Copy 2

GQ 30

THE UNIVERSITY OF TEXAS
BUREAU OF ECONOMIC GEOLOGY

TO ACCOMPANY MAP—GEOLOGIC
QUADRANGLE MAP NO. 30

GEOLOGY OF BLACK GAP AREA, BREWSTER COUNTY, TEXAS

BILL E. ST. JOHN[1]

CONTENTS

ILLUSTRATIONS

[1] Department of Geology and Bureau of Economic Geology, The University of Texas, Austin.

INTRODUCTION

The wedge-shaped Black Gap area in southern Brewster County, Texas, occupies approximately 450 square miles east of the Big Bend National Park. The southwestern boundary of the map area is the eastern boundary of the Park; the southeastern boundary is the Rio Grande; the north boundary is drawn at lat. 29°45′ N. The area lies in the Trans-Pecos province and throughout this arid to semiarid region the climate, flora, and fauna are similar.

The Black Gap region can be divided into four physiographic areas: (1) the topographically high and imposing Sierra del Carmen to the southwest, which is an area of stepped plateaus separated by steep, northwest-trending scarps; (2) the Cupola Mountain highland in the northeast corner of the map area; (3) a topographically low area extending from the Rio Grande northwest through the middle of the Black Gap area and characterized by low, steep-sided hills capped with basalt; and (4) the gravel-covered lowland to the northwest which is an area of low, rounded hills.

The outcropping strata of the Black Gap area are principally Cretaceous but include Tertiary volcanic rock and Quaternary alluvium. No rocks older than the Cretaceous Glen Rose Limestone crop out within the map area, although Paleozoic strata of the Ouachita System are exposed near the northwest corner.

The area is on the plunging northwest end of the Serrania del Burro and astride the frontal and interior zones of the Ouachita System. To the north, northwest-trending monoclines and an east-trending igneous belt border the Marathon Basin; to the south lies the block-faulted and reverse-faulted eastern margin of the Big Bend structural belt.

Basically, the area is a large northwest-trending graben flanked by a stable block to the northeast and a series of tilted fault blocks to the southwest. The stable block and graben are terminated to the north by a large northeast-trending faulted anticline. The mosaic of structural features is the result of several events. Uplift of the Sierra del Carmen followed by décollement to the northeast across the Black Gap area formed the asymmetric Stillwell anticline and other folds. Rejuvenation of northeast-trending Paleozoic faults is probably the cause of the northeast-striking Dove Mountain Ranch anticline and associated faults. The re-occurrence of northwestward thrusting of the underlying Paleozoic strata, possibly resulting from sub-crustal activity, compressed the strata, forming conjugate shear sets striking approximately N. 20° W. and N. 75° W. in the massive Cretaceous limestones. Release of compression resulted in block faulting along the zones of weakness set up by the compression. A left-lateral rift movement accompanied the normal faulting.

R. T. Hill (1900) discussed general physiographic features of this area in his study of the physical geography of Texas. Udden (1907) made the first stratigraphic studies, and it is upon his work that current nomenclature and understanding of gross features are based. Baker and Bowman (1917) entered this region during their study of the southeastern Front Range. King (1937) accomplished the next major work in this area with his study of the Marathon Basin. Eifler (1943) and Graves (1954) mapped 15-minute quadrangles to the north and northwest of the Black Gap area. Their work is referred to in many places in this report. Numerous unpublished master's theses for areas of varying shapes and sizes within Brewster County are in the libraries of The University of Texas, Texas A&M University, and elsewhere (Brown, 1963). Of these, Wilson's (1951) and Shambaugh's (1951) study of a part of the Black Gap area must be mentioned. Their maps served as a starting point. International Boundary and Water Commission geologists have mapped a strip along the Rio Grande extending about 3 miles from either side of the river from Lajitas to Del Rio. The West Texas Geological Society guidebook for the Big Bend National Park is of special interest (Lonsdale et al., 1955). A comprehensive report on the geology of the Big Bend National Park by Maxwell and others (MS.) is in preparation by the Bureau of Economic Geology. The Park report redefines numerous stratigraphic units and proposes the nomenclatural scheme used in this report.

The writer is grateful for the assistance of the following: W. R. Muehlberger, R. K. DeFord, P. T. Flawn, C. I. Smith, R. A. Maxwell, J. W. Macon, and D. F. Scranton. K. P. Young identified the fossils. D. S. Barker made an X-ray analysis of a whole rock sample. The text is an abridgment of a doctoral dissertation (St. John, 1965).

STRATIGRAPHY

PRE-CRETACEOUS ROCKS

No Precambrian rock is exposed in the Black Gap area and little is known about the Precambrian rocks of the surrounding region. Numerous writers (*see* Flawn et al., 1961, p. 53) have commented on the occurrence of granite and rhyolite boulders of probably Precambrian age in the Haymond boulder beds near Haymond Station, east of Marathon, 25 miles north of the map area. Muehlberger et al. (in preparation) reported two ages from a granite-gneiss boulder from near Housetop Mountain. They assumed that the total-rock Rb-Sr age of 570 million years (early Cambrian) is the age of the origin of the rock and believed that the biotite K-Ar age of 360 million years represents the age of the latest metamorphism of the rock.

Near Persimmon Gap in the northwest corner of the map area is an outcrop of limestone, shale, novaculite, and ortho-quartzite. Udden (1907, p. 18) mentioned this outcrop but assigned no age other than including his discussion of it in a section on Paleozoic rocks. Baker and Bowman (1917, p. 103) assigned the outcrop to the Tesnus Formation of Pennsylvanian age. Lonsdale et al. (1955, p. 56), who mapped the area, depicted it as an area of thrust faults involving Maravillas, Caballos, and Tesnus Formations ranging in age from Ordovician to Carboniferous. C. L. Baker discovered outcrops of schist east of the village of Boquillas, Mexico (Böse, 1923, p. 113). Flawn et al. (1961, p. 99) reported ages of 240 and 370 million years from the schist. These ages indicate that metamorphism of the rock occurred during the Paleozoic Era but give no information regarding the age of origin of the rock. King (1937) discussed the Paleozoic strata of the Marathon Basin in detail, both as to stratigraphy and structure. Flawn et al. (1961) extended this study into the subsurface with available well data plus exposures in Mexico.

Post-Paleozoic erosion planed the deformed Paleozoic strata over an extensive area. Hill (1901, p. 363) named the erosional surface the Wichita paleoplain. The only pre-Cretaceous Mesozoic rock reported in this region is the Bissett Conglomerate (King, 1927, p. 212) which crops out along the northwest flank of the Glass Mountains 45 miles north of the map area. Diastrophism and erosion indicated at the end of the Paleozoic Era possibly extended through the Triassic and Jurassic Periods.

CRETACEOUS ROCKS

Unconformably overlying the deformed Paleozoic rocks are Comanchean strata. These marine deposits continue upward into the Gulf Series whose uppermost section, missing in the Black Gap area, is typified by a continental clastic facies.

Stratigraphic nomenclature of the Cretaceous rocks is that set forth by Maxwell et al. (MS.) in their study of the geology of the adjoining Big Bend National Park.

COMANCHEAN SERIES

Approximately 3,000 feet of Cretaceous rock is exposed in the Black Gap area. Most of the section is massive limestone of Comanchean age. A distinct lithologic change between the Buda Limestone and Boquillas Formation marks the contact between the Comanchean and Gulfian strata.

Glen Rose Limestone

Maxwell et al. (MS.) used Glen Rose Limestone for the thin-bedded rocks beneath the massive Del Carmen Limestone in the Big Bend National Park.

The Glen Rose Limestone is the lowest Cretaceous formation exposed in the map area. It rests with angular unconformity on underlying Paleozoic strata to the north in the Hood Spring quadrangle (Graves, 1954, p. 16). Exposures of Glen Rose are found where the Rio Grande has deeply incised the Cretaceous rocks northeast from the mouth of Maravillas Creek and in the Sierra del Carmen in the southern part of the map area.

MS-3 (*see* Pl. III) includes an incomplete thickness of 733 feet of Glen Rose; the base is not exposed. At this locality, the formation consists predominantly of biomicrite with interbedded biosparite and calcareous clay. A foot-thick bed of quartz siltstone 161 feet below the top is the only siliciclastic rock in MS-3. Near the mouth of Big Canyon in the northeast part of the map area, approximately 25 feet of silty, fine-grained, ripple-marked sandstone occurs in the upper part of the Glen Rose. There is a 14-foot caprinid bioherm near the base of MS-3.

Orbitolina cfr. *texana* Roemer is abundant throughout the lower 566 feet of the Glen Rose at MS-3. The composite section (Pl. III) records other fossils from the Glen Rose.

King (1937, pp. 112–113) reported different thicknesses: 312 feet at Housetop Mountain, 500 feet along the south edge of the Marathon Basin, and 559 feet on the west side of the Basin in the Del Norte Mountains. He mentioned the abundant occurrence of *O. texana* and *Exogyra quitmanensis*. King also remarked that Glen Rose beds terminate against the flanks of the Glass Mountains and that the Maxon Sandstone overlaps them. In the Cochran Mountains, Eifler (1943, p. 1620) reported a thickness of 458 feet with a marly zone in the upper 150 feet, the whole section characterized by *O. texana* and *E. quitmanensis*. Graves (1954, p. 16) measured a complete section 475 feet thick in the Hood Spring quadrangle. His section includes a basal conglomerate. Graves pointed out the abundance of *O. texana* and *Porocystis globularis* in the upper marly part of the section and rudistids in the lower, thick-bedded limestone section. Freeman (1964) mapped Glen Rose Limestone to the northeast in the Indian Wells quadrangle but gave neither thickness nor fossil content. He termed it "gray limestone that crops out in bottom of Rio Grande Canyon." Santiago Charleston[2] reported an incomplete Glen Rose thickness of 485 feet at Cerro el Barco, Mexico, across the Rio Grande slightly downstream from the mouth of Maravillas Creek, lat. 29°36′43″ N., long. 102°43′25″ W. (letter from C. I. Smith, February 16, 1965).

The Glen Rose probably thins northward through the Black Gap area toward the Glass Mountains. King (1937, p. 110) stated that the Glass Mountains stood as an asymmetric ridge during the advance of the Cretaceous sea. An increase of silt and sand to the north in the upper Glen Rose supports King's idea.

General lithology, ripple marks, and plant fragments

[2] Geologist, Petroleos Mexicanos, Monterrey, Mexico.

in the Glen Rose Limestone indicate a shallow-water environment. The lower, rudistid-bearing limestone is a neritic facies, and the clayey, sandy upper section represents littoral, near-shore deposition.

