

Editor's Note: This summary has been written by Thomas Ewing during the Covid-19 shut-down to accompany his textbook Texas Through Time. It was designed to explore in depth the topics in the first chapter.

GEOMORPHIC PROVINCES AND REGIONS OF TEXAS

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ABSTRACT

Texas is a state and region with varied landforms, but they have received only limited attention. Reanalysis of geomorphic regions in Texas indicates three major provinces. The **Coastal Plains** include plains to gentle hilly uplands constructed on poorly consolidated sediments of Late Cretaceous and Cenozoic age that dip gently toward the Gulf of Mexico, containing an important set of escarpments of Oligocene to Late Miocene resistant strata, and bounded (in North Texas) on the west by the White Rock Escarpment. The **Interior Plains and Plateaus** include three major subgroups: those underlain mainly by limestone and dolomite, mainly of Cretaceous age (the Edwards Plateau, Stockton Dissected Plateau, Balcones Canyonlands dissected plateau, Lampasas 'Cutplain' dissected plateau, and the Grand Prairie and adjoining sandy timbered belts, with the Llano Country an anomalous inlier); those underlain by mainly clastic deposits (with evaporites and carbonates) mainly of Paleozoic and Triassic ages (Palo Pinto cuesta plain, Red Plains, Caprock Escarpment Breaks, Pecos Valley); and two high plateaus underlain by Neogene alluvial and eolian sediment and caliche (Southern High Plains, Cimarron High Plains). The **Mountains and Valleys** province includes some 20 mountain ranges (of volcanic, tilted fault-block, and complex character), a few plateaus, and a series of broad valleys, either bolsons or drained bolsons, mainly created by Neogene and Quaternary extension.

INTRODUCTION

The state of Texas occupies a large part of the south-central United States. It is home to a diverse collection of landscapes, from flat and marshy coastal prairies to high desert mountains. These features have been described since the first geologic exploration of the 1840s, and were first systematically described by Hill (1890) and in Hill (1900) in a Topographic Folio of the USGS. Further discussion was provided in nationwide studies, particularly the defining works of Fenneman (1931, 1938); but the distinctive features of Texas geomorphology were considerably generalized. Fenneman's physiographic provinces and regions were much quoted elsewhere, and redescribed by Hunt (1974). A set of papers arranged by geomorphic province were created for the GSA Decade of North American Geology centennial volume, but these did not describe landscape regions but rather processes and current topics (Graf, ed., 1987).

No specifically statewide studies of Texas geomorphic provinces have been undertaken in recent years. Wermund (1996) published a map and brief explanation as a public information map sheet from the Bureau of Economic Geology.

In preparing a volume on the geology of Texas for general audiences (Ewing, 2016), the opening chapter that introduces the subject was focused on the varied landscapes of Texas. As part of that, a new and fairly detailed presentation map of geomorphic regions ('landscape regions') was created; a modified version is shown here as Figure 1. This paper supplies a more thorough documentation of this

map with brief descriptions of the regions, how they were classified previously, and how their borders may best be defined. The current state of knowledge of Texas geology and better understanding of depositional and erosional processes help to update our understanding of the various landscapes. Hopefully this work will provide a common set of terms for geomorphic provinces that may be used in more region- and site-specific studies.

DEFINITIONS

As used in this paper, a "geomorphic province" (physiographic province) or division is a broad area, usually continental in extent (though here defined by their expression in Texas), characterized by a common set of landforms, possibly containing or bounded by distinctive escarpments. In one case, a province is divided into three subprovinces based on surface lithology and its expression in landforms. Each province or subprovince is divided into "regions" (Hill used the term "country") characterized by a common landform assemblage that expresses near-surface lithology and contemporary geomorphic processes. Some region boundaries are gradational, but others are quite sharp. Geomorphic provinces and regions are not dependent upon vegetation or climate for their definition, although they commonly have characteristic suites of both. A full definition of vegetation characteristics leads to the definition of "ecoregions" (Griffith et al., 2004); a map of ecoregions bears many similarities to a map of landforms, as shown in Ewing (2016).

"Plains" are areas of little relief (generally less than a few hundred feet), and include rolling plains or uplands and flat plains or lowlands. Plains areas may include local areas of fairly rugged topography and may have sharply incised drainages. They may also include notable regional escarpments - laterally continuous sharp changes in elevation, such as the facing edge of a cuesta formed by dipping resistant strata. "Cuesta" in this paper is restricted to uplands with a clearly defined escarpment and dip slope; linear belts of upland that lack these features are better described as "wolds". "Plateaus" are areas with a low-relief upland surface, variably dissected by entrenched streams and bounded on several sides by high escarpments (100-2000 ft). Plateaus are often capped by resistant strata that maintain the plateau relief, a larger version of a mesa. Where the original plateau surface is highly dissected by stream erosion such that comparatively little of the original surface remains, the area may be called a "dissected plateau" (Hill used the term "cutplain"). Mountains are either ranges with linear extent, or collections of isolated peaks, with relief of over 1000 ft. The intervening basins of Trans-Pecos Texas may be either "bolsons", basins with interior drainage, frequently with thick accumulations of recent alluvium; or "drained bolsons" which have either been connected into a larger drainage or have had a river incised through it that has eroded much of the basin fill.

GEOMORPHIC PROVINCES AND REGIONS OF TEXAS

Texas landscapes fall into three broad provinces: the **Coastal Plains** (east and south of Dallas, Austin, San Antonio and Del Rio); the **Interior Plains and Plateaus**, including as subprovinces the carbonate plateaus, clastic plains, and high plateaus; and the **Mountains and Valleys** of Trans-Pecos Texas. Each of these can be split into a number of landscape regions (Figure 1). The provinces are generally similar to those defined by Fenneman (1931, 1938) but also include significant differences.

