thick (Dean and Schmidt, 2008). (USGS I-3142)

Qe - Eolian sand (Holocene)

Unconsolidated, moderately sorted, silty fine to medium sand, locally intermixed with small amounts of fine gravel likely introduced by surface wash or bioturbation. Very pale brown. Commonly forms small coppice dunes (nabkhas) around base of brushy vegetation; individual dunes too small to map separately. Thickness generally less than 1 m. (USGS I-3142)

Qyw1 - Younger of the young axial deposits (Holocene)

Differentiated from other types of alluvial deposits only along the Rio Grande. Forms low-level terraces generally within 3 m of active flood plain. Meander scroll topography commonly well preserved. Typically fine-grained deposits of unconsolidated to weakly consolidated sand and silt with pebble lenses and stringers. Near Boquillas Canyon, ^{14}C date on organic material from buried A horizon suggests that upper 2 m of alluvium at that locale was deposited within the last 3,000 yr (Mandel, 2002). Surfaces deflated locally by eolian processes, and covered in places by small dunes. Little or no pavement, varnish, or soil-carbonate development. Thickness 3 to 4 m or more. (USGS I-3142)

Qyw2 - Older of the young axial river deposits (late Pleistocene to Holocene)

Differentiated from other types of alluvial deposits only along the Rio Grande. Unconsolidated to weakly consolidated, moderately to well-sorted, moderately to well-bedded gravel, sand, and silt forming low-level terraces generally 4–9 m above active flood plain. Limited preservation of meander scroll topography. Cobble- and small boulder-size clasts common; clasts typically subrounded to well rounded. Pavement moderately developed to densely packed and uniform with strong-brown, yellowish-red, dark reddish-brown, dark reddish-gray, and black varnish colors. Development of soil carbonate generally stage I+ or less[1]. Thickness less than 1 m to about 4 m. (USGS I-3142)

[1] In gravelly deposits, the progressive development of soil-carbonate morphology is described briefly as follows: Stage I- thin, discontinuous coatings of $CaCO_3$ are present on the bottom side of clasts. Stage II- $CaCO_3$ coatings are continuous around clasts; the soil matrix is mostly loose, but several clasts may be cemented together locally. Stage III- $CaCO_3$ is disseminated throughout the soil matrix, cementing the horizon and giving it a whitish color. Stage IV- thin laminar layers of almost pure $CaCO_3$ are present in the upper part of the horizon; the rest of the horizon is plugged with accumulated $CaCO_3$. For further discussion, see Birkeland (1999).

Qya - Young alluvial deposits, undivided (late Pleistocene to Holocene)

Pediment, fan, stream, and sheet-flow deposits. Unconsolidated to weakly consolidated, poorly to moderately sorted, poorly to moderately bedded gravel, sand, and silt. Cobble- and small boulder-size

clasts common. Locally mostly silty sand or sandy silt with interspersed fine gravel. Clasts typically subangular to subrounded, locally angular or well rounded. Typically has low relative height where alluvial surfaces are incised. Elsewhere may veneer older deposits. Includes Qaw too narrow to map separately. Unit subdivided into Qya1 and Qya2 where divisions are evident and large enough to map separately. Thickness variable from less than 1 m to 8 m or more. (USGS I-3142)

Qya1 - Younger of the young alluvial deposits (Holocene)

On or within several meters of valley floor. Occasionally flooded and (or) modified by sheet flow. Bar-and-swale topography and braided-channel morphology commonly well preserved. Surfaces deflated locally by eolian processes, and covered in places by dunes too small to map separately. Little or no pavement, varnish, or soil-carbonate development. Thickness variable from less than 1 m to 8 m or more. (USGS I-3142)

Qya2 - Older of the young alluvial deposits (late Pleistocene to Holocene)

Typically elevated 3 m or more above valley floor. Limited preservation of bar-and-swale topography and braided-channel morphology. Surfaces commonly partly incised. Pavement weakly developed to densely packed and uniform. Pavement clasts lightly to well varnished with strong brown, yellowish-red, dark reddish-brown, and black varnish colors. Soil-carbonate development generally stage I or less. Thickness variable from less than 1 m to 8 m or more. (USGS I-3142)

Qrf - Rock fall deposits (Holocene and late Pleistocene)

Generally unsorted, angular, cobble- to boulder-sized rock fragments forming talus on steep slopes. Thickness variable from about 2 m to more than 6 m. (USGS I-3142)

Qc - Colluvium and colluvial-fan deposits (Holocene and Pleistocene)

Unconsolidated to moderately consolidated, unsorted to poorly sorted, unbedded to weakly bedded mixture of gravel, sand, silt, and clay, forming thin mantle or thicker fan-shaped accumulations of debris on the flanks of slopes. Cobble- to boulder-size clasts common. Clasts angular to subangular. Locally cemented by carbonate. Commonly ribbed and fluted due to various combinations of mass movement, rain splash, and wash processes active on slopes. Locally includes bedrock outcrops too small to map separately. Thickness variable from about 1 m to more than 6 m. (USGS I-3142)

Qls - Landslide deposits (Holocene and Pleistocene)

Slumps, flows, and slides of bedrock, colluvium, and alluvium. Terrain typically hummocky or irregular with closed depressions and spires. Large areas of landslide deposits, such as at Chilicotal and Talley Mountains (Collins and others, 2007, 2008), represent multiple landslide events. Most likely Pleistocene in age. Thickness as much as 50 to 100 m. (USGS I-3142)

Qs - Spring deposits (Holocene and Pleistocene)

Powdery to well-cemented, white, very pale-brown, light brownish-gray, or gray, fine-grained, spring-generated calcium carbonate mixed with fine sand and silt; locally nodular or laminated. Mapped mostly near Grapevine Spring and northwest of Kit Mountain. Thickness about 5 m near Grapevine Spring. (USGS I-3142)

QTu - Quaternary to Tertiary deposits, undivided (Miocene to Holocene)

Shown in cross section only. (USGS I-3142)

Qiw - Intermediate axial river deposits, undivided (late and middle Pleistocene)

Differentiated from other types of alluvial deposits only along the Rio Grande and upper Tornillo Creek. Weakly to moderately well-consolidated, moderately to well-sorted, moderately to well-bedded gravel, sand, and silt; sand locally crossbedded. In Rio Grande deposits, cobble- and small boulder-size clasts common to abundant. Clasts subrounded to well rounded. Some surface and subsurface clasts weathered. Unit subdivided into Qiw1, Qiw2, and Qiw3 where divisions are evident and large enough to map separately. Thickness commonly 3 to 4 m, but ranges from less than 1 m to more than 15 m. (USGS I-3142)

Qiw1 - Youngest intermediate axial river deposits (late Pleistocene)

Terrace surfaces generally 12–18 m above Rio Grande flood plain. Surfaces typically broad and flat with a stage II soil-carbonate horizon, and a moderately to densely packed, uniform pavement. Pavement clasts moderately to well varnished; varnish colors typically strong brown, yellowish red, dark reddish brown, and black. Thickness commonly 3 to 4 m. (USGS I-3142)

Qiw2 - Older intermediate axial river deposits (middle to late Pleistocene)

Terrace surfaces generally 18–25 m above Rio Grande flood plain. Surfaces typically broad and flat with a stage II to weakly cemented stage III soil-carbonate horizon 1 m or more thick, and a moderately to densely packed, uniform pavement. Pavement clasts moderately to well varnished; varnish colors typically strong brown, yellowish red and dark reddish brown. Thickness commonly 3 to 4 m. (USGS I-3142)

Qiw3 - Oldest intermediate axial river deposits (middle Pleistocene)

Terrace surfaces generally 30–45 m above Rio Grande flood plain and about 40 m above upper Tornillo Creek flood plain. Surfaces vary from broad and flat to gently undulatory or irregular, with a stage I+ to moderately-cemented stage IV soil-carbonate horizon, and a weak to well-formed uniform pavement. Where pavement well preserved, pavement clasts moderately to well varnished; varnish colors typically yellowish red and dark reddish brown. Thickness commonly 3 to 4 m. (USGS I-3142)

Qia - Intermediate alluvial deposits, undivided (late and middle Pleistocene)

Pediment, fan, and stream deposits. Weakly to moderately well consolidated, poorly to moderately sorted, poorly to moderately bedded gravel, sand, and silt. Cobble- and small boulder-size clasts common to abundant. Clasts typically subangular to subrounded, locally angular or rounded. Typically has intermediate relative height where alluvial surfaces are incised. Surfaces typically uniform due to loss of bar-and-swale topography and braided channel morphology (smoothed by post-depositional surface processes); partly incised, and slightly rounded at the edges. Pavement weakly developed to densely packed and uniform. Varnish on pavement clasts ranges from almost none where pavement contains mostly limestone clasts, to moderately varnished with strong-brown, yellowish-red, and dark reddish-brown colors. Locally includes Qaw and Qya too narrow or small to map separately. Unit subdivided into Qia1 and Qia2 where divisions are evident and large enough to map separately. Seismic data indicate that on the northeast side of the Chisos Mountains, stacked alluvial sequences that include Qia and buried older alluvium (Qoa) reach total thicknesses in excess of 50 m (Monti, 1984). Thickness of Qia variable from less than 1 m to about 10 m. (USGS I-3142)

Qia1 - Younger of the intermediate alluvial deposits (middle to late Pleistocene)

Typically has stage I–II soil-carbonate horizon 1–1.5 m thick. Less commonly has weak to moderately cemented stage III carbonate horizon 30–50 cm thick, especially where deposit contains mostly limestone clasts. Some surface clasts weathered and (or) split. Pediment surfaces generally 6–24 m above valley floor. Along Rio Grande, intertongues with, and grades into or overlaps Qiw1 and Qiw2

terraces. Thickness variable from less than 1 m to about 10 m. (USGS I-3142)