Absence of Maxon Formation

Baker and Bowman (1917, pp. 113–114) discussed basal clastic Comanche beds in the Marathon region, describing a 40-foot sandstone around the east margin of the Basin and a cross-bedded sandstone beneath the "Edwards" in the southeast corner of the Basin. They did not name this unit, but King (1930, p. 92) named it Maxon Sandstone from Maxon Station, Brewster County, Texas.

The writer did not recognize a Maxon unit in the Black Gap area nor did R. A. Maxwell (oral communication, 1965) in the Big Bend National Park. At King's type locality 23 miles north of the map area the sandstone overlies and overlaps the Glen Rose Limestone and underlies the "Edwards." King described the sandstone as medium to coarse grained, cross-bedded, and broken by joints. He found no fossils at the type locality. Eifler (1943, p. 1622) described a 73-foot section in the north part of the Santiago Peak quadrangle and 114 feet in the southeast corner. He mentioned prominent cross-bedding and large, weathered joint blocks. Eifler correlated the Maxon with the Fredericksburg Group of Central Texas on the basis of *Corbis* and *Volvulina dolium*. Graves (1954, p. 19) measured sections of Maxon Sandstone 115 and 157 feet thick 10 miles northwest of the map area. He described it as a gray to brown, fine- to medium-grained, friable to dense, cross-bedded sandstone with fossiliferous limestone lenses. Because of the gradational contact with the underlying Glen Rose Limestone and lack of definitive fossils, Graves correlated the Maxon Sandstone with the Trinity Group of Central Texas. Geologists of the International Boundary and Water Commission extended the Maxon Formation through the Black Gap area south into the Big Bend National Park. They described it as a gray, thin-bedded marl and limestone with thin, cross-bedded sandstone members. Freeman (1964) utilized their mapping in his compilation of the Indian Wells quadrangle but termed the unit "Maxon Limestone." Freeman described it as limestone and clayey limestone with subordinate sandstone and siltstone comprising about 10 percent of the unit. He gave an estimated thickness of 250 feet.

The writer does not believe that the Maxon Formation is present in the Black Gap area. The sandstone beneath the Telephone Canyon Formation in the northeast part of the map area consists of lenses or tongues within the upper Glen Rose Limestone. Possibly these are tongues that thicken and occur at progressively higher levels to the north.

Telephone Canyon Formation

The Telephone Canyon Formation is named for Telephone Canyon where Heath Creek crosses the Sierra del Carmen near the southern boundary of the map area. Maxwell et al. (MS.) defined this unit on the basis of stratigraphic relations in the Big Bend region and used a local name; other authors have used the term "Walnut-Comanche Peak" for the same rocks, thus implying a correlation with Central Texas rocks which cannot be demonstrated.

The Telephone Canyon is poorly exposed in the Black Gap area because of talus cover; in MS-3, however, there is an interval of 86 feet between the top of the Glen Rose and the base of the Del Carmen Limestone. At MS-3 the Telephone Canyon Formation is mostly covered but with scattered exposures of silty calcareous clay and interbedded biomicrite. Other exposures reveal a clayey limestone that weathers into nodules. *Exogyra texana* and *Protocardia texana* Conrad are present in MS-3. Both the upper and lower contacts of the formation are conformable. It crops out along the scarp northeast from the mouth of Maravillas Creek and along the northwest-trending fault scarps of the Sierra del Carmen to the south. Typical of the latter exposures are the outcrops on the west side of Margaret Basin and along Heath Creek.

Graves (1954, p. 22) reported 57.5 feet of Telephone Canyon section but with neither the top nor bottom exposed. Freeman (1964) estimated a thickness of 60 feet for exposures in the Indian Wells quadrangle.

Exposures previously referred to as "Walnut-Comanche Peak" crop out in Brewster County. King (1937, p. 114) assigned 50 feet of marl and thin limestone beds along the east side of the Marathon Basin to the "Walnut-Comanche Peak" but recognized lateral facies changes. Eifler (1943, p. 1626) assigned an equivalent unit to Member No. 1 of the Devils River Limestone. Lozo and Smith (1964, p. 297) have suggested that equivalent beds be assigned to the West Nueces Formation in eastern Kinney and western Uvalde counties.

The unit is a shallow-water, neritic to littoral, transgressive sequence.

Del Carmen Limestone

The Del Carmen Limestone is named for the Sierra del Carmen of the Big Bend National Park adjacent to the map area. Maxwell et al. (MS.) defined this unit on the basis of stratigraphic relations in the Big Bend region and used a local name. Other authors have used the term "Edwards Limestone" for these rocks.

The Del Carmen Limestone is 445 feet thick at MS-3 and in conformable contact with the Telephone Canyon below and the Sue Peaks Formation above.

The limestone crops out along the Rio Grande northeast of Maravillas Creek and in the fault scarps of the Sierra del Carmen and Stairway Mountain. It is also exposed in the core of the Dove Mountain Ranch anticline.

The formation is principally a biomicrite containing chert and a various marine fauna, especially *Toucasia*. Of two intervals containing bioherms, the lower has cherty biomicrite beds flanking the bioherms whereas the upper has silty calcareous clay between the bioherms.

Graves (1954, p. 24) measured a section 309 feet thick.

To the west, Eifler measured 209 and 255 feet (1943, p. 1629). King (1937, p. 115) reported a maximum thickness of 200 feet. Both Eifler and Graves commented on the abundance of *Toucasia.* Freeman (1964) estimated a thickness of about 400 feet for exposures along the Rio Grande in the Indian Wells quadrangle. Santiago Charleston reported a thickness of 138 meters (453 feet) at Cerro el Barco, Mexico, across and downstream from the mouth of Maravillas Creek, lat. 29°36′43″ N., long. 102°43′25″ W. (letter from C. I. Smith, February 16, 1965).

The Del Carmen Limestone becomes thinner toward the Glass Mountains. It is possible that the Marathon area was uplifted during deposition of the Comanchean sediments.

The Del Carmen Limestone correlates with Udden's Member No. 2 of the Devils River Limestone and with the Edwards Limestone of Graves (1954). It is also correlative with the upper part of the West Nueces Formation and the McKnight Formation of the southern Edwards Plateau and southwest Texas (Lozo and Smith, 1964, p. 290).

The Del Carmen Limestone of southern Brewster County is the product of a neritic environment. The bioherms are shallow-water reefs.

Sue Peaks Formation

The Sue Peaks Formation is named from Sue Peaks in the southeast part of the Big Bend National Park. Maxwell et al. (MS.) defined this unit for use in the Big Bend National Park. King (1930, p. 96) and Graves (1954, p. 25) used the term "Kiamichi Formation" and Eifler (1943, p. 1627) used "Member No. 3 of the Devils River Formation" for the same rocks. The implied correlation has not been demonstrated.

The Sue Peaks Formation is 86 feet thick at MS-3; MS-4 includes an incomplete section. At Stairway Mountain west of the Black Gap headquarters it is 73 feet thick. The formation is easily eroded and mostly covered. It has scattered exposures of calcareous clayey siltstone. Micrite and biomicrite beds near the top contain an abundant marine fauna. The composite section (units 25 and 26, Pl. III) gives a list of fossils collected from this interval within the map area. Other fossils from the Sue Peaks Formation of the Black Gap area include *Adkinites imlayi* from an exposure near the thrust fault north of Maravillas Canyon (Pl. I, K-7) and from the Dove Mountain Ranch anticline (Pl. I, H-1). The writer also collected an *Adkinites bravoensis* (Böse) and a single shark vertebra from the latter locality and a *Protocardia texana* from an exposure on the road along Maravillas Canyon. The Sue Peaks Formation forms a distinctive light-colored, slope-forming, vegetation-free band on scarps throughout the area. The change from the Del Carmen Limestone below and the Santa Elena Limestone above is abrupt, and the contacts are sharp except where obscured by talus.

King (1930, p. 96) measured 62 feet of "Kiamichi" marl containing *Gryphaea navia* overlain by 21 feet of "Duck Creek" nodular marly limestone in the Glass Mountains. K. P. Young (oral communication, 1965) believed equivalents of both units, as indicated by fossils, are present at MS-4. Eifler (1943, p. 1627) reported thicknesses of 30 to 70 feet of Member No. 3 of the Devils River Limestone, stating that the member is "strikingly fossiliferous." Graves (1954, p. 26) measured thicknesses of 35, 46, and 57 feet in the Hood Spring quadrangle. He described the coquina marker bed and stated that it was overlain by massive limestone, whereas 10 to 12 feet of calcareous siltstone separates these units in the Black Gap area. *Oxytropidoceras* sp., *Gryphaea* sp., and *Enallaster texanus* characterize the Sue Peaks Formation in Graves' area. Freeman (1964) mapped the "Kiamichi(?) Formation" in the Indian Wells quadrangle and estimated its thickness at about 50 feet. Santiago Charleston reported a section of Sue Peaks Formation 24 meters (79 feet) thick at Cañon Ceferino, Coahuila, 10 miles east of the map area, lat. 29°30′43″ N., long. 102°45′43″ W. (letter from C. I. Smith, February 16, 1965).

The Sue Peaks Formation of the Black Gap area is correlative with the "Kiamichi" marl of other workers in Brewster County and probably includes the "Duck Creek" of King. The Sue Peaks Formation of the Black Gap area is not equivalent to the McKnight Formation in Uvalde and Kinney counties but rather to the lower part of the Salmon Peak Formation (letter from C. I. Smith, April 29, 1965).

The Sue Peaks Formation represents a shallow, neritic environment and contains clastic material derived from a nearby positive landmass.

Santa Elena Limestone

The Santa Elena Limestone was named from Santa Elena Canyon in the Big Bend National Park. Maxwell et al. (MS.) defined the unit. The "Santa Elena Limestone" replaces the "Georgetown Limestone" of other authors.

The section at Santa Elena Canyon is 740 feet thick. The writer measured a composite section at MS-4 for a total thickness of 943 feet, and Santiago Charleston reported a thickness of 305 meters (1,000 feet) at Cañon Ceferino, Coahuila, lat. 29°30′43″ N., long. 102°45′48″ W., 10 miles east of the map area (letter from C. I. Smith, February 16, 1965).

The Santa Elena Limestone of the Black Gap area is predominantly biomicrite with beds of micrite and biosparite. There are rudistid bioherms midway in the section, and chert nodules are scattered throughout the section. *Toucasia* sp. is relatively abundant. The composite section (Pl. III) lists other fossils. The writer found a single specimen of *Durnovarites* sp. cfr. *quadratus* Spath in talus derived from this limestone.