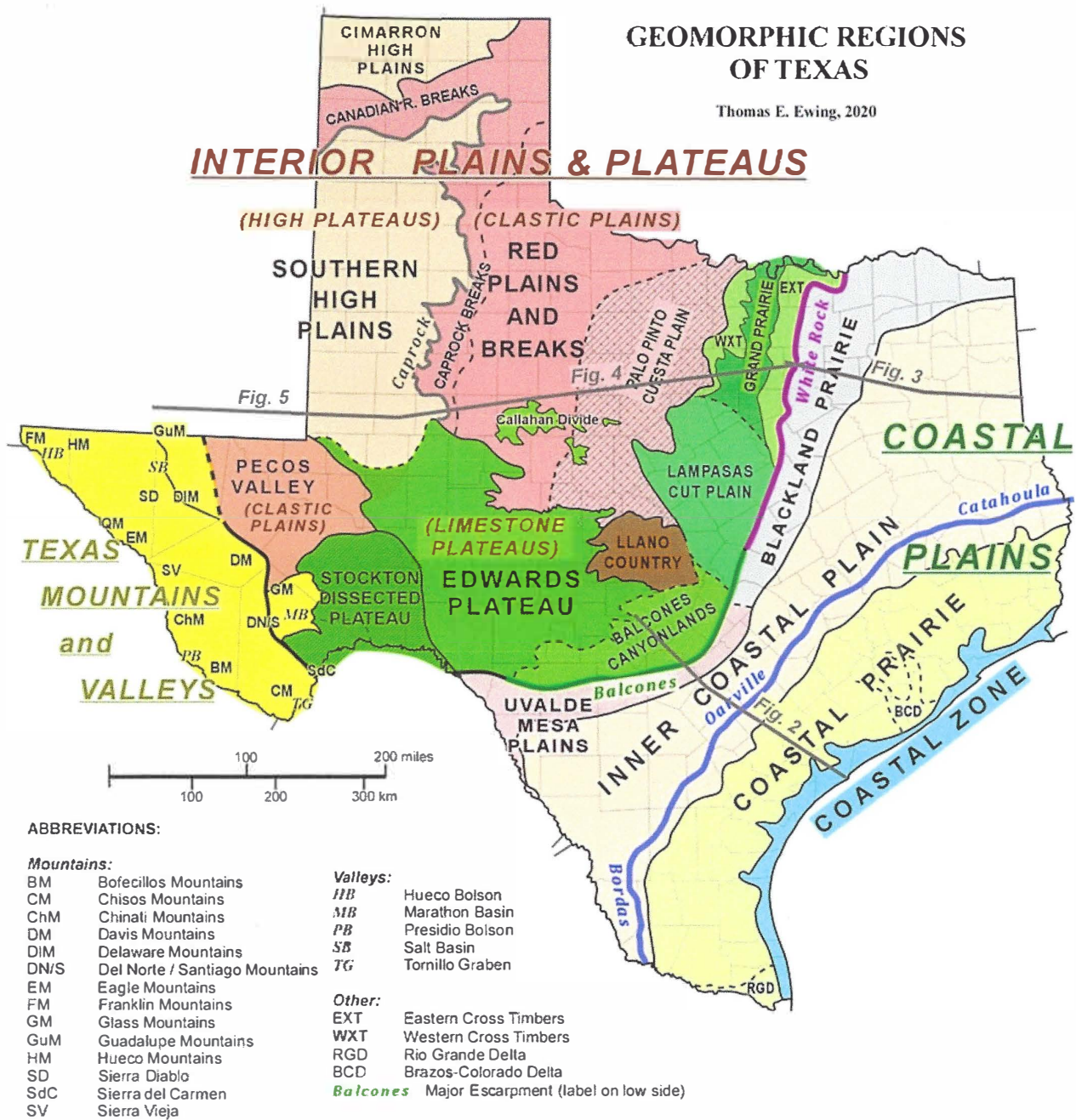


Figure 1. Geomorphic Regions of Texas as redefined. A few key escarpments are shown by thick lines; lines of sections in Figures 2-5 are shown.

THE COASTAL PLAINS

The Coastal Plains province consists of flat to rolling plains and gentle hills, built on sandy and clay-rich soils with little consolidated rock at the surface. The division is constructed on Upper Cretaceous and Cenozoic sediments deposited on the margins of the Gulf of Mexico Basin (Figure 2); these sediments (gravel, sand and mud) have never been deeply buried and are largely unconsolidated near the land surface. The province corresponds to the Atlantic and Gulf Coastal Plain province of Fenneman (1938) and Murray (1961), and includes the Southern, Eastern and much of the East-Central province of Hill (1900).

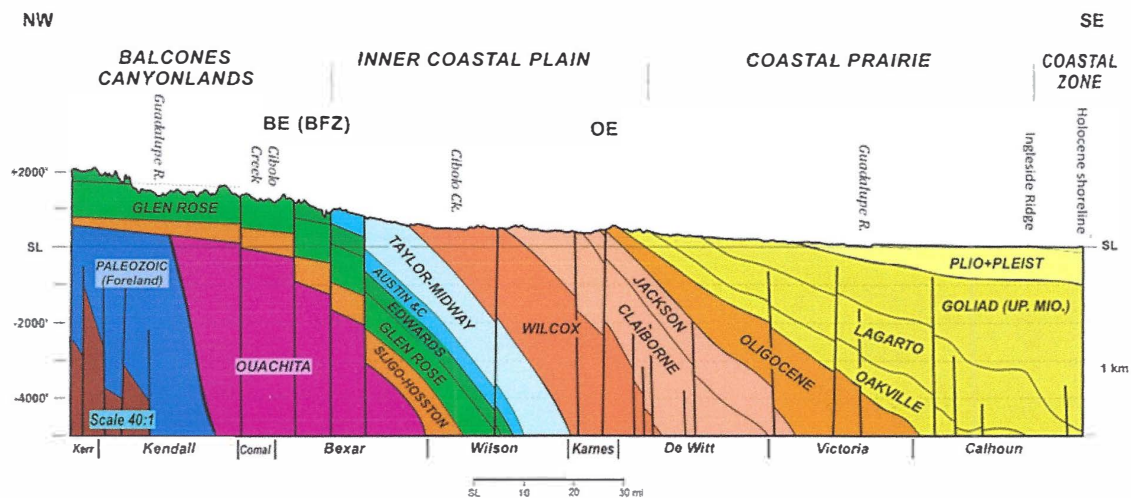


Figure 2. Northwest-southeast cross section San Antonio - Victoria; vertical exaggeration 40x. BE (BFZ) - Balcones Escarpment (Balcones Fault Zone); OE -Oakville Escarpment.

The province includes two mainly constructional environments in what is collectively known as the "Outer Coastal Plain": the narrow but irregular **Coastal Zone**, with barrier islands, lagoons, and other related marginal marine environments of Holocene to Late Pleistocene age, and, farther inland a broad, flat **Coastal Prairie** with a few incised stream valleys. North and west from the coastal prairie, the **Inner Coastal Plain** consists of gentle hills and valleys with a well-drained stream pattern and a belted distribution of uplands and lowlands, cut by a few extrabasinal river valleys. In its seaward portion, a set of northwest-facing escarpments punctuate the plain: the *Bordas, Oakville and Catahoula escarpments*. The innermost part of the Coastal Plain as defined here is the **Blackland Prairie**, a belt of gently rolling prairie with deep clay soils constructed on Upper Cretaceous marine chalk and clay. The western edge of the Blackland Prairie is formed by a west-facing *White Rock Escarpment in North Texas*, and by the fault-line *Balcones Escarpment* in South Texas. The inner coastal plain, particularly the Blackland Prairie, is modified in the area from Central Texas to the Rio Grande by extensive gravel-capped mesas (and some peculiar features in the Uvalde area), forming the **Uvalde mesa plains**.

Coastal Zone

The Coastal Zone is the area of Holocene shorezone development from the shoreface to the inland edge of estuaries and wetlands (Walker and Coleman, 1987; Anderson, 2007). The zone exhibits the active constructional processes of longshore transport, spit and barrier bar development, back-barrier dunes, and extensive coastal lagoons, along with two delta complexes: the Brazos-Colorado delta south of Houston, and the Rio Grande delta at the Mexican border. Many of these features were only

developed since about 4000 years BP; earlier features were transgressed during postglacial sea-level rise and now form shoals offshore. Also within the Coastal Zone is the pronounced Ingleside barrier complex, a barrier feature developed during the last interglacial about 120,000 to 100,000 years BP when sea levels were slightly higher than present. Relief of some 20-50 ft is obtained, particularly on the Ingleside ridge as at Aransas NWR. The inland boundary of the Coastal Zone is the landward limit of Holocene lagoon and marsh sedimentation.