Qia2 - Older of the intermediate alluvial deposits (middle Pleistocene)

Typically has weakly to moderately cemented stage III–IV soil-carbonate horizon 1 m or more thick. Weathered and (or) split surface and subsurface clasts common at some locales. Has higher relative height than Qia1 where alluvial surfaces are incised; pediment surfaces generally 12–40 m above valley floor. Along upper Tornillo Creek, grades to Qiw3 terrace. Thickness variable from less than 1 m to about 10 m. (USGS I-3142)

Qow - Old axial river deposits (early? to middle Pleistocene)

Differentiated from other types of alluvial deposits primarily along the Rio Grande; mostly preserved as isolated terrace remnants 55 to 60 m above flood plain. Weakly to well-consolidated, poorly to moderately well sorted, moderately bedded gravel, sand, and silt; sand commonly crossbedded. Pebble-, cobble- and boulder-size clasts common to abundant. Clasts mostly subrounded to well rounded. Where preserved, soil has weakly cemented stage II+–III soil-carbonate horizon; pavement moderately packed and uniform with strong-brown, yellowish-red, and dark reddish-brown varnish colors. Thickness typically 2 to 6 m. (USGS I-3142)

Qoa - Old alluvial deposits, undivided (early? to middle Pleistocene)

Pediment, fan, and stream deposits. Typically moderately to well-consolidated, poorly to moderately sorted, poorly to moderately bedded gravel, sand, and silt. Cobble- and small boulder-size clasts common to abundant. Clasts typically subangular to subrounded, locally angular or rounded. Has higher relative height than Qia where alluvial surfaces are incised. Surfaces dissected into ridge and ravine (ballena) topography where gravel deposits are thick (in fans), or preserved as planar to gently undulatory remnants 30–50 m above valley floor where gravel deposits are thin (on pediments). Where preserved, soils have weakly to moderately cemented stage IV carbonate horizon 1–1.5 m or more thick. Weathered surface and subsurface clasts common. Pavement ranges from weakly developed to moderately packed and uniform. Varnish on pavement clasts ranges from none where pavement contains mostly limestone clasts, to moderately varnished with yellowish-red and dark reddish-brown colors. Locally includes Qaw and Qya too narrow or small to map separately. Thickness variable from less than 1 m to about 15 m, but based on seismic data, may be as much as 30 m thick on the north side of the Chisos Mountains (Monti, 1984). (USGS I-3142)

QTa - Very old alluvium (early Pleistocene and Pliocene)

Mostly moderately to well-consolidated or indurated, poorly bedded, poorly to moderately sorted, alluvial-fan deposits of cobble gravel, sand and silt; clasts mostly subangular to subrounded. Also includes lesser amounts of moderately to well-consolidated, poorly to moderately sorted, poorly to moderately bedded, commonly crossbedded, gravelly stream deposits with subrounded to rounded clasts, and moderately consolidated, fine-grained deposits of possible playa-lake origin. Beds tilted near faults. Deposits eroded and deeply dissected to form ridge and ravine (ballena) topography. Surface soils, where preserved, have cemented stage III–IV carbonate morphology in horizons as much as 2 m thick. Includes informal Fingers formation (Burro Mesa area; Stevens, 1969, 1988; Stevens and Stevens, 1989), considered upper basin fill of the Delaho bolson (Lehman and Busbey, 2007), and informal Estufa Canyon formation (Stevens and Stevens, 1989, 2003; also called Estufa member by Thurwachter, 1984), comprising upper basin fill of Estufa bolson (lower Tornillo Creek area). In Sierra del Carmen, where very old alluvium has not been studied in detail, unit may also include some undifferentiated lower basin-fill deposits (Ta). Thickness 18 to 208 m for informal Fingers formation (Stevens, 1988), and about 284 m for informal Estufa Canyon formation (Stevens and Stevens, 1989). (USGS I-3142)

Ta - Basin-fill deposits (Miocene)

Alluvial-fan, stream, and playa deposits in fault-bounded basins (bolsons). Weakly to well-consolidated or indurated, poorly to moderately bedded, poorly to moderately sorted gravel, sand, silt, and clay. Formerly combined with Quaternary deposits by Maxwell and others (1967). Deeply dissected. Beds tilted by faulting; in Cerro Castellan area, dips as steep as 20°–35° reported (Maxwell and others, 1967). Clasts subangular to rounded. Near Castolon, deposits formally named Delaho Formation by Stevens and others (1969). Delaho Formation consists of pinkish- to brownish-buff siltstone, sandstone, mudstone, and gray conglomerate deposited in Delaho bolson (Stevens and Stevens, 1985, 1989). Lower (unnamed) member of Delaho Formation contains earliest Miocene vertebrate fossils of Castolon local fauna (Stevens and others, 1969; Stevens, 1977, 1991), and near De la Ho Spring, is interbedded near its base with thin basaltic flow dated by K-Ar method at 23.3 ± 0.6 Ma (Stevens, 1988; Stevens and Stevens, 1989). Upper Smoky Creek Member of Delaho Formation disconformably overlies lower member and contains few fossils but is proposed as late early Miocene (Stevens and Stevens, 1989) or middle? Miocene (Stevens, 1988) in age. In lower Tornillo Creek area, deposits named informal Banta Shut-in formation by Stevens and Stevens (1989, 2003; also called informal La Noria member by Thurwachter, 1984). Informal Banta Shut-in formation consists of pinkish- to reddish-buff sandstone and siltstone, red mudstone, and pinkish-gray conglomerate, deposited as lower basin fill in Estufa bolson. Contains late Miocene vertebrate fossils of the Screw Bean local fauna. Thickness about 670 m for Delaho Formation (Stevens, 1988), and 300 to 360 m for Banta Shut-in formation (Stevens and Stevens, 2003). (USGS I-3142)

Tgs - Gravity slide blocks (Miocene?)

Blocks of Cretaceous limestone interpreted as gravity slide blocks (Maxwell and others, 1967; Poth, 1979) on southwest flank of the southern Santiago Mountains; age and origin unknown, but likely formed from uplift of Santiago Mountains related to Neogene basin-and-range faulting. Blocks consist mostly of Glen Rose Limestone, Boquillas Formation, and Buda Limestone, interpreted to have slid chiefly over Pen and Aguja Formations; stratigraphic order in blocks mostly preserved; 5 to 20 m thick. (USGS I-3142)

Tv - Volcanic rocks, undivided (Oligocene)

Volcanic rocks of unknown composition overlying units of South Rim Formation at northern end of Burro Mesa; about 60 m thick. (USGS I-3142)

Tirc - Intrusive complex at Rattlesnake Mountain (Oligocene)

Black to greenish-black analcime-bearing monzonite sill; contains bodies of syenite related to in-place differentiation of monzonite liquid (Carmen and others, 1975). Monzonite comprises about 90 percent of intrusion; composed of 65–70 percent plagioclase and alkali feldspar, and ophitic augite, biotite, olivine, Fe-Ti oxides, analcime, and secondary minerals. Grain size varies from 0.5 mm at the chilled margin to 2–5 mm in the central zone. Syenite is lighter colored, medium to coarse hypoautomorphic to pegmatitic texture, composed of mostly alkali feldspar with lesser plagioclase, ophitic to subophitic pyroxene, amphibole, and accessory minerals (Carmen and others, 1975). K-Ar ages 28.6 ± 0.4 Ma and 27.9 ± 0.4 Ma (Henry and McDowell, 1986); sill about 80 m thick. (USGS I-3142)

Tfb - Basaltic flow (Oligocene)

Lava flows overlying Burro Mesa Formation at Burro Mesa. Consists of several basaltic trachyandesite aa flows (Henry and others, 1989); microphenocrysts of highly altered olivine, biotite, minor amphibole; groundmass hypocrystalline with feldspar laths and altered olivine and opaques; dated at 29.53 ± 0.33 Ma and 29.10 ± 0.05 Ma (app.; 1). (USGS I-3142)

Burro Mesa Formation (Oligocene)

Includes rhyolite and Wasp Spring members, and related intrusive rocks, erupted from local vents in western Big Bend National Park (Henry and others, 1989; Holt, 1998; Adams, 2004). Descriptions from Becker (1976), Holt (1998), Adams (2004), and Benker (2005). (USGS I-3142)

Tbr - Burro Mesa Formation, Rhyolite member (Oligocene)

Blue-gray, rhyolitic ash-flow tuff and lava; contains anorthoclase and quartz phenocrysts and accessory minerals, including fayalite, arfvedsonite, acmite, and aenigmatite; upper part contains about 20 percent phenocrysts of anorthoclase with minor quartz and mafic inclusions (only present at Burro Mesa); rocks in lower part contain about 2 percent phenocrysts predominantly of alkali feldspar; lava often flow-banded and has ramp structures formed during emplacement of extrusive volcanic domes; dates range from 29.45 ± 0.08 Ma (app.; 6) to 29.25 ± 0.07 Ma (app.; 2); exposed at Burro Mesa, Goat and Kit Mountains, and in scattered outcrops between Castolon and Chisos Mountains; about 120 to 150 m thick at Burro Mesa. (USGS I-3142)

Tbw - Burro Mesa Formation, Wasp Spring member (Oligocene)