The Santa Elena Limestone crops out over approximately 75 percent of the Black Gap area. It constitutes the stripped structural surface of the northeast third of the map area and is the uppermost unit capping Sierra del Carmen and Stairway Mountain in the southern half of the area. It is also exposed near the intersection of the graded road to the Black Gap headquarters and State Highway 385 where it forms northwest-trending ridges. R. A. Maxwell (oral communication, 1965) found no complete section in the adjoining part of Big Bend National Park. Exposure of the basal contact of the Santa Elena Limestone is common, but the upper section at the same locality is usually eroded. The writer measured a complete section at MS-4 near the mouth of Drift Canyon. A complete section could also be described at the Cupola Mountain scarp but minor faulting would have to be considered.

Udden (1907, p. 22) estimated a total thickness of 2,000 feet of "Lower Cretaceous Limestones" in the Sierra del Carmen. Baker and Bowman (1917, p. 115) recognized strata of "Georgetown age" in the Marathon area but did not measure any clearly defined sections. King (1937, p. 115) described "Georgetown Limestone" as "about 200 feet thick" on the west side of the Marathon Basin but gave a thickness of 175 feet on a chart (p. 20) showing formations in the Marathon area. Eifler (1943, p. 1628) gave a thickness of 475 to 500 feet for Member No. 4 of the Devils River Limestone in the Santiago Peak quadrangle. He described the unit as massive and containing rudistids and *Gryphaea* sp. Graves (1954, p. 27) reported incomplete thicknesses of 385 and 393 feet and stated that the "Georgetown" is a dense to sublithographic limestone with a marly upper section. Lozo and Smith (1964, p. 303) have redefined the "Georgetown" of Kinney and Uvalde counties because of facies variation and proposed the term "Salmon Peak Formation." They also discussed the regional facies variations of this unit.

The Santa Elena Limestone appears to thin toward the Marathon Basin; this is added evidence for uplift during the Comanchean.

The Santa Elena Limestone of the Black Gap area represents a neritic environment. It contains shallow-water reefs as evidenced by unit 29 of the composite section (Pl. III).

Del Rio Formation

The term "Del Rio Clay" was used by Hill and Vaughan (1898, p. 236) for greenish laminated clay exposed near Del Rio in Val Verde County, Texas. R. A. Maxwell (oral communication, 1965) chose to apply the "Del Rio" term in the Big Bend National Park rather than "Grayson" as preferred by the Geologic Names Committee of the U. S. Geological Survey. Maxwell (oral communication, 1965) preferred to call this unit the Del Rio Formation because of geographic proximity of type locality. Lozo and Smith (1964, p. 290) concurred with Maxwell's usage.

Outcrops in the western part of the Black Gap area are mostly covered, as at MS-2, but scattered exposures reveal silty claystone grading to clayey siltstone with traces of gypsum and limonite pseudomorphs after pyrite. The formation is usually deeply weathered and typified by a very pale orange color. The greatest thickness of several measured is 185 feet in Big Brushy Canyon. The lower part is relatively fresh and dark gray at the thick exposure. The pale orange color results from weathering. No fossils were found in the lower part. Maxwell (oral communication, 1965) gave several thicknesses from within the Big Bend National Park. These are shown on the isopachous map (fig. 1). Santiago Charleston reported a section 3 meters (10 feet) thick from Arroyo Hormiga, Coahuila, 3 miles southeast of Cañon Ceferino at lat. 29°27′25″ N., long. 102°43′25″ W. (letter from C. I. Smith, February 16, 1965). This location is 10 miles east of the map area. The Del Rio is absent to the east along a line paralleling the Rio Grande (fig. 1). The isopachous map (fig. 1) suggests that during deposition of the Del Rio Formation a high existed in the area now occupied by the Rio Grande and also along a trend extending to the northwest, north of and parallel with the present course of Maravillas Creek. The Del Rio thins because of relief on the depositional surface rather than from erosion or post-depositional structural activity. Termination of lower beds and overlap by upper beds is demonstrable in the Black Gap area. The western deep basin indicated by the isopachous map could have resulted from continuous downwarp or faulting along the northwest-trending, down-to-the-east fault zone shown on the geologic map (Pl. I, D-7). The structure-contour map (Pl. II) drawn on top of the Santa Elena Limestone also suggests this.

Haplostiche texana is the diagnostic fossil for the Del Rio Formation in the Black Gap area and appears in soil formed on the limestone interbeds in Del Rio Formation slopes. The composite section (Pl. III) lists other fossils from this formation. *Exogyra arietina* characterizes this formation in other areas but was not found in the Black Gap area.

Udden (1907, p. 27) recognized the Del Rio "zone" and stated that it was much "heavier" at Terlingua than east of the Chisos Mountains; he believed that it thins or disappears to the east. Baker and Bowman (1917, p. 114) discussed a "yellowish marly clay, not more than 100 feet thick" above the "Georgetown" and below the "Buda" along the western edge of the Marathon Basin about 25 miles north of the Black Gap area. King (1937, p. 115) reported a thickness of 15 or 20 feet from the west slope of the Del Norte Mountains, 20 miles northwest of the map area. Eifler (1943, p. 1630) reported 73 feet from the southwest part of the Santiago Peak quadrangle. Graves (1954, p. 29) reported it in the Hood Spring area but gave no thickness because of faulting. Each of these writers mentioned the occurrence of *H. texana* in these beds. Freeman (1964) reported a thickening to the southwest within the Indian Wells quadrangle from 30 to 80 feet.

The clayey, silty rock of the Del Rio Formation marks it as a littoral deposit.

Buda Limestone

The Buda Limestone was named by Vaughan (1900, p. 18) to include hard, white, limestone beds. The type locality is on Shoal Creek, Austin, Texas.

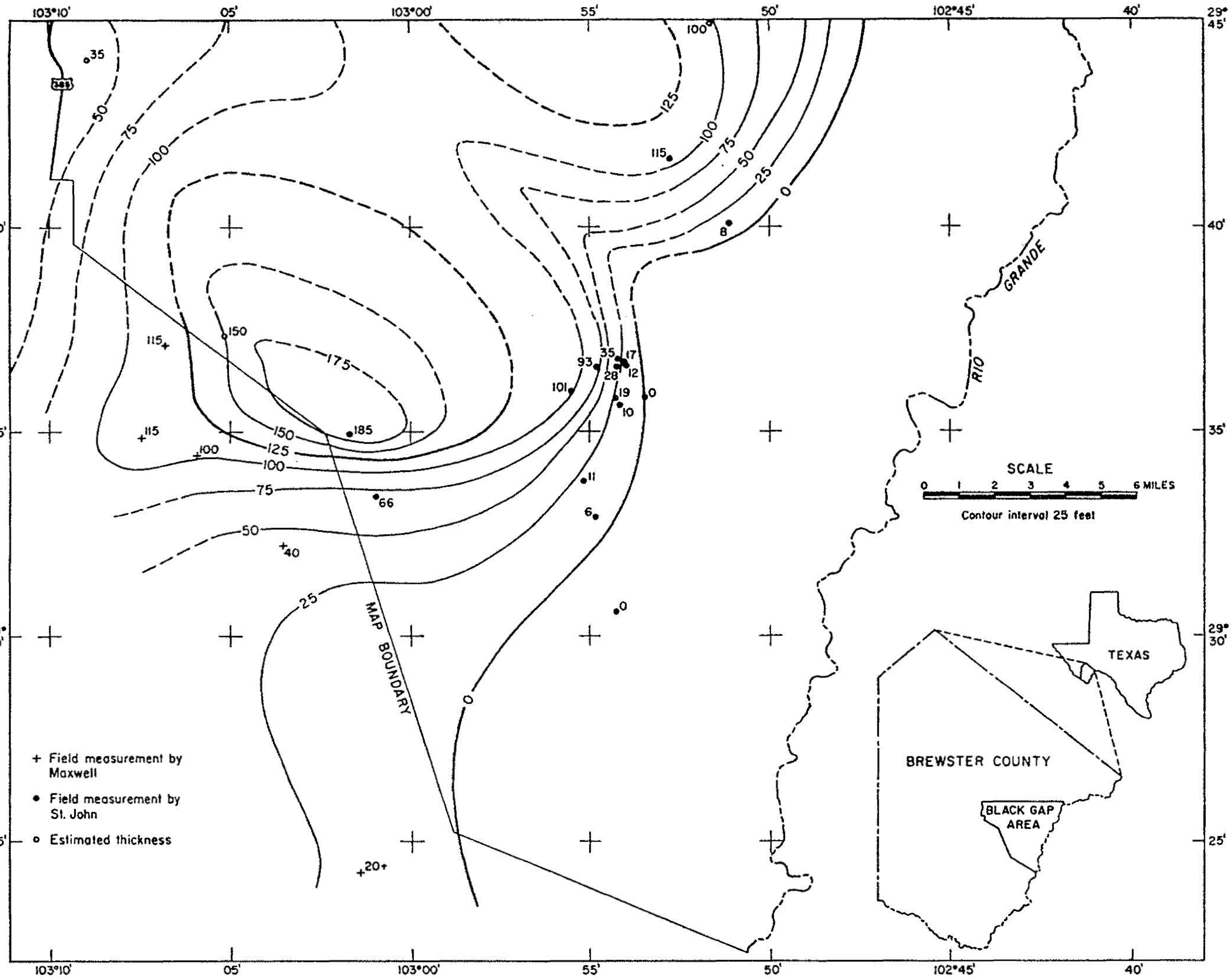

FIG. 1. Isopachous map of Del Rio Formation, Black Gap area, Brewster County, Texas. Thickness in feet. Isopach dashed where inferred.

The Buda Limestone has been elsewhere subdivided into three members. In the Black Gap area, however, there is a fourth, basal member, of varying thickness. The basal member is absent in some parts of the area and is up to 22 feet thick in others. The three members overlying the basal unit maintain a uniform total thickness of 80 feet. The basal member is a green-alga biosparite and overlies the Del Rio Formation. It forms a prominent ledge above the more easily eroded Del Rio Formation and is yellowish brown to yellowish orange, thereby forming a sharp color contrast with the overlying gray biomicrite. It is interesting that the Del Rio Formation and the green-alga biosparite of the Buda Limestone thicken, thin, and pinch-out at the same localities, suggesting a similar history. The upper surface of the green-alga biosparite at MS-1 has borings that indicate subaerial exposure and therefore a disconformity. In Big Brushy Canyon (Pl. I, E-6) a coquina layer 6 inches to a foot thick separates the basal member from the overlying beds. This same coquina layer can be traced from the top of the green-alga biosparite into the overlying gray limestone section along the north side of the saddle on the Airplane Tank road (Pl. I, H-5). At this place the coquina layer also contains bored cobbles.