Coastal Prairie

Inland of the Coastal Zone is a broad sweep of flat prairie, with very low slopes and little integrated drainage. Such rivers or drainages as exist are incised slightly into the regional surface and form inefficient drains for runoff. The prairie is built on the Pleistocene deposits of the Beaumont and Lissie Formations (or morphostratigraphic units; Winker, 1991) that form broad, undissected plains and associated river terraces. Constructional features such as meander belts and floodbasin lakes are preserved in many areas of the Beaumont. The prairie underlies the cities of Houston, Beaumont, Victoria, Corpus Christi and McAllen. Holocene deposits are restricted to the river drainages, although they are extensive in the delta plains of the Rio Grande and Brazos-Colorado deltas. The inland margin of the prairie is gradational, with older Pleistocene and Pliocene units (Willis Formation) marked by increasing elevation and relief, and more mature drainage; the border used here roughly follows the base of the Willis Formation sediments (upper Pliocene). In South Texas, much of the surface is covered by a thin but extensive eolian sand sheet, extending from the Coastal Zone at Laguna Madre westward to the west border of the Coastal Prairie.

Inner Coastal rolling plains

West and north of the Coastal Prairie is a wide and complex belted sequence of rolling plains and flat plains known collectively as the Inner Coastal Plain. In general, hills are developed on the sand-rich soils developed on gently southeastward-dipping sand units of Paleocene to Miocene age. Intervening mud-rich units underlie low-lying plains that separate the hilly upland belts. Drainage is maturely developed, but not strongly controlled by the low-standing mud-rich belts; the major rivers transect the upland and lowland units, and several are extrabasinal.

On the seaward edge of the subprovince, a high belt of rolling uplands leads up to a northwest-facing escarpment or cuesta. In the eastern part of Texas, the *Catahoula escarpment* is capped by Oligocene silica-cemented ashy sandstone; it continues into Louisiana where the highland is known as the "Kisatchie Wold" (see Murray, 1961). In central Texas, the *Oakville escarpment* is capped by Lower Miocene sandstone and gravel with abundant clasts of Cretaceous limestone derived from erosion of the Edwards Plateau and the Balcones Canyonlands (Figure 2). This escarpment is boldly developed at La Grange in the Colorado River valley. In south Texas, the *Bordas escarpment* is capped by Upper Miocene sediments of the Goliad Formation. This high side of the escarpment reaches over 900 feet in elevation, much higher than the others; its formation is likely due to uplift of the Mexican cordilleras in Neogene time, which has tilted all older units. The three escarpments (with minor overlaps) occupy about the same position in the Coastal Plain, and they face a low-lying area developed on Jackson (late Eocene) muds and sands.

To the northwest in central and south Texas, bands of higher sand hills (wolds) and lower flat areas are found that outline regional structural strike. The hilly areas (in central Texas, usually forested with post oaks) are developed on Eocene strata of the Yegua, Sparta, Queen City and Carrizo-Wilcox formations, while the thinner intervening clay-rich units of the Jackson, Cook Mountain, Weches and Reklaw form red-clay soils and prairie lowlands. The sand hills remain high because of their high permeability and porosity; most water sinks into the sand, and runoff events that might erode sediment are rare.

In East Texas, a gentle north-northeast trending syncline is developed atop of the East Texas Basin, and relatively younger units (pre-Yegua) are preserved in its core (Figure 3). The Weches marine unit is iron-rich and indurates the underlying Queen City sands, forming the bolder topography seen south of Tyler that continues southeastward to Nacogdoches (the "Nacogdoches escarpment" of Fenneman, 1938).

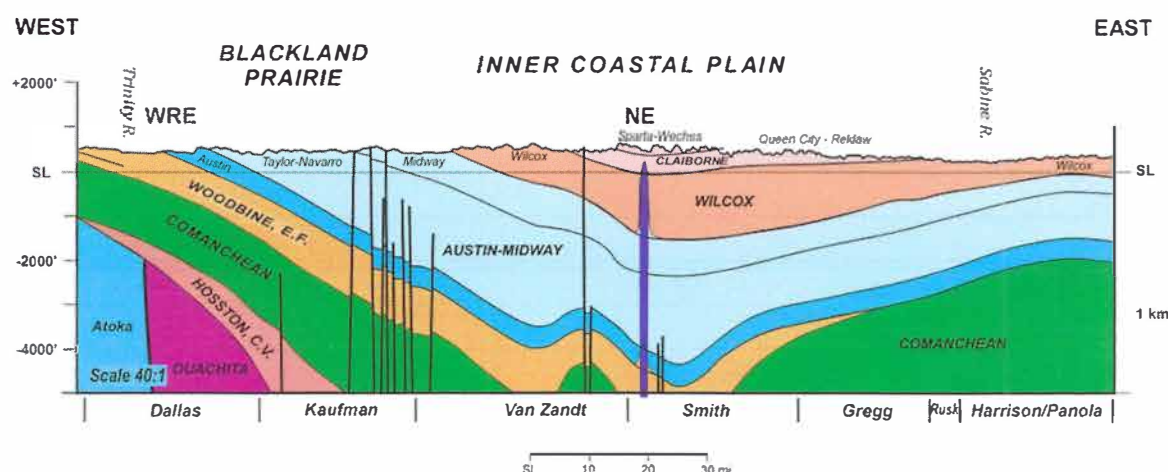


Figure 3. West to east cross-section Dallas-Tyler-Carthage; vertical exaggeration 40x. WRE - White Rock Escarpment. NE - Nacogdoches Escarpment.

Major extrabasinal rivers cross the Interior Coastal Plain forming broad bottomlands and a number of Quaternary terraces that line the valley. The northwestern margin of this region is taken at the edge of Wilcox sandstone outcrop, which is generally high ground facing lowlands developed on Midway (Paleocene) and Upper Cretaceous mudrocks.

Blackland Prairie

North and west of the Inner Coastal Plain uplands lies a wide lowland belt characterized by deep black clay soils and (in many areas) prairie vegetation. The eastern and southern portion of the belt is underlain by mudrocks of the Midway Formation (Paleocene) and various Upper Cretaceous mud-rich units. The northern and western portion rises into a gently hilly upland or wold constructed on the Austin Group chinks, but still carrying dark clay soils. This upland underlies Dallas and extends north-east past Bonham and south towards Waco and Austin. The western edge of this region is the *White Rock escarpment*, a west-facing escarpment capped by Austin chalky limestone (Figure 3); the escarpment overlooks lowlands built on older Eagle Ford mud-rich strata. This escarpment can be traced from the Red River southward nearly to Austin (at Georgetown). South of that point, the Austin and younger units are involved in Balcones normal faulting of Neogene age and generally lie down-thrown to the *Balcones fault-line escarpment*, which was developed where resistant Lower Cretaceous limestones are juxtaposed with weaker Austin and younger rocks.

