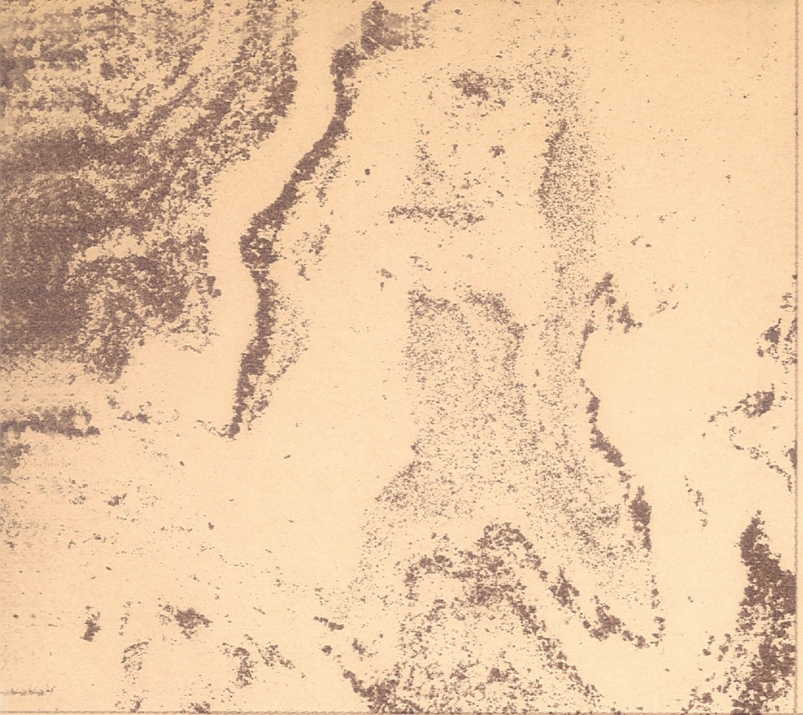

GEOLOGY OF THE LLANO REGION AND AUSTIN AREA

FIELD EXCURSION

By
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S. E. Clabaugh, P. E. Cloud, Jr.,
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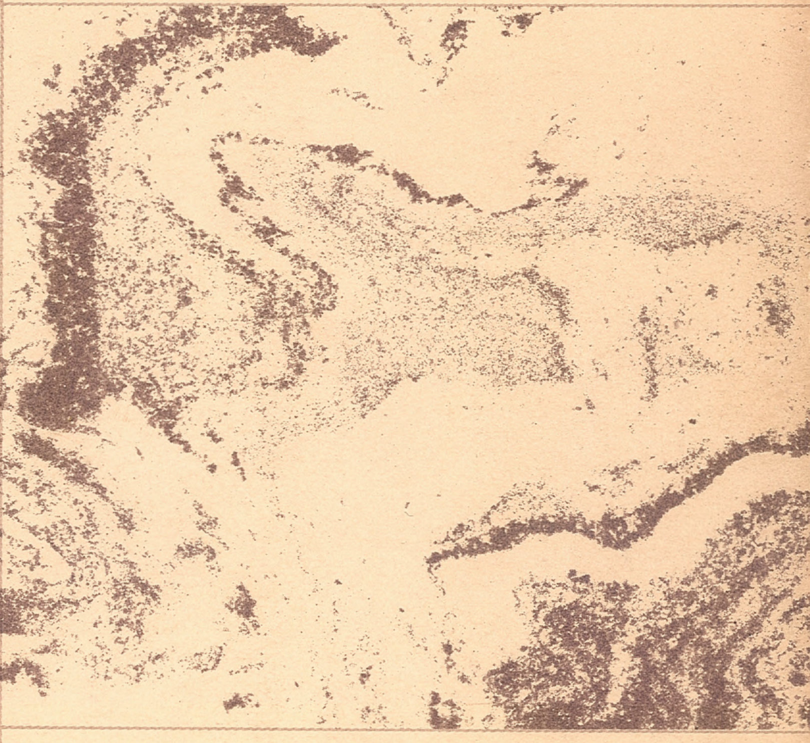

Guidebook Number 13

Bureau of Economic Geology
The University of Texas at Austin
Austin, Texas 78712

W. L. Fisher, Director

1972

Second Printing, July 1976

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(Bureau of Economic Geology *Guidebook No. 5*, 1963, updated and combined with Shreveport Geological Society's *Geology of the Llano Region and Austin Area, Texas*, 1971.)

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FOREWORD

This Guidebook represents an updating of Bureau of Economic Geology Guidebook No. 5, *Field Excursion—Geology of Llano Region and Austin Area.* It also represents a modification of *Geology of the Llano Region and Austin Area, Texas,* published by the Shreveport Geological Society in 1971.

W. L. FISHER
Director

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ILLUSTRATIONS

TABLES

ACKNOWLEDGMENTS

Much of the material included in this Guidebook has been used and reused in various publications and guidebooks until the original source is sometimes moot. For example, the present figure 14 appeared first in 1945 in The University of Texas Publication 4301 (p. 170); it appeared next in 1947 in the Geological Society of America Bulletin (vol. 58, p. 133); and, with redrafting, has since appeared in the following guidebooks: San Angelo Geological Society Guidebook, 1956 (p. 24); Bureau of Economic Geology Guidebook 1, 1958 (p. 12); Houston Geological Society Guidebook, 1962 (p. 119) (reprinted as Bureau of Economic Geology Guidebook 5); and possibly others.

Material has been freely used from various sources: Bureau of Economic Geology, Geological Society of America, *Science*, and geological society guidebooks—the latter in part compiled from previously published literature. Special acknowledgment is made to the Houston Geological Society's 1962 Guidebook, the San Angelo Geological Society's 1956 Guidebook, and the South Texas Geological Society's 1951 Guidebook. Whatever the source of the material used in this Guidebook, appreciation is here expressed to the organization responsible for it.

VIRGIL E. BARNES, STEPHEN E. CLABAUGH,
PETER U. RODDA, and KEITH YOUNG
—Field Trip Leaders

DISTANCES BETWEEN STOPS

Departing from Villa Capri Motel,
2630 North Interregional Highway (IH 35), Austin:

	Miles
Stop No. 1	56.5
Stop No. 2	36.1
Stop No. 3	16.3
Stop No. 4	25.7
Stop No. 5	8.8
Stop No. 6	10.4
Stop No. 7	6.3
Highlander Inn, Burnet	17.0
Total miles	177.1

Departing from Highlander Inn, Burnet:

	Miles
Stop No. 8	21.40
Stop No. 9	12.40
Stop No. 10	0.60
Stop No. 11	32.10
Stop No. 12	2.50
Stop No. 13	10.10
Stop No. 14	19.30
Stop No. 15	9.35
Stop No. 16	10.85
Stop No. 17	14.75
Total miles	133.35

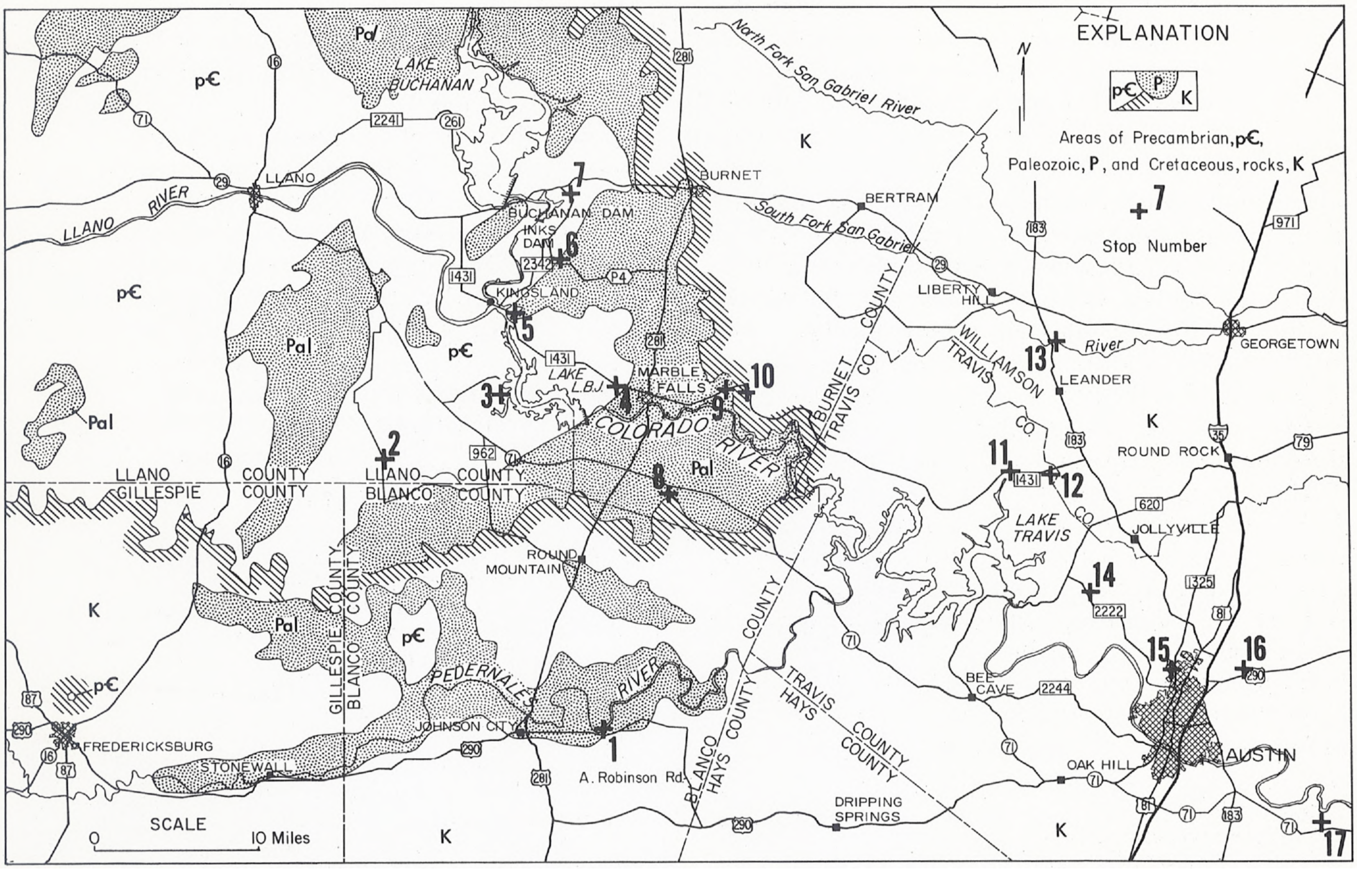

FIG. 1. Index map showing route of field trip, STOPS 1–17.

GEOLOGY OF THE LLANO REGION AND AUSTIN AREA, TEXAS

VIRGIL E. BARNES,[1] W. C. BELL,[2] STEPHEN E. CLABAUGH,[2]
PRESTON E. CLOUD, JR.,[3] R. V. McGEHEE,[4] PETER U. RODDA,[1] *
AND KEITH YOUNG[2]

INTRODUCTION

VIRGIL E. BARNES

Central Texas combines range of geologic section, quality of natural exposures, diversity of mineral commodities, and climate difficult to duplicate in an equivalent area elsewhere in the United States. A few of the interesting localities geologically (fig. 1) were chosen to acquaint the users of this guidebook with the diversity of rock types and the range of stratigraphic section available for study in the Llano region and Austin area.

The listing of geologic units recognized in the route area, the resume "Geologic History of Central Texas," and the "Schematic Section, Central Llano County to Eastern Travis County" (fig. 2) are included so that the geologic features seen at each locality can be more readily integrated into the geologic history of the region as a whole.

Geologic units recognized in the route area are as follows:

- Cretaceous
  - Lower Cretaceous
    - Fredericksburg Division
      - Edwards Limestone
      - Comanche Peak Limestone
      - Walnut Formation
        - Keys Valley Marl
        - Cedar Park Limestone
        - Bee Cave Marl
        - Bull Creek Limestone (included with Glen Rose Limestone on Austin and Llano Sheets of the Texas Geologic Atlas)
    - Trinity Division
      - Upper Trinity
        - Glen Rose Limestone
        - Hensel Sand
      - Middle Trinity
        - Cow Creek Limestone
        - Hammett Shale
      - Lower Trinity
        - Sycamore Sand
- Pennsylvanian
  - Lower Pennsylvanian
    - Strawn Group
    - Smithwick Shale
    - Marble Falls Limestone
    - Unnamed phosphorite
- Mississippian
  - Barnett Formation
  - Chappel Limestone
- Mississippian and Devonian
  - Houy Formation
    - Doublehorn Shale
    - Ives Breccia
- Devonian
  - Bear Spring Formation
  - Unnamed limestone
  - Stribling Formation
  - Pillar Bluff Limestone
- Silurian
  - Starcke Limestone
- Ordovician
  - Upper Ordovician
    - Burnam Limestone
  - Lower Ordovician
    - Ellenburger Group
      - Honeycut Formation
      - Gorman Formation
      - Tanyard Formation (part)
        - Staendebach Member
        - Threadgill Member (part)
- Cambrian and Ordovician
  - Tanyard Formation (part)
    - Threadgill Member (part)
  - Wilberns Formation (part)
    - San Saba Member (part)
- Cambrian
  - Upper Cambrian
    - Wilberns Formation (part)
      - San Saba Member (part)
      - Point Peak Member
      - Morgan Creek Limestone Member
      - Welge Sandstone Member
    - Riley Formation (part)
      - Lion Mountain Sandstone Member
      - Cap Mountain Limestone Member (part)
      - Hickory Sandstone Member (part)
  - Middle Cambrian (?)
    - Cap Mountain Limestone Member (part)
    - Hickory Sandstone Member (part)

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- Precambrian
  - Igneous rocks
    - Llanite (quartz porphyry dikes)
    - Sixmile Granite
    - Oatman Creek Granite
    - Town Mountain Granite
  - Meta-igneous rocks
    - Metagabbro and metadiorite
    - Red Mountain Gneiss
    - Big Branch Gneiss
  - Metasedimentary rocks (*see* Clabaugh and McGehee, p. 14, for subdivisions)
    - Packsaddle Schist
    - Lost Creek Gneiss
    - Valley Spring Gneiss

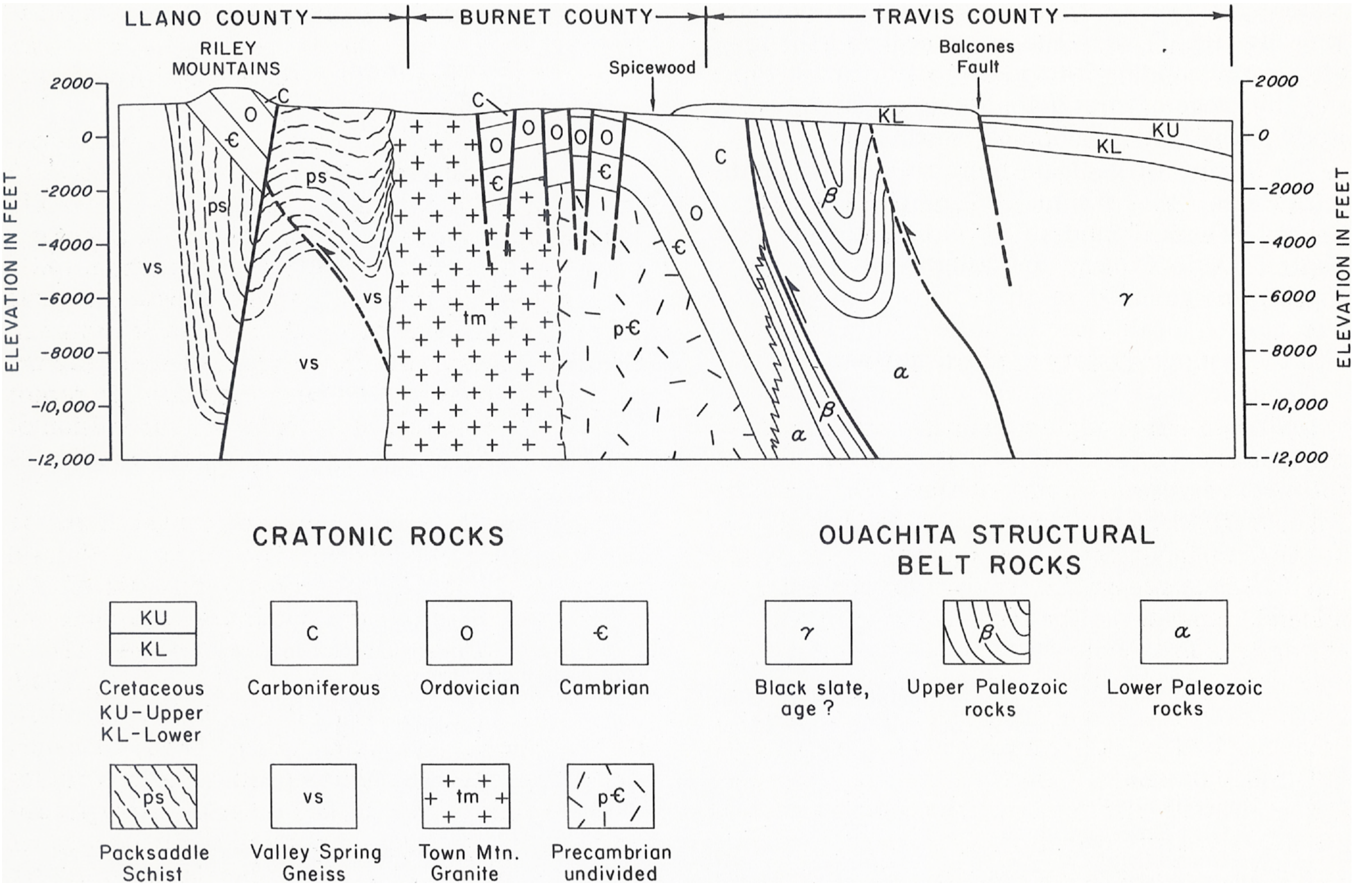

FIG. 2. Schematic section, central Llano County to eastern Travis County, Texas.

GEOLOGIC HISTORY OF CENTRAL TEXAS

PRECAMBRIAN ROCKS OF LLANO REGION

S. E. CLABAUGH and R. V. McGEHEE

REGIONAL SETTING

Precambrian rocks reach the surface in the Llano region of Central Texas in the highest part of a broad domal arch, the Llano uplift, which appears on a regional geologic map as an island of igneous and metamorphic rocks surrounded by Paleozoic and Cretaceous sedimentary rocks. The widest expanse of Precambrian rocks is about 65 miles, extending westward from the valley of the Colorado River through a subdued topographic basin drained by the Llano River. The broad, gentle basin carved into the Precambrian rocks is bordered by a discontinuous rim of flat-topped limestone hills which are the dissected edge of the Edwards Plateau. Within the basin and at its margins are erosional remnants and down-faulted blocks of Paleozoic rocks which form prominent hills, locally referred to as mountains.

HISTORY OF GEOLOGIC STUDY

Although earlier explorers and geologists reported the presence of ancient rocks in Central Texas, the first significant study of them was made by Walcott (1884), and he gave the name Llano Group to the metamorphosed sediments. Comstock (1890, 1891) prepared a largely speculative map of mineral deposits in the region and proposed an elaborate subdivision of the metamorphic rocks into several series. Careful mapping by a group of U. S. Geological Survey geologists led by Sidney Paige resulted in publication of the Llano-Burnet Folio (1912) and a report on mineral resources (1911). Paige and his associates recognized two metasedimentary formations for which they preserved two of Comstock's names. The lower unit is the Valley Spring Gneiss, which is chiefly pink microcline-quartz gneiss with subordinate biotite and hornblende. The upper unit, the Packsaddle Schist, includes graphite schist, quartzite, amphibole schist, and marble. These two units together constitute the Llano Series.

Although Paige considered the Valley Spring Gneiss to be chiefly of sedimentary origin, he suggested that it probably included granite orthogneiss as mapped. Subsequently, Stenzel (1935, p. 74) concluded that the Valley Spring is entirely orthogneiss, but his interpretation has not met with general acceptance. Recent studies of Precambrian basement rocks in the Mid-continent region of North America have disclosed large areas of rhyolitic volcanic rocks, including ancient ignimbrites or welded tuffs. Metamorphism of similar rhyolitic rocks and associated sediments are now thought to have produced the granitic Valley Spring Gneiss. No comprehensive study of the Valley Spring Gneiss has yet been undertaken.

The Packsaddle Schist is generally more schistose and darker than the Valley Spring Gneiss, although the Packsaddle includes a great variety of rocks ranging from coarse-grained biotite gneiss to exceedingly fine-grained amphibole schist and from white muscovite schist to black graphite schist. The most extensive exposures of the Packsaddle Schist are in the southeastern part of the region, where a program of detailed mapping has been carried on in recent years by graduate students under the supervision of Clabaugh. Figure 3 is a preliminary compilation of results.