Gray, yellowish-gray, and brownish-gray surge deposits, debris-flow breccia, and ash-flow tuff; unit has tuffaceous matrix with abundant lithic fragments, fiamme, and volcanic blocks and bombs; dates range from 29.48 ± 0.16 Ma (app.; 10) to 29.27 ± 0.07 Ma (app.; 7); thickest exposures in southern Burro Mesa area along Blue Creek; about 30 to 100 m thick. (USGS I-3142)

Tbi - Burro Mesa Formation, intrusive rocks, undivided (Oligocene)

Light-gray to blue-gray rhyolite, associated with plugs, domes, and dikes; mostly holocrystalline, fine- to medium-grained groundmass, and variably porphyritic with up to 15 percent phenocrysts of quartz and alkali feldspar commonly as glomerocrysts; poikilitic arfvedsonite within groundmass; dike north of Blue Creek Ranch dated at 29.09 ± 0.07 Ma (app.; 12), and intrusion west of Burro Mesa Pouroff dated at 29.03 ± 0.12 Ma (app.; 11). (USGS I-3142)

Tt - Trachytic lava, undivided (Oligocene)

Black and dark-brown porphyritic trachyte, trachyandesite, and basaltic trachyandesite lava; basaltic trachyandesite groundmass has trachytic texture composed of plagioclase laths, opaque minerals, and altered pyroxene; phenocrysts include plagioclase and alkali-feldspar glomerocrysts, and altered pyroxene; trachyte and trachyandesite groundmass are intergranular to intersertal and composed of feldspar, clinopyroxene, and opaque minerals; phenocrysts include glomerocrysts of alkali feldspar with minor plagioclase and clinopyroxene. Trachyandesite likely stratigraphically below trachyte, relative stratigraphy of basaltic trachyandesite unknown; trachyandesite from Tuff Canyon dated at 30.42 ± 0.06 Ma (app.; 15); trachyte from Goat Mountain dated at 30.29 ± 0.05 Ma (app.; 14) and from Blue Creek Ranch area dated at 30.23 ± 0.11 Ma (app.; 13). Present in southwestern part of Big Bend National Park north and west of Punta de la Sierra southward to Sierra de Chino where previously mapped as Tule Mountain Trachyandesite Member of Chisos Formation by Maxwell and others (1967); about 100 to 250 m thick. (USGS I-3142)

Sierra Quemada related rocks (Oligocene)

Intrusive complex in southern part of Chisos Mountains composed primarily of rhyolitic intrusive rocks (Duex and Tucker, 1989; Duex and others, 1994; Duex, 2007; Scott and others, 2007). (USGS I-3142)

Tqd - Sierra Quemada ring dike (Oligocene)

Pink, mildly altered, porphyritic rhyolite with 20 to 30 percent phenocrysts and glomerocrysts of altered alkali feldspar and quartz; fine- to medium-grained groundmass with micrographic to granophyric texture; U-Pb zircon age of 29.93 ± 0.40 Ma (app.; 21). (USGS I-3142)

Tqi - Sierra Quemada intrusive rocks, undivided (Oligocene)

Pink rhyolite, dark-gray gabbro, and medium-gray syenite intrusive bodies; rhyolite typically in dike-like intrusions and similar in composition to ring-dikes (Tqd); gabbro intrusions contain plagioclase, pyroxene, and alteration minerals, including epidote, sulfide, and possibly fibrous arfvedsonite; syenite is porphyritic and arfvedsonite-bearing and has glomerocrystic feldspar with resorbed edges; U-Pb zircon ages range from 31.09 ± 0.48 Ma (app.; 23) to 29.06 ± 0.91 Ma (app.; 19). (USGS I-3142)

Tqv - Sierra Quemada vent breccia (Oligocene)

Light-pink, extremely lithic-rich volcanic breccia with minor rhyolitic ash matrix; lithic clasts consist of volcanic rocks, Cretaceous limestone, and Paleozoic rocks, and range in size from microscopic to Cretaceous limestone blocks 200 m in length; greater than 150 m thick in central part of Sierra Quemada. (USGS I-3142)

Dominguez Mountain related rocks (Oligocene)

Mafic to intermediate intrusive and volcanic complex to east of Punta de la Sierra, in southern Chisos Mountains (Maxwell and others, 1967; Bohannon, 2011). Extensive dike swarm associated with complex is best exposed on west side where dikes appear to merge upward with trachytic lavas (Tt) (Bohannon, 2011). (USGS I-3142)

Tdm - Dominguez Mountain mafic lava flows (Oligocene)

Unstudied dark-gray to black lava flows and mafic tuff in core of Dominguez Mountain; flows are of basaltic to andesitic composition; in places, metamorphosed to dense hornfels. (USGS I-3142)

Tdd - Dominguez Mountain dike swarm (Oligocene)

Dikes consist of wide range of compositions, including granite, rhyolite, syenite, trachyte, gabbro, and basalt. Intermediate dikes are abundant, particularly southwest of volcanic center where they pass upward into trachyte flows at Punta de la Sierra. Most rocks are porphyritic; mapped as a discrete unit where dike-on-dike intrusion forms a wide body; maximum dike thickness about 10 m. (USGS I-3142)

Tdi - Dominguez Mountain intrusive rocks, undivided (Oligocene)

Light-gray to pale yellowish-brown rhyolite to dacite porphyry, but also includes more mafic compositions; rhyolite is fine-grained, vuggy, and contains sparse white subhedral feldspar phenocrysts. Intermediate to mafic composition intrusions are coarse-grained and porphyritic olivine syenodiorite and syenogabbro (Maxwell and others, 1967). (USGS I-3142)

South Rim Formation (Oligocene)

Includes Emory Peak rhyolite, Boot Rock, and Pine Canyon rhyolite informal members and related intrusive rocks. Descriptions from Maxwell and others (1967), Barker and others (1986), Benker (2005), and White and others (2006). (USGS I-3142)

Tse - South Rim Formation, Emory Peak rhyolite member (Oligocene)

Gray, welded, devitrified, rhyolite ash-flow tuff, lava, and vitrophyre erupted from intracaldera and extracaldera vents; lava is holocrystalline and with minor granophyric texture, and contains up to 12 percent euhedral anorthoclase and 12 percent quartz; ash-flow tuff and vitrophyre are eutaxitic with up to 2 percent phenocrysts of alkali feldspar; accessory minerals include biotite, magnetite, monazite, and zircon. Exposed at Emory Peak and in Blue Creek Ranch area. Dates range from 32.25 ± 0.07 Ma (app.; 27) to 31.93 ± 0.13 Ma (app.; 24); about 100 m thick. (USGS I-3142)

Tsb - South Rim Formation, Boot Rock member (Oligocene)

Gray to pinkish-gray quartz trachyte to rhyolite ash-flow tuff, lava flows, and maar surge breccia, erupted from intracaldera and extracaldera vents of the Pine Canyon caldera (Barker and others, 1986; White and others, 2006); lava has trachytic texture and ash-flow tuff is pilotaxitic to eutaxitic; contains less than 10 percent euhedral to subhedral anorthoclase and quartz phenocrysts, and trace amounts of clinopyroxene, ilmenite, and magnetite (Benker, 2005). Intracaldera units contain subangular quartz trachyte and rhyolite lithic fragments; overlies Pine Canyon rhyolite member (Tsp) in Pine Canyon caldera area. Extracaldera units poorly to non-welded, and consist mostly of breccia and ash-flow tuff; exposed in South Rim area and northern Burro Mesa. Dated at 32.33 ± 0.07 Ma (app.; 29) and 32.17 ± 0.09 Ma (app.; 28); about 100 to 120 m thick. (USGS I-3142)

Tsp - South Rim Formation, Pine Canyon rhyolite member (Oligocene)

Brown to light brownish-gray, densely welded, intracaldera rhyolitic tuff with pilotaxitic to eutaxitic texture; contains 2 to 7 percent euhedral to subhedral anorthoclase phenocrysts, and minor fayalite, apatite, hedenbergite, and ilmenite (Barker and others, 1986; Benker, 2005; White and others, 2006); exposed within Pine Canyon caldera; dated at 32.33 ± 0.07 Ma (app.; 31) and 32.11 ± 0.23 Ma (app.; 30); thickness from 300 to greater than 500 m. (USGS I-3142)

Tsr - South Rim Formation, outflow deposits, undivided (Oligocene)

Includes unstudied outflow deposits, which may include Boot Rock and (or) Emory Peak rhyolite members; exposed west of Pulliam Peak and near Blue Creek Ranch. (USGS I-3142)

Tsd - South Rim Formation, ring dike (Oligocene)

Reddish-brown to tan rhyolite with granophyric groundmass; contains 5 to 7 percent phenocrysts of quartz and sanidine and glomerocrysts of highly altered sanidine. Unit includes Hayes Ridge ring dike with a U-Pb zircon age of 32.6 ± 0.3 Ma, and an $^{40}Ar/^{39}Ar$ age on K-feldspar of 31.99 ± 0.32 Ma (app.; 32); about 20 to 400 m thick. (USGS I-3142)

Tsi - South Rim Formation, intrusive rocks, undivided (Oligocene)

Consists of pre- and post-caldera intrusive rocks; 1 to 7 percent phenocrysts of highly to mildly altered alkali feldspar, unaltered alkali feldspar, quartz with resorbed edges, and clinopyroxene, orthopyroxene, and euhedral arfvedsonite; groundmass varies from trachytic texture, with interstitial poikilitic alkali feldspar, to granular and micrographic texture; interstitial arfvedsonite common. Unit includes intrusions at Ward Mountain and Pulliam Peak (32.4 ± 0.4 Ma; app.; 37), K-bar area (32.4 ± 0.3 Ma; app.; 36), Nugent Mountain (31.5 ± 0.3 Ma, app.; 33), Lone Mountain, Panther Spring, and other smaller intrusions in The Basin area. (USGS I-3142)