Uvalde mesa plains

South of Austin, the character of the Blackland Prairie is gradually modified by increasingly abundant low mesas, capped by caliche-rich gravels (Uvalde and Lockhart gravels). These high gravels

as well as many lower gravels are derived from erosion of the Lower Cretaceous resistant limestones and their contained chert from the uplifted areas northwest of the Balcones escarpment. Similar gravels exist north of Austin as well, but do not dominate the landscape. In the San Antonio area and westward, most of the 'Blackland' outcrop is covered by these gravels, forming mesas of older gravels and extensive sheets of younger (probably Pleistocene) alluvium. West of Uvalde, the high gravels form virtually a continuous sheet westward and southward to the Rio Grande; similar gravels continue into northern Mexico. This area of low mesa topography with intervening lower terraces and gravel-choked streams is here called the Uvalde mesa plains. This region ends northward against the Balcones escarpment; or, west of that escarpment, the monocline which brings the resistant Lower Cretaceous carbonates to the surface.

Also in the Uvalde area are two local features of note. Late Cretaceous igneous activity created hundreds of volcanic and intrusive centers which are variably exposed in Uvalde and Kinney counties (a few also in the Austin area). Hills cored by intrusive or extrusive igneous rock have been termed the "Shumard Hills" by Hill. West of these hills, a north-facing cuesta of hard limestones forms the Anacacho Mountains; these limestones formed as a thick shoal on the flank of the igneous-generated Uvalde uplift (see Ewing, 2016).

THE INTERIOR PLAINS AND PLATEAUS

The Texas Interior Plains and Plateaus province consists of higher country (including both true plateaus and rolling plains) built on older, harder rocks than the Coastal Plain division. The province can be separated into three main subprovinces: a southern and eastern area of plains and plateaus developed on carbonate rocks, primarily of Early Cretaceous age; a central and northern area (and a western outlier) developed mainly on clastic rocks of Paleozoic and Triassic age; and two plateaus with caprock of Neogene age forming the High Plains regions in the west and northwest.

This province includes elements of the Coastal Plains, Interior Lowlands and Great Plains provinces of Fenneman (1931, 1938). He included the High Plains plateaus and the Edwards Plateau and (in 1938) the Llano and Lampasas/Comanche areas in his Great Plains province, and the rest either in the Lowlands (his Osage plains) or in the Coastal Plain (Grand Prairie and Cross Timbers). However, the dissected eastern portion of the Edwards Plateau up to the Balcones escarpment continues in character northward into the Grand Prairie region, such that a true 'Great Plains' boundary is not easy to define. The Cretaceous limestone substrate creates distinctive landforms that are obscured by the province boundaries previously suggested.

LIMESTONE PLAINS AND PLATEAUS

In this subprovince, flat-lying limestone holds up the **Edwards Plateau** and the adjacent **Stockton Dissected Plateau** areas (including the Pecos Valley Canyonlands). The eastern edge of the Edwards Plateau is extensively eroded into a dissected plateau called the "Texas Hill Country" or the **Balcones Canyonlands**. The east end of the Canyonlands and south end of the Edwards Plateau is marked by a sharp physiographic boundary, the *Balcones Escarpment*, along which major springs are located. To the north, an anomalous patch of country is underlain by hard igneous and metamorphic rocks, fringed by Lower Paleozoic limestone – the **Llano Country**. This area is marked by a wide rolling plain studded with isolated hills and upland masses, hard granitic rocks near the surface, and rugged limestone highlands to the north. Northeast of the Llano Country, the **Lampasas Cut Plain** is a dissected slightly east-dipping plateau rimmed with limestone cliffs, somewhat similar to the Edwards Plateau and Canyonlands. It passes northward into the **Grand Prairie** underlain by similar limestones forming broad

treeless hills but lacking cliffs. The Grand Prairie is fringed to the east by the '**Eastern Cross Timbers**', a narrow band of sandy soils with hills and post-oak timber; and to the west by the broader '**Western Cross Timbers**', of similar character.

Edwards Plateau

Thick, resistant Lower Cretaceous limestone and dolomite underlie a broad, nearly undissected plateau in southwest Texas. It has an average elevation of 2300 ft above sea level, rising to 2700 ft in the west. It is bounded by escarpments on all sides. To the south and east major spring-fed rivers have extensively eroded the plateau, forming the Balcones Canyonlands region where the upland surface is reduced to remnants. To the west, the Pecos River has cut a deep canyon through the plateau surface. To the north, the surface first lowers (across an axis from Brady west to Christoval and near Iraan) due to facies change, then comes to an irregular escarpment that surrounds the Concho valley (the Lipan plain, at and east of San Angelo) and finally forms north-facing hills near Big Spring and Sweetwater. Discontinuous plateau remnants continue to the northeast past Abilene as the mesas of the Callahan Divide. To the southwest, the surface gradually descends toward the Rio Grande with younger carbonate units (Eagle Ford and Austin) preserved.

Drainage on the upland surface is sparse and ephemeral, with most precipitation recharging the Edwards carbonate aquifer. The aquifer discharges into river-head springs around the plateau margins.

Stockton Dissected Plateau

Lower Cretaceous limestones continue west of the Pecos River, forming the Stockton dissected plateau. Elevations on the plateau surface rise to over 5000 ft on the eastern flank of the Marathon dome. Streams have extensively cut into this surface forming a varied and rather mountainous country. The northern boundary is marked by the effective termination of resistant Cretaceous strata north of Fort Stockton. Similar plateaus extend south of the Rio Grande until they are deformed into monoclinical and anticlinal mountain ranges. The area south of the Marathon Basin (Marathon window) is a high plateau with some folding and igneous-cored hills, which is transitional to the Mountains and Valleys province.

Balcones Canyonlands

The area east of the Edwards Plateau shares the same geology, but major east-flowing and south-flowing rivers have extensively dissected the plateau. At present, the plateau surface is less than 10% of the area; most of the area is a hilly region formed in less resistant Lower Cretaceous carbonates and basal sands and locally eroded into Paleozoic and Proterozoic rocks (as near Fredericksburg). This area is traditionally known as the "Texas Hill Country", although that name is also applied to the Llano country and other areas to the north. The southern and eastern boundaries of the region lie on the Balcones fault-line escarpment (Figure 2). Major springs issue from the escarpment along its length, with water derived from the buried Edwards (Balcones Fault Zone) aquifer that receives water from the surface streams of the Canyonlands. Bottomlands and lower slopes along major streams have significant soil and are agriculturally productive.

To the northeast, the area reaches the deep valley of the Colorado River, to the north of which is the Lampasas Cut Plain. To the north, a sharp escarpment forms the south rim of the Llano basin.

Lampasas Cut Plain (Comanche plain of Fenneman)

The Lampasas 'Cut plain' (dissected plateau) extends north from the Colorado River to the southern termination of the Cross Timbers units near the Brazos River. It is a gently eastward-dipping plateau with several resistant layers, forming a series of cuestas with west-facing escarpments that are deeply embayed by cross-cutting streams. The Cretaceous limestones here are thicker and more resistant than those to the north, but less resistant than those to the south and west on the Edwards Plateau and Callahan Divide. The eastern boundary is formed by the onlap of Upper Cretaceous units at or near the White Rock and Balcones escarpments. Significant springflow occurs along this boundary from water percolating through the limestone aquifer.