The Buda Limestone above the green-alga biosparite is divisible into three members in the western part of the map area. A massive biomicrite 10 feet thick overlies the basal biosparite and forms a prominent ledge. In some places the lower surface of this unit is burrowed. Above the biomicrite bed is an easily eroded clayey micrite 40 feet thick devoid of vegetation.

The uppermost member is a sublithographic, nodular-weathering biomicrite 31 feet thick. The upper three members are yellowish gray to grayish pink and distinctive on aerial photographs. The Buda Limestone is 80 feet thick at MS-4, but both the Del Rio Formation and the basal green-alga biosparite are missing and the Buda rests on the Santa Elena Limestone. The Buda Limestone appears thin to medium bedded at MS-4 and is not divisible into members.

Budaiceras characterizes this formation and *Pecten roemeri* occurs near the base. Other mollusks were also collected throughout the section.

Udden (1907, p. 27) reported thinning of the Buda in the Big Bend National Park to the east of the Chisos Mountains. King (1937, p. 115) reported about 60 feet of Buda Limestone on the west flank of the Del Norte Mountains, 20 miles northwest of the map area, where it varies from nodular to regularly bedded. Eifler (1943, p. 1632) measured 75 feet of Buda Limestone in the southwestern part of the Santiago Peak quadrangle. Graves (1954) reported three members within the Buda Limestone. Freeman (1964) also mentioned the three members within the Indian Wells quadrangle and reported thickening to the west from 78 to 90 feet. Santiago Charleston reported a thickness of 30 meters (98 feet) in Arroyo Hormiga, Coahuila, lat. 29°27′25″ N., long. 102°43′25″ W., 7 miles west of the map area (letter from C. I. Smith, February 16, 1965).

Lozo and Smith (1964, p. 290) pointed out that workers have demonstrated lithologic continuity of the Buda throughout southwest Texas.

The basal green-alga biosparite is a marginal basin facies, and the abundance of sparry calcite suggests a relatively high-energy environment. A disconformity separates the basal member of the Buda from the overlying section, which represents a deeper water, low-energy environment. The disconformity is indicated by a coquina zone containing bored cobbles.

GULFIAN SERIES (TERLINGUA GROUP)

In the Black Gap area the Gulfian Series is represented by the Boquillas and Pen Formations of the Terlingua Group.

Udden (1907, p. 33) used the term "Terlingua beds" for exposures along Terlingua Creek, Brewster County, 35 miles west of Black Gap. He defined the Terlingua as chalky, marly clay that grades downward into the Boquillas Flags and upward into the Rattlesnake beds (Aguja Formation). Udden included those units he believed equivalent to the Austin Chalk and Taylor Marl of Central Texas.

Maxwell et al. (MS.) divided the rocks Udden mapped as Terlingua and Boquillas into three lithologic units: the Pen Formation and the Ernst and San Vicente Members of the Boquillas (revised). They applied the name Terlingua Group to the two formations. The Cretaceous formations above the Terlingua Group in the Big Bend National Park are not present in the map area.

Boquillas Formation

Udden (1907, p. 29) originally used the term "Boquillas Flags" for rocks on Tornillo Creek, Chisos Mountain quadrangle, Brewster County. Udden's Boquillas included a lower, thin-bedded, fossiliferous, flaggy limestone and an overlying chalky limestone. Eifler (1943, p. 1632) redefined the "Boquillas Limestone" in the Santiago Peak quadrangle to include limestone beds above the Buda Limestone and below the top part of the *Inoceramus undulatoplicatus* zone. Maxwell et al. (MS.) defined the Boquillas Formation to include the flaggy, marly units and subdivided the Boquillas Formation into the Ernst Member, which includes the lower flaggy beds, and the San Vicente Member, which includes the chalky limestone and calcareous shale above the flaggy beds and below the gypsiferous Pen Clay.

This unit is not subdivided on the geologic map but is lumped as the Boquillas Formation. MS-1 and MS-5 together give a composite thickness of 551 feet.

The Boquillas Formation crops out in the Black Gap area within the northwest-trending structural and topographic low extending from Stillwell, Heath, and Horse Canyons northwest through the Black Gap headquarters to State Highway 385. The broadest area of outcrop is between Black Gap and Maravillas Canyon.

Erosional remnants of the Boquillas Formation crop out at Cupola Mountain, Black Mountain, and west of Dove Mountain. Other exposures are in the low hills between Big Brushy Canyon (Pl. I, E-7) and the Stillwell ranchhouse and along the gravel-covered scarp west of Bear Creek west of the Dove Mountain Ranch anticline (Pl. I, E-2).

Ernst Member.—Maxwell et al. (MS.) named the Ernst Member of the Boquillas Formation from Ernst Tank on the west side of the Sierra del Carmen. They defined the Ernst as the basal member of the Boquillas Formation.

The writer measured 277 feet of silty, thin- to medium-bedded, flaggy, brown to gray micrite and biomicrite beds at MS-1. A sharp lithologic change marks the contact with the underlying Buda Formation and a topographic and lithologic change marks the gradational contact with the overlying San Vicente Member. Previous workers suggested that sinkholes in the Buda Formation containing flaggy Ernst beds are evidence of unconformity. These same features occur in the Black Gap area but the writer is convinced these karst features are younger than the flaggy limestone beds. The flaggy beds in the sinkholes are brecciated, indicating collapse after lithification. Other than the sharp lithologic change from massive, sublithographic limestone of the Buda to the overlying silty, thin-bedded limestone of the Ernst Member, there is no physical evidence to suggest an unconformity between these units in the Black Gap area.

Fragments of *Inoceramus labiatus* are common in the Ernst Member, especially in the upper part. Other fossils are present (Pl. III) but not abundant.

Freeman (1964) described about 100 feet of "Boquillas Flags" which belong to the Ernst Member. Maxwell correlated the Ernst Member with Eagle Ford Shale of Central Texas.

The Ernst Member, as mapped in the Big Bend National Park and Black Gap area, includes the lower part of Udden's original Boquillas Formation and the lower part of Eifler's Boquillas Limestone. King (1937, p. 116) tentatively correlated equivalent beds near the Del Norte Mountains with the Eagle Ford Formation of Central Texas.

The occurrence of well-rounded and sorted quartz silt and sand grains in the lower beds indicates deposition near a shoreline. Lack of coarse sand, gravel, or coquina layers plus well-defined bedding suggest a slow advance or retreat of the shoreline associated with relatively low-energy wave action.

San Vicente Member.—Maxwell et al. (MS.) named the San Vicente Member from the abandoned village of San Vicente in the Big Bend National Park.

Composite thickness of the San Vicente Member in the Black Gap area is 274 feet. This member differs from the underlying Ernst Member; it has thicker beds and weathers yellow gray. The lower 125 feet is composed of thin- to medium-bedded nodular micrite containing *I. labiatus.* Above this micrite layer is a covered interval 66 feet thick with scattered exposures of easily eroded calcareous clay. Without exposure of the associated micrite beds this clay interval could not be differentiated from the younger Pen Clay. No fossils were found in the clay interval. A clayey micrite 83 feet thick overlies the clay and is gradational into the overlying Pen Clay. The contact between the San Vicente Member and the overlying Pen Clay is drawn at the top of the uppermost limestone bed. *Inoceramus* sp. is common throughout this micrite, and a concentration of *Inoceramus undulatoplicatus* occurs 35 to 50 feet above the base of the San Vicente Member. This is the *Inoceramus undulatoplicatus* zone (Maxwell et al., MS.; Eifler, 1943, p. 1634). Graves (1954, p. 30) reported an exposure in the Hood Spring quadrangle of chalky limestone 15 feet thick, which he called "Terlingua Formation." The strata he described belong not in the Pen Clay of this report but in the San Vicente Member.

Maxwell et al. (MS.) correlated the San Vicente Member with the Austin Chalk of Central Texas. They included Udden's lower flagstone member of the Boquillas Formation and the lower flagstone member and middle marl member of Udden's Terlingua Formation.

The upper and lower micrite beds containing *Inoceramus* sp. are probably a result of deposition in water deeper than that which received the sediments of the Ernst Member. As the sea transgressed, the sea bottom became deeper, the shoreline was farther from the area of deposition, and the low-energy environment continued. The calcareous clay suggests a seaward retreat of the shoreline and reworking of the newly deposited calcareous sediments with a resulting transport of clay-size particles into clear water. The sudden abundance of clay particles would have muddied the water and probably killed the fauna, so that fossils are lacking. Re-establishment of the trangressive movement cleared the water and the fauna flourished again, leaving the abundant fossils of the *Inoceramus undulatoplicatus* zone.

Pen Clay

Maxwell et al. (MS.) named the Pen Clay from Chisos Pen north of the Chisos Mountains in the Big Bend National Park. The Pen Clay is the same as the upper clay member of Udden's "Terlingua clay."

The Pen Clay crops out only in the basalt-capped center part of the map area. No Cretaceous strata younger than Pen Clay remain in the Black Gap area. The highly resistant basalt cover has protected the easily eroded Pen Clay; otherwise it too would have been removed long ago. At MS-5 only 50 feet of Pen Clay is present beneath the basalt. From outcrop width, estimated dip, and the topographic map, the writer calculated a thickness of 500 feet west of the Black Gap syncline and immediately north of the Black Gap headquarters. Udden estimated a thickness of 1,280 feet near Chisos Pen in the Big Bend National Park including, at the base, 100 feet equivalent to the upper part of the San Vicente Member of the Black Gap area. Eifler (1943, p. 1634) reported approximately 200 feet of gray marl overlying the Boquillas Formation along the west side of YE Mesa 12 miles northwest of the map area. The gray marl probably is correlative with the Pen Clay.

The Pen Clay is calcareous and gypsiferous in the Black Gap area. *Inoceramus grandis* occurs near Bee Cave Tank 3 miles northwest of the Black Gap headquarters, and *Inoceramus* prisms are not uncommon in the Pen Clay.

The Pen Clay consists of strata formerly termed "Terlingua (restricted)" in the Big Bend area. Maxwell et al. (MS.) correlated it with the upper chalk member of the Austin Chalk near Austin.