Barnes made many important contributions to knowledge of the Precambrian rocks of Central Texas in his studies of mineral deposits of the region and in systematic quadrangle mapping for the Bureau of Economic Geology (Barnes, 1946a, 1946b, 1952a, 1952b; Barnes and Romberg, 1943, 1944, 1949; Barnes, Dawson, and Parkinson, 1947; Barnes, Shock, and Cunningham, 1950; Clabaugh and Barnes, 1959). He mapped numerous bodies of serpentine, soapstone, and other metamorphosed mafic igneous rocks, the greatest abundance of which lies south of the quadrangles mapped by Paige and his associates. Also widespread in the southern part of the region is a metamorphosed quartz diorite to which Barnes gave the name Big Branch Gneiss. Metamorphosed granite in the southeastern part of the region (fig. 3) had been recorded by Paige, and to this Barnes assigned the name Red Mountain Gneiss. Clabaugh and Boyer (1961) found the granite gneiss to be slightly younger than the quartz diorite gneiss. Some of the metamorphosed mafic igneous rocks are younger

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FIGURE 3 (opposite)—

- Paleozoic rocks—
  - Sedimentary rocks
    - Pal — Undivided
- Precambrian rocks—
  - Igneous rocks
    - gr — Granite
  - Metamorphosed igneous rocks
    - ma — Metamorphosed aplitic granite
    - rm — Red Mountain Gneiss
    - mg — Metagabbro and metadiorite
    - s — Serpentine and soapstone
    - bb — Big Branch Gneiss
  - Metamorphosed sedimentary rocks
    - Packsaddle Schist
      - pse — Unit E, quartz-feldspar-mica schist, hornblende schist, and actinolite schist
      - psd — Unit D, leptite and quartz-feldspar-mica schist
      - psc — Unit C, hornblende schist and leptite
      - psb — Unit B, graphite schist and hornblende schist
      - psa — Unit A, graphite schist, hornblende schist, leptite, muscovite schist, and marble (m)
    - Valley Spring Gneiss
      - vsc — Unit C, pink quartz-feldspar-mica gneiss with augen gneiss near top
      - vsb — Unit B, gray biotite gneiss
      - vsa — Unit A, pink quartz-felspar-mica gneiss

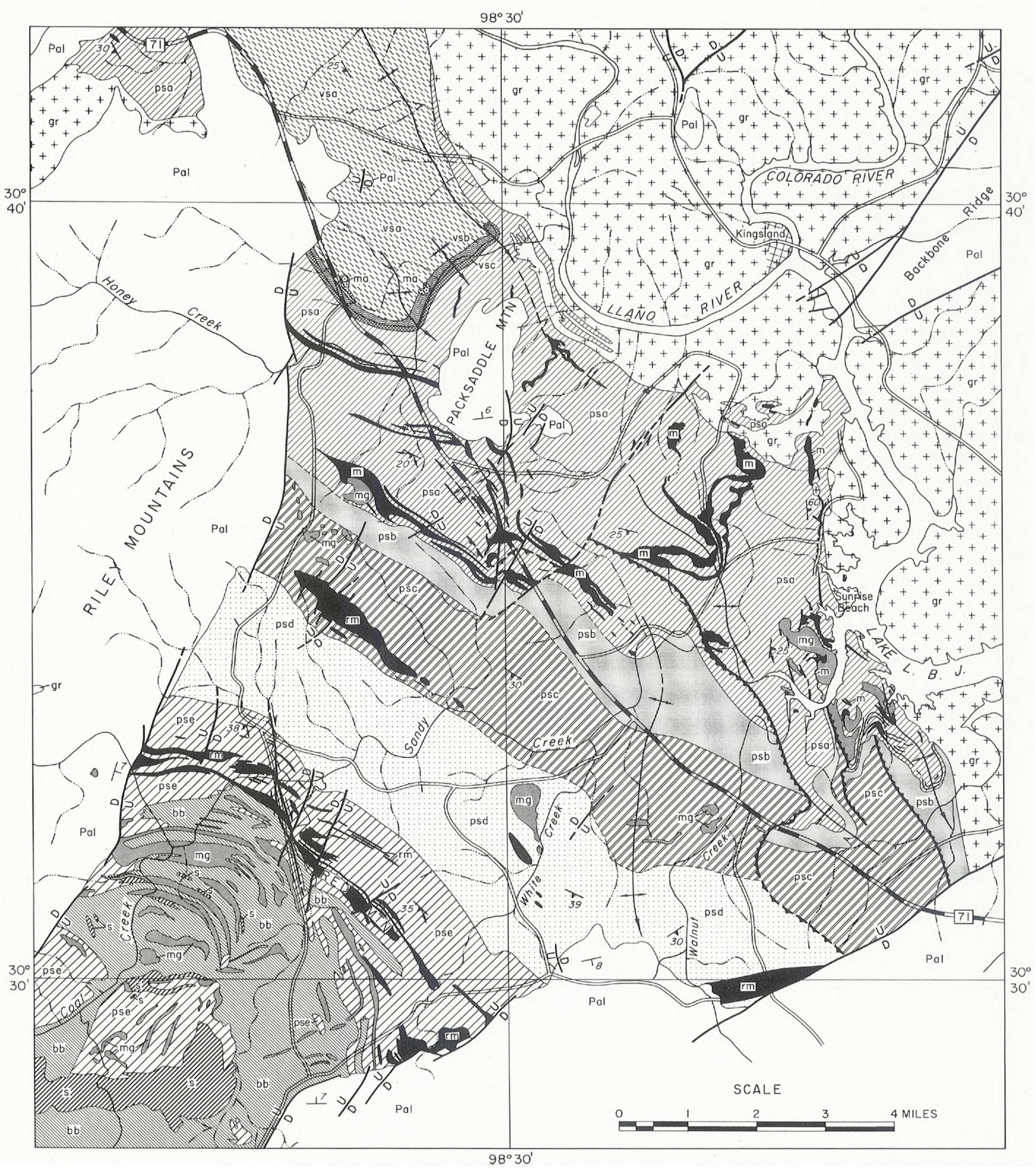


FIG. 3. Geologic map of Precambrian rocks in southeastern Llano region, Texas (explanation opposite).

than the quartz diorite gneiss, but most of them appear to be older. A few small unmetamorphosed mafic dikes are present also.

Large bodies of granite were intruded forcibly into the framework of folded metasedimentary rocks at the final stages of regional metamorphism. Paige distinguished two types, a very coarse-grained pink granite and finer grained pink to gray granite, as well as dikes of granite porphyry and felsite. Stenzel (1932, 1935) proposed a more elaborate classification of the granites on the basis of color, grain size, and field relations. He named the oldest type of granite (coarse grained to porphyritic with large pink microcline crystals) Town Mountain; the intermediate medium-grained gray to pink type he called Oatman Creek Granite; and to the youngest fine-grained gray granite he applied the name Sixmile. Keppel (1940) mapped the internal structure of several of the large elliptical granite bodies and Goldich (1941) studied the chemistry of the granites.

Town Mountain Granite ranges from granite to granodiorite in composition, and the large bodies in which it occurs tend to be circular and concordant, although they are locally discordant. Hutchinson (1956) made a detailed study of the Enchanted Rock batholith which seems to have the shape of a giant vertical cylinder with a liplike extension on the north side. Flow structure and elongate inclusions of metasedimentary rock are common, especially near the margins where large platy microcline crystals show preferred orientation parallel to the walls of the intrusive body. At many localities the contact of Town Mountain Granite with country rock is sharp and regular; at other places it is highly irregular and wide zones of mixed rock are present. Small bodies of gray granite and granodiorite in the southern part of the region appear to be granitized quartz diorite gneiss metasomatically altered under the influence of nearby Town Mountain Granite plutons. Pegmatites and aplites are numerous in and near the granite bodies, and most of them are mineralogically simple, consisting chiefly of quartz and microcline with subordinate albite and mica. Rare-earth minerals, beryl, and gem topaz are present in a few. The pegmatite that once supplied commercial quantities of rare-earth minerals at Baringer Hill is now covered by the waters of Lake Buchanan.

Oatman Creek Granite occurs in smaller irregular bodies and elongate en echelon dikes or sills which Stenzel attributed to intrusion along faults or fractures approximately parallel to the strike of the enclosing foliated rocks. Most of it has a mildly cataclastic texture and appears to be a late differentiate of Town Mountain Granite. Sixmile Granite is uniformly fine grained and it tends to be gray rather than pink, but the color is variable. The intrusive bodies are irregular, and they penetrate metasedimentary rocks and Town Mountain Granite iin an intricate pattern which is vaguely suggestive of large phacoliths in the axial portions of major folds.

The youngest of the granitic rocks are dikes of dark felsite or metarhyolite and a dikelike series of small irregular bodies of a distinctive granite porphyry to which Iddings (1904) gave the name llanite. The porphyry is characterized by phenocrysts of red feldspar and blue chatoyant quartz in a dark aphanitic groundmass; it was marketed for awhile under the trade name of opaline granite.

AGE DETERMINATIONS

Age determinations on minerals from the Llano region were summarized by Flawn (1956, table 4) and by Flawn and Muehlberger (1970, table 3). They include an uraninite determination by Holmes which yielded the figure 1,100 million years, a magnetite determination by Hurley and Goodman which gave the figure 1,050 million years, and a number of alpha-lead determinations on zircons by Jaffe and Gottfried which yielded values ranging from 850 to 970 million years. The zircon ages bear the correct relation to each other, the oldest being from the Big Branch Gneiss and the youngest from the granite porphyry, but they appear to be low by a factor of about 10 percent. Using lead, uranium, and thorium isotope ratios from zircon and rubidium-strontium and potassium-argon ratios from biotite, Tilton and coworkers (1957, table 3 and footnote a) obtained figures for the age of Town Mountain Granite samples ranging from 890 to 1,100 million years, with the most reliable being 990±15 and 1,070±25. Zartman (1962, 1964, 1965; Zartman and Wasserburg, 1962) made extensive determinations on total-rock samples and separated minerals from the granites and the Valley Spring Gneiss using rubidium-strontium and potassium-argon methods. His results indicate that the major granite bodies are 1,030±30 million years old and the Valley Spring Gneiss is 1,120±25 million years old.

MINERAL DEPOSITS

The Llano region is also called the Central Mineral Region of Texas because of the great variety of minerals and the number of prospects in the Precambrian rocks. The principal mineral resources currently produced from the area are graphite, soapstone, and building stone. In past years relatively small mines have yielded yttrium and other rare-earth minerals, magnetite, feldspar, vermiculite, gem topaz, and galena (from Cambrian limestone lying above granite knobs). Prospect pits have also been opened on minor showings of gold, silver, copper, tin, bismuth, molybdenum, tungsten, and uranium minerals. For the last 20 years the Southwestern Graphite mine northwest of Burnet has been the only major producer of high-purity graphite in North America. Large quantities of soapstone have been gathered from outcrops south of Llano and ground for use as insecticide carrier and inert filler in various products. Granite has been quarried from almost innumerable localities, and very active production of dimension stone continues today from a dome of coarse pink Town Mountain Granite near Marble Falls.

GEOLOGY OF SOUTHEASTERN PART OF LLANO REGION

Detailed recent studies of Precambrian rocks in the area to be traversed have not yet been compiled for publication; therefore, it is desirable to present here a fairly complete summary of the geology of the southeastern part of the Llano region. Special attention is given to the Red Mountain and Sunrise Beach areas (STOPS 2 and 3).

STRATIGRAPHY OF THE METASEDIMENTARY ROCKS

Valley Spring Gneiss makes up the core of a broad anticline north of Packsaddle Mountain, and successively younger rocks appear to the southwest. Three subdivisions of the Valley Spring and five subdivisions of the Packsaddle Schist are denoted by letter symbols and patterns on figure 3. During the spring of 1962, R. V. McGehee and D. N. Blount measured the approximate thicknesses of most of these units by making plane-table traverses from the lower reaches of Honey Creek north of Packsaddle Mountain along various tributaries of Honey and Sandy Creeks into the vicinity of Red Mountain. It is obvious that the apparent thicknesses of the units are no more than suggestive of original thicknesses before deformation and metamorphism. The stratigraphic column is summarized in table 1.

The Valley Spring Gneiss is a thick, monotonous rock sequence consisting chiefly of pink to pale brown quartz-feldspar gneiss. Gray gneiss containing biotite and hornblende makes up a distinctive stratigraphic unit near the top of the formation, and traces of biotite schist, hornblende schist, and actinolite schists are widespread through the gneiss. Hutchinson (1956) measured at least 6,000 feet of Valley Spring Gneiss in western Llano County, and Paige (1912) mapped a calcium silicate mineral layer within the gneiss southwest of Llano. Lidiak et al. (1961) also found a distinctive augen gneiss at the top of the formation in northern Llano County. Clabaugh and Barnes (1959) found biotite schist and hornblende gneiss derived from intrusive mafic igneous rocks to be common but poorly exposed in Valley Spring Gneiss north and west of Llano. Small bodies of metamorphosed aplitic granite were mapped in the gneiss north of Packsaddle Mountain (fig. 3). The average composition of the Valley Spring Gneiss is very close to that of granite; therefore, the original sediments are assumed to have been arkoses of surprisingly uniform mineralogy, or more likely to have been rhyolitic volcanic rocks, ash flows, and tuffaceous sediments.

The Packsaddle Schist is characterized more by its variability, both vertically and laterally, than by any one kind of rock or texture in the formation, as table 1 shows. The two most abundant kinds of rocks are hornblende schist and light-colored quartz-feldspar rocks which range from mica-rich varieties (schists) to fine-grained mica-poor varieties (leptites). The term leptite is adopted for the fine-grained granulites in order to avoid implication that they belong in the granulite metamorphic facies. No implication that they were derived from siliceous volcanic rocks is intended, and for the most part they were probably derived from shale and argillaceous siltstone. Marble is abundant only in the lowermost major subdivision (psa) of the formation, and it provides excellent key beds for mapping (fig. 3), even though the layers thicken and thin, branch, pinch out, and show extreme deformation. Graphite schist occurs only in the lower two units, generally in close association with marble, indicating perhaps that both were produced by organisms.

TABLE 1. *Subdivisions of Precambrian metasedimentary rocks, southeastern part of Llano region.*

Formation	Subdivision	Lithology	Thickness *(feet)*	
PACKSADDLE SCHIST	pse	Dominantly hornblende schist, poor continuity because of intrusive igneous rocks; thickness uncertain	3,800	7,220
		Leptite and quartz-feldspar-mica schist; grades into hornblende schist toward southeast	2,920	
		Green actinolite schist, well foliated; grades into mica schist and hornblende schist toward southeast	500	
	psd	Leptite and quartz-feldspar-mica schist	1,165	5,245
		Gray biotite gneiss with large cordierite porphyroblasts near base	515	
		Gray leptite with subordinate muscovite schist which locally contains pink andalusite porphyroblasts	3,565	
	psc	Hornblende schist	790	2,130
		Leptite and quartz-feldspar-mica schist	835	
		Hornblende schist	260	
		Quartz-feldspar-mica schist and leptite	245	
	psb	Graphite schist and hornblende schist in lower part, hornblende schist and leptite in upper part		1,765
	psa	Marble with graphite schist interbeds	200	6,045
		Dominantly muscovite schist, changes to leptite, graphite schist, and hornblende schist toward southeast; one prominent marble unit	2,275	
		Graphite schist	930	
		Hornblende schist	630	
		Graphite schist and marble	540	
		Hornblende schist, leptite, and marble	1,470	
VALLEY SPRING GNEISS	vsc	Pink quartz-feldspar gneiss, well foliated, conspicuous development of feldspar augen near top		130
	vsb	Gray quartz-feldspar-biotite gneiss		250
	vsa	Pink quartz-feldspar gneiss, moderately to poorly foliated, injected by much pegmatitic material, especially in lower part of unit		8,000 (base not reached)

The original sedimentary setting may have been one of limestone reefs in shallow water with intervening euxinic lagoons where carbon-rich organic debris, iron sulfides, and fine mud accumulated. Most of the graphite schist is highly pyritic. Noncarbonaceous silt, clay, and fine sand accumulated in the more open sea where reducing conditions did not obtain, and at irregular intervals similar sediments spread across the reefs and lagoons. They were converted to light-colored schist and leptite upon metamorphism. Muds containing an abundance of iron, magnesium, and calcium compounds ultimately became hornblende schist.

META-IGNEOUS ROCKS

Some of the metamorphosed mafic igneous rocks southwest of Red Mountain are probably the oldest intrusive rocks in the area. Barnes recognized that the soapstone might have been derived from siliceous dolomite in the Packsaddle Schist, but he found that the associated rocks contain amounts of chromium and nickel similar to those in peridotite and pyroxenite (Barnes, Shock, and Cunningham, 1950, p. 15). The Coal Creek Serpentine body at the southwestern margin of the map (fig. 3) is the largest body of metamorphosed dunite or peridotite in the region, and it was investigated carefully as a potential source of magnesium by Barnes and his coworkers. The Big Branch Gneiss is metamorphosed quartz diorite so heavily contaminated with partly digested remnants of Packsaddle Schist that Barnes (1946a, p. 57) found it difficult in the field to determine which part of an outcrop should be designated as igneous and which as sedimentary in origin. Some of the mafic igneous bodies are clearly younger than the Big Branch Gneiss, but others appear to bear intrusive relations to the gneiss only because the quartz diorite magma selectively assimilated the Packsaddle Schist into which they had earlier been injected. The hybrid origin of the Big Branch Gneiss was further compounded near Red Mountain where potassium metasomatism caused the development of so many pink microcline porphyroblasts that the rock is locally a quartz monzonite augen gneiss (fig. 4).

The Red Mountain Gneiss occurs as numerous concordant and barely discordant sills and lenticular bodies in the upper part of the Packsaddle Schist (fig. 3). It is a pink granite consisting almost exclusively of quartz, microcline, and sodic plagioclase. Biotite is present locally. Texture of the rock is variable, partly because deformation was markedly nonuniform. The quartz in some samples has been flattened into thin elongate flakes, giving the rock pronounced foliation and lineation. Nearby in the same body no appreciable deformation is apparent. The southernmost sill in the Red Mountain area (fig. 4) is coarse grained, whereas the smaller sills are generally fine grained, and a few show relict porphyritic texture. Fine-grained sills of Red Mountain Gneiss are almost indistinguishable from pink leptite layers in the Packsaddle Schist, just as fine-grained amphibolites of igneous origin are nearly identical with metasedimentary hornblende schists in the same formation.

STRUCTURE

The Precambrian metamorphic rocks throughout the Llano region were folded into broad open anticlines and synclines trending northwest. Subsequently, granite plutons as much as 10 miles wide were wedged into the folded rocks, chiefly as vertical cylindrical masses which appear to have made room for themselves by pushing sideways as well as upward. Near the plutons the folds were intensified and deflected. Southeast of Packsaddle Mountain (fig. 3) compression near the granite was particularly intense, resulting in a series of thrust faults which were first recognized by McCandless (1957). The outcrop patterns of marble beds near Packsaddle Mountain clearly reflect the compression introduced by granite intrusion. Foliation in the metasedimentary rocks seems to have developed parallel to bedding during regional metamorphism, and lineation was parallel to the axes of the northwest-trending folds. In the syntectonic igneous rocks (Big Branch and Red Mountain Gneisses) lineation and foliation are generally parallel to that in the enclosing metasediments (Clabaugh and Boyer, 1961). But the emplacement of the large Town Mountain Granite bodies at the close of regional metamorphism introduced additional foliation and lineation in susceptible rocks. A second (and rarely even a third) lineation developed locally in mica schist and graphite schist. Drag folds with a second foliation parallel to axial planes developed in a few spots, especially in cordierite schist.

Nearly all of the northeast-trending faults shown in figure 3 are Paleozoic normal faults. Most of them have small displacements, but the vertical separation along several exceeds 2,000 feet.

METAMORPHISM

The maximum grade of regional metamorphism attained by the Precambrian sedimentary rocks in Central Texas was not lower than the sillimanite-almandine-muscovite subfacies of the almandine amphibolite facies as defined by Turner and Verhoogen (1960). It is not unlikely that the sillimanite-almandine-orthoclase subfacies was reached locally but obscured by retrograde development of muscovite. Almandine and sillimanite are widespread; staurolite and kyanite are totally absent. This suggests relatively low pressure and high temperature conditions for regional metamorphism, which is further indicated by widespread occurrences of cordierite, andalusite, and wollastonite. In the southeastern part of the Llano region wollastonite is abundant only in marble beds near granite, where conditions may have approached those of the pyroxene hornfels facies. Andalusite occurrences are sporadic and most of them are near granite bodies, although no distinct zones of contact metamorphism can be detected. Where andalusite and sillimanite occur together, the mineral relations seem to indicate that andalusite is younger, as would be anticipated if it formed when the large bodies of granite were emplaced at the close of regional metamorphism. Cordierite is more uniformly distributed in a few layers of aluminous rock, although it is best developed near Red Mountain where syntectonic intrusions probably intensified the heating that accompanied regional metamorphism.