Grand Prairie and Cross Timbers

The Grand Prairie lies west of the White Rock escarpment, north of the Brazos River. It is a broad rolling prairie plain or wold, increasing in elevation westward, developed on the relatively thin and soft, gently east-dipping Lower Cretaceous carbonate, with an indefinite westward scarp. It underlies Fort Worth and extends west to Weatherford. On the east side of the Grand Prairie, a timbered belt (the Eastern Cross Timbers) follows sandy soils developed on the mid-Cretaceous Woodbine Group and the overlying Eagle Ford Group. On the west side, another timbered belt (the Western Cross Timbers) follows sandy soils developed on the basal Cretaceous (Antlers) sands. The eastern border lies on the White Rock escarpment, and the western at the limit of Cretaceous (Figure 4). The border to the south is gradational, as the sandy units become thinner and the carbonate thickens and becomes more resistant. The trenched valley of the Brazos River forms a convenient dividing point, as pointed out by Fenneman (1938). He included the Grand Prairie in the Coastal Plain province, by analogy to the inclusion of Cretaceous strata in the province east of Texas. However, the limy character of the prairie and its gradational southern boundary into higher limestone plains and plateaus in Texas argue for inclusion in the Interior Plains and Plateaus province of Texas.

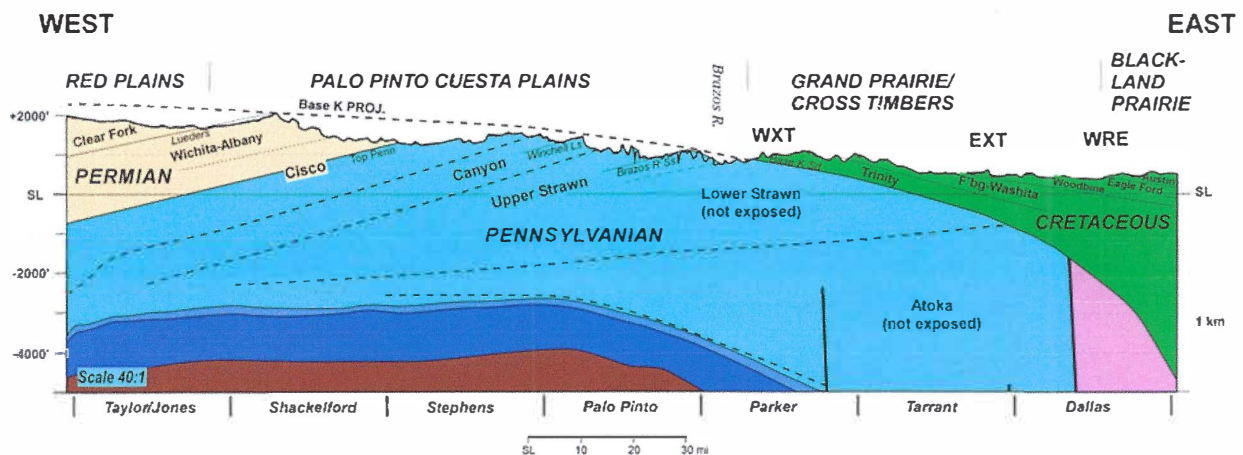


Figure 4. West to east cross section Abilene - Dallas, showing the Palo Pinto Cuesta Plain, Grand Prairie, and its neighbors; vertical exaggeration 40x. WXT - Western Cross Timbers; EXT - Eastern Cross Timbers; WRE - White Rock Escarpment.

LLANO COUNTRY

The Llano Country is a subcircular area in the center of Texas that does not fit easily in the structure of geomorphic provinces. It is primarily a broad erosional basin formed by the Llano and San Saba rivers, tributaries to the Colorado. The southern two-thirds is a rolling plain underlain primarily by Proterozoic gneiss, schist and granite; the northern third is a highland underlain by Lower Paleozoic carbonate rocks (mainly Ellenburger Group). The Proterozoic (Precambrian) rocks are generally not highly resistant to erosion, although isolated mountains (inselbergs and exfoliation domes) of granite (Enchanted Rock), gneiss and schist (Packsaddle Mountain) are sprinkled across the area. Downfaulted north-trending blocks of Cambrian carbonate and sandstone are resistant and form belts of high hills or low mountains (Riley Mountains, Backbone Ridge). The area is bounded by unnamed escarpments of Cretaceous limestone on the south and northeast. The Proterozoic rocks are not significant aquifers, so surface water is relatively abundant. By contrast, the northern carbonate area is marked by rugged hills and host significant springs along the entrenched Colorado River.

The Llano country, although a topographic basin, is exposing a high-standing area of metamorphic basement, generally called the Llano Uplift. Geomorphically, the area is a window formed by erosion into these older rocks. The northern limit with the Palo Pinto cuesta plain occurs where Pennsylvanian strata onlap the older Paleozoic rocks and north-trending, west-dipping and east-facing cuestas replace the limestone uplands.

CLASTIC PLAINS

This subprovince occupies north and parts of west Texas. North of the Edwards Plateau and Llano Country and west of the Western Cross Timbers and the Lampasas Cut Plain is a broad area known as the 'North Central Plains' or 'Rolling Plains'; Fenneman (1938) included the area in the "Osage Plains", which continues northeastward into Oklahoma and Kansas (see Madole and others, 1991). The eastern portion is characterized by pronounced north-trending sandstone and limestone cuestas – ridges with sharp eastern sides and gentle western sides trending north-south for long distances. This distinctive area, with its characteristic tree cover of post oak and Ashe juniper, is here distinguished as the '**Palo Pinto cuesta plain**'. To the west, the cuestas become less conspicuous, and the soils become red and sometimes contain gypsum. Badland areas become more frequent, interspersed with flat cultivated plains. These '**Red Plains and Breaks**' continue west until the breaks of the *Caprock Escarpment* are reached. In the southern parts of the Red Plains and Palo Pinto cuesta plain, a remnant of the flat Edwards limestone surface remains as isolated mesas along a trend called the Callahan Divide, the interfluvium separating the more deeply eroded areas of the Brazos and Colorado river valleys.

Southwest of the Southern High Plains lies the disjunct area of the **Pecos Valley**, a region extending to the Guadalupe, Delaware and Davis Mountains of the Texas Mountains and Valleys province that is underlain by Permian and Triassic redbed sandstone and shale and buried evaporites.