Although younger Cretaceous rocks are missing in the Black Gap area, the Pen Clay is overlain by the Aguja Formation in the Big Bend National Park. The clay itself suggests sediments laid down by a regressing sea. The occurrence of gypsum in the clay suggests shallow-water evaporitic conditions.

TERTIARY ROCKS

EXTRUSIVE ROCKS

Tertiary extrusive basalt covers a large area near the Black Gap headquarters in the central part of the map area. This outcrop is in the major northwest-trending graben between the Sierra del Carmen and the Cupola Mountain area.

A conglomerate containing chert similar to that found in the Paleozoic rocks of the Marathon Basin occurs beneath the basalt in the Black Gap area (Wilson, 1951, p. 68).

The basalt extrusion followed down-to-the-west faulting which brought Pen Clay to the west of the Black Gap syncline into contact with Boquillas Formation to the east. The basalt overlies Cretaceous rocks with slight angular unconformity. Near the mouth of Maravillas Canyon, the basalt rests on Santa Elena Limestone.

Other exposures of extrusive basalt occur at Dove and Black Mountains and Cupola Mountain peak to the north. The edges of an outcrop of extrusive basalt in the gravel-covered lowland of the northwest part of the map area (Pl. I, C-2) are covered by alluvium. It is not definitely known which rock unit underlies the basalt.

The thickness of the basalt depends on the amount of post-basalt erosion and on the pre-basalt topography. Maximum thickness of 450 feet occurs on the east side of Stillwell Mountain (Wilson, 1951, p. 68).

The thick basalt section is divisible into two units. The lower unit is dark gray and weathers to a smooth slope. The upper unit is reddish brown, weathers into massive angular blocks, and forms near-vertical scarps. Petrographic studies by Wilson (1951) show that the two units are similar, if not identical, in thin section. Both basalt units consist of several flows separated by vesicular zones. The vesicles are elongated horizontally and filled with chalcedony or calcite. Both units are nonporphyritic and fine grained. Both units exhibit flow structure and each is composed of plagioclase (labradorite), titaniferous augite, olivine, iddingsite, and minor accessory minerals.

No one has attempted to date the series of flows in these outcrops.

Pinto Tank, on the Dove Mountain ranch, is the site of an intrusive plug in the core of a collapse feature. Olivine basalt has extruded along the faults bordering the collapse area. The olivine basalt is holocrystalline, nonporphyritic, and trachytoid. The rock was originally composed of 67 percent plagioclase, 31 percent olivine, and 2 percent magnetite. The olivine has altered to iddingsite so that the rock now contains 24 percent iddingsite pseudomorphs after olivine and 7 percent olivine. Also, the plagioclase is partly altered to sericite.

Volcanic activity resulting in the extrusion of the basalt occurred prior to much of the great folding and faulting now evident. A good example of this is Black Gap syncline where the basalt forms the upper surface of this feature.

Several small plugs in the Black Gap area and other nearby plugs may account for the mass of lava which blanketed the area at one time.

Lonsdale et al. (1955, p. 47) reported extrusive olivine basalt between the Chisos Mountains and the Rio Grande to the west of the Black Gap area but also stated that "this lava has not been found on the east side of the Chisos Mountains." J. A. Wilson (oral communication, 1965) believed the flow to be of Middle or Late Eocene age. He has collected Middle Eocene fauna from the continental sedimentary rocks beneath the basalt. J. A. Wilson also reported Late Eocene fauna from tuffs overlying the basalt at Castolon on the west side of the Chisos Mountains.

INTRUSIVE ROCKS

Agglomerate.—An agglomerate is exposed beside the graded road 2 miles northwest of the Black Gap headquarters. The area of exposure is small and an extensive gravel mantle masks the true dimensions. This agglomerate probably marks a volcanic vent. The agglomerate contains basalt boulders as much as 4 feet in diameter. The basalt is dark gray to pale brown, vesicular and scoriaceous. The matrix material is fine grained, extremely weathered, and light olive gray to pale brown. Pebbles of limestone and clay are also scattered through the matrix. This was the only agglomerate observed in the Black Gap area.

Sills.—There are two sills in the Black Gap area. A basalt sill intruded into Glen Rose Limestone is exposed along the Rio Grande in the northeast corner of the map area (Pl. I, P-3). An abandoned mine shaft exposes a section 12 feet thick. Debris from the Glen Rose Limestone masks the outcrop and makes it difficult to define the lateral limits. The basalt is nonporphyritic, fine-grained holocrystalline and is composed of 49 percent plagioclase plus biotite, titanaugite, amphibole, iddingsite, augite, magnetite, and analcime plus traces of apatite, calcite, and leucoxene.

An analcime gabbro sill intruded into the Ernst Member extends over much of the west-central part of the map area. It is exposed in the low hills west and northwest of the Black Gap headquarters, where it is 112 feet thick. It is also exposed in Big Brushy Canyon, in the valley behind Guliher's house (Pl. I, D-5), and in the low gravel-capped hills 5 miles west of Stillwell Mountain. The sill is also exposed on the sides of Stillwell Mountain and beside the road just east of Black Gap. The sill is deeply weathered wherever exposed and has a dark reddish-brown mottled appearance. It weathers into subspheroidal blocks. Petrographic examination reveals that it is fine- to medium-holocrystalline and nonporphyritic. The rock is 76 percent plagioclase, plus analcime, aegirine-augite, and iron oxide. Lesser amounts of accessory minerals are present. The analcime is late- or post-magmatic and fills void spaces in the feldspar. The aegirine-augite crystals are zoned.

Dikes.—Along the fault trace on the eastern edge of Dove Mountain Ranch anticline are several exposures of igneous rock. Petrographic examination indicates a fine- to medium-holocrystalline, porphyritic olivine basalt. Flow structure is manifest and euhedral olivine crystals have altered completely to iddingsite. The rock also contains abundant augite. Samples from an unusual rock at this same location reveal an intrusive basalt breccia. The rock is merocrystalline and porphyritic. Micro-xenoliths or volcanic-rock fragments up to 6.5 mm long are basalt and exhibit vesicles and oriented plagioclase laths. This is the only dike the writer found in the Black Gap area.

Plugs.—Numerous small plugs seldom exceeding 50 feet in diameter occur in the Black Gap area. The plugs are concentrated west and south from Dove Mountain.

A basalt plug (Pl. I, H-2) east of the Dove Mountain Ranch anticline is composed of holocrystalline, porphyritic, and trachytic rock. The basalt is 74 percent plagioclase. The plagioclase crystals are rounded and partially resorbed, suggesting crystallization at depth followed by intrusion with temperature-pressure changes. The rock also has partly resorbed augite phenocrysts and augite with leucoxene coronas surrounded by hematite rims.

West of Cupola Mountain peak (Pl. I, K-3) is a plug exposing unusually fresh rock. The rock is holocrystalline, nonporphyritic, fine- to medium-grained basalt. It is composed of 62 percent plagioclase plus pyroxene, iddingsite, and magnetite. Iddingsite has completely replaced olivine. The pyroxene in this plug is not the same as that in the sills mentioned earlier; the difference suggests different sources or at least different times of intrusion.

At Pinto Tank, Dove Mountain ranch, is a basalt plug associated with a collapse feature. The magma of the plug was probably very hot and "wet" (D. S. Barker, oral communication, 1965). The plug is in contact at the surface with the Buda Limestone and the Del Rio Formation. Surrounding the plug is a resistant rim of skarn resulting from metamorphism. The resistant rim is about 10 feet wide and surrounded by marble for a distance of 50 feet. No trace of fossils or bedding appears in the marble, which consists of equant grains averaging 3 mm diameter. The skarn rim contains an abundance of chalcedony and hydrogrossularite garnet (D. S. Barker, oral communication, 1965) plus significant percentages of calcite, epidote, and aegirine-augite. The basalt plug is porphyritic with a cryptocrystalline matrix composing 42 percent of the rock. X-ray analysis indicates the matrix is composed of analcime, plagioclase, pyroxene, biotite, and amphibole.

Associated with this plug is basalt extruded along a fault trace. Perhaps at some unknown depth the intrusive plug left a void, which resulted in the "collapse" of the overlying sedimentary rock along faults. Basalt later passed through these fault zones, extruding on the surface and metamorphosing the Santa Elena Limestone on either side of the fault trace for a distance of 5 to 10 feet.

Southeast of Dove Mountain and northeast from Black Mountain is a circular rim of intrusive basalt (Pl. I, K-1) several hundred feet in diameter. The surrounding Santa Elena Limestone is metamorphosed for a distance of 10 to 20 feet. The limestone around the plug does not seem to be tilted to any degree. The crater is breached to the northwest and the interior is covered with alluvium. Probably it is a remnant of a vent and the rim represents more resistant rock near the contact zone.

SUMMARY OF TERTIARY ROCKS

The Tertiary igneous and volcanic rocks of the Black Gap area are part of an alkalic kindred. Differences in mineral composition are not so great as to require different sources; such differences as exist could be a result of pre-intrusive differentiation.

TERTIARY-QUATERNARY BOLSON FILL

A partially dissected bolson fill is located on the Adams ranch in the extreme south end of the map area. Two miles south of the turnoff to Stillwell Canyon, terrace levels are cut into deposits of pinkish-orange silty clay. The clay extends south to the Rio Grande. No bones have been found in the bolson deposits; however, an extensive search was not made. Possibly the bolson was deposited during both Quaternary and Tertiary periods.

The bolson fill is predominantly silty clay with interbedded gravel. The gravel layers are 2 to 5 feet thick and are composed of coarse sand, pebbles, and cobbles of limestone and igneous and volcanic rock. No chert or novaculite was noted in these gravels.

The bolson extends south into Mexico an undetermined distance. Terrace levels are visible on the Mexican side of the river which are not present on the Texas side.

QUATERNARY ROCKS YOUNGER THAN BOLSON FILL

OLDER GRAVEL

Certain gravels in the Black Gap area are deposits from older erosion cycles and can be mapped separately. Most of these older gravels are composed principally of igneous rocks uncommon in later deposits.

A mile south of Maravillas Creek along the dirt road from State Highway 385 to the Black Gap headquarters is an extensive, topographically high, gravel deposit. The gravel consists of pebbles and cobbles of white, black, green, and red chert from the Marathon region. Abundant igneous rock types including cobbles of agate are also present. Similar gravel deposits occur to the west along the edge of the mountain range bordering the Big Bend National Park. Maxwell et al. (MS.) mapped these deposits as "older gravel." The writer has extended this unit into the Black Gap area.