South of Packsaddle Mountain the marble layers contain mineral assemblages indicative of more moderate temperature, including the pair tremolite-dolomite. At one locality quartz and dolomite occur together, but this low-temperature assemblage can almost surely be dismissed as Paleozoic or

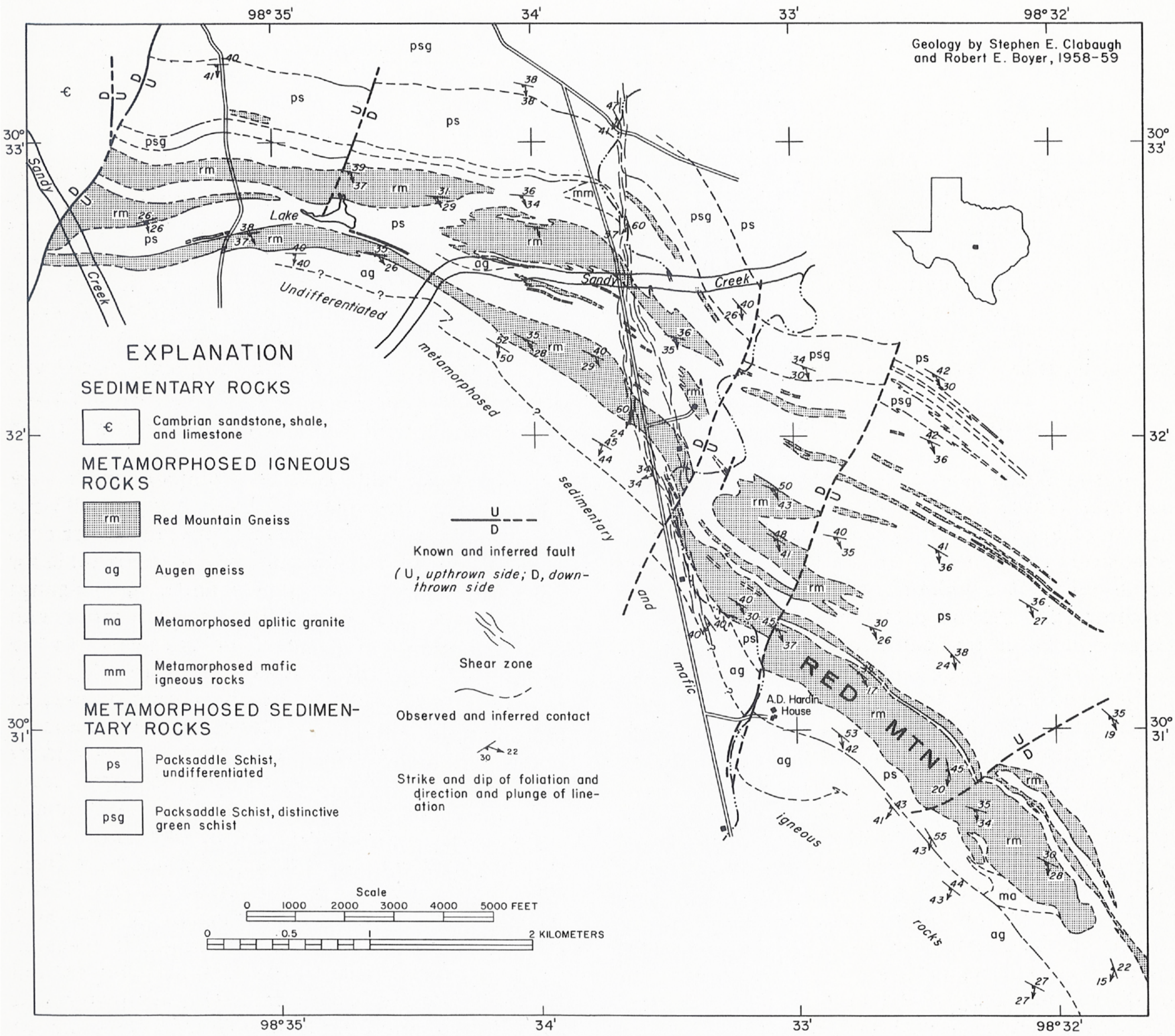


FIG. 4. Geologic map of Red Mountain area, southeastern Llano County, Texas.

younger dolomitization of a fractured Precambrian quartz-calcite marble near Paleozoic faults which transected overlying Paleozoic dolomite beds.

Retrograde metamorphic changes and alkali metasomatism affected nearly all of the metamorphic rocks to some extent. Pegmatites and quartz veins were emplaced following the main period of granite intrusion, and small-scale fracturing and penetrative movements continued even after intrusion of the youngest of the granitic rocks, the granite porphyry and felsite dikes. Sillimanite, andalusite, and spinel were replaced by muscovite, metagabbro was converted to biotite schist and epidote-oligoclase rock, serpentine to talc and chlorite, and garnet to biotite and plagioclase-hornblende intergrowths.

FIELD TRIP STOPS ON PRECAMBRIAN ROCKS

STOP 2, RED MOUNTAIN AREA

In the bed of a small creek in front of the A. D. Hardin ranchhouse (fig. 4) are excellent exposures of metasedimentary rocks of the Packsaddle Schist, augen gneiss related to the Big Branch Gneiss, and Red Mountain Gneiss, as well as fault breccias and boulders of metagabbro and other rocks. Knobby porphyroblasts of cordierite are conspicuous in some of the mica schist.

STOP 3, SUNRISE BEACH

Sunrise Beach is an area beside Lake Lyndon B. Johnson (formerly Granite Shoals Lake) at the mouth of Sandy Creek; this area has been developed intensively as a summer resort and retirement home community. It is underlain by Packsaddle Schist in its central and western parts and by Town Mountain Granite in the eastern part (fig. 5). From the granite contact westward, the metasedimentary rocks may be grouped roughly into the following three subdivisions: (1) leptite and quartz-mica schist, (2) graphite schist, and (3) mixed marble and leptite. All of these are part of the lowest unit of Packsaddle Schist shown on figure 3. One large and several smaller bodies of metamorphosed gabbro lie west of the graphite schist. Pale green andalusite and dark brown tourmaline porphyroblasts are locally abundant in the graphite schist, and some of the marble has been converted to almost pure diopside hornfels. Small pegmatites are numerous, and one small one near Sunrise Marina contains interesting mica pseudomorphs after topaz. The area lies about a mile east of the crest of a broad southeast-plunging anticline, but in this vicinity adjacent to the granite the structure is disturbed, and dips are generally steep. Large-scale disharmonic folding is common where graphite schist is present in the sequence of metamorphic rocks.

STOP 4, GRANITE MOUNTAIN

The Granite Mountain quarry was opened in 1882 on an exfoliation dome about a mile northwest of Marble Falls (fig. 6). The rock is coarsely crystalline granite of the Town Mountain type composed chiefly of microcline, plagioclase, and quartz with minor amounts of biotite, hornblende, rutile, apatite, zircon, and allanite. A few of the large microcline crystals are complexly zoned and mantled by plagioclase. Dark biotite-bearing xenoliths and schlieren are not uncommon in the granite.

The Texas Pink Granite Company took over operation of the quarry in 1893, and in 1895 the owners agreed to donate sufficient granite for construction of the State Capitol Building. Prison labor was used to operate the quarry, and a narrow-gauge railroad was built by the State to haul more than 15,000 carloads of granite from the quarry to the Capitol Building site in Austin. Granite Mountain also provided the stone for the Galveston seawall and most of the jetties along the Gulf Coast of Texas and Louisiana. By 1940 approximately 34 million tons of stone had been shipped from the quarry for use in buildings and monuments throughout the country, including two wings of the American Museum of Natural History in New York, the Times Building in Los Angeles, the Northwestern Life Insurance Building in Seattle, and, surprisingly, the Leif Erickson Memorial in Iceland.

During 1950 the Texas Granite Corporation acquired Granite Mountain. This company is a subsidiary of the Cold Spring Granite Company of Minnesota, which operates quarries at several other places in the United States and Canada and distributes at least 24 different colors of commercial granite. Stone from Granite Mountain is currently marketed as "Sunset Red"; it was formerly known as "Texas Pink." Among the buildings built of this

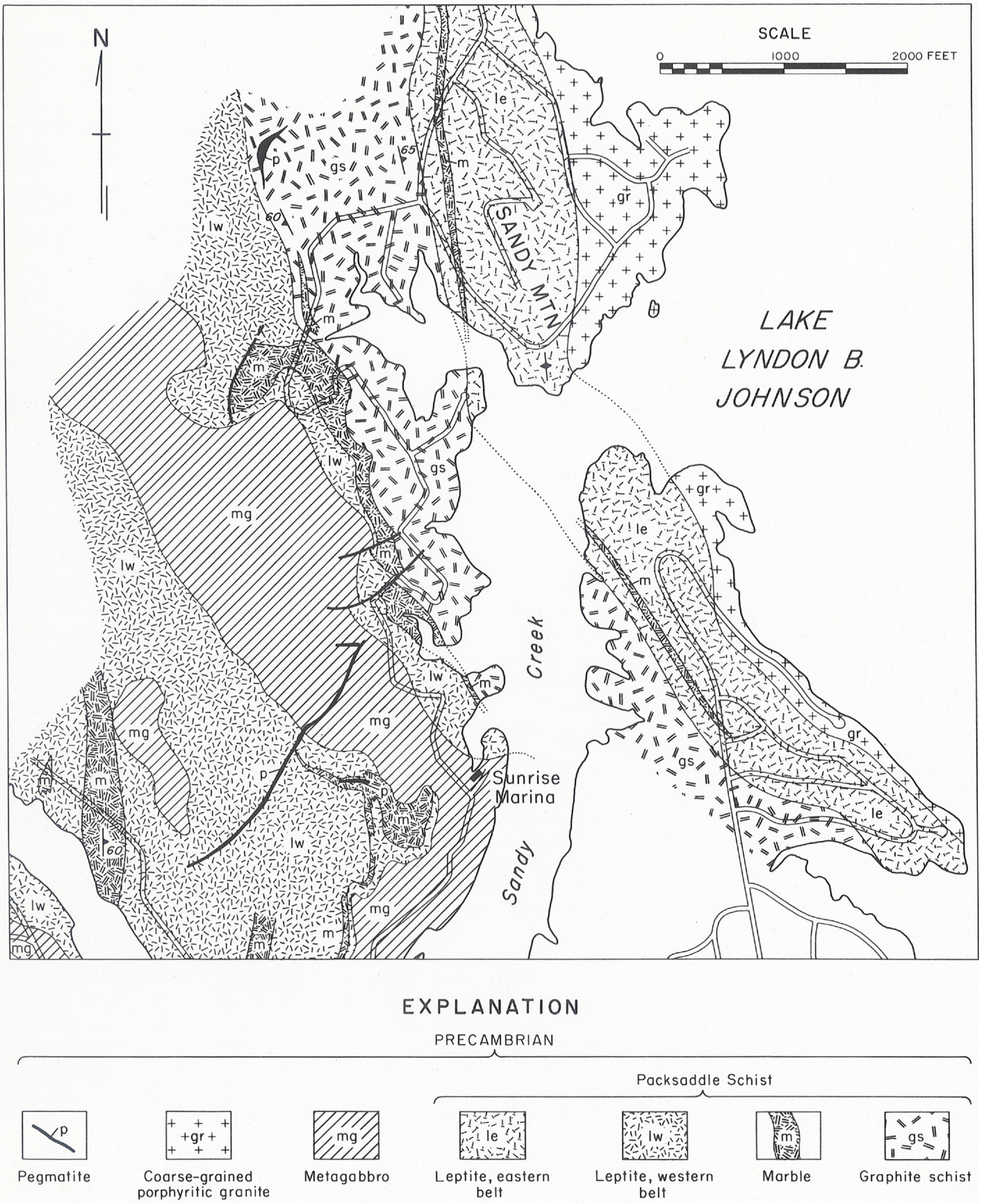


FIG. 5. Geologic map of Sandy Mountain—Sunrise Beach area, eastern Llano County, Texas.

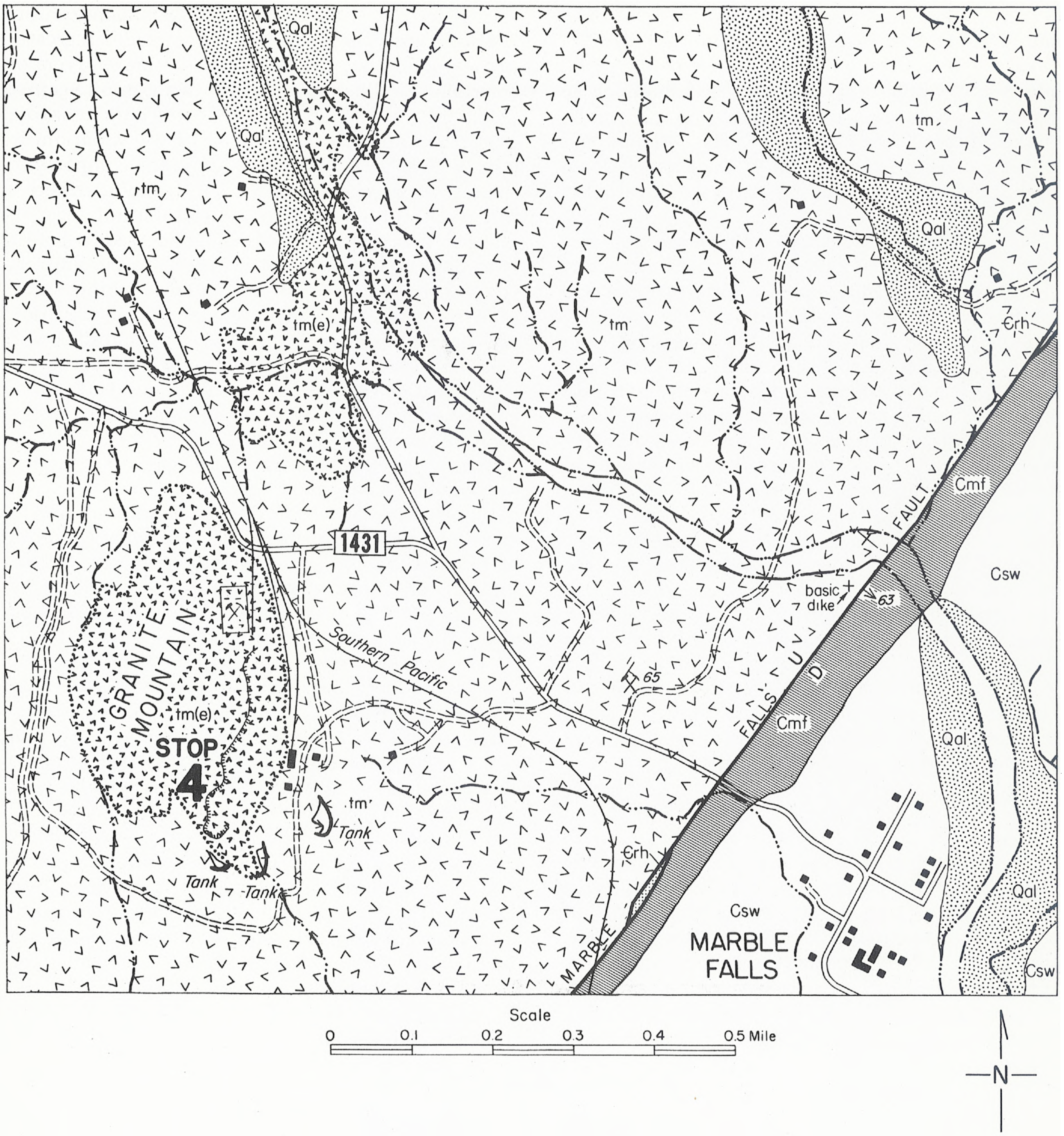


FIG. 6. Geologic map of Granite Mountain area, Burnet County, Texas.

The geologic units mapped are shown by the following letter symbols: Quaternary deposits—alluvium, Qal; Pennsylvanian rocks—Smithwick Shale, Csw, and Marble Falls Limestone, Cmf; Cambrian rocks—Hickory Sandstone, Ꞓrh; and Precambrian rocks—Town Mountain Granite, tm, showing larger exfoliation domes and bare rock surfaces, tm(e). Base from U. S. Department of Agriculture Soil Conservation Service, aerial photographs flown by Park Aerial Surveys, Inc., 1939-1940. Geology by Virgil E. Barnes and T. A. Anderson, 1951.

stone in recent years are the new State office buildings near the Capitol in Austin, the Los Angeles County Courthouse, and the Prudential Life Insurance Buildings in Houston and Minneapolis. The Texas Granite Corporation also operates a second quarry a few miles west of Granite Mountain, from which it produces a popular grayish-pink granite marketed as "Texas Pearl." This granite was recently used in construction of the First National Bank Building in Chicago, the world's tallest granite-clad building.

In the quarry, blocks of granite are cut free chiefly by wire sawing in which twisted strands of tough steel wire rapidly move a slurry of water and abrasive through a slot in the stone. Other methods, including closely spaced drilling, wedging, and blasting are also used. Especially effective is a method of "jet piercing" or burning channels into the granite with a jet of oxygen and kerosene flame. This method is expensive, but it can be used to free large blocks of strained granite that would expand and bind drills and cutting wires.

Most of the granite is sawed into relatively thin slabs for facing buildings, and the slabs are polished by conventional methods. An interesting method which produces a very attractive rough frosty finish is also used. The sawed surface of the stone is heated rapidly by moving it through a set of blowtorch flames followed immediately by a line of cooling water jets. A thin layer of the granite spalls off to the natural mineral cleavages in a snow of flakes. The resulting surface is preferred for granite floors and walks and for nonreflecting walls.

STOP 7, INKS LAKE AREA

The Valley Spring Gneiss is well exposed on hillsides adjacent to the eastern shore of Inks Lake near the mouth of Spring Creek. In the eastern part of the Llano region the Valley Spring Gneiss is predominantly microcline-quartz gneiss with subordinate amounts of biotite, magnetite, epidote, and hornblende. Some layers are richer in biotite and therefore darker; a few lenses and layers are black amphibolite, but these were probably diabase dikes and other mafic igneous bodies intruded into the original rock before or during metamorphism. Farther west the Valley Spring includes a greater variety of rocks, including one or more layers of marble (locally converted to wollastonite-garnet rock) and more numerous layers of dark schistose rocks and amphibole. In spite of the variations in the Valley Spring Gneiss, its average composition closely approximates that of granite, whereas its distribution, layering, and structural features suggest that it, like the overlying Packsaddle Schist, was deposited as a sediment. Perhaps the simplest hypothesis to account for granitic composition and sedimentlike distribution and local variation is that the original rocks were ignimbrites and related rhyolitic volcanic rocks in which there were local mafic igneous rocks, calcareous tuffs, nonmarine limestone, and sediments derived from the volcanic rocks.

During metamorphism of the gneiss some of it appears to have undergone partial melting or to have been invaded intricately by granite magma to produce complex migmatites. Following the peak of metamorphism innumerable small pegmatites, aplites, and quartz veins were emplaced in the gneiss. Most of these appear to have been derived from the large granite plutons.

Of the Precambrian rocks, the Valley Spring Gneiss produces the roughest topography, especially in the eastern part of the Llano region. The rocky, rough character of the surface is well displayed in Inks Lake State Park and along the road between Buchanan Dam and the edge of the Cretaceous toward Burnet. When the Cambrian sea encroached on the Llano region, the topography of the Valley Spring Gneiss was equally rough with peaks standing more than 700 feet above the surrounding lowlands. The Morgan Creek Limestone Member of the Wilberns Formation rests in places directly on the Valley Spring Gneiss (fig. 7). Within the Kingsland quadrangle the average thickness of the Cambrian rocks beneath the Morgan Creek Limestone is 715 feet.

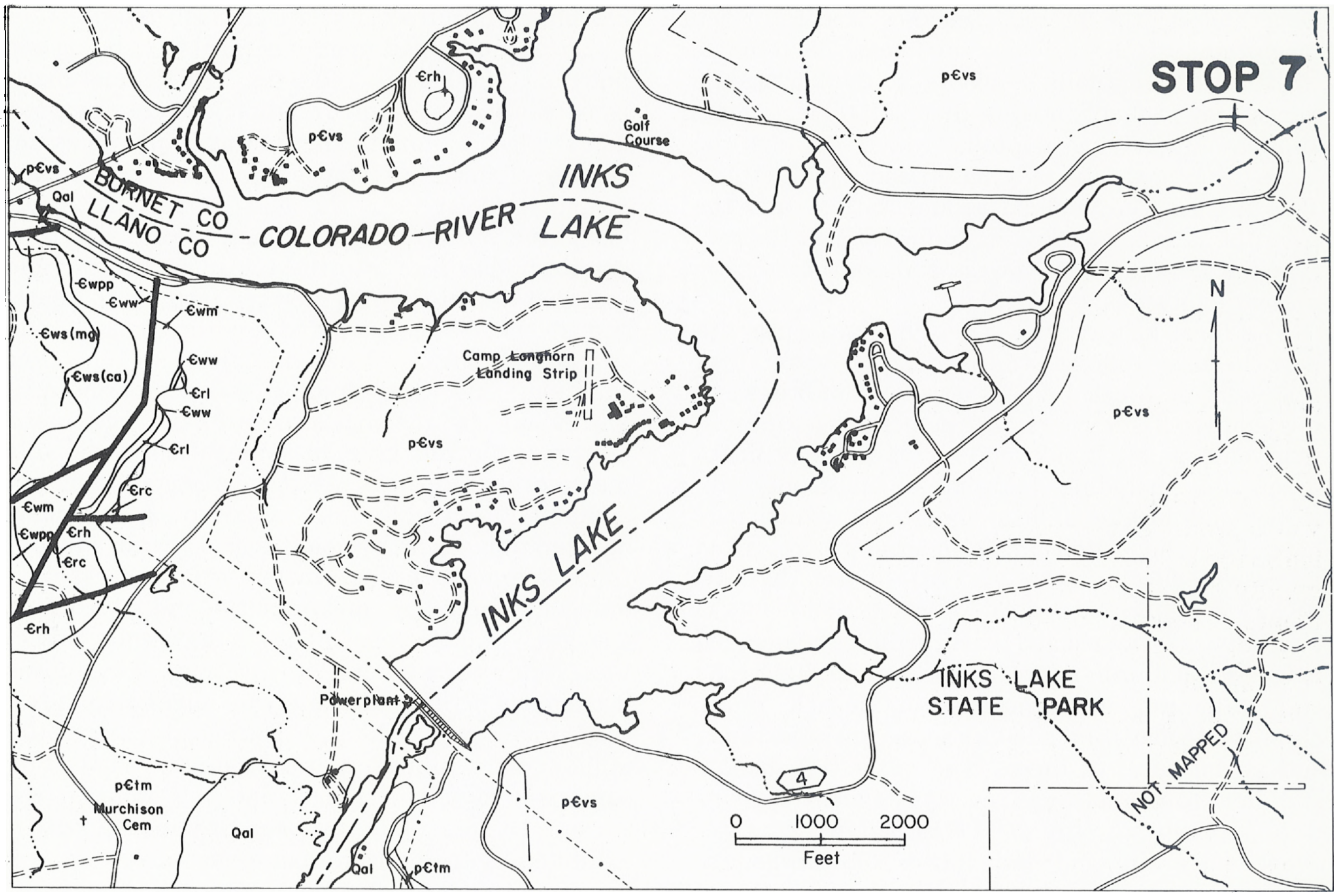


FIG. 7. Geologic map of Inks Lake area, Burnet and Llano counties, Texas.