Tigh - Fayalite syenite of Grapevine Hills (Oligocene)

Gray, fine- to medium-grained syenite; consists of euhedral phenocrysts of alkali feldspar, quartz, fayalite, and pyroxene; minor granophyric and porphyritic texture with phenocrysts of carlsbad-twinned alkali feldspar. U-Pb zircon age of 31.9 ± 0.2 Ma, and an $^{40}Ar/^{39}Ar$ age on K-feldspar at 31.62 ± 0.30 Ma (app.; 81); about 200 m thick. (USGS I-3142)

Timh - Fayalite syenite of McKinney Hills (Oligocene)

Blue to blue-green, fine-grained syenite; consists of subhedral phenocrysts of alkali feldspar, quartz, fayalite, augite, plagioclase, and hornblende. U-Pb zircon age of 32.2 ± 0.3 Ma (app.; 83); individual bodies range from about 200 to 400 m thick. (USGS I-3142)

Tirm - Syenite of Rosillos Mountains (Oligocene)

Blue to blue-green, fine- to medium-grained syenite; consists of euhedral to subhedral phenocrysts of alkali feldspar, augite, fayalite, and quartz. U-Pb zircon age of 32.1 ± 0.2 Ma (app.; 82); about 200 to 600 m thick. (USGS I-3142)

Ti - Intrusive rocks, undivided (Eocene to Oligocene)

Scattered intrusive bodies and dikes throughout park of unknown composition and includes intrusions of multiple compositions such as Pena Mountain (28.77 ± 0.08 Ma; app.; 75; and 28.7 ± 0.4 Ma; app.; 74), which is compositionally similar to intrusive complex at Rattlesnake Mountian (Tirc). Also shown in east end of cross section B-B' as undivided intrusive rocks. (USGS I-3142)

Tir - Rhyolitic and other felsic composition intrusive rocks, undivided (Eocene to Oligocene)

Sills, dikes, and other irregular bodies with rhyolitic and other felsic compositions as defined below. Where chemical analysis available, includes rocks with SiO_2 greater than 63 percent (volatile-free), and where chemical analysis unavailable, composition based on determinations of Maxwell and others (1967) to include quartz syenite, quartz diorite, and granite. Unit mostly exposed southeast and northwest of Chisos Mountains. Isotopic age determinations range from 41.6 ± 0.4 Ma (Maverick Mountain; app.; 85) to 28.1 ± 0.3 Ma (Tortuga Mountain; app.; 72). Also includes intrusions at Chilicotal and Talley Mountains, Government Spring (33.0 ± 0.2 Ma; app.; 84), Slickrock Mountain (31.7 ± 0.6 Ma; app.; 80), Glenn Spring (30.22 ± 0.09 Ma; app.; 77), and intrusion encompassing Paint Gap Hills and Croton Peak. (USGS I-3142)

Tia - Andesitic and other intermediate composition intrusive rocks, undivided (Eocene to Oligocene)

Sills, dikes, and other tabular bodies with andesitic and other intermediate compositions as defined below. Where chemical analysis available, includes rocks with SiO_2 between 52 and 63 percent (volatile-free); where chemical analysis unavailable, composition based on determinations of Maxwell and others (1967) to include syenite, syenodiorite, diorite, and alkali syenite. Exposed north of Rosillos Mountains, west of Nugent Mountain (31.45 ± 0.18 Ma; app.; 79), and southern end of Christmas Mountains. (USGS I-3142)

Tib - Basaltic and other mafic composition intrusive rocks, undivided (Eocene to Oligocene)

Sills, dikes, and other tabular bodies with mafic compositions as defined below. Where chemical analyses available, includes rocks with SiO_2 less than 52 percent (volatile-free); where chemical analyses unavailable, composition based on determinations of Maxwell and others (1967) to include basalt, diabase, gabbro, syenogabbro, and trachydolerite. Includes intrusive bodies at Bone Spring, Dagger Flat, Mariscal Mountain, Cow Heaven Mountain, Mesa de Anguila, and north of Rosillos Mountains. (USGS I-3142)

Chisos Formation (Oligocene and Eocene)

Includes younger and older parts (table 1) described below. Rocks of younger part of Chisos Formation (Tcy) are widely exposed in western Big Bend National Park, but they also are exposed in the northeastern Chisos Mountains where they flank the Pine Canyon caldera, and unconformably overlie rocks of the older part of the Chisos Formation. Rocks of older part are restricted to the Chisos Mountains, east of Sierra Quemada and Burro Mesa. (USGS I-3142)

Tcy - Chisos Formation, younger part, undivided (Oligocene and Eocene)

Gray, white, red, pink, and brown tuffaceous clay, mudstone, sandstone, siltstone, tuff, conglomerate, and some lacustrine limestone. In western Big Bend National Park, base of unit defined by Alamo Creek Basalt, and variably includes lava and ash-flow members described below (Tcac, Tcas, Tcbm, Tcme, and Tctm). In Chisos Mountains, consists mostly of tuffaceous sedimentary rocks and most lava and ash-flow members present in western Big Bend National Park are absent, but base of unit is locally defined by Ash Spring Basalt Member north of Pulliam Bluff and west of Panther Spring, and between Ward Mountain and Burro Mesa; in most places in Chisos Mountains, however, tuffaceous sedimentary rocks of unit unconformably overlie sedimentary rocks of older part of Chisos Formation. Contains Eocene mammal and turtle bone fragments, and fresh water gastropods (Maxwell and others, 1967). $^{40}Ar/^{39}Ar$ ages on sanidine range from 42.31 ± 0.10 Ma (app.; 62) to 32.96 ± 0.06 Ma (app.; 38), and U-Pb zircon ages at 45.3 ± 0.7 Ma (app.; 63) and 42.6 ± 0.4 Ma (app.; 62). About 400 to 600 m thick. (USGS I-3142)

Tctm - Chisos Formation, Tule Mountain Trachyandesite Member (Oligocene)

Brownish-gray porphyritic trachyte to trachyandesite lava; phenocrysts and glomerocrysts consist of skeletal plagioclase, alkali feldspar, clinopyroxene, and orthopyroxene. Exposed at Burro Mesa, Tule Mountain, and Sierra Aguja. $^{40}Ar/^{39}Ar$ ages on groundmass concentrate range from 33.88 ± 0.54 Ma (app.; 40) to 33.18 ± 0.10 Ma (app.; 39). About 20 to 60 m thick. (USGS I-3142)

Tcbm - Chisos Formation, Bee Mountain Basalt Member (Oligocene)

Dark-gray, fine- to medium-grained, vesicular to nonvesicular, basalt to basaltic trachyandesite lava; includes phenocrysts of plagioclase, olivine, and clinopyroxene. Vesicles often filled with secondary minerals of calcite, zeolite, and microcrystalline quartz. In southwestern Big Bend National Park, consists of several flows above and below Mule Ear Spring Tuff Member. Dates range from 34.03 ± 0.17 Ma (app.; 52) to 33.07 ± 0.15 Ma (app.; 41); about 90 m thick in Blue Creek Ranch area, and 160 m at Bee Mountain and south of Cerro Castellan (Maxwell and others, 1967). (USGS I-3142)

Tcme - Chisos Formation, Mule Ear Spring Tuff Member (Oligocene)

Gray, brown, and red, densely to poorly welded, silicified ash-flow tuff; phenocrysts of alkali feldspar, biotite, and clinopyroxene. Generally overlain and underlain by tuffaceous sedimentary units, but in places in contact with Bee Mountain Basalt Member (Tcbm) above or below. Dates range from 33.67 ± 0.09 Ma (app.; 47) to 33.64 ± 0.08 Ma (app.; 43); about 2 to 3 m thick. (USGS I-3142)

Tcl - Chisos Formation, undifferentiated lava flows (Eocene)

Lava flows east of Burro Mesa mapped by Maxwell and others (1967) as undifferentiated lava; lava is dark gray, porphyritic with fine-grained groundmass; phenocrysts include large plagioclase laths up to 2 cm in length, and completely altered pyroxene and olivine. Dated at 38.87 ± 0.09 Ma (app.; 53). About 20 m thick. (USGS I-3142)

Tcas - Chisos Formation, Ash Spring Basalt Member (Eocene)

Dark-gray, porphyritic, fine-grained basaltic to trachyandesitic lava, with large white plagioclase laths from 1 to 2 cm long, and equant plagioclase grains and glomerocrysts; also contains olivine and pyroxene. $^{40}Ar/^{39}Ar$ age on groundmass concentrate of 40.92 ± 0.07 Ma (app.; 58). Exposed in northern and western Chisos Mountains, and in Tule Mountain and Kit Mountain areas. About 30 m thick. (USGS I-3142)

Tcac - Chisos Formation, Alamo Creek Basalt Member (Eocene)

Dark-gray, dense, fine-grained basalt to trachybasalt, and basaltic trachyandesite to trachyandesite; scoriaceous in places. Consists of several flows; locally, some of the flows are porphyritic and contain

plagioclase phenocrysts and glomerocrysts, but in other places, such as the Alamo Creek area, lacks visible phenocrysts. Dates range from 47.09 ± 0.33 Ma (app.; 71) to 44.41 ± 0.22 Ma (app.; 64). Defines base of Chisos Formation in western Big Bend National Park; about 30 to 60 m thick. (USGS I-3142)

Tco - Chisos Formation, older part, undivided (Eocene)

Includes 3 informal units of Bohannon (2011) described below. Restricted to Chisos Mountains, east of Sierra Quemada and Burro Mesa. Unconformably overlies Aguja Formation in southern Chisos Mountains, and Black Peaks Formation on east flank of Chisos Mountains. (USGS I-3142)

Shown in cross section only and includes units described below.