At the mouth of Big Canyon, in the northeast corner of the map area, is a remnant of an older gravel composed entirely of limestone cobbles and boulders cemented with calcite. The remnant exhibits massive, torrential cross-bedding and is not related to the surrounding uncemented terrace gravel and alluvium.

PEDIMENT GRAVEL AND UNDIFFERENTIATED GRAVEL

Pediment gravels of mappable extent occur along Maravillas Canyon near the Rio Grande and along the Rio Grande northeast from the mouth of Maravillas Creek. These gravels contain subangular to rounded cobbles and pebbles of locally derived limestone plus the colored cherts indicative of Marathon Basin Paleozoic rocks. Different levels are mapped where identifiable. In some areas these gravels are cemented with caliche.

About 100 square miles of the northwest corner of the map area is mantled by gravel. The gravel is composed mainly of limestone pebbles and cobbles plus a significant amount of chert from Paleozoic rocks of the Marathon Basin and a few pebbles of igneous rock. The gravel deposits appear to be nowhere more than 30 feet thick and the entire gravel mantle may have been deposited by a meandering Maravillas Creek. For this reason, the deposit in this area has been mapped as "undifferentiated gravel" and not as bolson fill.

LANDSLIDE MATERIAL

The term "landslide material" is virtually self-explanatory and, as expected, the material occurs on the slopes beneath fault and erosion scarps. The landslide deposits, however, present a problem of presentation on the geologic map; for example, on the southwest side of Stillwell Canyon (K-10). To the north, the landslide deposit covers the fault trace and laps onto the Santa Elena Limestone, whereas to the south the fault marks separation of the limestone beds from the landslide material. This is a function of the dip of the fault plane. Where the dip is inclined from the vertical, the fault trace is partly covered by debris. Where the dip is nearly vertical and the scarp has not yet retreated through erosion, the fault trace must separate the limestone from the landslide material whatever the thickness of the material.

ALLUVIUM

Unconsolidated, relatively fine-grained clastic material is deposited along the banks of the Rio Grande and Maravillas Creek plus innumerable small drainage creeks.

Two levels are discernible along Maravillas Creek between State Highway 385 and the Santa Elena Limestone scarp east of the Stillwell ranch. Considering the vast amounts of runoff handled by this creek, however, and the volume of coarse material that can be moved in a short time by such torrential flooding, these alluvial levels have not been differentiated. They may not be there tomorrow.

STRUCTURE

The Black Gap area is at the junction of several structural provinces. It lies astride the boundary between the frontal and interior zones of the Ouachita System. The Serrania del Burro Arch of Mexico terminates in the area. Immediately to the north is the hinge line of the upwarp of the Marathon Dome marked by an east-trending belt of igneous plugs marking a line of vents. Black Hills and East Black Hills on the Dove Mountain quadrangle are the easternmost of these. To the west along the same trend are unnamed plugs in the Hood Spring quadrangle, Santiago Peak plug in the Santiago Peak quadrangle, and the Butcherknife Hill plug in the Buck Hill quadrangle. The northwest trend of faulting shown in the Cretaceous and younger rocks on either side of this belt becomes west-northwest within the belt. The block- and reverse-faulted eastern margin of the Big Bend structural block forms the southwest boundary of the map area.

Near-vertical northwest-trending fault blocks dominate the structure, which is further complicated by small reverse faults and minor strike-slip movement along faults, tight narrow anticlinal and synclinal folds, plus faulted monoclines.

STRUCTURE OF SIERRA DEL CARMEN

Massive block faulting has occurred in the topographically high Sierra del Carmen. Most of the fault blocks are folded and tilted to the southwest (cross sections C and D, Pl. I).

Near Persimmon Gap are several reverse faults overthrust to the southwest. The reverse faults extend south as far as Dog Canyon. A monoclinal fold occurs farther south along the same trend but has reversed the sense of movement and is down-to-the-northeast.

BLOCK FAULTS

Numerous faults trending approximately N. 20° W. with hanging wall down-to-the-east form a host complex of difficult access terrain in the southern part of the Sierra del Carmen. The dip of these faults appears to deviate from vertical by less than 10°.

A seemingly anomalous feature in the Sierra del Carmen is the bending of the N. 20° W. fault traces to approximately N. 75° W. This is readily observed west of Red House Tank, at the north end of Stairway Mountain, and at the entrance to Big Brushy Canyon.

Throw within the Black Gap area is at a maximum in the Sierra del Carmen. The major faults in this area average 1,700 to 2,000 feet throw with a maximum of approximately 2,300 feet. The throw is graphically illustrated on the cross sections (Pl. I) and on the structure-contour map (Pl. II) with the inset indicating relative displacement.

The most prominent fault scarp in the Sierra del Carmen extends from the northeast side of Stairway Mountain south to the Rio Grande along the southwest side of Stillwell Canyon. The fault is not the one with the most throw but it marks the eastern edge of the Sierra del Carmen and forms an imposing scarp overlooking the topographically low Black Gap graben.

BIG BRUSHY CANYON GRABEN

Big Brushy Canyon (Pl. I, D-7) is in a graben whereon rocks of the Del Rio, Buda, and Boquillas Formations are exposed. Flanking the graben are structurally and topographically high blocks of Santa Elena Limestone. The isopachous map of the Del Rio Formation (fig. 1) indicates maximum thickness in the graben area and suggests downwarp of this area during deposition of the Del Rio Formation.

The uplifted block of Santa Elena Limestone on the east flank of the graben is domed and reveals a sharp roll-over into the fault bordering the graben. The roll-over may be the result of drag-folding or more probably draping over faulted basement blocks. The northwest-trending fault forming the southwest edge of the graben is nearly vertical. Throw along each side of the graben is approximately 600 feet.

REVERSE FAULTS

Northwest-trending reverse faults near Persimmon Gap have brought Paleozoic rock (Ordovician to Pennsylvanian) to the northeast into contact with Cretaceous (Glen Rose Limestone) rocks to the southwest. Six miles north of Persimmon Gap where State Highway 385 crosses Maravillas Creek is another area of reverse faulting where only Cretaceous rocks are exposed. Strike of the reverse vaults is the same at both locations but in opposite directions. At Persimmon Gap the fault surface dips to the northeast whereas at Maravillas Creek the fault surfaces dip to the southwest. Everett (1964) has shown that reverse faults near Del Norte Gap, north of Persimmon Gap, become vertical at depth. Probably the same situation occurs in the Black Gap area.

BIG BRUSHY MONOCLINE

A northwest-trending monocline down-to-the-east 2 miles west of Big Brushy Canyon is on trend wth the Persimmon Gap reverse faults, but the sense of movement is reversed. The monocline begins just south of Dog Canyon and extends south to the fault scarp north of Stuart Peak. Maximum structural relief along the monocline is 500 feet. The axis of the monocline has the same strike as the major fault trend, N. 20° W.

A major northwest-trending fault terminates the monocline to the south, proving that the folding is older than the faulting.

STRUCTURE OF THE BLACK GAP GRABEN

The northwest-trending Black Gap graben extends from the Rio Grande northwest to State Highway 385. It is bounded on the southwest by the Sierra del Carmen horst complex and on the northeast by the fault scarp marking the Cupola Dome. It encompasses an area containing normal and near-vertical northwest-trending faults, the narrow and tight Stillwell anticline plus monoclinal and synclinal folds associated with faults, plus a reverse fault and a complex collapse structure.

MAJOR FAULTS

A northwest-trending down-to-the-west fault hereafter referred to as the Black Gap fault occurs along the northeast flank of the Black Gap syncline. More than 500 feet of Pen Clay to the west of the fault and its absence east of the fault is evidence that the faulting antedated extrusion of the basalt. It is probably the oldest fault in the area. A mile west of the Big Horn sheep pasture the fault surface is exposed in a water gap. Dip of the fault is 62° W. This is the only normal fault in the area definitely not near-vertical.

A mile south of Black Gap a near-vertical normal fault down-to-the-east terminates at the older Black Gap fault. The fault extends southeast to the Rio Grande and forms the northeast edge of the fault block southwest of Horse Canyon. The fault has approximately 600 feet of throw.

The total displacement of normal faults separating the Black Gap graben and the Cupola Dome is down-to-the-southwest a maximum of 1,200 feet. At the head of Whiskey Canyon (Pl. I, K-5) a fault exposes Glen Rose Limestone to the northeast in contact with Santa Elena Limestone to the southwest.

There are several northeast-trending faults in the map area, but only two are large enough to be significant. Whiskey Canyon, northeast of Maravillas Canyon, and Dog Canyon (Pl. I, J-7) to the southwest are located along the trace of a northeast-trending fault down-to-the-northwest with less than 200 feet of throw. The fault is significant because of its length.

The northeast-trending fault which marks the eastern flank of Dove Mountain Ranch anticline extends more than 12 miles and terminates the tight fold of Stillwell anticline. This suggests that the faulting is older than folding in the area. The fault also terminates the Serrania del Burro Arch. Throw is variable along this fault and actually reverses near the intersection with Stillwell anticline. The throw is at a maximum of 1,400 feet near the north boundary of the map area.

STILLWELL ANTICLINE

Stillwell anticline is probably the most impressive single structural feature in the Black Gap area. It is asymmetrical with its axial plane inclined to the northeast. Although less than a quarter of a mile wide, it is nearly 8 miles long. Structural relief along the anticline is approximately 300 feet.

All strata younger than Santa Elena Limestone have been stripped from the anticline leaving the competent, resistant limestone core. This feature is a décollement which slid along the underlying incompetent Sue Peaks Formation over the massive Del Carmen Limestone. Inclination of the axial plane to the northeast suggests overthrust movement from the southwest. There are similarly shaped folds in the lower Ernst Member flaggy limestone beds.

The asymmetrical folding was caused by uplift of the Sierra del Carmen area followed by décollement sliding of massive limestone over incompetent shale and silty claystone to the northeast across the Black Gap area. Vertical movement of basement blocks possibly initiated uplift of the Sierra del Carmen. Gravity moved the rocks downdip away from the Sierra del Carmen high and toward the northeast. Shortening of the crust by folding resulted in folds with axes normal to direction of movement, such as the Stillwell anticline with an axis trending N. 40° W.

BLACK GAP SYNCLINE

Parallel with and 2 miles to the west of Stillwell anticline is the Black Gap syncline. This feature is a relatively tight fold in the area of the Black Gap headquarters but opens out into the broad alluvium-filled valley to the northwest (Pls. I and II). Negative movement in this area had begun prior to vulcanism.