The geological units mapped are shown by the following letter symbols: Quaternary deposits—alluvium, Qal. Cambrian rocks—Wilberns Formation showing San Saba Member, dolomitic facies, Єws (mg), and calcitic facies, Єws (ca), Point Peak Member, Єwpp, Morgan Creek Limestone Member, Єwm, and Welge Sandstone Member, Єww; and Riley Formation showing Lion Mountain Sandstone Member, Єrl, Cap Mountain Limestone Member, Єrc, and Hickory Sandstone Member, Єrh. Precambrian rocks—Town Mountain Granite, pЄtm, and Valley Spring Gneiss, pЄvs. Planimetric base from U.S. Geological Survey, Kingsland and Longhorn Cavern topographic quadrangle maps. Geology by Virgil E. Barnes, 1970-1971.

PRECAMBRIAN GEOLOGIC HISTORY

A single major cycle of sedimentation, deformation, metamorphism, and granite intrusion is recorded in the Precambrian rocks of the Llano uplift. The original thickness of sediments cannot be measured; neither the top nor the bottom of the section is known and deformation has thickened some units by isoclinal folding and thinned others. Nevertheless, the present thickness indicates the magnitude of the original thickness. Sediments which were eventually converted to the Packsaddle Schist were probably not less than 20,000 feet thick, and the underlying deposits which became the Valley Spring Gneiss may have been equally thick. This implies geosynclinal sedimentation, and the trend of subsequent folding indicates that the geosyncline extended northwest and southeast from present exposures.

The local history of the geosyncline appears to have been as follows. Early deposits were rhyolitic volcanic rocks, perhaps largely ignimbrites and related pyroclastic rocks, with associated tuffaceous sediments and a small amount of more ordinary sediments, including feldspathic sandstone, siltstone, and locally a little limestone, which may have been deposited in nonmarine basins in an extensive volcanic terrain. Above the rhyolitic rocks was deposited a great variety of sediments in a rapidly sinking trough. These sediments included magnesian and iron-rich calcareous muds, limestone and dolomite, carbonaceous sulfide-rich muds, clean white clays and siltstones, arkosic sandstones, and all mixtures of these. The water was shallow and limestone reefs and nearly stagnant lagoons were present at times. Gradually the water deepened again and the influx of terrigenous sediments increased, so that limestone and carbon-rich muds ceased to be formed. Perhaps there were outpourings of basaltic lava and intrusions of gabbroic rocks as deformation began in the geosyncline. The sediments were folded into elongate anticlines and synclines; thrust faulting probably occurred, and at moderate depth regional metamorphism occurred at relatively high temperature. Foliation developed mainly parallel to bedding and lineation parallel to fold axes. Additional mafic igneous rocks and quartz diorite were intruded, and the Red Mountain granite was emplaced as sills before regional metamorphism and deformation ceased. Then near the end of regional metamorphism about 1,000 million years ago large granite bodies rose into the folded framework and crowded the intervening metasediments into tighter and steeper folds disrupted by thrust faults and strike-slip faults. New directions of lineation, foliation, and drag folding were superimposed locally on the regional structure, and new metamorphic minerals grew in some of the regionally metamorphosed rocks. As the large granite masses endured the feeble final stages of geosynclinal deformation, their pegmatites and warm aqueous fluids permeated the metamorphic rocks and induced numerous metasomatic and retrograde changes. Emplacement of the large granite bodies was followed by smaller invasions of granitic magma and perhaps ultimately by injection of a few very small mafic dikes. During the next 400 million years uplift and erosion destroyed the Precambrian mountain range, and a Cambrian sea advanced across subdued topography about like that exhibited by the Precambrian rocks today.

REFERENCES

Anderson, J. E. (1960) Geology of the Green Mountain area, Llano County, Texas: Univ. Texas, Austin, M.A. thesis 95 pp.

Barnes, V. E. (1946a) Soapstone and serpentine in the Central Mineral Region of Texas, *in* Texas mineral resources: Univ. Texas Pub. 4301 (Jan. 1, 1943), pp. 59-91.

_______ (1946b) Feldspar in the Central Mineral Region of Texas, *in* Texas mineral resources: Univ. Texas Pub. 4301 (Jan. 1, 1943), pp. 93-104.

_______ (1952a) Blowout quadrangle, Gillespie and Llano counties, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map No. 5.

_______ (1952b) Willow City quadrangle, Gillespie and Llano counties, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map No. 4.

_______, Dawson, R. F., and Parkinson, G. A. (1947) Building stones of Central Texas: Univ. Texas Pub. 4246 (Dec. 8, 1942), 198 pp.

_______ and Romberg, Frederick (1943) Gravity and magnetic observations on Iron Mountain magnetite deposit, Llano County, Texas: Geophysics, vol. 8, pp. 32–45.

_______ and _______ (1944) Correlation of gravity observations with the geology of the Smoothingiron granite mass, Llano County, Texas: Geophysics, vol. 9, pp. 79–93.

_______ and _______ (1949) Correlation of gravity observations with the geology of the Coal Creek serpentine mass, Blanco and Gillespie counties, Texas: Geophysics, vol. 14, pp. 151–161.

_______, Shock, D. A., and Cunningham, W. A. (1950) Utilization of Texas serpentine: Univ. Texas Pub. 5020, 52 pp.

Blount, D. N. (1962) Geology of the Honey Creek area, Llano County, Texas: Univ. Texas, Austin, M.A. thesis, 117 pp.

Burnitt, S. C. (1961) Geology of the Red Mountain area, Llano County, Texas: Univ. Texas, Austin, M.A. thesis, 205 pp.

Clabaugh, S. E., and Barnes, V. E. (1959) Vermiculite in Central Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 40, 32 pp.

_______ and Boyer, R. E. (1961) Origin and structure of the Red Mountain Gneiss, Llano County, Texas: Texas Jour. Sci., vol. 13, pp. 7-16.

Comstock, T. B. (1890) A preliminary report on the geology of the Central Mineral Region of Texas: Texas Geol. Surv., 1st Ann. Rept. (1889), pp. 237-391.

_______ (1891) Report on the geology and mineral resources of the Central Mineral Region of Texas: Texas Geol. Surv., 2d Ann. Rept. (1890), pp. 555-668.

Doyle, R. E. (1957) Petrology of the Packsaddle Mountain area, Llano and Burnet counties, Texas: Univ. Texas, Austin, M.A. thesis, 113 pp.

Flawn, P. T. (1956) Basement rocks of Texas and southeast New Mexico: Univ. Texas Pub. 5605, 261 pp.

_______, and Muehlberger, W. R. (1970) The Precambrian of the United States of America: South-Central United States, *in* The Geologic Systems, The Precambrian, vol. 4, Interscience, pp. 72-143.

Goldich, S. S. (1941) Evolution of the Central Texas granites: Jour. Geol., vol. 49, pp. 697-720.

Hutchinson, R. M. (1956) Structure and petrology of Enchanted Rock batholith, Llano and Gillespie counties, Texas: Bull. Geol. Soc. America, vol. 67, pp. 763-806.

Iddings, J. P. (1904) Quartz feldspar porphyry from Llano, Texas: Jour. Geol., vol. 12, pp. 225-231.

Keppel, David (1940) Concentric patterns in the granites of the Llano-Burnet region, Texas: Bull. Geol. Soc. America, vol. 51, pp. 971-1000.

Lidiak, E. G., Almy, C. C., Jr., and Rogers, J. J. W. (1961) Precambrian geology of part of the Little Llano River area, Llano and San Saba counties, Texas: Texas Jour. Sci., vol. 13, pp. 255-289.

McCandless, G. C., Jr. (1957) Geology of the Indian Flat area, Llano County, Texas: Univ. Texas, Austin, M.A. thesis, 70 pp.

McGehee, R. V. (1963) Precambrian geology of southeastern Llano uplift, Texas: Univ. Texas, Austin, Ph.D. dissert., 290 pp.

Paige, Sidney (1911) Mineral resources of the Llano-Burnet region, Texas: U. S. Geol. Survey Bull. 450, 103 pp.

_______ (1912) Description of the Llano and Burnet quadrangles: U. S. Geol. Survey Geol. Atlas, Llano-Burnet Folio (No. 183), 16 pp.

Sims, S. J. (1957) Geology of the Sandy Mountain area, Llano County, Texas: Univ. Texas, Austin, M.A. thesis, 62 pp.

Stenzel, H. B. (1932) Precambrian of the Llano uplift, Texas: Bull. Geol. Soc. America, vol. 43, pp. 143-144.

_______ (1935) Precambrian structural conditions in the Llano region, *in* The geology of Texas, Vol. II, Structural and economic geology: Univ. Texas Bull. 3401 (Jan. 1, 1934), pp. 74-79.

Tilton, G. R., Davis, G. D., Wetherill, G. W., and Aldrich, L. T. (1957) Isotopic ages of zircon from granites and pegmatites: Amer. Geophys. Union Trans., vol. 38, pp. 360-371.

Turner, F. J., and Verhoogen, John (1960) Igneous and metamorphic petrology (2d ed.): McGraw-Hill Book Co., New York, 694 pp.

Walcott, C. D. (1884) Notes on Paleozoic rocks of Central Texas: Amer. Jour. Sci., 3d ser., vol. 28, pp. 431-433.

Zartman, R. E. (1962) Rb^{87}-Sr^{87} and K^{40}-Ar^{40} ages of Precambrian rocks from the Llano uplift, Texas (abst.): Geol. Soc. America Program, 1962 Ann. Mtgs., pp. 166A-167A.

_______ (1964) A geochronologic study of the Lone Grove pluton from the Llano uplift, Texas: Jour. Petrology, vol. 5, pp. 359-408.

_______ (1965) Rubidium-strontium age of some metamorphic rocks from the Llano uplift, Texas: Jour. Petrology, vol. 6, pp. 28-36.

_______ and Wasserburg, G. J. (1962) A geochronologic study of a granite pluton from the Llano uplift, Texas (abst.): Jour. Geophys. Res., vol. 67, p. 1664.

CAMBRIAN HISTORY, LLANO REGION

W. C. BELL AND VIRGIL E. BARNES

RILEY FORMATION

Several miles of Precambrian rock were removed by erosion during the 400-million year interval between the emplacement of llanite (the youngest Precambrian igneous rock identified in the region) and the start of Paleozoic sedimentation in Middle Cambrian time. The first fossils useful for dating belong to latest Middle Cambrian *(Bolaspidella)* time (fig. 8). These fossils occur above sandstone which is barren except for lebenspuren, such as *Cruziana*, *Climactonites*, and various other forms. The Cambrian sea spread northward (fig. 9) across an area of Precambrian igneous, meta-igneous, and metasedimentary rocks having local relief as great as 800 feet. Locally derived residual material, principally quartz that in part is wind-abraded, constitutes a thin, discontinuous cobble conglomerate at the base of the Hickory Member.

The Riley Formation, ranging in thickness from 800 feet along the south edge of the Llano region to 600 feet along the north edge, represents a transgressive-regressive cycle of marine sedimentation. It is bounded below by the Precambrian nonconformi-

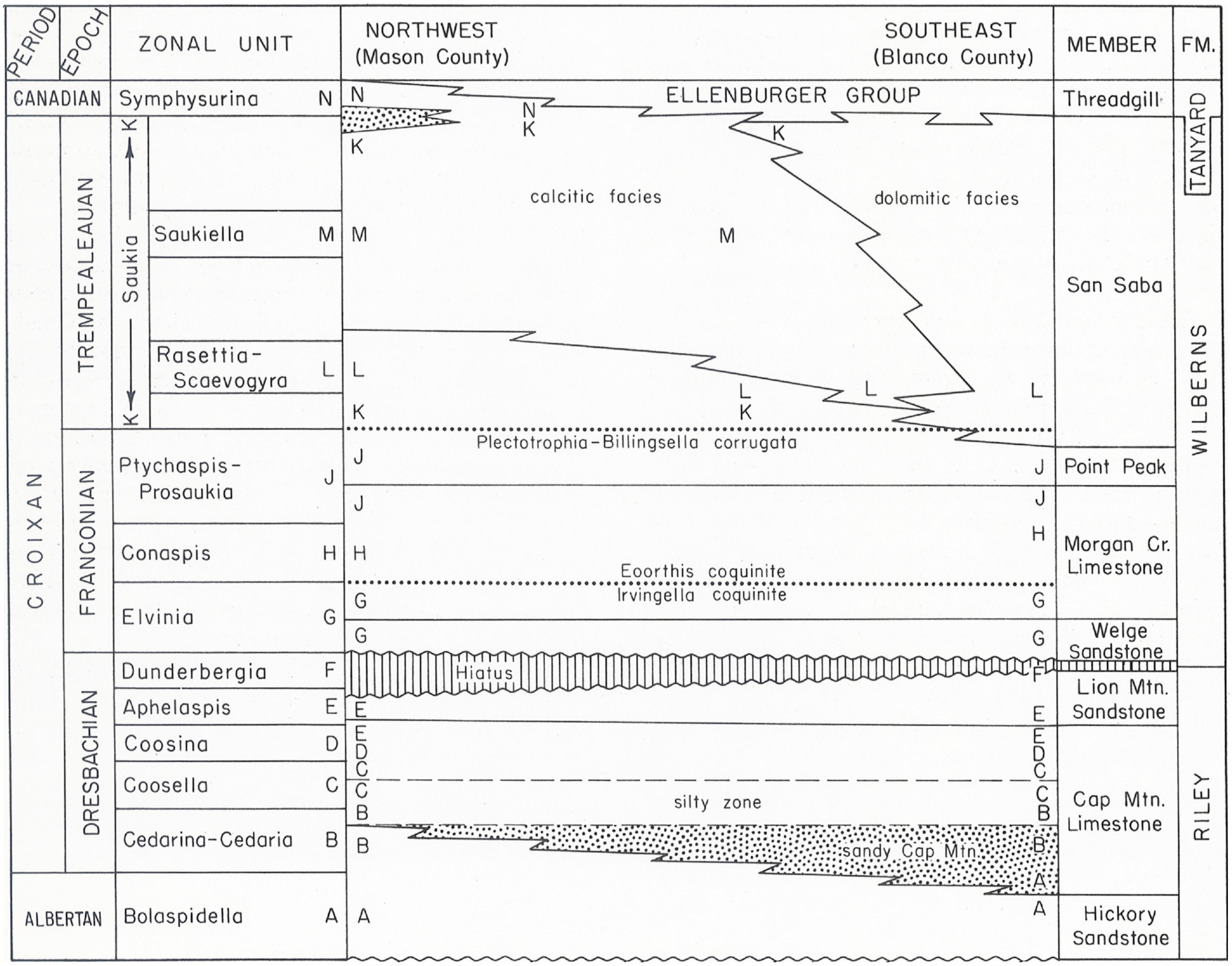


FIG. 8. Correlation of Croixan Series in Llano region, Texas.

ty and above by the Dresbachian-Franconian regional disconformity and includes in stratigraphic order the Hickory Sandstone Member (noncalcareous quartz sandstone, 276 to 434 feet thick), Cap Mountain Limestone Member (arenaceous, argillaceous, and glauconitic limestone, 156 to 497 feet thick), and Lion Mountain Sandstone Member (highly glauconitic quartz sandstone, 29 to 68 feet thick). Assuming that faunal zones are approximately contemporaneous in the area here being considered, control is sufficient to justify the following conclusions with respect to depositional history of the Riley Formation.

Quartz sandstone accumulated in a transgressing sea whose strandline probably was more nearly east-west (fig. 9) than it was northeast-southwest. Deposition kept pace with depression, resulting in a rather constant and shallow depth of water all over Central Texas; consequently, uppermost sandstone beds in the vicinity of partly buried hills contain pebbles as large but not as abundant as those in the basal conglomerate. By the end of *Cedarina-Cedaria* time, or slightly later, sand-size quartz ceased to reach Central Texas, and through most of *Coosella* time the only terrigenous material deposited was silt. The top of the silt roughly parallels the top of the sand, and both surfaces tend to parallel if not coincide with boundaries of faunal zones.

During *Bolaspidella* time, carbonate together with quartz sand began to accumulate along an east-west line between White Creek and Threadgill Creek (fig. 9). The margin of carbonate deposition moved slowly northward and by the end of *Cedarina-Cedaria* time had reached a line between Little Llano River and Pontotoc. Consequently, there accumulated a northward-thinning wedge of calcareous sandstone and sandy limestone that constitutes the lower part of the Cap Mountain to the south and is laterally equivalent to much of the upper part of the Hickory to the north. Faunal planes cross northward from sandy Cap Mountain into noncalcareous Hickory.

During *Coosina* time the marine transgression reached its maximum, and the strandline was many tens of miles north of the Llano region; fragmental fossiliferous and glauconitic limestone of the upper part of the Cap Mountain above the "silty zone" accumulated in Central Texas. These sediments were deposited either farther from shore or in deeper water, or both, than were any others in the Riley Formation.

Near the beginning of *Aphelaspis* time either uplift or eustatic lowering of sea level drove the strandline southward and revived a shallow and/or near-shore depositional environment. Supporting evidence is the influx of quartz sand that coarsens upward, increased high-angle cross-lamination, tangential lenses of dismembered and current-transported trilobite tests and linguloid brachiopod shells, and an over-all decline in carbonate content. Simultaneously, pelletized glauconite grains accumulated in sufficient quantity to produce a greensand, supporting but not confirming a regressive wave-agitated depositional environment. The part of the deposit just described that lacks continuously bedded carbonate, consists mostly of quartz and glauconite, erodes to a flat bench, and supports sparse vegetation, is defined as the Lion Mountain Sandstone; its base is stratigraphically erratic.

Thickness distribution of the *Aphelaspis* and *Dunderbergia* zones indicates that 10 to 20 feet of Lion Mountain strata younger than any found elsewhere are present at James River, Threadgill Creek, White Creek, and Morgan Creek. Evidently the strandline swung more nearly northeast-southwest during regression, deposition continued longer in the southeastern quadrant, and more Lion Mountain was removed by erosion in the northwestern quadrant of the region. The fact that the overlying Welge Sandstone is glauconitic at Morgan Creek, White Creek, and in the Magnolia Petroleum Company No. 1 Below well, Kendall County, suggests that deposition was very nearly continuous in the southeastern corner of the uplift.

This regression closed Dresbachian history in Central Texas.

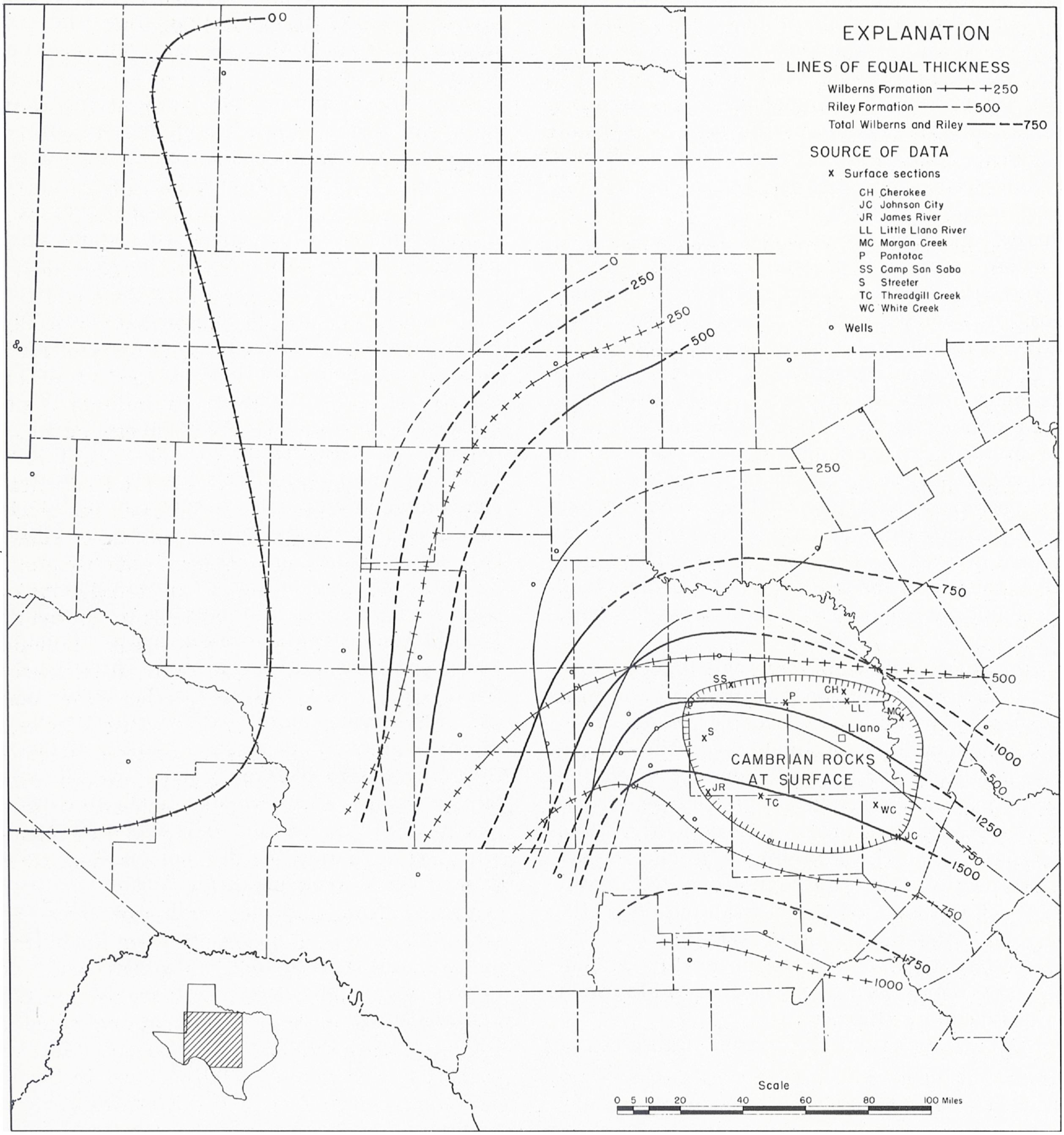


FIG. 9. Isopach map of Riley and Wilberns Formations in Central Texas.