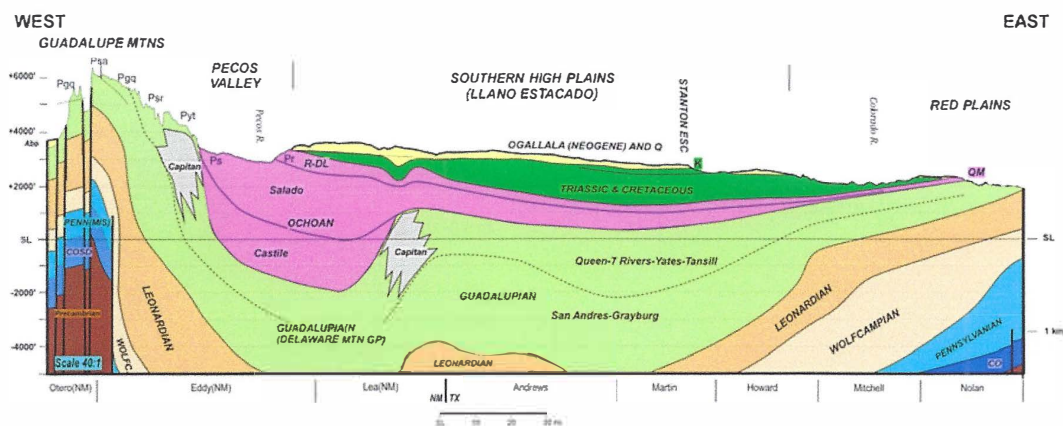
Palo Pinto Cuesta plain

The Palo Pinto country forms a distinctive region, marked by north-trending and east-facing cuestas of sandstone and limestone separated by valleys and plains developed on shale. The rocks are Pennsylvanian to early Permian strata of the Fort Worth Basin that dip gently west towards the Permian Basin (Figure 4). In the eastern part of the area, highland cuestas predominate; to the west, in Cisco Group exposures, the landscape is flatter with a few small cuestas; the western border of the area is formed by several cuestas formed by limestone and sandstone of the Wichita (Albany) Group. The

The Palo Pinto cuesta plain is bounded by the Grand Prairie (Western Cross Timbers) and the Lampasas Cut Plain on the east, and the Llano Country to the south. To the west, the border is taken here as the westernmost Wichita Group cuesta capped by the Lueders Formation, just east of Abilene.

In the southern part of the Red Plains, a number of high mesas are capped with Cretaceous limestone along an east-west trend called the Callahan Divide. Isolated mesas of Cretaceous rock also occur, notably Double Mountain north of Sweetwater.

At the western end of the Red Plains, the terrain picks up substantial relief and climbs toward the high Caprock escarpment that forms the border of the Southern High Plains (Figure 5). Rocks in this area include red Permian strata overlain by darker red-brown Triassic strata. The area of the breaks includes a number of high mesas that are now isolated from the retreating escarpment; deep canyons into the high plains (as Palo Duro Canyon); and the broad Canadian River breaks which separate the two high plateaus of the Southern High Plains and the Cimarron High Plains. Salt dissolution has been active throughout this area, resulting in large salt springs and saline lakes and some surface subsidence.



South Texas Geological Society

Pecos Valley

A disjoint area of exposure of red rocks and soils is found west of the Southern High Plains and north of the Cretaceous plateaus in the Pecos Valley (Figure 5). This area has been eroded by the Pecos River as it extended northward into New Mexico. The Pecos River runs through the valley, but there is some interior drainage (Toyah Lake). Some areas are underlain by gypsum and salt, and most of the valley is affected by salt dissolution, forming jumbled surface landforms in many areas.

On the eastern margin, a belt of active to inactive sand dunes is found below the lip of the west-facing Mescalero escarpment which bounds the southern High Plains. The region rises west of the Pecos, joining in the long 'Toyah slope' upwards to the Delaware and Guadalupe mountains of the Mountains and Valleys province. This region was included by Fenneman (1931) in the High Plains, but is distinct in landforms from the classic High Plains regions described next.

HIGH PLATEAUS

This subprovince lies in west and northwest Texas, above the Caprock Escarpment and its equivalents. It is divided into two units; the **Southern High Plains** (or 'Llano Estacado', literally the Palisaded Plains) south of the Canadian River, and the **Cimarron High Plains** north of the Canadian. Both regions are flat to the eye but slope gently southeastward, with sandy soils (including sand dunes and sand sheets) and numerous playa lakes and some larger depressions. The zone along the Canadian River is a broad broken valley known as the **Canadian River Breaks**; it blends eastward into the Breaks region of the Red Plains and westward into the varied tablelands of New Mexico and the Pecos Valley region.

Southern High Plains

The Southern High Plains form a classic plateau or tableland (Figure 5), bounded on most of its margin by a high escarpment - the Caprock escarpment to the east and north, and the Mescalero escarpment to the west (mainly in New Mexico). The caprock consists of Neogene alluvial and eolian sands and gravels of the Ogallala Formation that have been tightly cemented with caliche, and overlain by north-eastward-fining eolian sand and silt deposits (Blackwater Draw Formation; Gustavson and others, 1991) and local lacustrine units. The plain dips slightly but steadily to the east-southeast (about 1.7m/km, 9 ft/mi). It is creased by a few shallow draws, but has no permanent drainage. There are thousands of small playa lakes, gentle rounded depressions in the plain that accumulate water during rain events; and a number of larger and deeper depressions with alkaline lakes, some of which expose older rocks and have associated ephemeral lakes and clay dunes. The Ogallala Formation is a very extensive aquifer, that supports irrigated agriculture over most of the region as well as a number of cities, Lubbock and Amarillo being the largest.

On the southeast margin, the plains grade into the northwestern Edwards Plateau; the Neogene caprock materials thin out onto the Cretaceous limestones somewhat south of Midland and fill valleys between Cretaceous limestone mesas. The northeast corner of the region is also irregular; the thicker Ogallala in this area east of Amarillo develops a broad dissected plateau that merges gradually with the breaks and descends to the Red Plains surface.

Cimarron High Plains

North of the Canadian River breaks, the Ogallala alluvial cover resumes and extends across most of the northern Texas Panhandle, connecting northward into Oklahoma and Kansas and westward into northeasternmost New Mexico and southeastern Colorado. This section of the High Plains, between the

Canadian and the Arkansas rivers, can be termed the 'Cimarron High Plains' after the Cimarron River that transects it. Its eastern margin is indefinite, as the thick Ogallala in this area is dissected by small streams and dissolves into a dissected plateau that extends into western Oklahoma.

TEXAS MOUNTAINS AND VALLEYS ("TRANS-PECOS TEXAS")

The Texas Mountains and Valleys province is characterized by wide alluvial valleys, frequently with internal drainage, that are interspersed with low hills and high mountain ranges. This area is equivalent to the Texas part of the Basin and Range province of Fenneman (1931), specifically his Mexican Highlands subprovince and Sacramento section. Since his work, the extent and distinctive character of the Rio Grande rift and the presence of active faulting in several areas have become better understood. The Texas area includes a complex set of mountains and basins, reflecting the diverse geologic forces that have shaped the area through time (Fig. 6).