Continued downwarp and faulting occurred after the basalt cover was extruded. The basalt layers now dip approximately 35° toward the synclinal axis along both sides of the syncline.

DOVE MOUNTAIN RANCH ANTICLINE

In the north-central part of the map area is the broad, asymmetrical, north-northeast-trending Dove Mountain Ranch anticline. The anticline has been breached along its crest by erosion and the Del Carmen Limestone is exposed in the center. The Santa Elena Limestone is exposed along the flanks and on the southward-plunging nose.

The anticlinal axis of the fold is less than half a mile west of the termination of the southeast flank against the northeast-trending fault. East of the anticlinal axis the average dip is 25° SE. Immediately west of the axis the average dip is 10° to 15° W., but 3 miles west the average dip is 5° W. The westward-dipping west flank of the anticline also is the northeast flank of the alluvium-filled part of the Black Gap syncline (Pls. I and II). The fold plunges southward immediately north of Maravillas Creek (Pl. I, G-3). The anticline follows an arcuate course through the Dove Mountain quadrangle and opens out to the north into the Marathon Dome.

A major fault striking approximately N. 30° E. marks the eastern edge of the anticline. The interior part of the fold is faulted (Pls. I and II) and throw is reversed along some of these faults. The anticline and associated faults have the same trend as do the Paleozoic structures to the north in the Marathon Basin. This suggests that the anticline is a result of rejuvenation along Paleozoic fault trends and probably marks the border between the frontal and interior zones of the Ouachita System.

MARAVILLAS CANYON MONOCLINE

A monocline extending northwest from the mouth of Maravillas Canyon has lowered the section on the southwest side of the canyon approximately 200 feet relative to the northeast side. Maravillas Canyon occupies the zone of flexure and the monocline is not obvious. Nevertheless, there is a distinct roll-over of beds in Maravillas Canyon 5 miles from the Rio Grande.

The Maravillas Canyon monocline has a sense of motion opposite to that of the Big Brushy monocline. Relative stratigraphic separation in Maravillas Canyon is down-to-the-southwest, whereas in the Big Brushy monocline it is down-to-the-northeast.

To the northeast, near Bullis Gap, is a series of monoclinal flexures, each down-to-the-southwest. For these to have resulted from horizontal compression would require a maximum stress directed along a northeast-southwest line. Outside of these monoclines, there is no evidence for such a stress. Indeed, such a stress is inconsistent with the regional structural pattern. More likely, the monoclines of the area formed as a result of draping over basement blocks. If so, a series of faults down-to-the-southwest must extend from the north beyond Bullis Gap southward to the fault marking the northeast boundary of the Black Gap graben. Stratigraphic separation dies out to the west and northwest along each of the monoclines.

MARAVILLAS CANYON THRUST FAULT

Five miles northwest from the Rio Grande and 1 mile northeast of Maravillas Canyon is a spoon-shaped thrust fault terminated at its lower end by a normal fault. Exact displacement is unknown but approximately 100 feet of reverse throw can be demonstrated. The upper part of the Del Carmen Limestone in the hanging wall is in contact with the lower part of the Santa Elena Limestone in the footwall.

The east trace of the thrust fault is well exposed where the fault surface dips 25° to the west. The fault can be traced along a narrow ridge to the north and along the top of the mountain to the west. At its northernmost limit, dip of the fault surface is approximately 20° to the south. The fault can be traced to the west where it enters a topographic trough extending to the southwest; the trough is littered with debris and caliche. Numerous joints in the trough area dip 20° to 25° to the southeast. The southern extremity of the trough is the same down-to-the-south normal fault that terminates the eastern fault trace.

Thus, the fault trace surrounds an area approximately half a mile in diameter and it dips toward the center. This feature is additional evidence for northeastern movement away from the uplifted Sierra del Carmen.

STRUCTURE OF CUPOLA DOME

In the northeast corner of the map area is a broad, domed area representing the northwest extension of the Serrania del Burro. An arcuate fault zone with maximum throw of 1,200 feet (Pls. I and II), extending northwest from the Rio Grande to Cupola Mountain and north to the west of Dove Mountain, separates the uplifted block from the Black Gap graben to the southwest.

Cupola Dome (Pl. II) is elongated along a northwest trend and has approximately 200 feet of closure. Erosional remnants of younger Cretaceous rocks capped with Tertiary extrusive basalt remain at Cupola Mountain peak, Black Mountain, and Dove Mountain, thus dating the marginal faulting as post-basalt. The dome itself is unfaulted except for very minor north-northwest-trending faults on the east flank.

Big Canyon and Rio Grande Canyon are to the east of Cupola Dome. A narrow ridge cut by minor northwest-trending faults separates Big Canyon and Rio Grande Canyon.

ANALYSIS OF STRUCTURAL FEATURES

The fracture and fold pattern of the Black Gap area indicates several structural events, distinct yet related.

Dove Mountain Ranch anticline lies athwart the trend of all other structures in the area. If it is projected southwest along trend to the Sierra del Carmen, it is found to divide the reverse faulted portion to the north from the asymmetric folding to the south. This difference is inferred to reflect a change in rock types underlying the Cretaceous from Paleozoic sedimentary rocks such as are exposed in the Marathon Basin immediately to the north to metamorphic rocks such as are exposed near Boquillas, Mexico, immediately southwest of the area. The Dove Mountain Ranch anticline thus lies above the inferred boundary between the frontal and interior zones of the Ouachita System as used by Flawn et al. (1961, p. 169).

Stillwell anticline, Big Brushy monocline, and the Maravillas Canyon thrust fault are believed to have resulted from décollement to the northeast from an uplifted Sierra del Carmen. The Sierra del Carmen strikes approximately N. 20° W.; therefore, movement away from the uplift would be in a N. 70° E. direction. This is approximately the direction of movement of the thrust fault, and both Big Brushy monocline and Stillwell anticline strike normal to the proposed direction of movement. Big Brushy monocline is down-to-the-east and Stillwell anticline is asymmetrical to the east. These relations are additional evidence for movement to the northeast. Each of these features is cut by younger near-vertical normal faults.

A rhombic pattern of joints and faults in two principal sets is found in the Sierra del Carmen area. The dominant set strikes approximately N. 20° W. and the minor set approximately N. 75° W. Throw suggests that movement was contemporaneous along both sets. The sets have essentially vertical dips and an intersection angle of approximately 55°. This suggests an origin as conjugate strike-slip faults having maximum principal stress trending approximately N. 47° W. and minimum principal stress striking approximately N. 43° E.

The stress pattern requires maximum horizontal compression acting along a N. 47° W. trend. This is the direction of motion of the late Paleozoic thrusts of the Marathon Basin (King, 1937, pl. 15). The frontal edge of the thrust sheet is believed to extend through the Black Gap area from the Dove Mountain Ranch anticline in the north to the vicinity of Dog Canyon in the southwest. Rejuvenation of northwestward thrusting of the underlying sheet sets up compression in the overlying Cretaceous massive limestone. Horizontal movement of 100 feet or less was probably sufficient.

The northwest trend of fractures found in the Cretaceous limestones of the Black Gap areas is not restricted either to the map area or to Cretaceous rocks. Geologic maps of nearby areas, in other words, Hood Spring and Santiago Peak quadrangles plus the Marathon Basin map by King (1937), show faults trending dominantly northwest in Paleozoic, Cretaceous, and Tertiary strata. The northwest trend of fractures observed throughout the region is probably related to the same source. Late Paleozoic northwest overthrusting can be demonstrated. It is possible that the Paleozoic orogeny was caused by sub-crustal movement. A recurrence of sub-crustal activity following Tertiary vulcanism explains the northwest-trending fracture pattern in the Cretaceous and younger rocks. The sub-crustal movement caused compression of the overlying crystalline and sedimentary rocks, setting up conjugate shear sets. It is possible that the shear sets developed in the crystalline and overlying sedimentary rock and even the extrusive Tertiary basalt. Strike-slip movement along the shear sets or, more probably, cessation of the sub-crustal activity effected a release of horizontal compression which was followed by block faulting involving vertical movement of basement blocks.

King (1937, p. 140) inferred that the latest uplift of the Marathon Dome to the north accompanied by subsidiary folding along the flanks occurred in Late Eocene or Early Oligocene at which time dip-slip movement probably occurred along the older near-vertical shear sets.

Everett (1964) has shown that the thrust faults of Del Norte Gap, north of Persimmon Gap, become vertical faults at depth. The same situation probably is true at Persimmon Gap and Dog Canyon, thus explaining the so-called thrust faults.

A mile east of Black Gap along the south bank of the main drainage course is a near-vertical fault down to the west approximately 20 feet. The fault strikes N. 24° W. On the east side of the fault are drag folds in the Ernst Member of the Boquillas Formation. The folds in the flaggy limestone beds strike N. 06° E. The folds are in beds 2 inches thick and have an amplitude of 6 inches and a period of 24 inches. The folds make an angle of 30° with the fault, indicating left-lateral strike-slip movement. Preferential movement along the N. 20° W. shear of the conjugate shear-set would cause the required stress.

From the evidence presented it appears the sequence of structural events was as follows:

1. Uplift of the Sierra del Carmen and Dove Mountain Ranch anticline followed by décollement to the northeast across the Black Gap area made the tight asymmetric fold of Stillwell anticline.
2. Vulcanism covered the area with a layer of basalt.
3. Northwestward movement of the underlying thrust sheet, accompanied by slight rejuvenation of Paleozoic structural features, resulted in horizontal compression in the massive Cretaceous limestones. Conjugate shear sets striking N. 20° W. and N. 75° W. formed but little or no movement occurred.
4. Reduction of horizontal compression permitted block faulting along the previously formed shear sets.
5. Left-lateral strike-slip movement occurred along the N. 20° W. set contemporaneous with or immediately subsequent to block faulting.

GEOLOGIC HISTORY

The lack of surface exposures of pre-Cretaceous rocks within the map area precludes interpretation on a local basis for that era. Consideration of regional geology, based on the work of others, does, however, furnish information for the interpretation of pre-Cretaceous geologic history. The following pre-Cretaceous history briefly summarizes previous work.