WILBERNS FORMATION

The Wilberns Formation, as presently defined, includes four members named, in ascending order, Welge Sandstone, Morgan Creek Limestone, Point Peak, and San Saba—the latter consisting of calcitic, dolomitic, and sandstone facies. The Point Peak has been termed a "shale," but its content of siltstone, limestone, intraformational conglomerate, and stromatolitic bioherms encourages dropping a simple lithic designation.

The Dresbachian-Franconian disconformity present in Central Texas beneath the Wilberns Formation has been recognized at several places on the North American craton. Nowhere is there evidence of substantial erosion of underlying rock, nor does the faunal hiatus appear to be great. Central Texas lay on a shelf closely adjacent to a geosyncline to the south or southeast, and the faunal hiatus in the Llano region is appreciably less than it is in the upper Mississippi Valley. The Lion Mountain and Welge, as revealed by the drill, merge southward and become finer grained as the area of continuous deposition is approached.

Over most of the Llano region the Welge Sandstone (coarse to medium grained, typically nonglauconitic, 8 to 35 feet thick) is clearly transgressive across a surface either of marine or subaerial erosion. Some relief on that surface is indicated by small and erratic differences in thickness of the Welge; in the Little Llano River area thicknesses of 27 and 15 feet occur less than a mile apart. As the Franconian transgression began, topographic depressions on the Lion Mountain were quickly filled, and probably a flat profile of equilibrium, similar to that on top of the sandy Cap Mountain, was attained either at the top of the Welge or in the lower 10 to 20 feet of sandy Morgan Creek.

The environment in which the noncalcareous quartz sandstone of the Welge accumulated was quickly succeeded over Central Texas by a remarkably uniform environment in which, on the average, 130 to 140 feet of fossiliferous, glauconitic Morgan Creek calcarenite accumulated. Faunal control in the Morgan Creek is good, and faunal planes not only tend to parallel each other but very nearly parallel the base and top of the member. Welge Sandstone and the lower 40 (northwest) and 60 (southeast) feet of Morgan Creek Limestone accumulated during *Elvinia* time, and the overlying 50 (northwest) to 30 (southeast) feet of limestone accumulated during *Conaspis* time. These compensatory changes in thickness, producing a remarkably constant 90 feet of limestone in the combined *Elvinia* and *Conaspis* zones, can be explained either by differential rates of deposition in surprisingly delicate balance, or by assumption that *Elvinia* and *Conaspis* "times" were in fact partly contemporaneous. The latter possibility deserves critical appraisal and is consistent with Bell's (1950, p. 493) interpretation that the *Irvingella* and *Eoorthis* coquinites constitute the record of migrating contiguous biotopes.

Deposition of Morgan Creek calcarenite in the Llano region ceased about the middle of *Ptychaspis-Prosaukia* time. In the upper part of the member, notably in the western sections, a few small stromatolitic bioherms and thin biostromes are forerunners of a new biologic factor that was to disrupt the rather simple depositional pattern thus far characteristic of Cambrian strata in Central Texas.

Several factors combine to militate against a satisfactory reconstruction of Wilberns depositional history above the Morgan Creek Limestone. An influx of silt resulted in the Point Peak Member, which not only is poorly fossiliferous but erodes to flat benches or gentle slopes that are in large part covered. Biohermal development not only produced an erratic pattern of Point Peak terrigenous deposition but also makes it difficult to choose stratigraphically consistent Point Peak boundaries. Dolomitization of the San Saba, particularly on the eastern side of the area where the member occurs typically in its dolomitic facies, has obliterated not only fossils but most megascopic original depositional texture and structure. Finally, the calcitic San Saba in the northeastern sections, where it is overlain by the dolomitic facies, is essentially unfossiliferous except for small spherical stromatolites called girvanella.

The Point Peak Member represents a temporary influx of silt, probably mainly from the northwest or west, and its wave-agitated shallow-water depositional environment was conducive to the development of ripple marks, intraformational conglomerate, and stromatolitic bioherms and biostromes. It ranges in thickness from 216 feet in the Riley Mountains to 25 feet in the Klett-Walker section near Johnson City. Throughout most of the area its average thickness is about 130 feet, the thinning to the southeast being rapid.

Silt deposition was initiated in middle *Ptychaspis-Prosaukia* time and continued well into the Trempealeauan, as its area of accumulation shifted westward and northwestward through the *Rasettia-*

Scaevogyra horizon. The assumption that faunal lines are approximately synchronous in this part of the sequence is substantiated by the distribution of the *Plectrotrophia-Billingsella* bed. This is a laterally persistent, 1- to 3-foot, fossiliferous, intraclastic limestone interval that can be mapped in the upper Point Peak Member over much of the Llano region, and it is especially characterized by the silicified valves of the brachiopods *Plectrotrophia* and *Billingsella*—represented by species confined to this interval. The calcitic interval passes southeastward out of the Point Peak into calcitic and dolomitic San Saba, where its lithic identity disappears and its position can be determined only by the presence of the same silicified brachiopods.

As Point Peak terrigenous deposition moved slowly northwestward it was replaced by a return to a carbonate depositional environment that in the western Llano region resulted in strata much like Morgan Creek Limestone, differing principally in the presence of abundant stromatolites and intraformational conglomerate.

Along the extreme western edge of the Llano region, at Calf Creek, Leon Creek, and James River, calcitic San Saba deposition was interrupted at or near the Cambrian-Ordovician boundary by an influx of quartz sand from the west. The faunally barren sandstone, ranging in thickness from 23 to 69 feet, intervenes between a high Trempealeauan trilobite assemblage containing *Corbinia*, *Theodenisia*, *Triarthropsis*, *Eurekia*, and *Plethometopus*, and a low Canadian trilobite assemblage containing *Symphysurina*, *Hystricurus*, *Missisquoia*, and others. The change in trilobites is at the family level, but there seems to be no coincident change among brachiopods and gastropods, and there is no evidence of unconformity. At Camp San Saba and Threadgill Creek, localities somewhat east of those previously mentioned, no quartz sand is present, the two faunas are no more than a couple of feet apart in a calcitic sequence, and there is no evidence of sedimentary discontinuity.

From the preceding it can be concluded that in the western part of the Llano region the only changes associated with what the writers—*by definition*—call the Cambrian-Ordovician boundary were a probable shallowing of the sea accompanied by the migration into the area of a group of trilobites whose prior development had taken place elsewhere.

Along the eastern and southeastern edges of the Llano region at the present time, the Wilberns-Ellenburger boundary cannot be unequivocally defined. The effects of dolomitization and disappearance of the Point Peak, combined with relatively poor exposures in the areas thus far investigated, have prevented a clear and detailed reconstruction of rock relationships, but there is little doubt that those relationships are complex. "Typical" dolomitic ("Pedernales") San Saba is fine grained and varicolored, commonly mottled pale red purple; this type of rock in large part probably will continue to be assigned to the Wilberns Formation. It is, however, seemingly intertongued in a complex way with dolomite that is "typical" of the Threadgill Member, Tanyard Formation, Ellenburger Group. The problem, or even its discussion, is complicated by the fact that all published maps, and almost all published literature since 1945, have equated the Cambrian-Ordovician and Wilberns-Ellenburger boundaries, which are boundaries whose definition and identification depend on different criteria and which do not coincide anywhere in Central Texas where both types of criteria are available.

On the western side of the Llano region, strata of the San Saba Member of the Wilberns Formation classified as belonging to the Ordovician, range in thickness from 35 to 91 feet; they record the same history of carbonate accumulation indicated by underlying Cambrian San Saba strata. On the eastern side of the area Wilberns deposition ended in late Cambrian time, but the details are not known.

REFERENCES

BARNES, V. E., and BELL, W. C. (1954) Cambrian rocks of Central Texas: San Angelo Geol. Soc. Guidebook, Cambrian field trip—Llano area, March 19-20, pp. 35-69.

BELL, W. C. (1950) Stratigraphy: a factor in paleontologic taxonomy: Jour. Paleont., vol. 24, pp. 492-496.

_______ and ELLINWOOD, H. L. (1962) Upper Franconian and lower Trempealeauan Cambrian trilobites and brachiopods, Wilberns Formation, Central Texas: Jour. Paleont., vol. 36, pp. 385-423. *Reprinted as* Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 47.

BRIDGE, JOSIAH, BARNES, V. E., and CLOUD, P. E., Jr. (1947) Stratigraphy of the Upper Cambrian, Llano uplift, Texas: Bull. Geol. Soc. America, vol. 58, pp. 109-124.

LOCHMAN-BALK, CHRISTINA, and WILSON, J. L. (1958) Cambrian biostratigraphy in North America: Jour. Paleont., vol. 32, pp. 312-350.

PALMER, A. R. (1954) The faunas of the Riley Formation in Central Texas: Jour. Paleont., vol. 28, pp. 709-786. *Reprinted as* Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 24.

WILSON, J. L. (1949) The trilobite fauna of the *Elvinia* zone in the basal Wilberns limestone of Texas: Jour. Paleont., vol. 23, pp. 25-44.

ORDOVICIAN TO EARLIEST MISSISSIPPIAN ROCKS, LLANO REGION

VIRGIL E. BARNES AND PRESTON E. CLOUD, JR.

LOWER ORDOVICIAN

The incomplete sequence of Lower Ordovician carbonate rocks known as the Ellenburger Group (Cloud and Barnes, 1948, 1957) includes, from the base up, the Tanyard, Gorman, and Honeycut Formations, each including both calcitic and dolomitic facies. Excluding subsurface records, it is essentially equivalent to the lower half of the Lower Ordovician sequence of the Ozark uplift of Missouri and Arkansas.

The Ellenburger has its maximum development at the surface in the southeastern corner of the Llano region where it is 1,820 feet thick. It thins to only 830 feet in the northwestern corner of the region, mainly by pre-Devonian truncation but in part by westward thinning of the Tanyard Formation. The rocks of the Ellenburger Group are essentially nonglauconitic and, at most places, are sparingly fossiliferous. Its limestones are dominantly aphanitic, commonly with a pelleted texture, and very light gray; the purer ones are in the upper part of the section (from upper Gorman upward). Its dolomites range from microgranular to coarse grained; the coarser-grained, paler ones ordinarily are in the lower part of the section, the finer-grained, more brightly colored ones above.

Figure 10 is a diagrammatic representation of lateral changes in the Ellenburger Group and underlying Upper Cambrian Wilberns Formation.

The carbonate rocks that overlie the Ellenburger Group are dominantly nondolomitic, typically dark, commonly granular, and may contain organic remains in relative abundance. The limestones of the Upper Cambrian in Central Texas are ordinarily granular, glauconitic, and darker than those of the overlying Ellenburger. The Cambrian dolomites at most places are darker and finer in grain than the Ellenburger dolomites.

The basal third of the complete surface Ellenburger sequence constitutes the Tanyard Formation, correlative with the Gasconade Dolomite and Van Buren Formation of Missouri. The Tanyard averages 590 feet thick and thins westward. The Threadgill Member constitutes its lower part and the Staendebach Member its upper part. The dolomites of the Threadgill Member are medium to coarse grained, and the distribution of limestone and dolomite is irregular. Dolomite predominates, except in the western part of the Llano region where the member is wholly limestone. The dolomites of the Staendebach Member are dominantly fine to medium grained. The member is wholly dolomite at places in the western part of the Llano region. To the east, however, erratically occurring limestone is conspicuous and locally dominant. Chert is rare in the Threadgill Member or consists of principally drusy and dolomoldic types. The Staendebach Member, especially toward the east, differs from the Threadgill in containing compact cherts that weather smooth and shiny white. Much of the chert in the Staendebach is oolitic. With rare and inconspicuous exceptions, grains of quartz are absent from the Tanyard Formation. The Tanyard fauna is dominated by gastropods and cephalopods.

Westward from the Llano region in the subsurface, the Threadgill Member rapidly thins and disappears because of lateral gradation to rock which by definition belongs to the San Saba Member of the Wilberns Formation. An almost total absence of sand grains, characteristic of the Tanyard in the Llano region, is not characteristic a short distance to the south, southwest, west, and northwest; in the same directions the Gorman becomes nonsandy, whereas in the Llano region it is sandy.

The Gorman Formation, correlative with the Roubidoux Formation of Missouri, constitutes the middle third of the Ellenburger Group; it averages 470 feet thick. Dominantly microgranular to very fine-grained dolomite constitutes a lower dolomitic facies except in the northwestern corner of the region, where the grain size of the dolomite is coarser and where erratic lateral transition to calcitic rocks occurs. The upper half of the formation is principally limestone, with a median intrafacies of dolomite coming in eastward, and with the uppermost limestones unusually pure and thickly bedded. The chert of the Gorman Formation is apt to be chalcedonic to porcelaneous. Sand is a characteristic feature of the Gorman Formation in its surface exposures—not as well-defined beds but as scattered to abundant grains in dolomite, limestone, or chert. Where sand occurs in Ellenburger rocks of the Llano region, it constitutes

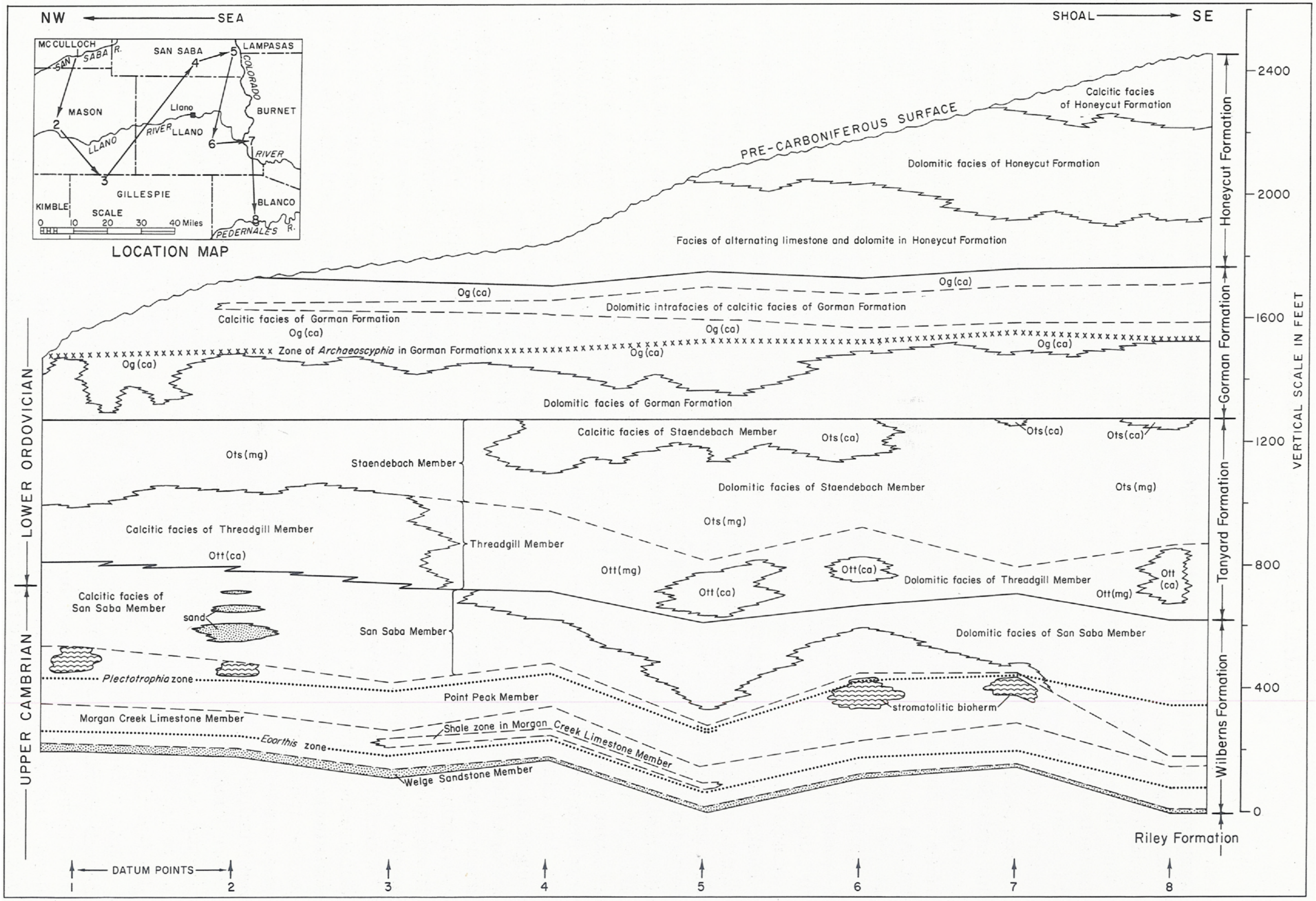


FIG. 10. Diagrammatic representation of the Ellenburger Group and Wilberns Formation in the Llano region of Central Texas.

presumptive evidence but not proof that the strata are younger than the Tanyard Formation. Moreover, it suggests that they are older than the lower 50 feet of the Honeycut Formation. Relatively large low-spired gastropods are the most conspicuous fossils in the Gorman Formation. The lithistid sponge *Archaeoscyphia* has been found in the Gorman Formation only near its middle, at many places dividing the calcitic facies above from the dolomitic facies below.

Figure 11 is an isopach map showing a general westward thinning of the combined Tanyard and Gorman time-equivalents (*from* Barnes, 1959, p. 40). This map also shows the area where post-Ellenburger erosion has partly removed these equivalents, and the area far from the Llano region where the Tanyard and Gorman equivalents lap onto the Precambrian. The great distance here indicated of the Llano region from the shore may explain the paucity of terrigenous material in the Ellenburger rocks of the Llano region; although, as shown by the distribution of sand in the Gorman and lower Honeycut, land of low relief underlain by quartz-bearing rocks probably lay near enough to the east for windborne sand to reach the Llano region.

The upper third of the surface Ellenburger sequence, essentially correlative with the Jefferson City Dolomite of the Ozark uplift, is called the Honeycut Formation. It is known to be present only in the eastern part of the Llano region where it attains a thickness of about 680 feet. It disappears by truncation west of 98°55′ longitude in western San Saba County. Where thickest in outcrop it is divisible into three facies—a lower one of alternating limestone and dolomite, a middle dolomitic facies, and an upper calcitic facies. Locally, the middle dolomitic facies grades abruptly to limestone. Lithically, individual samples of limestone, dolomite, or chert are very like those of the Gorman Formation. Sand grains are much less common than in the Gorman Formation, however, and are rare at most places above the lower 50 feet. *Ceratopea* and *Archaeoscyphia* are locally common, and some beds containing them are useful local datum markers. The fauna of the Honeycut Formation is dominated by gastropods of many sizes and shapes and by the sponge *Archeoscyphia.* Trilobites are more common in the Honeycut than in the lower Ellenburger strata except in the upper 100 feet of the Tanyard Formation.

Eastward from the Llano region in the subsurface, younger Honeycut beds were found in Shell Oil Company No. 1 Purcell, Williamson County, but the top portion of the formation was missing. Westward, post-Honeycut Ellenburger rocks were first recognized in Pecos and Upton counties. Figure 12 is an isopach map of Honeycut and post-Honeycut time-equivalents (*from* Barnes, 1959, p. 41). Everywhere in this area the top of the Ellenburger appears to be an erosional unconformity, and over a large central area the Honeycut and post-Honeycut equivalents have been completely removed.