Tcstr - Chisos Formation, sandstone, tuff, and rhyolite unit (Eocene)

Brown sandstone with accessory tuffaceous sandstone and rhyolite. Bedding is mostly parallel with even bedding surfaces and uniform bed thickness maintained over large distances. Many beds cross-stratified internally, others are more massive. Some beds have a conglomeratic base with clasts typically of limestone. Sand grains are mostly quartz; fragments of tuff and glass shards are abundant in places. Present in Fresno Creek area, south of Hayes Ridge, and around perimeter of Pine Canyon caldera; 690 m thick. (USGS I-3142)

Tcks - Chisos Formation, siltstone unit (Eocene)

Greenish, purplish, and gray siltstone, probably derived from Upper Cretaceous Javelina Formation (Kj), and white to brown quartz-rich beds that are probably altered and silicified airfall tuff beds; unit altered to hornfels near Juniper Canyon. Intertongues with map unit Tcstr; thickness is variable with a maximum of 175 m near Juniper Canyon on the east flank of Chisos Mountains. (USGS I-3142)

Tcrt - Chisos Formation, rhyolite tuff unit (Eocene)

Light-pink to light-gray rhyolite tuff; fine grained to very fine grained; in discontinuous, irregular beds a few centimeters to a few tens of centimeters thick; characteristically contains small (1–2 cm) medium-gray globular concretions. Most glass shards altered to clay. Also includes silt and clay with parallel, continuous, and even bedding, and interbedded layers of air-fall tuff and siltstone; tuff and siltstone beds are parallel to one another and are 3–50 cm thick, and bedding surfaces are even and beds are uniform in thickness. Beds of each lithology are internally laminated. Sandy lenses as thick as 1–2 m occur locally. Disconformably overlies metamorphosed Aguja Formation; present between Fresno Creek and Dominguez Mountain. About 65 m thick. (USGS I-3142)

Tx - Christmas Mountains related volcanic rocks (Eocene)

Orangish-gray air-fall and ash-flow tuff, lava, and debris flows associated with initial eruptive events of the Christmas Mountains caldera complex; tuff is rhyolitic with up to 30 percent pumice, alkali feldspar phenocrysts, and sparse biotite; lava is porphyritic quartz trachyte with up to 20 percent alkali feldspar phenocrysts and altered pyroxene; groundmass has trachytic texture composed of alkali feldspar and interstitial to poikilitic quartz. K-Ar dates range from 42.8 ± 0.9 to 41.2 ± 0.9 Ma (Henry and others, 1989). About 246 m thick at Little Christmas Mountain, and about 40 m thick at Dogie Mountain. (USGS I-3142)

Tc - Canoe Formation (Eocene)

Light-gray, reddish-gray, brownish-gray, and yellowish-gray sandstone and conglomeratic sandstone, purple and gray tuffaceous mudstone and claystone, gray to whitish-gray nodular tuff, basaltic lava, and minor limestone at top of unit. Tuffaceous sediments and tuff dominates upper part of formation; base includes 10-m-thick Big Yellow Sandstone Member (Maxwell and others, 1967), consisting of fine- to coarse-grained sandstone; conglomeratic at the base. Vertebrate fossils (Maxwell and others, 1967;

Runkel, 1988; Busbey and Lehman, 1989; Lehman and Busbey, 2007), including a wide variety of mammals, and some crocodile and turtle bones, and petrified wood. Unit mostly exposed in Tornillo Flat, but includes several small exposures in Estufa Spring and Dawson Creek areas. About 350 m thick. (USGS I-3142)

Thh - Hannold Hill Formation (Eocene)

Mostly gray and red mudstone, and gray to reddish-brown conglomeratic sandstone; also contains some lignite beds and calcareous nodules. Unit subdivided into following units (Beatty, 1992), from top to base: upper mudstone, upper conglomeratic sandstone, lower mudstone, and Exhibit Sandstone Member, a basal conglomeratic sandstone. Exhibit Sandstone Member consists of conglomeratic sandstone with clasts of Cretaceous limestone, chert, sandstone, oyster shell fragments, and petrified wood. Unit contains abundant vertebrate fossils (Maxwell and others, 1967; Hartnell, 1980; Busbey and Lehman, 1989; Lehman and Busbey, 2007). Unit exposed in Tornillo Flat area where it is unconformable with overlying Canoe Formation, and as much as 70 m thick. (USGS I-3142)

TKbp - Black Peaks Formation (Upper Cretaceous to Paleocene)

Mostly variegated gray, black, red, and white mudstone, and interbedded white, light-gray, grayish-brown, and yellowish-gray, medium- to coarse-grained, partly conglomeratic sandstone; also includes freshwater limestone about 65 m above base containing gastropods and pelecypods. Sandstone contains reddish-brown “cannonball” concretions. Upper contact with Hannold Hill Formation disconformable; base of formation is marked by conglomeratic, crossbedded sandstone. Formation contains vertebrate fossils, including dinosaur, turtle, and crocodile bones, fish scales and bones, Paleocene mammals, and petrified logs and wood fragments (Maxwell and others, 1967; Schiebout, 1974; Schiebout and others, 1987; Busbey and Lehman, 1989; Lehman and Busbey, 2007). About 300 to 400 m thick. (USGS I-3142)

Kj - Javelina Formation (Upper Cretaceous)

Variegated, gray, brown, red, and purple calcareous mudstone, and yellowish-gray, yellowish-brown, and dark-brown, lenticular, crossbedded, partly conglomeratic sandstone. Mudstone contains calcareous nodules associated with paleosol zones; unit contains vertebrate fossils (Maxwell and others, 1967; Busbey and Lehman, 1989; Lehman and Busbey, 2007) and petrified wood; tuff bed in middle part of formation dated at 69.0 + 0.9 Ma (Lehman and others, 2006); formation conformable with overlying Black Peaks Formation, and is about 100 to 200 m thick. (USGS I-3142)

Ka - Aguja Formation (Upper Cretaceous)

Consists of six informal members described below in descending order (Lehman, 1985): (1) upper shale member is light- to dark-gray and reddish shale and mudstone, and interbedded light-brown to reddish-brown sandstone near top; mudstone is carbonaceous and lignitic, and contains some petrified tree stumps; (2) Terlingua Creek sandstone is light-gray, calcareous, fine- to medium-grained sandstone, and some light-gray shale and lignite interbeds; (3) middle shale member is light-gray to dark-gray, calcareous, carbonaceous, and lignitic shale; (4) Rattlesnake Mountain sandstone member is mostly light-gray, fine-grained, calcareous sandstone; sandstone is ripple marked and trough crossbedded, and contains oysters and *Ophiomorpha* burrows; (5) lower shale member is light-gray to dark-gray, laminated, silty, carbonaceous shale, and some brown and gray sandstone and siltstone; contains some coal and lignite, and reddish-brown concretions and oysters; and (6) basal sandstone member consists of yellowish-gray to dark reddish-brown, fine-grained, calcareous sandstone; contains some conglomeratic beds near base with light-gray claystone clasts derived from underlying Pen Formation. Formation contains vertebrate fossils and petrified tree stumps (Maxwell and other, 1967; Busbey and Lehman, 1989; Lehman and Busbey, 2007). Mafic pyroclastic deposits in uppermost part of formation dated at 76.9 ± 1.2 Ma (Breyer and others, 2007; Befus and others, 2008). Upper contact with Javelina Formation is gradational and placed at the top of sandstone beds in the Aguja, which are overlain by

predominantly variegated mudstone of the Javelina. Combined maximum thickness about 100 to 280 m thick. (USGS I-3142)

Kp - Pen Formation (Upper Cretaceous)

Mostly light-gray, yellowish-gray, and yellowish-brown claystone, and some sandstone and chalk; claystone is calcareous and sandy. Unit contains yellowish-gray to dark-brown concretions, up to 1 m in diameter, some which form layers, and others that are isolated; concretions are sandy and fossiliferous. Formation includes sandstone beds, up to 1.5 m thick, which increase in number and thickness upward; sandstone beds near top of formation contain gastropods and bivalves. Upper contact with Aguja Formation is gradational and intertonguing with Aguja sandstone units. Formation contains ammonites, pelecypods, and gastropods. Forms slope and about 100 to 230 m thick. (USGS I-3142)

Kb - Boquillas Formation, undivided (Upper Cretaceous)

Thin-bedded, medium-gray, light-gray, yellowish-gray, and brownish-gray limestone, shale, claystone, marl, chalk, and very minor siltstone and sandstone. Contact with overlying Pen Formation gradational (Lehman, 1985); contact with underlying Buda Limestone is sharp and disconformable, and marked by a distinctive color change from gray tones in Buda Limestone to light-brown tones in the lowermost Boquillas Formation. Formation contains abundant inoceramids, as well as ammonites, echinoids, cephalopods, foraminifera, and fish bones. Unit subdivided into San Vicente and Ernst Members in areas along the western flank of Sierra del Carmen, and near Sierra San Vicente and Mariscal Mountain, but in other areas of Big Bend National Park, unit mapped undivided. About 220 to 245 m thick. (USGS I-3142)

Kbs - Boquillas Formation, San Vicente Member (Upper Cretaceous)

Medium-gray, finely crystalline, thin-bedded limestone, and brownish-gray and yellowish- to light-gray claystone, calcareous shale, marl, and chalk. Limestone is argillaceous and chalky; claystone is calcareous and contains some clay minerals including kaolinite, montmorillonite, and illite; about 145 m. (USGS I-3142)