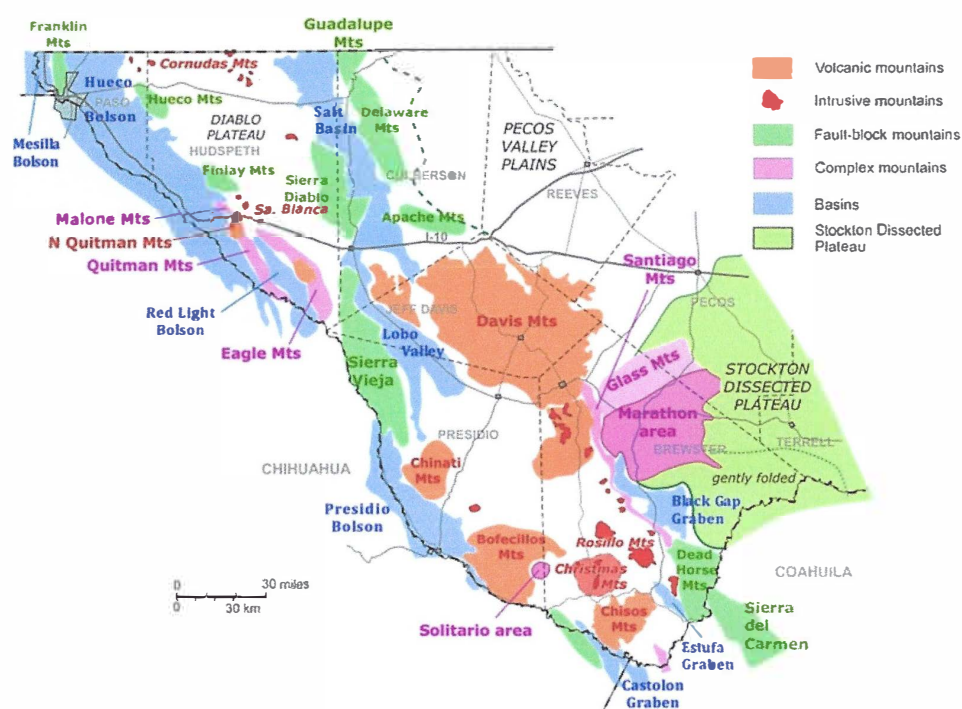


Figure 6. Mountains and basins in the Texas Mountains and Valleys province.

The mountain areas include igneous mountains, fault-block mountains, and complex folded and faulted ranges. High mountains host forest ecosystems, lower desert ranges tend to tobosa-grama grasslands and yucca-ocotillo-lechuguilla scrub. The major basins (Hueco Bolson, Salt Basin, Marfa Valley, Presidio Graben, Tornillo Graben) are fault-bounded and filled with thick alluvial sequences (bolsons and drained bolsons) and host Chihuahuan Desert scrub; but some tobosa-grama grassland areas form on flat-lying limestone plateaus (Hueco Plateau) and on complex but shale-rich rocks punctuated by ridges of novaculite (Marathon Basin).

Igneous mountains

Several mountain ranges or groups of peaks are due to igneous activity, either accumulations of volcanic rocks or intrusions of igneous material that form necks, laccoliths or small stocks. Major volcanic accumulations occur in the Davis Mountains, the Chinati Mountains, the Bofecillos Mountains, and the Chisos Mountains; some also occur in the northern Quitman Mountains and Eagle Mountains. Volcanic rocks tend to form a series of thin to thick flows, ash flows, breccias and ash deposits that are highly irregular and may have original depositional slopes from volcano flanks. Some rocks (notably in the Quitman, Eagle, northern Davis, Chinati and Chisos mountains) originated as sheets of ash flowing from calderas (subcircular subsided blocks with ring faults), but these sheets are small by the standards of other volcanic fields in New Mexico and Colorado. Domes of felsic rock and related shallow intrusions are frequent and can develop high continuous cliffs. In general, the volcanic mountains show a confused topography with numerous horizons of cliff development and extensive dissection by stream erosion. Where the volcanic deposits overlie weak Upper Cretaceous muds and marlstones, steep cliffs with abundant landslide debris are formed; these dominate the north and northeast flanks of the Davis Mountains.

Scattered or isolated peaks and small ranges underlain by resistant igneous rock are widespread in the province. These igneous masses formed as isolated domes, volcanic necks, small stocks or laccoliths that bowed up the shallow rocks (red on Figure 6). Notable occurrences are the Cornudas Mountains on the New Mexico border (including the Hueco Tanks intrusion); the Sierra Blanca intrusions (strikingly visible from I-10); numerous intrusions around and south of Alpine and north of Terlingua; the Christmas Mountains and Rosillo Mountains just north of Big Bend National Park; and various intrusive bodies near and south of Marathon at the transition to the Stockton Plateau. The rock forming these peaks cooled below the earth's surface, so the height of the mountain is a minimum estimate of erosion in the area (which can be several thousand feet).

No recent (post-12 Ma) volcanic or igneous features are found in Texas, but some occur just to the northwest in New Mexico. Volcanic ranges host the second and third highest peaks in Texas, Mount Livermore in the Davis Mountains and Emory Peak in the Chisos Mountains.

Fault-block mountains

Many of the mountains of this province consist of tilted fault blocks, with major normal faults on one or both sides, and varying amounts of internal faulting. The most coherent tilted fault block is that formed by the Guadalupe and Delaware Mountains, which continues northward in New Mexico to connect with the Sacramento Mountains. This area has a long eastern slope (Toyah slope) developed on Permian rocks, and a sharp western slope with active faulting into the Salt Basin (Figure 5). The Guadalupe Mountains stand high (including the highest point in Texas) as they expose resistant limestones of the Capitan Reef and other Permian units; the western cliff of these mountains is the most impressive escarpment in Texas. The Delaware Mountains are lower, as they expose the Permian deep-water sandstone and shale that were deposited in the Delaware Basin at the same time as the rocks exposed in the Guadalupe Mountains. The east-dipping fault block continues south to I-10; to the southeast, the similar Apache Mountains trend southeasterly and may form the southern end of the overall block. This zone was considered a separate subprovince ('Sacramento section') by Fenneman (1931).

In the far western tip of Texas the Franklin Mountains form a strongly west-tilted desert mountain range running north from El Paso. They expose a variety of rocks from Precambrian granite and volcanic rock to Paleozoic carbonates. The range lies between the active Mesilla and Hueco basins, and forms part of the Rio Grande Rift. Between the Franklin and Guadalupe mountain ranges (or rather the Hueco and Salt basins) is the broad Diablo Plateau, underlain by Permian and Cretaceous limestones. The plateau contains three small mountain ranges around its upturned rim. In the west are the Hueco Mountains, formed by an uplifted dome of Paleozoic carbonates; to the southwest are the Finlay Mountains, an updomed area perhaps related to igneous intrusion; and to the east are the Sierra Diablo, a

rugged range facing east into the active Salt Basin and exposing Permian carbonate rocks correlative to those in the Guadalupe.

To the south are several additional areas of tilted fault blocks. The Sierra Vieja, southwest of Van Horn, are a complex set of mainly east-dipping fault blocks with west-dipping normal faults, perhaps related to the Rio Grande Rift. In the Big Bend National Park area, the east side is formed by east-dipping fault blocks of the Dead Horse Mountains, rising southward in Mexico into the majestic Sierra del Carmen. The west side of the area is formed by the gently west-dipping Mesa de Anguila fault block, through which the Rio Grande has cut the steep-walled Santa Elena canyon.