During Early Ordovician time the Llano region remained relatively stable, with minor fluctuations in depth and temperature of water, condition of the bottom, and nearness of land. The marine waters of the region were primarily warm, intermittently turbulent, and relatively well-oxygenated shoal waters, deepening to the northwest. Sedimentationally and ecologically the region was like the Bahama Banks off the southeast coast of Florida. Its generally soft bottom of pure carbonate muds and the intermittently turbid nature of its waters inhibited the development of shell-bearing bottom dwellers except in local areas where firm bottom conditions occurred. Where and when favorable bottom conditions prevailed, these local colonies were enabled to coalesce and extend more widely through the region. The faunal changes coincident with changes of rock type at the formational boundaries correlate with similar faunal changes in other regions and probably are related to eustatic (or epeirogenic) movements—an interesting and characteristic feature of Lower Ordovician rocks in the eastern and central United States. Departure from prevailing conditions (thermal, depth, chemical) of the ancient waters at any particular time is suggested by the nature, persistence, and frequency of penecontemporaneous dolomitization.

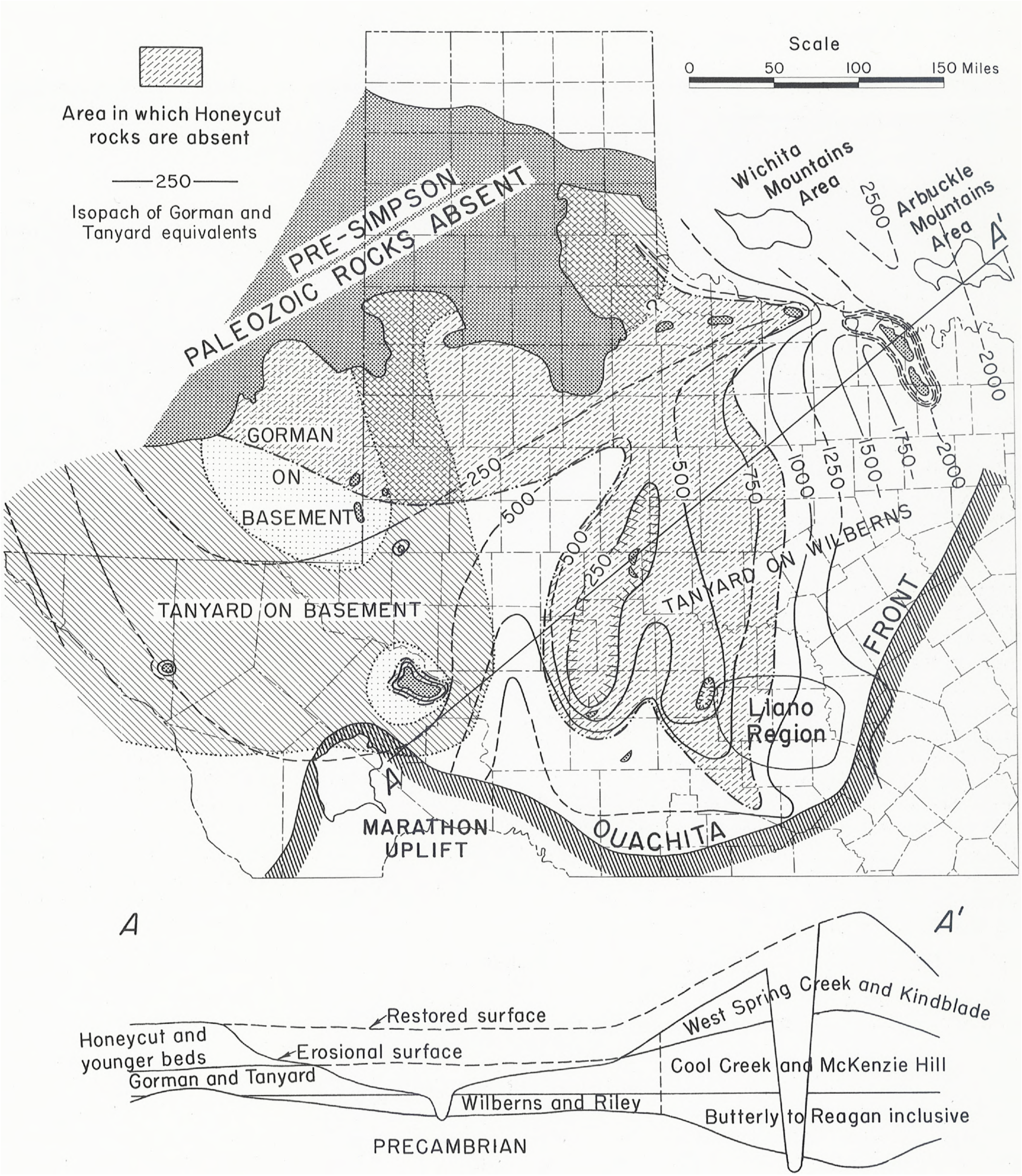


FIG. 11. Isopach map of Tanyard and Gorman equivalents in Texas, southeast New Mexico, and southern Oklahoma.

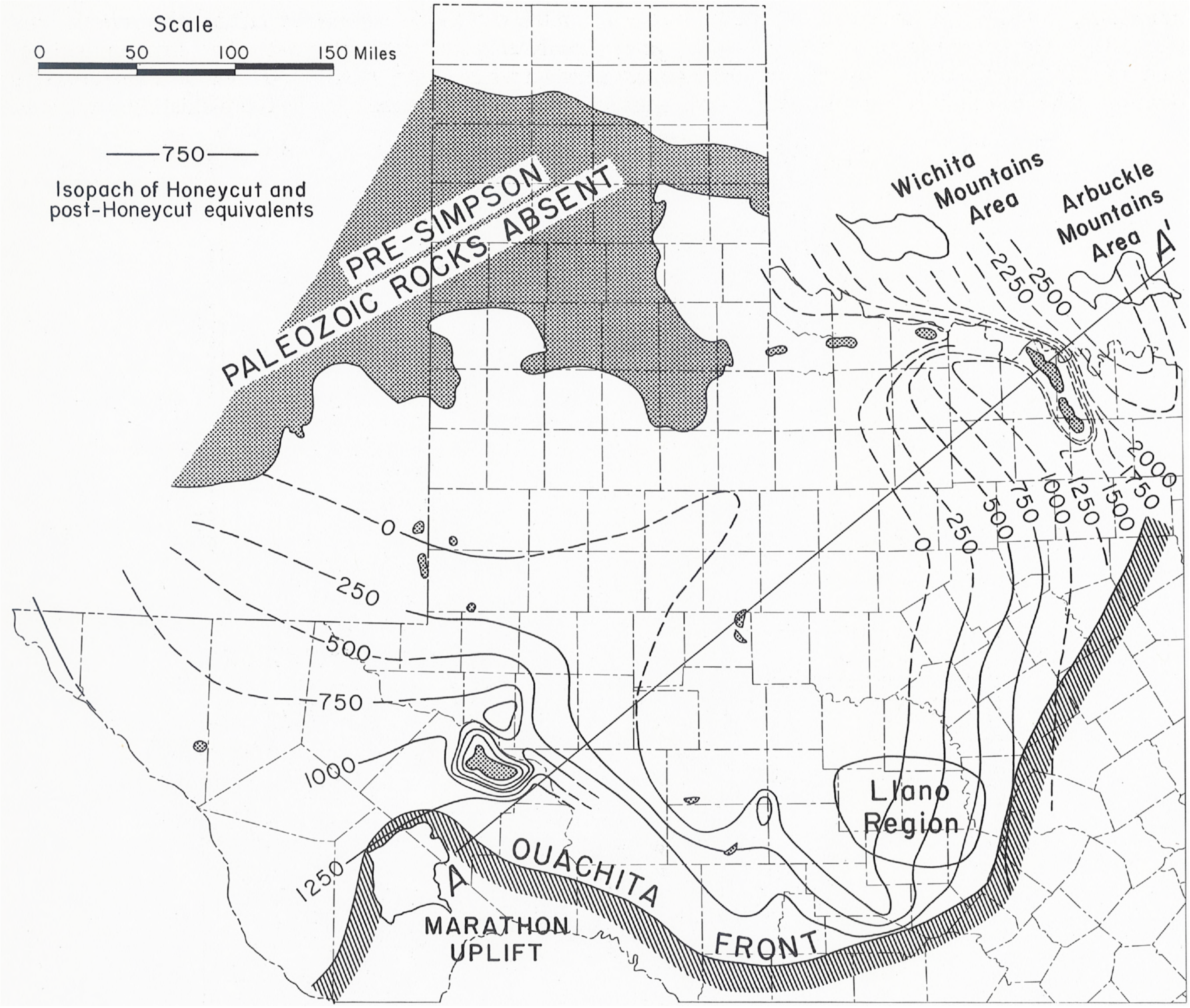


FIG. 12. Isopach map of Honeycut and post-Honeycut equivalents in Texas, southeast New Mexico, and southern Oklahoma.

MIDDLE ORDOVICIAN

If the possible Middle Ordovician conodonts *(Chirognathus)* found in a mixed conodont assemblage in earliest Mississippian rock in Blanco County prove in fact to be Middle Ordovician forms, then they may be "ghosts" of Simpson Group rocks formerly present in the area (Barnes, Cloud, and Warren, 1946).

UPPER ORDOVICIAN

The Upper Ordovician presently is represented by only one small outcrop area of limestone, the Burnam (Barnes, Cloud, and Duncan, 1953). This limestone, located in southern Burnet County (fig. 13), is considered to be correlative with some part of the Cincinnatian, possibly the Richmond Group. The Burnam is exceptionally pure, very coarse grained, light colored, fossiliferous, and is preserved in a collapse structure in the Ellenburger. The nature and worn character of the large and relatively solid fossils, such as the corals and cephalopods, suggest that the environment of deposition may have been near a wave-breaking organic reef (or reefs) or near pre-existing coral beds.

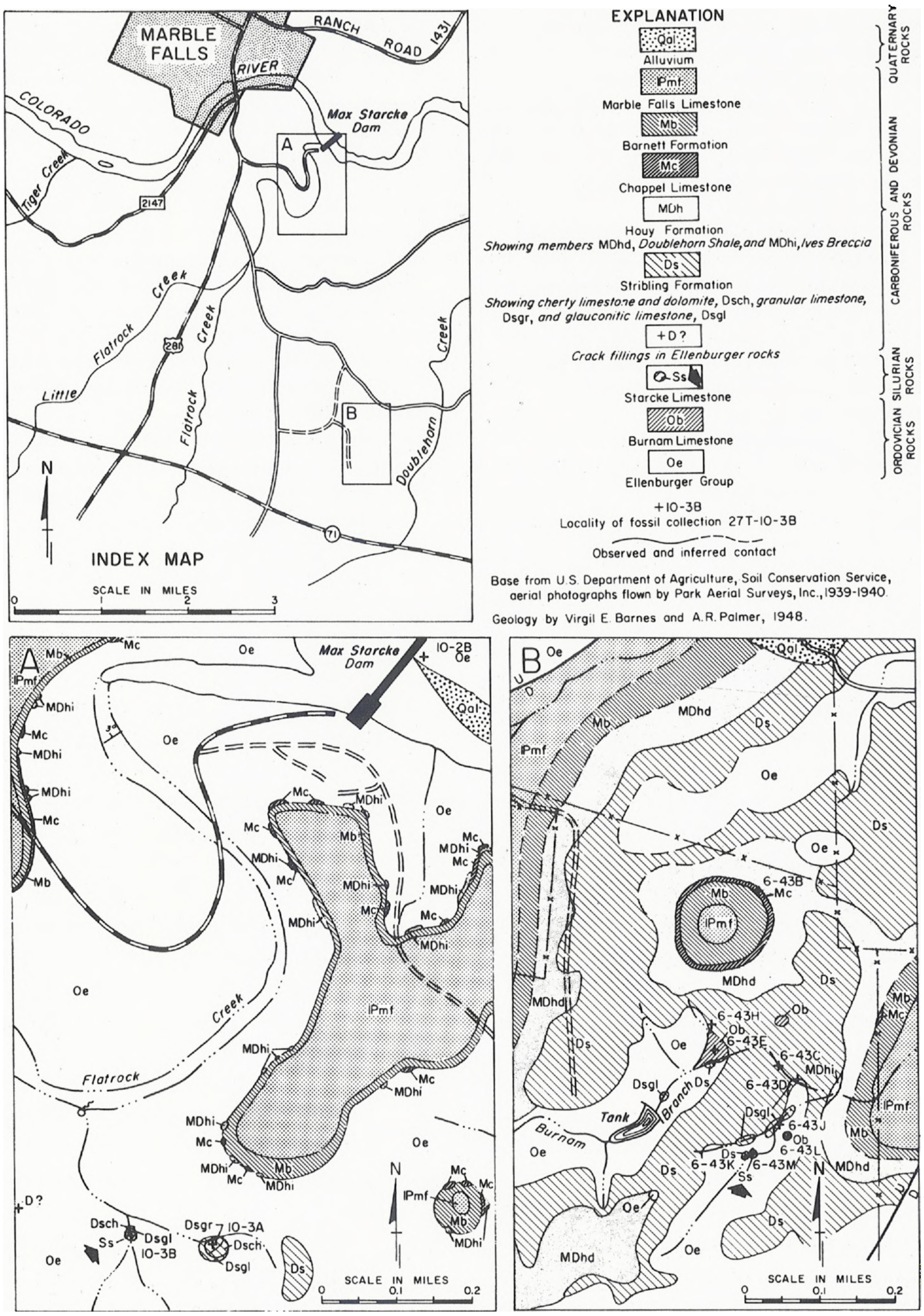


FIG. 13. Location and geology of Upper Ordovician and Silurian outcrops in Central Texas.

SILURIAN

The first description of Silurian rocks from Central Texas was by Barnes et al. (1966) who stated:

> Rocks younger than Early Ordovician and older than Carboniferous were once believed to be missing from the Llano uplift of Central Texas, a tectonic outpost of older rocks surrounded by a vast expanse of Carboniferous and younger sediments. Beginning in 1945, however, a picture has emerged of remnants of once-extensive deposits of Upper Ordovician and Lower, Middle, and Upper Devonian age, preserved in collapse structures and fissures in older rocks, and as minute erosional remnants, after the parent sediments were mainly removed by erosion during one or more of many episodes of emergence. To these we now add Silurian, giving the region a known representation of all Paleozoic systems except the Permian.
>
> Although the fossils which establish a Silurian date were originally collected from the type locality (fig. 1, locality 27T-10-3B) [fig. 13] by James Lee Wilson and Barnes, on 26 March 1952, and again by W. H. Hass, Cloud, and Barnes in March 1956, and were then tentatively identified as Silurian by Cloud, other obligations at that time prevented definitive analysis of the fauna. Impetus for this came when the fossils were shown to Boucot in April 1966. He then identified the brachiopods as Middle Silurian (Wenlock)—an assignment that was later supported by Palmer, who found the trilobites to be similar to those of the St. Clair Limestone near Batesville, Arkansas, and by W. A. Oliver, Jr., U. S. Geological Survey, who identified the corals as closest to (but not necessarily correlative with) species from the Brownsport and Henryhouse Formations. As a result, Barnes, Boucot, and Cloud, in company with W. C. Bell and James Lee Wilson, re-collected the type locality on 8 June 1966 and shipped about ½ ton of fossiliferous limestone blocks to Pasadena for processing.
>
> The brachiopods from locality 27T-10-3B are most similar to those of the St. Clair and Clarita Limestones of Oklahoma and Arkansas, although the two assemblages are by no means identical. A pre-Ludlow age is demonstrated by the presence of *Streptis?*, *Laengella*, and *"Dolerorthis" flabellites*. The *Amphistrophia?* is a form not known in beds as old as Llandovery. The *Kozlowskiellina* is a form known in North America so far only from the St. Clair Limestone. This combination indicates that we are dealing with beds of Wenlock age, with an outside limit of possible age in terms of European equivalents between about C_3 (late Llandovery) through Wenlock.
>
> Associated trilobites and corals are consistent with a Wenlock age as indicated by the brachiopods. Fragments of associated cephalopods appear to belong to the distinctive Middle Silurian to Lower Devonian genus *Dawsonoceras*.
>
> A large quantity of the limestone from locality 27T-10-3B has also been dissolved in acetic acid, and the residues have been studied by Miller. Microfossils obtained include a mixed conodont assemblage in which forms of Silurian aspect are abundant. Reworked elements include Burnam and other Ordovician conodonts.

DEVONIAN

The stratigraphic record of the Llano region between Wenlock Silurian and Early Mississippian time is a complex of formerly extensive units, the remnants of which have been described piecemeal as they have been discovered.

Devonian units so far identified (Barnes, Cloud, and Warren, 1947; Cloud, Barnes, and Hass, 1957) are as follows:

1. Pillar Bluff Limestone (Helderberg)—coquinite, fills a crevasse or cave in the Ellenburger, northern Burnet County.
2. Stribling Formation (Onesquethaw)—microgranular limestone, basal 1 to 2 inches sandy, mostly cherty, and 11 feet thick and in normal stratigraphic position in type section, Honeycut Bend, Blanco County. In southern Burnet County sandy glauconitic dolomite and limestone a foot or two thick is thought to be a basal unit of the Stribling.
3. Unnamed limestone (Onesquethaw)—coarse grained, contains fossils indicating equivalence with the Onandaga Limestone, in collapse structures, southern Burnet County.
4. Bear Spring Formation (Cazenovia)—granular limestone, light colored to brownish, in part cherty, several tens of feet thick, in a collapse structure, western Mason County.
5. Houy Formation—units of Upper Devonian, Lower Mississippian, and possibly Middle Devonian age. The writers wish to acknowledge frankly that they are still very much puzzled about the proper relationships of beds and faunas of this formation, even though they have seen a probably very high percentage of the available data on them. The principal unit of the Houy Formation, the Doublehorn Shale Member, cropping out in the eastern part of the Llano region, is a black, fissile, radioactive, spore-bearing shale up to 15 feet thick. A more widely distributed unit, the Ives Breccia Member, is a chert breccia rarely as much as 3 feet thick. Other units, unnamed, include pockets of siliceous limestone beneath the Ives Breccia in Blanco County and an upper phosphoritic unit 2 feet or less thick, common in the eastern area.

Seddon (1970) reinstated the Zesch Formation of Barnes, Cloud, and Warren (1947) which had been lumped with the Ives Breccia Member of the Houy Formation by Cloud, Barnes, and Hass (1957) and assigned it to the Middle Devonian Tioughniogo Stage.

REFERENCES

BARNES, V. E. (1959) General discussion, *in* Stratigraphy of the pre-Simpson Paleozoic subsurface rocks of Texas and southeast New Mexico: Univ. Texas Pub. 5924, pp. 1-72.

_______, BOUCOT, A. J., CLOUD, P. E., Jr., MILLER, R. H., and PALMER, A. R. (1966) Silurian of Central Texas: A first record for the region: Science, vol. 154, pp. 1007-1008.

_______, CLOUD, P. E., Jr., and DUNCAN, HELEN (1953) Upper Ordovician of Central Texas: Bull. Amer. Assoc. Petrol. Geol., vol. 37, pp. 1030-1043.

_______, _______, and WARREN, L. E. (1946) The Devonian of Central Texas, *in* Texas mineral resources: Univ. Texas Pub. 4301 (Jan. 1, 1943), pp. 163-177.

_______, _______, and _______ (1947) Devonian rocks of Central Texas: Bull. Geol. Soc. America, vol. 58, pp. 125-140.

CLOUD, P. E., Jr., and BARNES, V. E. (1948) The Ellenburger Group of Central Texas: Univ. Texas Pub. 4621 (June 1, 1946), 473 pp.

_______, and _______ (1957) Early Ordovician sea in Central Texas: Geol. Soc. America Mem. 67, vol. 2, pp. 163-214.

_______, _______, and HASS, W. H. (1957) Devonian-Mississippian transition in Central Texas: Bull. Geol. Soc. America, vol. 68, pp. 807-816.

SEDDON, GEORGE (1970) Pre-Chappel conodonts of the Llano region, Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 68, 130 pp.

CARBONIFEROUS HISTORY, LLANO REGION

W. C. BELL

Carboniferous strata in the Llano region have been described and discussed by numerous eminent geologists during the past 85 years. Outcrops in the area have served as the basis for such names as Bend, Lampasas, Chappel, Barnett, Marble Falls, Big Saline, Smithwick, Sloan, Aylor, Lemons Bluff, Brister, Gibbons, Brooks Ranch, and Soldiers Hole. Almost without exception every discussion has had strong paleontologic overtones, and almost every stratigraphic conclusion has been derived in part or entirely from a paleontologic argument. Only Sidney Paige and Virgil E. Barnes have published maps at quadrangle scales, and neither of them subdivided the Marble Falls, whereas F. B. Plummer defined or sponsored 8 subdivisions of the Marble Falls but mapped none of them at any scale. For my part, I am in the embarrassing position of disbelieving most previously published interpretations because of too many data, but not having proposed an integrated alternative because, until recently, of too few data.

Carboniferous strata in the Llano region are in large part exposed in three noncontiguous areas, almost all of which have been investigated at least in part by my students and myself in recent years. The following comments are intended to be primarily factual and descriptive; interpretations are left for the moment to others.

MARBLE FALLS AREA

The Marble Falls area in southwestern Burnet County is situated and isolated on the southeastern periphery of the Llano region. It contains the type section (385 feet thick and now mostly under water) of the Marble Falls Limestone, described by Barnes (1952), and conformable type Smithwick. The Marble Falls Limestone in the Marble Falls area was investigated in detail by Namy (1969). He found numerous facies, most of which change rapidly laterally and vertically, and a disconformity within the Marble Falls.

Kimberly (1961) investigated the Smithwick in the Marble Falls area. According to him the Smithwick, at least 450 feet thick, consists of claystone deposited at the toe of a delta building westward from Llanoria and interbedded lenticular sandstone beds that "were derived from deltaic sediments northeast of Burnet County and were carried to their present location by turbidity currents" (p. 87). "Type" Smithwick and "Smithwick" of San Saba County and the subsurface of North Texas are quite different lithologically; both overlie Marble Falls Limestone, but whether or not they are genetically related is at present unknown.