Kbe - Boquillas Formation, Ernst Member (Upper Cretaceous)

Mostly medium-gray, finely crystalline, thin-bedded silty limestone, and brownish-gray to light-brown calcareous shale, and some siltstone, claystone, and marl. Top of member marked by brown-weathering limestone and shale beds that contain *Allocrioceras hazzardi* Zone (Cooper, 2000; Cooper and others, 2007, 2008); about 75 to 100 m thick. (USGS I-3142)

Kbd - Buda Limestone and Del Rio Clay, undivided (Upper Cretaceous)

Unit shown in cross section only. (USGS I-3142)

Kbu - Buda Limestone (Upper Cretaceous)

Consists of an upper cliff-forming limestone, a middle slope-forming marly limestone, and a lower cliff-forming basal limestone; upper limestone thicker than lower limestone. Upper and basal limestones are white to light-gray, finely crystalline, partly burrowed, massive bedded, and have distinctive conchoidal fractures; middle marly limestone is light gray, nodular, and dense. Formation contains gastropods and pelecypods. Contact with overlying Boquillas Formation is unconformable. Exposed in southern Santiago Mountains, Sierra del Carmen, Mariscal Mountain, and Mesa de Anguila; about 20 to 30 m thick. (USGS I-3142)

Kdr - Del Rio Clay (Upper Cretaceous)

Pale-red, yellowish-gray, and light-gray claystone, interbedded dark yellowish-orange to moderate yellowish-brown, thin-bedded to laminated limestone, and some yellowish-brown, friable sandstone;

formation is limonitic. Limestone contains abundant foraminifera (*Haplostiche texana* most common) and ammonite shell fragments. Contact with overlying Buda Limestone is sharp. About 36 m thick in Dog Canyon area, 30 m thick in the Mesa de Anguila area, and only about 1.5 m thick in Sierra Del Carmen near the Rio Grande, where basal parts of formation are absent (Maxwell and others, 1967). (USGS I-3142)

Kse - Santa Elena Limestone (Lower Cretaceous)

Light-gray, thin- to thick-bedded, finely crystalline limestone and some yellowish-gray marly limestone, and brown chert nodules; contains abundant silicified rudistids and some gastropods. Forms massive cliffs and exposed in Sierra del Carmen, Mariscal Mountain, and Mesa de Anguila; about 225 m thick. (USGS I-3142)

Ksp - Sue Peaks Formation (Lower Cretaceous)

Upper part is light-gray nodular, thin-bedded limestone and interbedded yellowish-gray shale. Middle part is a 6-m-thick massive gray limestone ledge. Lower part is yellowish-gray marly shale and lesser amounts of thin-bedded, nodular limestone. Unit contains gastropods, echinoids, and ammonites. Unit forms slope between the more resistant Santa Elena Limestone above and the Del Carmen Limestone below. About 76 m thick in Sierra del Carmen and 80 m thick in Santa Elena Canyon. (USGS I-3142)

Kdc - Del Carmen Limestone (Lower Cretaceous)

Massive cliff-forming, light-gray to yellowish-gray, finely crystalline limestone and brown chert layers and nodules. Unit contains rudistids and ammonites. Sharp contact with underlying Telephone Canyon Formation. About 100 m thick in Sierra del Carmen and Santiago Mountains, and 144 m thick in Mesa de Anguila area. (USGS I-3142)

Ktm - Telephone Canyon Formation and Maxon Sandstone, undivided (Lower Cretaceous)

Telephone Canyon Formation is alternating yellowish- to brownish-gray nodular limestone and yellowish-gray marl; contact with overlying Del Carmen Limestone sharp and disconformable. Maxon Sandstone is reddish-weathering, fine-grained, calcareous, silty sandstone; lower and upper contacts gradational with underlying Glen Rose Limestone and overlying Telephone Canyon Formation (Poth, 1979); Maxon reported to be about 3 m thick in Big Bend National Park (Maxwell and others, 1967). Combined unit forms slope between more resistant Glen Rose Limestone below and Del Carmen Limestone above; exposed in Santiago Mountains, Sierra del Carmen, and Santa Elena Canyon area; about 20 to 45 m thick. (USGS I-3142)

Kgr - Glen Rose Limestone (Lower Cretaceous)

Most of unit consists of alternating resistant limestone and less resistant marl beds. Limestone is medium to light gray, finely to medium crystalline, and mostly thick bedded, and includes interbeds of light-brown marl; contains pelecypods, gastropods, and echinoids. Basal 20 m of unit consists of pale-red pebble to cobble conglomerate and interbedded gray and red sandstone, and pale-red claystone. Conglomerate is crudely bedded with some clast imbrication and graded bedding; clasts are subangular to subrounded and consist mostly of gray sandstone, siltstone, and mudstone derived from underlying Tesnus Formation. A 10-m-thick nodular limestone unit above basal conglomerate and clastic beds contains a distinctive coquina of *Exogyra quitmanensis*. Unit exposed in Santiago Mountains where it unconformably overlies Pennsylvanian-Mississippian Tesnus Formation, and in Sierra del Carmen; about 100 to 150 m thick. (USGS I-3142)

PMt - Tesnus Formation (Lower Pennsylvanian and Upper Mississippian)

Shale, sandstone, and siltstone. Shale is black, brown, and gray, and sandstone and siltstone is light gray to light brown. Pebble conglomerate at base of unit about 0.3 m thick and consists of subangular chert clasts derived from Caballos Novaculite below; unconformable with underlying Caballos Novaculite. Unit exposed in Persimmon Gap area; about 150–200 m thick; incomplete thickness. (USGS I-3142)

PZu - Paleozoic rocks, undivided (Ordovician through Lower Pennsylvanian)

Mapped where individual units could not be subdivided. Includes parts of units described below, but some exposures may include parts of older units including the Lower Ordovician Marathon Limestone and Alsate Shale (Maxwell and others, 1967); exposed in southern Santiago Mountains and southeast of Dog Canyon. Unit shown in cross section as Paleozoic rocks, undivided. (USGS I-3142)

MOu - Mississippian to Ordovician rocks, undivided (Ordovician to Mississippian)

Includes the Caballos Novaculite (Mississippian to Silurian) and Maravillas Formation (Upper and Middle Ordovician). Caballos Novaculite is novaculite, chert, and some shale. Upper part is black to brown thin-bedded to laminated chert with interbeds of brown silicious shale. Lower part is light-gray to white novaculite that forms resistant ledge; Caballos Novaculite unconformable with underlying Maravillas Formation and about 20 m thick. Maravillas Formation includes limestone and alternating chert, and interbedded shale. Upper 10 to 12 m includes Persimmon Gap Shale of Wilson (1954), which consists of interbedded reddish-weathering shale and black chert of Late Ordovician age. Below Persimmon Gap Shale is alternating limestone and interbedded chert. Limestone is medium gray, finely to medium crystalline, and thin bedded; some beds contain silicified brachiopod, crinoid, and bryozoan fragments; limestone beds contain Late Ordovician conodonts including *Amorphognathus ordovicicus*, *Belodina*, *Oistodus venustus*, *Panderodus gracilis*, *Panderodus unicostatus*, and *Phragmodus undatus* (Page and Harris, 2007). Chert is black and thin bedded to laminated. Exposed in Persimmon Gap area of Santiago Mountains; about 60 to 80 m thick; base not exposed. (USGS I-3142)

Geologic Cross Sections

The geologic cross sections present in the GRI digital geologic-GIS data produced for Big Bend National Park, Texas (BIBE) are presented below. Note that some cross section abbreviations (e.g., A - A') may have been changed from their source map abbreviation in the GRI data so that each GRI cross section abbreviation is unique.

The following cross sections are from "Geologic map of Big Bend National Park" (USGS I-3142) *GRI Source Map 7246*.

*****These cross sections have x2 Vertical Exaggeration and are at 1:75,000 horizontal scale*****

Cross Section A-A'

Cross Section B-B'

Cross Section C-C'

GRI Source Map Citations

The GRI digital geologic-GIS map for Big Bend National Park, Texas (BIBE) was compiled from the following source:

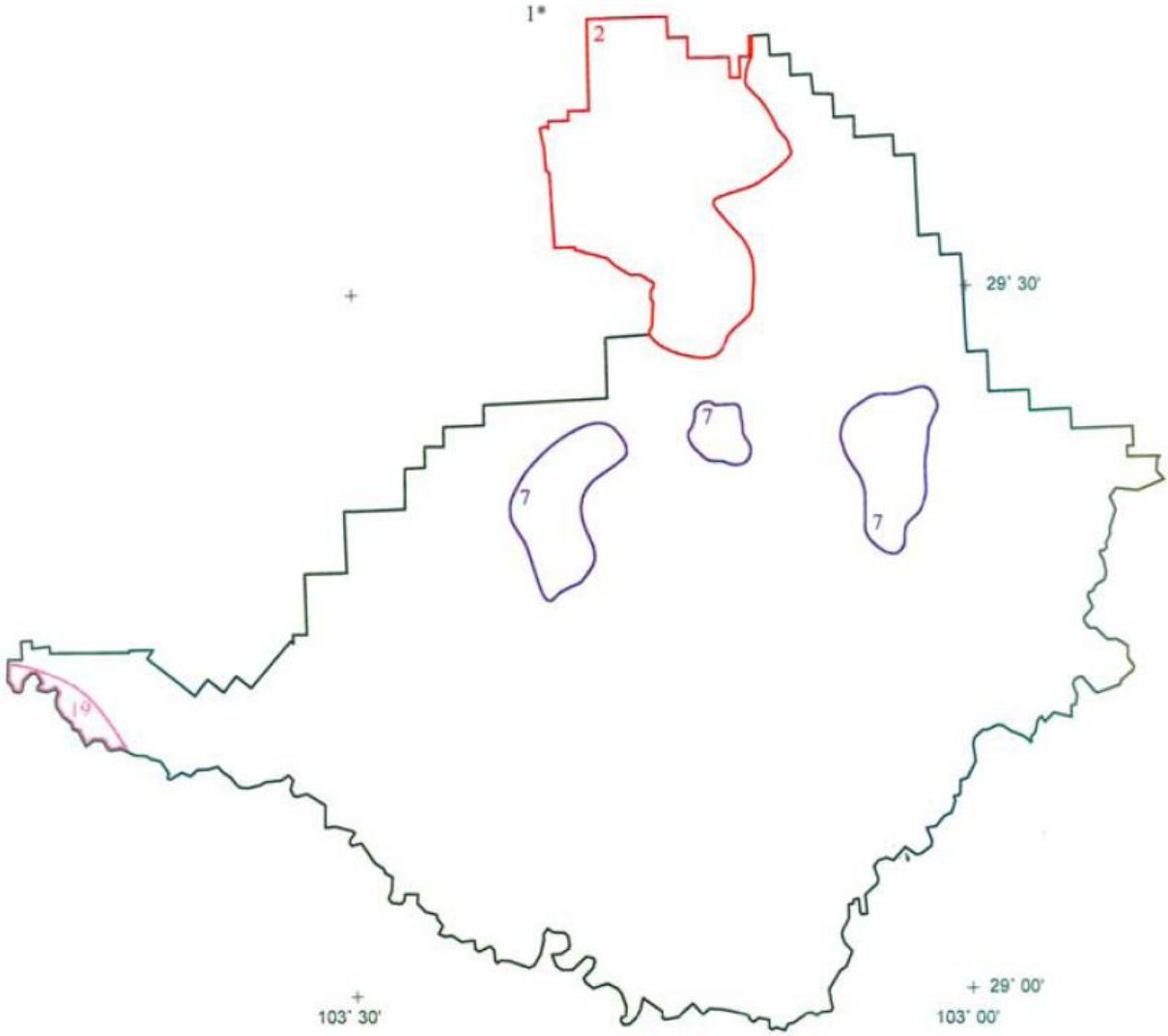
Turner, K.J., Berry, M.E., Page, W.R., Lehman, T.M., Bohannon, R.G., Scott, R.B., Miggins, D.P., Budahn, J.R., Cooper, R.W., Drenth, B.J., Anderson, E.D., and Williams, V.S., 2011, Geologic map of Big Bend National Park, Texas, U.S. Geological Survey, Scientific Investigations Map 3142, 1:75000 scale (USGS I-3142) *GRI Source Map 7246*.

Additional information pertaining to each source map is also presented in the Source Map Information (MAP) table included with the GRI geology-GIS data.

Geologic map of Big Bend National Park

Turner, K.J., Berry, M.E., Page, W.R., Lehman, T.M., Bohannon, R.G., Scott, R.B., Miggins, D.P., Budahn, J.R., Cooper, R.W., Drenth, B.J., Anderson, E.D., and Williams, V.S., 2011, Geologic map of Big Bend National Park, Texas, U.S. Geological Survey, Scientific Investigations Map 3142, 1:75000 scale, *GRI Source Map 7246*.

I-3142 Index 1



1* M.E. Berry and V.S. Williams, new mapping this report; surficial deposits throughout park with the exception of reference 16 where primary mapping was integrated by M.E. Berry

2 R.B. Scott, W.R. Page, and L.Snee, new mapping this report

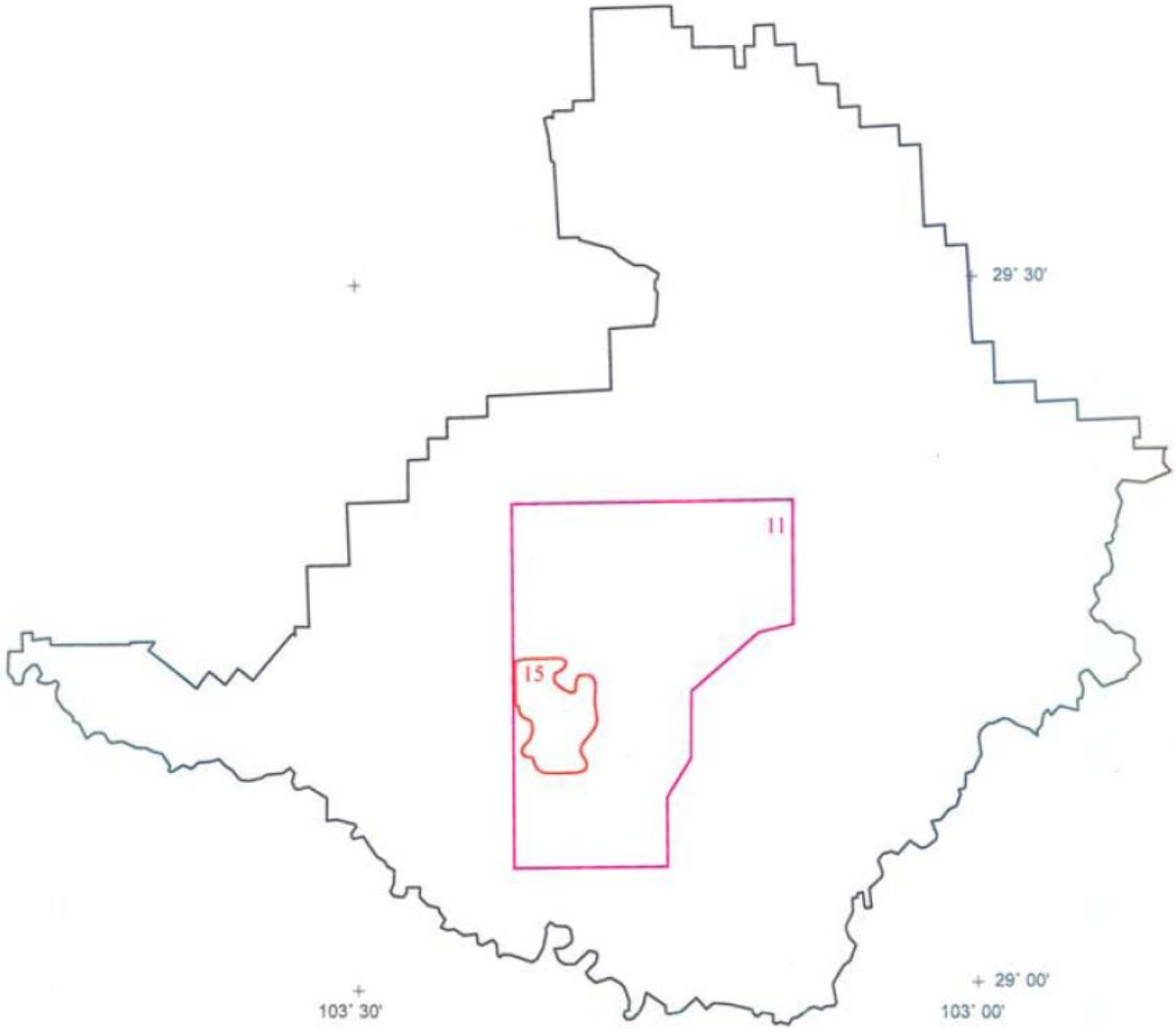
7 R.B. Scott and L.Snee, new mapping this report

19 R.B. Scott, new mapping this project

Index to mapping - 1 of 5

Extracted from: (USGS I-3142).