Complex (folded and faulted) mountains

A number of mountain ranges are composed of folded and faulted rocks, showing the signs of earlier compression as well as the pervasive Neogene normal faulting. In the western part of the province, the Quitman, Eagle and Malone Mountains all display complex folds and faults in Cretaceous carbonate units, forming the northeastern edge of the Chihuahua fold belt of Laramide age (latest Cretaceous to early Paleogene). In the southeast (south of US 90) is the long ribbon-like Santiago mountain range (also called the Ord Mountains and Del Norte Mountains in its northern extent). This range contains folded Cretaceous carbonates at the southwestern edge of the Marathon dome of Laramide age. These folded rocks are then cut and uplifted by west-down Neogene normal faults, forming a thin ribbon of uplifted rock. A smaller complex range, the Mariscal Mountains, form a north-south range cut by the Rio Grande at the southernmost point of Big Bend National Park.

Especially complex mountains and ridges are formed to the east in the Marathon area. Here an overall erosional basin has exposed older Paleozoic rocks that were folded on northeast axes and thrust-northwestward during the Late Paleozoic Ouachita orogeny. Resistant ridges, most notably of novaculite (bedded chert) but also of limestone, create complex squiggles across the basin, outlining individual folds and thrust-generated repetitions. The erosional basin is rimmed on the east and south by a high escarpment of Cretaceous limestones of the Stockton dissected plateau and its somewhat deformed southwestern equivalent; to the north side by the north-dipping Permian carbonate cuesta of the Glass Mountains; and to the west by the complex ribbon chain of the Santiago Mountains.

A truly complex mountain area is found at the location called 'El Solitario' northwest of Big Bend National Park. Here, a domal uplift related to igneous activity (with some volcanic and intrusive rocks exposed) has exposed a small patch of folded rocks closely similar in lithology, age and deformation to the Marathon strata, surrounded by outward-dipping Cretaceous limestones. Just to the east are hills of the Terlingua uplift exposing rocks deformed in Laramide compression and later normal faulting.

Valleys, bolsons and pediments

Between the mountain groups mentioned above are broad basins of substantial complexity. Many are rimmed by bajada slopes which may be cut as pediments into the older rocks of the mountains. Others are thick accumulations of alluvial and lacustrine debris that fill Neogene to Quaternary fault-bounded basins. They include bolsons (with interior drainage), connected valleys, and drained bolsons (where the Rio Grande transects and erodes an older bolson).

We can distinguish six basins as showing signs of Quaternary activity. In the El Paso area, the Mesilla bolson west of the Franklin Mountains and the Hueco bolson between the Franklin and Hueco mountains are both active features with significant Holocene faulting. They form part of the Rio Grande rift valley that extends north to Colorado. To the east across the Diablo Plateau is the Salt Basin graben, which has active faults on both sides and thick alluvial accumulations. To the south, the Lobo Valley through Valentine and Marfa is less deep, but is the site of the two largest historic earthquakes in Texas, the Valentine and Alpine quakes. To the west is the Red Light bolson between the Quitman and Eagle

ranges; to the southwest, the fault-bounded Presidio bolson lies southwest of the Chinati Mountains and contains thick alluvial accumulations.

The Rio Grande cuts through all of these valleys except the Salt Basin and Lobo Valley. It has trenched several hundred feet into the alluvium, leaving a complex set of terraces and creating a broad bottomland that is irrigated near El Paso. In the Mesilla and Hueco bolsons, the Rio Grande interrupts the bolson floor which can still be traced; in the Presidio bolson, the old floor is only intermittently preserved as most of the basin is dissected by tributary washes to the Rio Grande. This condition persists to the south in a number of smaller alluvium-filled grabens in the Big Bend country, notably the Estufa and Castolon graben areas on either side of the Chisos range. In these areas the original valley configuration is hard to see, because most of the (originally thick) alluvium has been eroded by tributary washes into the Rio Grande.

There are a number of other shallower valleys separating the various ranges. In many of these studies have been insufficient to show the depth of alluvium fill and possible fault control.

Drainage and Evolution of the Rio Grande system

Most of the Texas Mountains and Valleys province exhibits interior drainage, with primary sinks in the Salt Basin and the Hueco Bolson. The southern section (in and around Big Bend National Park and the Marathon area) are drained by washes that reach the Rio Grande. Upstream, there are no substantial tributaries that extend more than a few miles from the stream. The major influx of water to the lower Rio Grande comes from the Rio Conchos, which drains the high mountains to the west in Chihuahua and joins the river at Presidio/Ojinaga.

Upstream from Presidio, the Rio Grande generally follows the line of bolsons, with occasional cuts through passes in the mountain ranges. The most famous of these is the 'El Paso del Norte' at the south end of the Franklin Mountains. Downstream from Presidio, the stream has a strongly superimposed character, with deep canyons cut through the Mesa de Anguila, Mariscal and Carmen/Dead Horse mountains and extending eastward into deep canyons with entrenched meanders at the southern side of the Stockton and Edwards Plateaus nearly to the Coastal Plain.

Two scenarios seem possible. In the first, the Concho - lower Rio Grande form a continuous antecedent stream originating in mid-Cenozoic time. Uplift and rifting generated the impulse to incise and excavate the southern bolsons; at some point the upper Rio Grande integrated through the bolson network. In the second scenario, Neogene faulting disrupted older drainage and formed a large lake in the Big Bend area. Upstream capture by a lower Rio Grande tributary allowed integration of the stream, rapid downcutting of the canyons and excavation of the southern bolsons. The absence of a Rio Grande delta in the Gulf of Mexico from mid-Miocene through Pliocene time (Ewing and Galloway, 2019) may favor the second scenario, but improved dating of uplift and erosion events will be required to resolve this history.

UNRESOLVED QUESTIONS

As shown by the length of this brief survey, Texas has a wide diversity of geomorphic regions. Within the area are significant unresolved questions, mainly dealing with the geomorphic history of the area. Particularly significant are the following:

-- What is the history of the integration of the Rio Grande and Rio Conchos? How extensive was the Neogene drainage disruption?

-- The Southern High Plains plateau margin has been extensively eroded since Pliocene time; can we document ages and landscape response to this erosion? What is the role of salt dissolution in form-

ing these sharp plateau margins?

-- A broad part of the carbonate subprovince shows major streams with deeply incised meander bends; especially from the Rio Grande northeast to the Brazos River. The meanders must have formed on a much flatter surface. Neogene uplift has entrenched them and fossilized the meander patterns. Can we date this more exactly?

-- The dating and correlation of the various terraces and gravels around the fringe of the Balcones escarpment and the rivers draining it is still not well understood. Uvalde gravels have been correlated nearly to the Coastal Prairie, is this a reliable correlation?

-- The nearly continuous Bordas - Oakville - Catahoula escarpment is remarkable and needs further study. Parts of it are related to uplift and tilting history of the Inner Coastal Plain.

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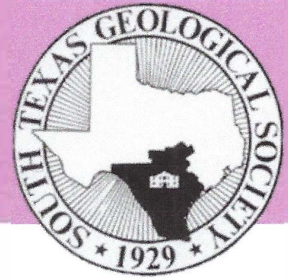
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Lone Star Geology, Landscapes, and Resources



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