Stratigraphy of the Chappel and Barnett in the Marble Falls area is not well known, and two isolated areas of Carboniferous strata to the south at Cypress Mills and along Pedernales River from Pedernales Falls to Honeycut Bend have received little attention.

MASON AREA

The Mason area in southwestern Mason County and northeastern Kimble County contains a half dozen Carboniferous fault blocks and is situated and isolated on the southwestern periphery of the Llano region.

The Marble Falls consists of 150 to 200 feet of fusulinid-, alga-, and *Chaetetes*-bearing limestone, divisible into a dozen facies types and perhaps eleven cycles but apparently not divisible into mappable members. Facies patterns are complex. This is the "Big Saline" of much of Texas literature, but it is unlikely that the name is either necessary or useful. The Mason area is also the area of the "rose" Chappel and Barnett "limesand" of Cloud and Barnes (1948, pp. 49-59).

Winston (1963) investigated the Mason area in great detail and presented his own observations on Marble Falls Limestone and the "rose" and "limesands." R. E. Janowsky (thesis in progress) is currently reinvestigating this same area in the light of new information derived from the Carboniferous exposures to the north. Interestingly and perhaps expectedly all of these workers have arrived at somewhat different conclusions about the Chappel, Barnett, and Marble Falls Limestones and their interrelationships.

NORTHERN AREA

The third area of Carboniferous outcrop is an almost continuous arcuate strip along the northwest, north, and northeast periphery of the Llano region in McCulloch, San Saba, and Lampasas counties. Eleven masters' theses have been completed under my direction (Bogardus, 1957; Bowers, MS.; Defandorf, 1960; Gries, 1970; Kuich, 1964; McKinney, 1963; Oden, 1958; Pickens, 1959; Rose, 1959; Schake, 1961; and Stitt, 1964) and four doctoral dissertations (Freeman, 1962; Kier, 1972; Turner, 1970; and Zachry, 1969).

Chappel crinoidal limestone (type section near San Saba) is discontinuously present and a foot or two thick throughout the area. Apparently its presence is partly related to a karst topography on the Ellenburger, and it can be as much as 25 feet thick in sinks; it has many of the attributes of a "basal conglomerate" transgressive across a carbonate terrane.

Barnett brown shale (type section near San Saba) is continuously 40 to 50 feet thick throughout the area and conformable both with the Chappel below and the Marble Falls above. Rarely, thicknesses as low as 5 feet are encountered, but these seem to be related to local aspects of the underlying karst topography. Large ellipsoidal limestone concretions are characteristic of the lower Barnett, and calcareous, phosphatic, and glauconitic strata are characteristic of the top 5 to 15 feet. It is this thin topmost interval that has been by many writers assigned to the Pennsylvanian and claimed to provide evidence of unconformity between Barnett and Marble Falls. From the standpoint of mapping, the interval belongs in the Barnett. There is evidence in the interval for slow rate of deposition, winnowing, and by-passing resulting in very slow accumulation, but none for unconformity. In fact three masters' students and three doctoral students reported that the boundary appears to be gradational, or that Barnett-like and Marble Falls-like lithologies are interbedded.

Across San Saba County and extending slightly into McCulloch and Lampasas counties, the Marble Falls is about 200 to 250 feet thick, and its outcrop is almost everywhere divisible on aerial photographs into three parts: a lower carbonate sequence, a middle shale or shaly sequence, and an upper carbonate sequence. Within these limits each unit differs from place to place in thickness and lithic character, and reconstruction of the regional lithofacies patterns, beyond each student's own area, has only begun. These sequences, *as mappable units*, have not heretofore been recognized in Texas literature. Southeast of San Saba the "type" Sloan and south of Bend the "type" Aylor constitute part or all of the lower map unit; southeast of San Saba the "type" Lemons Bluff and midway between San Saba and Bend the "type" Brister constitute part or all of the upper map unit. At Rough Creek, where "type" Brister is exposed, Plummer (1950, p. 72) called the middle map unit "Lemons Bluff." Correlations between adjacent fault blocks are mostly known and almost certainly the map units are not time-stratigraphic units.

Minor faulting took place in some areas during deposition of the Marble Falls, and an unconformity at the base of the middle map unit has been identified in most places in the northern area. No other unconformities at the base, within, or at the top, at most places, of the Marble Falls have been recognized by me or any of my students. Only local erosion by sandstone-filled channels of the Strawn seems to have occurred.

Gross units of the sort mapped in San Saba County are time-transgressive northwesterly, and a complex facies pattern is evident. Plummer's Soldiers Hole and Brook Ranch "Members" are local patches of fusulinid-bearing carbonate facies with little lateral persistence; they are not mappable. "Cavern Ridge," referred to frequently by Plummer and others, is on the outcrop entirely fictitious, and the use of the term "Big Saline" in the Brady area is without merit.

The Carboniferous inlier near Lampasas has not been investigated, but enough is known to suspect that the Chappel and Barnett are "normal" and that although the Marble Falls appears different than it is in western Lampasas County, lithofacies in the two areas are genetically related.

In summary—and by way of warning—previously published interpretations of Carboniferous stratigraphy in the Llano region are based almost wholly on paleontologic bias and layer-cake "principles" of one sort or another. The only published observations sufficiently dependable that they can contribute to future interpretations are by Cloud and Barnes. These observations coupled with the unpublished detailed observations by my students should form the best base for future interpretations.

REFERENCES

BARNES, V. E. (1952) High purity Marble Falls Limestone, Burnet County, Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 17, 19 pp.

BOGARDUS, E. H. (1957) Lower Pennsylvanian of the Richland Springs area, San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 159 pp.

BOWERS, M. E. (MS.) Cephalopods of the Barnett Formation, Central Texas.

CLOUD, P. E., Jr., and BARNES, V. E. (1948) The Ellenburger Group in Central Texas: Univ. Texas Pub. 4621 (June 1, 1946), pp. 42-60.

DEFANDORF, MAY (1960) Paleontology and petrography of Carboniferous strata in the Sloan area, San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 215 pp.

FREEMAN, T. J., Jr. (1962) Carboniferous stratigraphy of the Brady area, San Saba and McCulloch counties, Texas: Univ. Texas, Austin, Ph.D. dissert., 219 pp.

GRIES, R. R. (1970) Carboniferous biostratigraphy, western San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 228 pp.

KIER, R. S. (1972) Carboniferous stratigraphy in eastern San Saba County and western Lampasas County, Texas: Univ. Texas, Austin, Ph.D. dissert., 437 pp.

KIMBERLY, J. E. (1961) Sedimentology of the Smithwick Formation, Burnet County, Texas: Univ. Texas, Austin, Master's thesis, 95 pp.

KUICH, N. F. (1964) Carboniferous stratigraphy of the Sloan area, San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 184 pp.

McKINNEY, W. N., Jr. (1963) Carboniferous stratigraphy of the San Saba area, San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 164 pp.

NAMY, J. N. (1969) Stratigraphy of the Marble Falls Group, southeast Burnet County, Texas: Univ. Texas, Austin, Ph.D. dissert., 385 pp.

ODEN, J. W. (1955) Carboniferous stratigraphy of the Leonard Ranch area, San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 158 pp.

PICKENS, W. R. (1959) Carboniferous stratigraphy of the Jackson Ranch area, Lampasas County, Texas: Univ. Texas, Austin, Master's thesis, 145 pp.

PLUMMER, F. B. (1950) The Carboniferous rocks of the Llano region of Central Texas: Univ. Texas Pub. 4329 (Aug. 1, 1943), 170 pp.

ROSE, P. R. (1959) Carboniferous stratigraphy of the Hall area, San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 254 pp.

SCHAKE, W. E. (1961) Carboniferous stratigraphy of the Wallace Creek area, San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 150 pp.

STITT, J. H. (1964) Carboniferous stratigraphy of the Bend area, San Saba County, Texas: Univ. Texas, Austin, Master's thesis, 152 pp.

TURNER, N. L. (1970) Carboniferous stratigraphy of western San Saba County, Texas: Univ. Texas, Austin, Ph.D. dissert., 377 pp.

WINSTON, DONALD, II (1963) Stratigraphy and carbonate petrography of the Marble Falls Formation, Mason and Kimble counties, Texas: Univ. Texas, Austin, Ph.D. dissert., 344 pp.

ZACHRY, D. L., Jr. (1969) Carboniferous stratigraphy of the Chappel area, San Saba County, Texas: Univ. Texas, Austin, Ph.D. dissert., 353 pp.

MESOZOIC HISTORY, LLANO REGION

KEITH YOUNG

The Mesozoic rocks of Texas are dominated by those of the Cretaceous System, and of the Mesozoic rocks only Cretaceous are known in the Llano region. The area of the Llano region was undergoing erosion throughout Triassic and Jurassic time. The thinned edge of the Triassic red beds may have reached almost to the Llano region on the west before being eroded back to its present position during Jurassic and early Cretaceous.

The Mesozoic history of the Llano region can be described in terms of gulfward tilting of the north flank of the Gulf of Mexico geosyncline and the sinking of the Gulf and its margins, resulting in the slow but continued transgressive flooding of the north flank of the Gulf geosyncline and hence that part of its northern flank known as the Llano uplift. To the east of the Llano uplift, in the East Texas Embayment, during the Triassic and Jurassic a thick sequence of evaporites and terrigenous rocks was laid down (Scott, Hays, and Fietz, 1961). In a slightly less restricted area the upper Jurassic terrigenous marine sequence was deposited, many miles to the east and south of the Llano uplift, and the Llano region was one of the source areas for these deposits. Since the region was a low-lying area, the Jurassic formations are not as thick toward the Llano source as toward other source areas.

The broad invasion of the Cretaceous sea gradually covered this land, which had been reduced to low relief by the preceding erosion. This surface of erosion has been termed the Wichita paleoplain by Hill (1901). Hill recognized the considerable local relief on this surface. Each of the formations up to the Edwards Limestone (table 2) is overlapped by younger formations, each of which in turn rests on pre-Cretaceous formations. Locally, in the Brady area, Mercury quadrangle (Jenkins, 1953), there is approximately 100 feet of differential elevation between the highest and lowest contacts of Cretaceous on Pennsylvanian. Not more than 20 or 25 feet of this can be attributed to regional dip. The remainder is due to deposition of pre-Walnut formations in pre-Cretaceous stream valleys to a thickness of 60 or 70 feet followed by deposition of the Walnut Clay as a blanket across the entire area. In other areas more or less relief on Hill's paleoplain can be seen (Barnes, 1952a, 1952b; Pavlovic, 1956), but it is not yet completely documented by topographic mapping. In the updip subsurface of Travis County some of the variation in thickness of the pre-Cow Creek rocks seems to result from widely spaced relief features on the Wichita paleoplain.

Over the relief of this surface the Cretaceous sea transgressed, and as the transgression proceeded, the near-shore, lagoonal, tidal, and fluvial environments led the inland edge of the normal marine environments. Thus, on the outcrop, the Sycamore Conglomerate is probably the updip edge of the lowest marine sequence—the Hosston-Sligo—and represents a fluvial environment (Lozo and Stricklin, 1956; Forgotson, 1956). It is restricted to the southeast side of the Llano uplift in the Colorado River valley and near tributaries. Local and slight rejuvenation of the uplift resulted in a local erosion surface at the top of the Sycamore Conglomerate (Lozo and Stricklin, 1956).

As the uplift was again worn down by erosion, the differential fluvial and marine environments again onlapped the older rocks, overlapping the Sycamore Conglomerate to rest on a Paleozoic terrain. This sequence is the Hammett Shale and the Cow Creek Limestone, which are two interfingering lithosomes. The marginal deposits of the Hammett Shale contain marine conglomerates and marine sandstones, but if there were once more marginal fluvial deposits, they have since been removed by erosion. The Hammett and the Cow Creek are also restricted to the southeast (the Gulf Coast geosyncline) side of the Llano uplift, marine waters having breeched neither the old Bend Arch to the north of the Llano uplift nor all of the San Marcos Platform to the south of the uplift during deposition of these rocks. The uppermost Cow Creek Limestone, near the uplift, is at many places beach rock, and during its deposition the area to the southeast of the uplift had reached a high-energy undaform surface for at least three counties, or perhaps 150 miles, to the southeast.

Further sinking of the Gulf Coast geosyncline resulted in shale deposition downdip (the Bexar Shale of Forgotson, 1956) while erosion and/or by-passing of the Cow Creek surface continued in the Llano region (Barnes, 1948; Barnes et al., 1949). Sinking then continued with the transgression of the upper Trinity or Shingle Hills couplet (Barnes, 1948; Lozo and Stricklin, 1956). The near-shore sandy deposits of the Hensel Sandstone (= Gillespie

TABLE 2. *Lithostratigraphic classification of Cretaceous rocks of Central Texas.*

SYSTEM	SERIES	DIVISION	FORMATION	MEMBER	THICKNESS *(Feet)*
Tertiary		Midway	Kincaid	Littig	
CRETACEOUS	GULF	Navarro	Kemp		350
			Corsicana		100
		Taylor	"Taylor"		360
			Pecan Gap		30 - 75
		Austin	Unnamed		0 - 300
			Big House		350
			Burditt		
			Dessau		
			Jonah		
			Vinson		
			Atco		
		Eagle Ford	South Bosque		20
			Lake Waco	Bouldin	8
				Cloice	12
		Woodbine	Pepper		3 - 5
	COMANCHE	Washita	Buda		40
			Del Rio		75
			Georgetown		80
		Fredericksburg	Edwards		150 - 350
			Comanche Peak		0 - 200
			Walnut	Upper clay	0 - 50
				Cedar Park	0 - 120
				Bee Cave	0 - 20
				Bull Creek	0 - 40
		Trinity	Shingle Hills	Glen Rose	0 - 700
				Hensel	0 - 40
			Cow Creek		0 - 80
			Hammett		0 - 30
			Sycamore		0 - 550
Precambrian, Paleozoic, or Jurassic					

Formation) represent fluvial, tide-channel, lagoonal, beach, and probably near-shore marine environments. During this time the carbonate evaporites associated with the Glen Rose Limestone were deposited offshore on an undaform that continued to the east-southeast and south for at least 150 miles to the trend of the Stuart City reef complex (Winter, 1961a, 1961b). This broad shelf gives no indication of any great difference in depth of water throughout the thousands of square miles now occupied by the Glen Rose Limestone. By the end of Glen Rose deposition the sea had extended part of the way around the Llano uplift, but the main part of the Llano uplift formed the end of a peninsula superimposed on the Texas Peninsula of Adams (1954a, 1954b) yet expanding more rapidly to the north and west.

Although there is disconformity between Trinity (Glen Rose) and Fredericksburg only in the vicinity of the Llano uplift (Moore, 1961a, 1961b), even in those areas which show no disconformity, the top of the Glen Rose represents the end of a cycle of deposition dominated by fine-grained dolomitic limestone, fine-grained limestone, and evaporites or rocks deposited in near-evaporite lithotopes. That the water was shallow during the deposition of the latest Trinity rocks is indicated by mudcracks, dinosaur tracks, and gastrochaenid and pholad borings in the top of the Glen Rose. Even the dinosaur tracks are bored, indicating that the borings represent the new-post-evaporite, high-energy zone that heralded the start of Fredericksburg deposition. During the deposition of the Fredericksburg and the lower part of the Washita, sedimentation was still controlled by the Stuart City reef complex; the site of deposition deepened so slowly that deposition was never completely below the high-energy zone except locally to the leeward of the various tabular reef or other masses that provided protective baffles from the main currents. Even then the non-rudistid sediments were continually worked and reworked by tropical storms.

Northeast of the Llano uplift there is in the lower Fredericksburg a fringe of quartz sandstone (Paluxy) which interfingers with the lower Walnut-age rocks to the east (Moore, 1961b). As the marine transgression continued and the site of deposition continued to sink, but with deposition keeping pace with sinking, the Fredericksburg marine invasion finally crossed the Bend Arch and the Callahan Divide from the east. These were joined with a marine advance from the southward on the west side of the Llano uplift. The joining of these two marine tongues, by at least middle Comanche Peak time, isolated the present Llano region as a few granite or limestone islands. Shortly thereafter these islands were drowned. By the end of Fredericksburg deposition there were probably no islands, and the marine transgression had continued to beyond Lubbock, and by earliest Washita time had joined with the marine transgression from the Arctic to form the continuous marine connection called the Cretaceous Rocky Mountains geosyncline or the Mesocordilleran geosyncline.

The Llano area, then, was covered by Fredericksburg and Washita rocks, as shown by regional dips and incomplete and unpublished isopachous studies. During the early part of the Washita, to the east and north of the Llano uplift, there were deposited nodular, neritic limestone sediments of a normal molluscan-ammonite facies, whereas to the southwest, the ammonite facies was replaced by the rudistid facies, which was not terminated with the deposition of the Edwards Limestone of the Fredericksburg Division but continued in some areas farther south of the uplift, to the base of the Del Rio (Adkins, 1933; Winter, 1961a, 1961b).

The Del Rio Formation, which is the middle formation of the Washita Division, constitutes as near a blanket deposit, off the uplift, as can be imagined. Since the Del Rio Formation is absent or extremely thin on the San Marcos Platform, south of the Llano uplift, it is doubtful if the formation ever covered the uplift. Whether it is absent by lacuna or by equivalents in some thin limestone unit, now absent by erosion, cannot be documented.

The Buda Limestone is a hard limestone, which gives way to Del Rio and Grayson Clay north of Williamson County. Again it is doubtful if Buda Limestone was ever deposited on the now exposed part of the Llano uplift (Hixon, 1959). The margin of the Buda Limestone probably just skirted the Llano uplift. However, it must be emphasized that because equivalents of the Georgetown Limestone are still preserved as far north as Colorado and New Mexico, only a carbonate terrain was exposed to furnish sediments for Buda Limestone immediately adjacent to the Llano uplift being eroded and deposited as intraclasts in the upper Buda as near as Austin (Hixon, 1959; Martin, 1961).

Whether the Llano region was exposed during Buda deposition or was in the high-energy zone, but under water, is difficult to say. However, the next overlying formation, the Eagle Ford, provides evidence that the Llano region was forested during its deposition. At least the number of fossil logs in the Bouldin Member of the Lake Waco Shale probably could not be supplied on the chance occurrence of a few trees here or there. Toward Austin the Eagle Ford seashore was probably at the northwest city limits, but unfavorable outcrops, erosion of Eagle Ford deposits, and the lack of detailed field work prevent further documentation. The Eagle Ford and Woodbine Divisions consist of terrigenous sediments that were derived from the Ouachita Mountains, from Arkansas, and even from farther east. The occurrence of terrigenous deposits of Woodbine and Eagle Ford at Austin can be explained only by longshore currents, since the locally exposed terrain at that time was of carbonate rock. The Llano uplift—San Marcos Platform element provided the barrier which prevented transport of even terrigenous clays farther west, and on the west side of this element during Eagle Ford and Woodbine were deposited the dominantly carbonate Boquillas Flags.

In the distribution of Upper Cenomanian (table 3) faunal realms, the Llano uplift—San Marcos Platform is extremely important. The East Texas Embayment rocks of this age contain a dominantly north European fauna. The rocks west of the Diablo Platform contain a dominantly Tethian fauna. The rocks between the Llano uplift and the Diablo Platform contain a mixed fauna, and unfortunately it has not yet been well studied.

The top of the Eagle Ford, at least on positive elements, abruptly ends the terrigenous cycle of sedimentation that begins with the Woodbine rocks. Everywhere on the tectonically high elements the same fossils (*Prionocyclus* spp.) underlie this surface, and everywhere the same fossils (*Peroniceras* spp.) overlie it, but in the subsurface the interfingering of the overlying and underlying lithosomes indicates a lack of disconformity, and in the Rio Grande Embayment Austin lithology drops to include the *Prionocyclus* and *Selwynoceras* faunas (Freeman, 1961). Notwithstanding, the Austin begins with the peculiar carbonate cycle long called Austin Chalk or Austin Limestone.

It was during Austin time that the volcanism forecasting the future site of the Balcones fault zone seems to have been most dominant. Volcanism actually began in the Del Rio (Cenomanian) and continued into Navarro (Maestrichtian). This belt of volcanism resulted in the distribution of small plugs of calc-alkaline basalt from Austin south and west along the present site of the Balcones fault zone.

The only effect of the Llano uplift—San Marcos Platform on the Austin Chalk was one of maintaining the platform area in a slightly higher energy zone than the surrounding basins; consequently, the unnamed clay of Schuchert (1943), commonly called the "lower Taylor Clay," becomes most calcareous and the lower part of it goes to chalk on the platform. Most of the Austin and all of the Taylor have been removed from this area except for a few outliers in small grabens along the eastern edge of the Edwards Plateau, but there is no sedimentological evidence to indicate that the formations did not pass over the Llano uplift. Furthermore, the presence of an equivalent formation in the Davis Mountains, and of collapsed blocks of formations of this age just south of the New Mexico border, leads one to believe that these deposits both there and in the East Texas Embayment were probably once present across Texas and continuous to the Rocky Mountain region.

Little can be told of the upper part of the Taylor Division and the Navarro Division from the standpoint of the Llano uplift. The lack of sedimentological evidence to indicate an exposed Llano region indicates that these later formations also were once continuous to their Rocky Mountain equivalents.