I-3142 Index 2



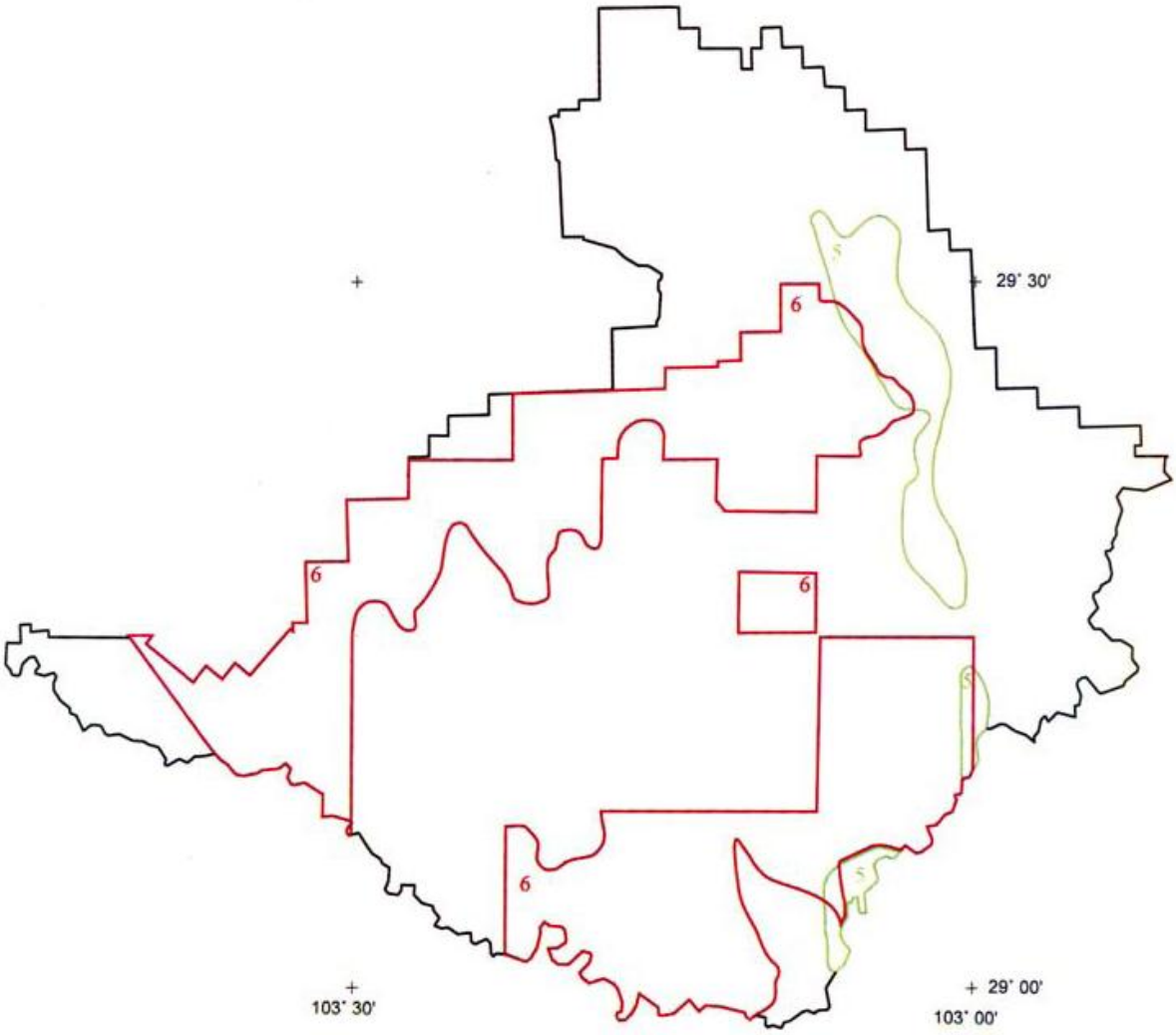
11 Bohannon (2011)

15 R.B. Scott, L.Snee, K.J. Turner, and D.P. Miggins, new mapping this report

Index to mapping - 2 of 5

Extracted from: (USGS I-3142).

I-3142 Index 3



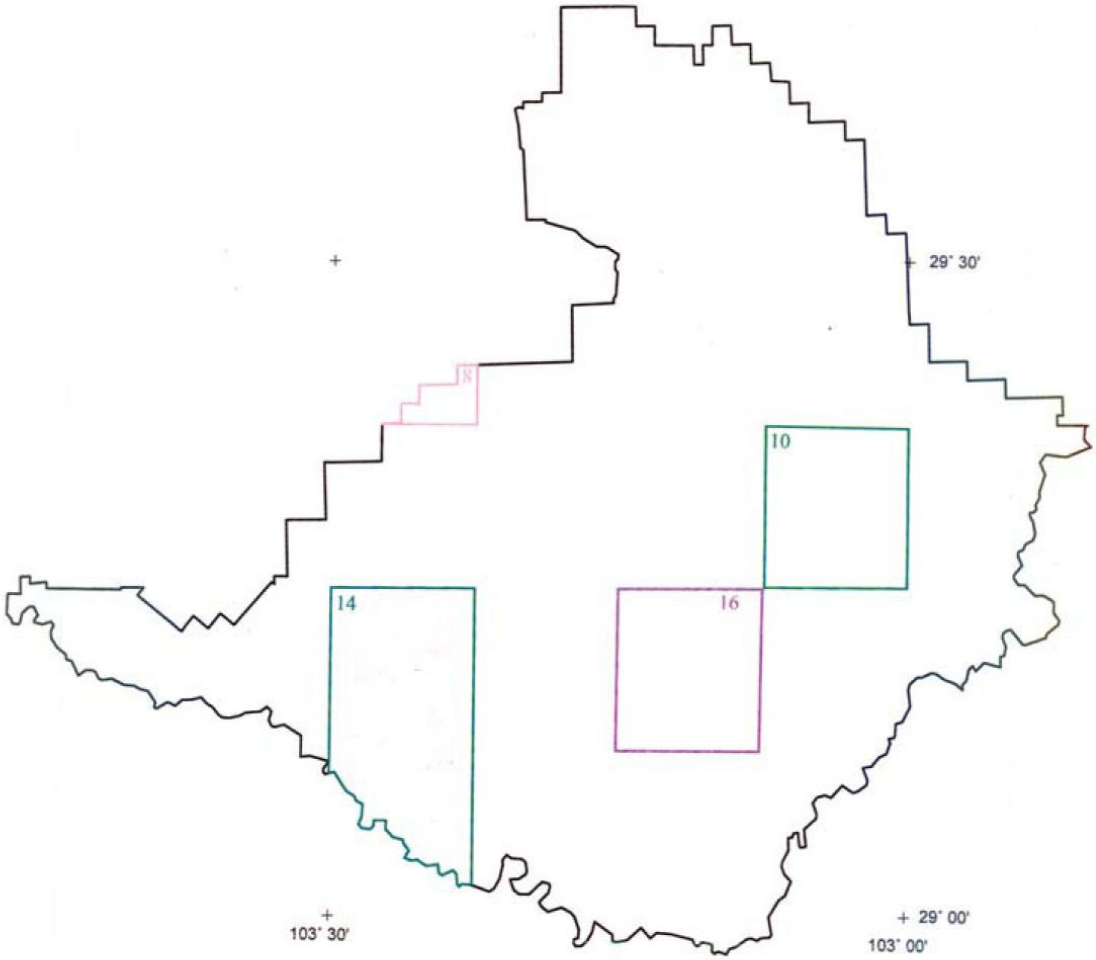
5 R.W. Cooper and D.A. Cooper, new mapping this report

6 T.Lehman, new mapping this report

Index to mapping - 3 of 5

Extracted from: (USGS I-3142).

I-3142 Index 4



8 Henry and others (1989)

10 Stevens (1969), and M.S. Stevens and J.B. Stevens, unpublished mapping

14 Stevens (1969)

16 Collins and others (2008)

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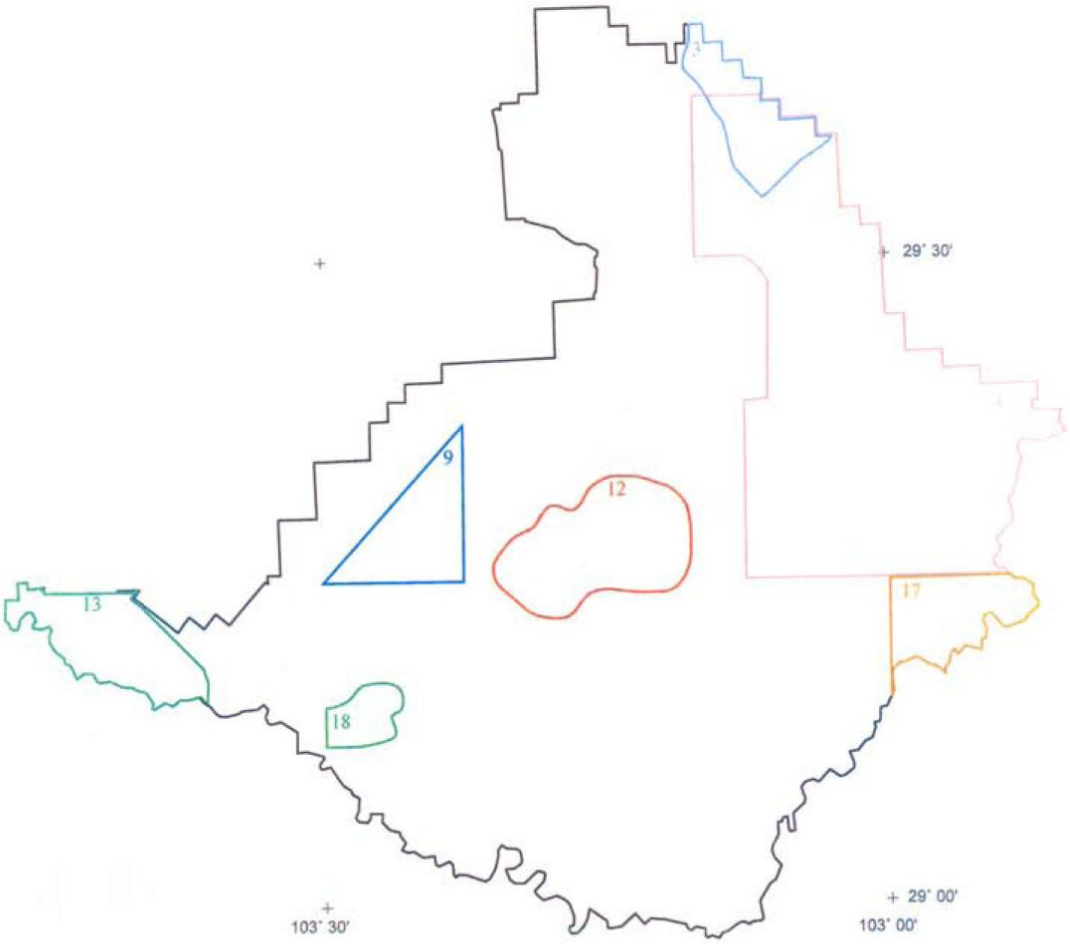
Extracted from: (USGS I-3142).

I-3142 Index 5



3 Poth (1979)
4 Moistala (1988)

9 K.Wache, new mapping this report

12 Ogley (1978)
13 DeCamp (1985)

17 Maier (1987)
18 Adams (2004)

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