Cambrian, Ordovician, and Devonian rocks of the Marathon region are transitional from a predominantly clastic facies to the south and southeast and a carbonate foreland shelf facies to the north and northwest. The Tesnus Formation of Mississippian and Pennsylvanian age is a southward-thickening wedge of flysch deposits, which marks the beginning of a major tectonic event. The axis of the geosyncline which had previously been located to the southeast shifted northwestward, and previously formed rocks to the southeast became source rocks for clastic sediments. Overthrusting from the south and southeast during the Pennsylvanian formed northeast-trending structures, which in part determine the present outcrop pattern. Another northward shift of the geosynclinal axis occurred near the end of the Pennsylvanian. Permian carbonate rocks overlying Pennsylvanian strata form the Glass Mountains, whereas older Permian clastic rocks are present to the north in the Val Verde Basin.

Flawn et al. (1961, p. 168), on the basis of petrographic studies, mapped two main structural units within the Ouachita System, a frontal zone containing unmetamorphosed to weakly metamorphosed sedimentary rocks and an interior zone containing sedimentary rocks showing weak to low-grade metamorphism and having shear features.

Overthrusting carried rocks of the interior zone northwest over rocks of the frontal zone along a northeast-trending front extending through the Black Gap area.

MESOZOIC ERA

Post-Permian uplift and erosion deformed and planed the Paleozoic strata. The Mesozoic sea filled the negative Mexican Geosyncline and Sabinas Basin to the south and continued its northward advance until the Coahuila and Tamaulipas Platforms were inundated. The Comanchean sea deposited the Glen Rose Limestone upon the eroded surface. The massive Del Carmen and Santa Elena Limestones thin toward the Glass Mountains, indicating incipient uplift of the Marathon area. Minor folding occurred before or during deposition of the Del Rio Formation.

Comanchean deposits are predominantly shallow-water limestones whereas the occurrence of silt and clay in the Gulfian rocks suggests retreat of the shoreline and emergence of the Marathon Dome.

LATE CRETACEOUS-TERTIARY PERIODS

Late Cretaceous or Early Tertiary uplift of the Sierra del Carmen and Dove Mountain Ranch anticline and associated décollement to the northeast formed the asymmetric Stillwell anticline. This activity was probably related to the Laramide Orogeny.

Igneous intrusive and extrusive rocks are possibly of Late Eocene or Early Oligocene age.

Rejuvenation of northwestward thrusting of the underlying Paleozoic thrust sheet caused compression and set up conjugate shear sets in the massive Cretaceous limestones and possibly in the Tertiary extrusive basalt. The northwestward thrusting of the Paleozoic thrust sheet may have been related to sub-crustal activity which would also have affected the underlying crystalline rocks.

Release of compression allowed block faulting along the conjugate shear sets. The block faulting involved vertical movement of basement blocks. The block faulting is probably younger than Oligocene and possibly related to Basin and Range events.

QUATERNARY PERIOD

Coarse clastic continental debris was deposited during the Quaternary. Deposition of bolson fill in the Adams ranch area probably began during the latter part of the Tertiary and continued into the Quaternary. Pediment and undifferentiated gravel plus landslide material and alluvium compose the remaining Quaternary strata.

ECONOMIC GEOLOGY

WATER

The paucity of water accounts for the scarcity of settlers in this country. Most of the rain falls rapidly as thundershowers and runs off into the intermittent streams which empty into the Rio Grande. Rainfall is infrequent and torrential. Flash-floods are common during the rainy season. There are no natural bodies of standing water in the area, although several man-made earthen tanks hold water and serve as gathering places for wildlife. Water wells in the area furnish good water at depths from 300 to 1,000 feet. The aquifers are without exception fractured, massive limestones.

Several valleys are filled with Quaternary alluvial material but attempts to develop water in them have not been successful. Numerous dug wells have proven that the gravel- and silt-filled valleys lack aquifers. Either the clay fraction in such deposits has resulted in low permeability or else fractures in the underlying limestone have drained reservoirs. Numerous sinkholes in the Buda Limestone and caves in the other massive limestones attest to solution.

SOIL

Attempts have been made to irrigate the alluvial soil along Maravillas Creek between the Stillwell ranch and State Highway 385 as well as similar soil in Stillwell Canyon and along the Rio Grande near the Adams ranch. Lack of an adequate water supply plus the presence of salt in the soil have made these efforts only partly successful.

BARITE

A barite deposite west of Big Brushy Canyon has been mined. A road leads from Big Brushy Canyon to the mine. The barite occurs as a joint filling in the fractured Santa Elena Limestone. No information on amount of ore mined is available.

SEMI-PRECIOUS STONES

The deposits of Quaternary older gravel contain chert, chalcedony, and an abundance of the so-called "moss-agate." Local rock shops sell the stone and it is used for inexpensive jewelry.

FLUORITE

Numerous fluorite deposits occur in nearby areas. East of the Black Gap area in Mexico is the La Linda fluorite deposit operated by Dow Chemical Company. Also, a deposit of commercial quality and quantity reportedly occurs to the west in the Big Bend National Park.

Daugherty (1962) determined that the fluorite of the La Linda deposit is a contact-metasomatic deposit associated with intrusion of rhyolite into the massive Cretaceous Santa Elena Limestone.

The presence of intrusive plugs and sills in the Black Gap area plus the presence of the massive Del Carmen and Santa Elena Limestones make the occurrence of fluorite possible, yet none has been found.

It is possible that Cupola Dome was caused by intrusion. If a petrologically favorable intrusion exists at depth, mineralization might be present in limestone of the Del Carmen and Santa Elena. Depth of a possible host might also affect the mineralization.

SILVER

A prospect pit in a calcite vein within the Glen Rose Limestone reportedly was a silver prospect. The pit location is shown on the geologic map (Pl. I, M, N-6).

A spectrographic analysis (Schofield, 1965) of samples from the prospect indicated only a trace of silver.

PETROLEUM

Traces of dead oil stain (?) occur in the Glen Rose Limestone, and freshly broken surfaces of Glen Rose Limestone and limestone beds in the Sue Peaks Formation have a petroliferous odor. An oil scum reportedly developed on cuttings from a well drilled near Dove Mountain. An odor of sulfide was also present.

Source rocks, reservoir rocks, and structural traps are present in the area, yet little or no petroleum exploration has been attempted. The prospective Cretaceous section is exposed at the surface, thereby eliminating it from consideration. The underlying Paleozoic section is considered to be of unfavorable facies in addition to being complexly faulted.

REFERENCES CITED

Baker, C. L., and Bowman, W. F. (1917) Geologic exploration of the southeastern Front Range of Trans-Pecos Texas: Univ. Texas Bull. 1753, pp. 60–177.

Böse, Emil (1923) Vestiges of an ancient continent in northeast Mexico: Amer. Jour. Sci., 5th ser., vol. 206, pp. 127–136, 196–214, 310–337.

Brown, T. E. (1963) Index to areal geologic maps in Texas, 1891–1961: Univ. Texas, Bur. Econ. Geology, 20 pp., map.

Daugherty, F. W. (1962) Geology of the Pico Etereo area, municipio de Acuña, Coahuila, Mexico: Univ. Texas Ph.D. dissertation, 154 pp.

Eifler, G. K., Jr. (1943) Geology of the Santiago Peak quadrangle, Texas: Bull. Geol. Soc. Amer., vol. 54, pp. 1613–1644.

Everett, J. R. (1964) Post-Cretaceous structural geology near Del Norte Gap, Brewster County, Texas: Univ. Texas M.A. thesis, 61 pp.

Flawn, P. T., Goldstein, August, Jr., King, P. B., and Weaver, C. E. (1961) The Ouachita System: Univ. Texas Pub. 6120, 401 pp.

Freeman, V. L. (1964) Geologic map of the Indian Wells quadrangle, Terrell and Brewster counties, Texas: U. S. Geol. Survey Misc. Geol. Inv. Map I-395.

Graves, R. W., Jr. (1954) Geology of Hood Spring quadrangle, Brewster County, Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 21, 51 pp.

Hill, R. T. (1900) Physical geography of the Texas region: U. S. Geol. Survey Topo. Atlas (folio No. 3), 12 pp.

———— (1901) Geography and geology of Black and Grand Prairies: U. S. Geol. Survey 21st Ann. Rept., pt. 7, 666 pp.

————, and Vaughan, T. W. (1898) Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Texas, with reference to the occurrence of underground waters: U. S. Geol. Survey 18th Ann. Rept., pt. 2, pp. 193–321.

International Boundary and Water Commission (1950–1955) Geologic strip maps, scale 1:50,000, covering an area about three miles on each side of the Rio Grande from Lajitas, Brewster County, to Del Rio, Val Verde County: on file at Bur. Econ. Geology.

King, P. B. (1927) The Bissett formation, a new stratigraphic unit in the Permian of west Texas: Amer. Jour. Sci., vol. 14, pp. 212–221.

———— (1930) Geology of the Glass Mountains, Texas, Part I, Descriptive geology: Univ. Texas Bull. 3038, 167 pp. (January 1931.)

———— (1937) Geology of the Marathon region, Texas: U. S. Geol. Survey Prof. Paper 187, 148 pp. (August 10, 1938.)

Lonsdale, J. T., Maxwell, R. A., Wilson, J. A., and Hazzard, R. T. (1955) Big Bend National Park, Texas: West Texas Geol. Soc., Field Trip, Guidebook, March 18–19, 142 pp.

Lozo, F. E., and Smith, C. I. (1964) Revision of Comanche Cretaceous stratigraphic nomenclature, southern Edwards Plateau, southwest Texas: Proc., Gulf Coast Assoc. Geol. Soc., vol. 14, pp. 285–307.

Maxwell, R. A., Lonsdale, J. T., Hazzard, R. T., and Wilson, J. A. (MS.) Geology of Big Bend National Park, Brewster County, Texas: Univ. Texas, Bur. Econ. Geology.

Muehlberger, W. R., Denison, R. E., and Hedge, C. E. (in preparation) Geochronology of the mid-continent region, United States, Part III, Southern area.

Schofield, D. A. (1965) Quantitative spectrographic analysis of samples 65014 and 65015: Univ. Texas, Bur. Econ. Geology Min. Studies Lab. report.

St. John, B. E. (1965) Structural geology of Black Gap area, Brewster County, Texas: Univ. Texas Ph.D. dissertation, 132 pp.

Shambaugh, J. S. (1951) Structure of the Black Gap area, Brewster County, Texas: Univ. Texas M.A. thesis, 60 pp.

Udden, J. A. (1907) A sketch of the geology of the Chisos country, Brewster County, Texas: Univ. Texas Bull. 93 (Sci. Ser. 11), 101 pp.

Vaughan, T. W. (1900) Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, 88 pp.

Wilson, D. C. O., Jr. (1951) Stratigraphy of Black Gap area, Brewster County, Texas: Univ. Texas M.A. thesis, 98 pp.