According to Helen Jeanne Plummer (unpublished) there were remnants of younger Navarro beds left as outliers on the pre-Midway surface. Mrs. Plummer's detailed studies are about the only evidence of lacuna by erosional vacuity at the top of the Cretaceous, since this often-discussed disconformity is one of the most difficult horizons to work with in the entire Coastal Plain.

How far west Midway (Paleocene) rocks originally extended cannot be determined, but it is possible that they covered the Llano region. Eocene and Oligocene rocks probably did not cover the Llano region, but Oligocene rocks probably extended farther updip originally than now. The Llano region was low and was only a very minor source of sediment for Tertiary rocks until the early Miocene. It was at this time that most, if not all, of the movement on the Balcones fault zone raised the Llano uplift—San Marcos Platform to such height that most of the Navarro, Taylor, and Austin rocks were stripped off and redeposited in the Gulf Coast geosyncline (Bailey, 1923; Weeks, 1945). Some of the holotypes of important Cretaceous fossils were originally described from Miocene collections (Applin, Ellisor, and Kniker, 1925; Frizzell, 1954).

Little physiographic and paleogeomorphologic work has been done in this area. It is probable that

TABLE 3. *Correlation of Central Texas Cretaceous formations with stages.*

SYSTEM	SERIES	STAGE	FORMATION	MEMBER
		Danian	Wills Point	
CRETACEOUS	UPPER	Maestrichtian	Kemp	
			Corsicana	
		Campanian	Taylor	
			Pecan Gap	
			Unnamed	
			Big House	
			Burditt	
			Dessau	
		Santonian	Jonah	
		Coniacian	Vinson	
			Atco	
		Turonian	South Bosque	
		Cenomanian	Lake Waco	Bouldin
				Cloice
			Pepper	
			Buda	
			Del Rio	
	LOWER	Albian	Georgetown	
			Edwards	
			Comanche Peak	
			Walnut	Upper clay
				Cedar Park
				Bee Cave
				Bull Creek
			Shingle Hills	Glen Rose
				Hensel
		Aptian	Cow Creek	
			Hammett	
		?		
		Neocomian	Sycamore	
			Paleozoic or Precambrian or Jurassic	

the Uvalde Gravel (if the term is restricted to the high-level siliceous gravels) shows a return of the gradient, upset by the Balcones faulting, back to near base level in the Pliocene or early Pleistocene. Certainly there seems to be a widespread pediment surface associated with the high siliceous gravels in the area south of the Llano uplift. The age of the high siliceous gravels is conjectural; no fossils have been recovered from these gravels, but they represent a drainage pattern with no relation to the modern drainage pattern.

Regardless of the post-Miocene history of the Llano region, when erosion had cut down to the Buda, and the Edwards Limestone where the Buda is absent, erosion was slowed to a snail's pace. Except for Paleozoic shale formation, somewhat removed from the Cretaceous scarp, and excepting valleys immediately associated with extant larger streams, the present topography on pre-Cretaceous rocks of the Llano region cannot be greatly different from the pre-Cretaceous topography.

REFERENCES

ADAMS, J. E. (1954a) Mid-Paleozoic paleogeography of Central Texas: Shale Shaker, vol. 4, no. 6, pp. 4-5, 8-9.

________ (1954b) Mid-Paleozoic paleogeography of Central Texas, *in* Cambrian Field Trip—Llano area: San Angelo Geol. Soc., Guidebook, pp. 70-73, 2 figs.

ADKINS, W. S. (1933) The Mesozoic systems in Texas, *in* SELLARDS, E. H., ADKINS, W. S., and PLUMMER, F. B., The geology of Texas, Vol. I, Stratigraphy: Univ. Texas Bull. 3232 (Aug. 22, 1932), pt. 2, pp. 239-518, figs. 13-27.

APPLIN, E. R., ELLISOR, A. E., and KNIKER, H. T. (1925) Subsurface stratigraphy of the coastal plain of Texas and Louisiana: Bull. Amer. Assoc. Petrol. Geol., vol. 9, pp. 79-122, fig. 1, pl. 3.

BAILEY, T. L. (1923) The geology and natural resources of Colorado County: Univ. Texas Bull. 2333, 163 pp.

BARNES, V. E. (1948) Ouachita facies in Central Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 2, 12 pp., 2 figs.

________ (1952a) Geologic map of Crabapple Creek quadrangle, Gillespie and Llano counties, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map No. 3.

________ (1952b) Geologic map of Gold quadrangle, Gillespie County, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map No. 9.

________ et al. (1949) Turkey Bend area, Burnet and Travis counties, Texas, *in* Cretaceous of Austin, Texas, area: Guidebook, 17th Ann. Field Trip, Shreveport Geol. Soc., p. 6, pls. 4, 5.

FORGOTSON, J. M., Jr. (1956) A correlation and regional stratigraphic analysis of the formations of the Trinity Group of the Comanchean Cretaceous of the Gulf Coastal Plain; and the genesis and petrography of the Ferry Lake anhydrite: Trans., Gulf Coast Assoc. Geol. Socs., vol. 6, pp. 91-108, 11 figs. (some unnumbered, others numbered without sequence).

FREEMAN, VAL (1961) Contact of Boquillas flags and Austin chalk in Val Verde and Terrell counties, Texas: Bull. Amer. Assoc. Petrol. Geol., vol. 45, pp. 105-107.

FRIZZELL, D. L. (1954) Handbook of Cretaceous Foraminifera of Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 22, 232 pp., 2 figs., 21 pls.

HILL, R. T. (1901) Geography and geology of the Black and Grand Prairies, Texas, with detailed descriptions of the Cretaceous formations and special reference to artesian waters: U. S. Geol. Survey 21st Ann. Rept., pt. 7, 666 pp., 80 figs., 71 pls.

HIXON, S. B. (1959) Facies and petrography of the Buda Limestone of Texas and northern Mexico: Univ. Texas, Austin, Master's thesis, 151 pp., 47 figs., 1 pl.

JENKINS, W. A. (1953) Geology of the Mercury quadrangle, McCulloch County, Texas: Univ. Texas, Austin, Ph.D. dissert., 113 pp., 32 figs., 3 pls.

LOZO, F. E., and STRICKLIN, F. L., Jr. (1956) Stratigraphic notes on the outcrop basal Cretaceous, Central Texas: Trans., Gulf Coast Assoc. Geol. Socs., vol. 6, pp. 67-78, 8 figs.

MARTIN, K. G. (1961) Washita Group stratigraphy, south-central Texas: Univ. Texas, Austin, Master's thesis, 83 pp., 26 figs.

MOORE, C. H. (1961a) Stratigraphy of the Walnut Formation, south-central Texas: Texas Jour. Sci., vol. 13, pp. 17-40, 10 figs.

________ (1961b) Stratigraphy of the Fredericksburg Division, south-central Texas: Univ. Texas, Austin, Ph.D. dissert., 91 pp., 31 figs., 3 pls.

PAVLOVIC, ROBERT (1956) Stop No. 2, "Pedernales Falls," Rogers Ranch, *in* Guidebook, Lower Cretaceous Field Trip: Gulf Coast Assoc. Geol. Socs., p. 11, fig. 4.

SCHUCHERT, CHARLES (1943) Stratigraphy of the eastern and central United States: John Wiley and Sons, New York, 1013 pp., 123 figs., 78 charts, 3 pls.

SCOTT, K. R., HAYES, W. E., and FIETZ, R. P. (1961) Geology of the Eagle Mills Formation: Trans., Gulf Coast Assoc. Geol. Socs., vol. 11, pp. 1-14, figs. 1-7.

WEEKS, A. W. (1945) Balcones, Luling, and Mexia fault zones in Texas: Bull. Amer. Assoc. Petrol. Geol., vol. 29, pp. 1721-1723.

WINTER, J. A. (1961a) Stratigraphy of the Lower Cretaceous (subsurface) of South Texas: Trans., Gulf Coast Assoc. Geol. Socs., vol. 11, pp. 15-24, figs. 1-4.

________ (1961b) Fredericksburg and Washita strata (subsurface Lower Cretaceous), southwest Texas: Univ. Texas, Austin, Ph.D. dissert., 135 pp., 21 figs.

FIELD TRIP ROAD LOG

STOPS 1-7

STEPHEN E. CLABAUGH AND VIRGIL E. BARNES

DEPART FROM VILLA CAPRI MOTOR HOTEL,
2630 North Interregional Highway (IH 35), Austin

Mileage		
Total	*Interval*	
0.0		Go south on access road of Interstate Highway 35 entering the expressway south of 19th Street.
2.4	2.4	Bridge over Colorado River. The Colorado River of Texas is a small stream by comparison with its big relative, the Colorado River of the West, which carved the Grand Canyon. The Colorado River of Texas was once a wilder stream capable of producing muddy floods that reached into the business district of Austin and wreaked havoc in the farmlands adjoining the river between Austin and the coast. During the past 30 years, seven dams have been built on the Colorado within 75 miles of Austin, creating more shoreline in Central Texas than on the Gulf Coast of the State. Some of the lakes may be seen as this route is traversed.
4.7	2.3	Leave Interstate Highway 35.
5.2	0.5	Turn right on Ben White Boulevard and follow State Highway 71 westward.
8.3	3.1	Follow cloverleaf right to Johnson City via U. S. Highway 290.
12.6	4.3	Pass through the small community of Oak Hill. In this vicinity the main branch of the Balcones fault system is crossed; this separates the low-lying coastal plain, underlain by soft Upper Cretaceous and Tertiary sedimentary rocks, from the Central Texas "highlands" or Edwards Plateau, underlain by harder Lower Cretaceous rocks. Most of land ahead is used for ranching, whereas much of that to the southeast is farmland. On north (right) side of road is a two-story stone store built in 1898 [1972, The Fortress]. At this point the route enters the Hill Country. To paraphrase from Jack Maguire in *A President's Country, A Guide to the Hill Country of Texas*, the Hill Country has been called a harsh land because, as Walter Prescott Webb said, it has been "burned by drought, beaten by hail, withered by hot winds, frozen by blizzards." It is a land of small ranches and smaller farms, of peach orchards and pastures. It is, by geographical definition, a part of the Nation's Southland, yet it is western in culture and tradition.
13.3	0.7	Keep left on U. S. Highway 290 leaving State Highway 71.
27.3	14.0	Dripping Springs. Many old stone buildings line Main Street, one block to the right of (north) U. S. Highway 290. Ranch Road 12, which intersects Highway 290 here, leads to Wimberley, 13 miles south, famous for its dude ranches.
35.4	8.1	Henly.
36.8	1.4	A. Robinson Road north to Honeycut Bend.
36.9	0.1	Note stairstep topography in Glen Rose Formation south of road.
37.1	0.2	Hays-Blanco County line.
46.2	9.1	U. S. Highway 281 intersection; go north.
46.3	0.1	Miller Creek bridge.
46.5	0.2	Roadside park on west side of highway.
51.6	5.1	Turn right on A. Robinson Road. This point is in the eastern part of Johnson City, "home" to President Johnson. Here the visitor may see the house in which he grew up, the high school from which he was graduated, and meet residents who have known the President since boyhood. The Blanco County Courthouse and jail, one block north of

Mileage
Total Interval

Highway 290, are typical of early construction in this part of Texas.

From Johnson City to STOP 1 the road traverses Ellenburger and Lower Cretaceous rocks. The Ellenburger rocks mostly are in the valleys and the Cretaceous rocks mostly on the hills. The first Ellenburger rocks encountered belong to the Gorman Formation, and massive limestone seen north of the road belongs to the calcitic facies of the Gorman. As STOP 1 is approached Ellenburger rocks of the Honeycut Formation will be crossed.

54.7 3.1 The prominent limestone bed extending north from the road contains silicified *Archeoscyphia* (a sponge) up to a foot in length. This bed is about 175 feet above the base of the Honeycut Formation.

56.5 1.8 STOP 1. Park vehicle west of culvert and walk a quarter mile to outcrops along Pedernales River.

Please refer to "Geologic map of Honeycut Bend area, Blanco County, Texas" (fig. 14), and "Pennsylvanian, Mississippian, Devonian, and Ordovician rocks, Honeycut Bend, Blanco County, Texas" (fig. 15). Enter pasture to north by way of retaining wall of culvert (do not climb fence) and follow along flat, east of drain, to southwest end of bluff.

The following stratigraphic units crop out in this area:

- Cretaceous
  - Lower Cretaceous
    - Upper Trinity
      - Shingle Hills Formation
        - Glen Rose Limestone Member
        - Hensel Sand Member
    - Middle Trinity
        - Cow Creek Limestone Member
- Pennsylvanian
  - Lower Pennsylvanian
      - Marble Falls Limestone
        - Spiculite facies
        - Biohermal limestone and shale facies
- Mississippian
      - Barnett Formation
      - Chappel Limestone
- Mississippian and Devonian
      - Houy Formation
        - Ives Breccia Member
- Devonian
  - Lower or Middle Devonian
      - Stribling Formation
  - Lower Devonian (?)
      - Pillar Bluff (?) Limestone
- Ordovician
  - Lower Ordovician
    - Ellenburger Group
      - Honeycut Formation

The thickest section (679 feet) of Honeycut rocks in the Llano region is exposed along Pedernales River. The Honeycut Formation is roughly divisible into three units in this section—a lower alternating limestone-dolomite unit, a middle dolomite unit, and an upper limestone unit. Only the uppermost part of the limestone unit can be seen. The limestone is aphanitic, very light gray, and in 6-inch to 2-foot beds. Chert, mostly in angular fragments, somewhat translucent, gray with an olive-green cast, is rather sparsely distributed. On the top surface some brownish, opaque, fossiliferous chert contains *Hormotoma* sp., *Ceratopea* cf. *C. tennesseensis* Oder, and *Orospira* sp. In places the top ledge is a coquinite of *Hormotoma*, mostly unsilicified.

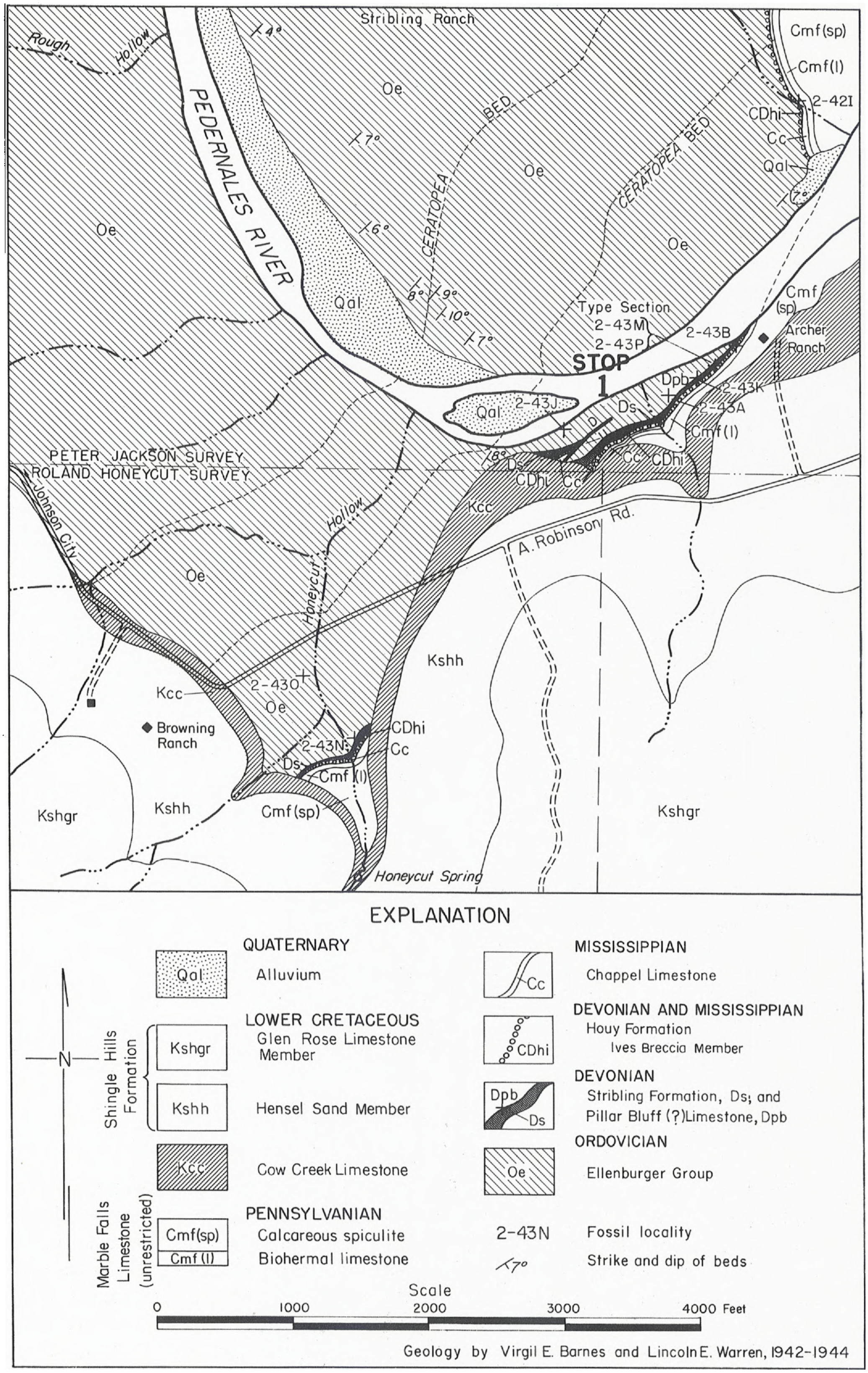
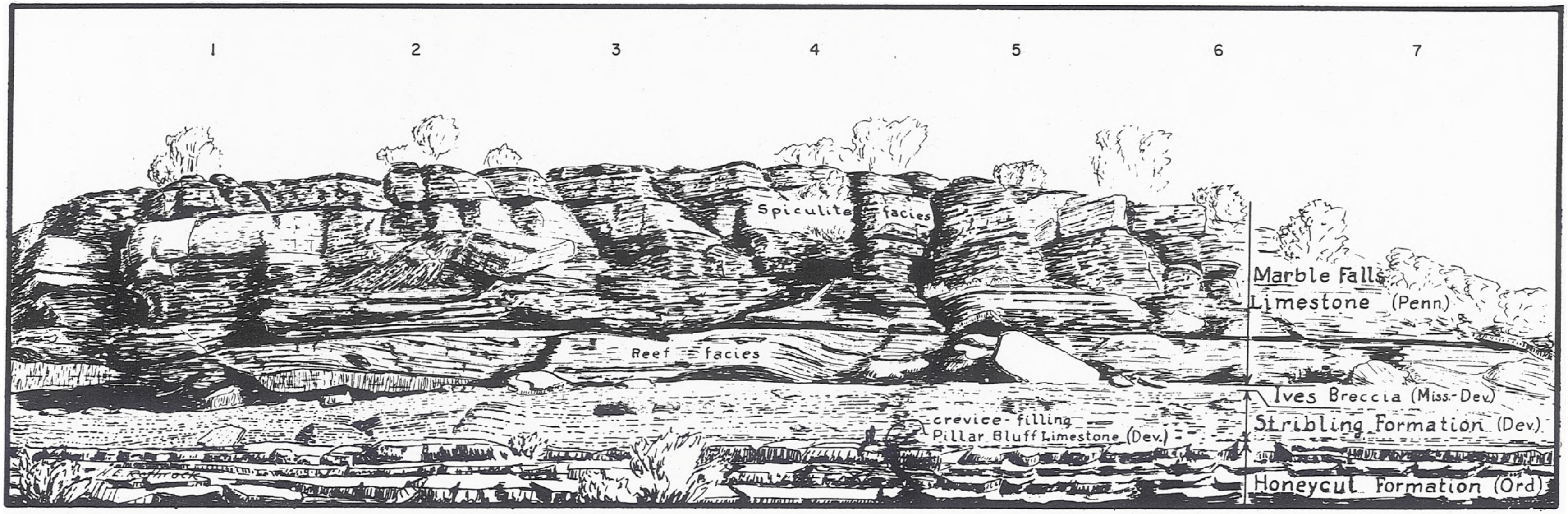


FIG. 14. Geologic map of Honeycut Bend area, Blanco County, Texas.



(Reproduced through the courtesy of the San Angelo Geological Society)

Fig. 15. Pennsylvanian, Mississippian, Devonian, and Ordovician rocks, Honeycut Bend, Blanco County, Texas.

(Reproduced through courtesy of the San Angelo Geological Society.)

A pocket of impure yellowish-brown limestone enclosed by the Ellenburger strata was assigned by Barnes, Cloud, and Warren (1947) to the Pillar Bluff (?) Limestone. The evidence of the brachiopods alone is equivocal, and the rock could be Helderberg, Oriskany, Onondaga, or even Silurian in age. There is no evidence that the material in question reached its present position through an opening that penetrated the Stribling Formation, thus representing strata that formerly overlay the Stribling rocks but are now absent from this vicinity. In a study of the conodonts, Seddon (1970, p. 22) concluded: "The red-stained conodonts which are abundant in the impure limestone are a Stribling fauna, and one may conclude either that the two rock units, although stratigraphically distinct, are not separated by any very great time interval, or, alternatively, that the "Stribling" conodonts in the impure limestone are stratigraphic leaks from the Stribling Formation. In view of the brachiopod evidence, the latter is perhaps the more probable explanation."

The Stribling Formation, about 10 feet thick, is a microgranular limestone, medium light gray ranging to reddish gray and yellowish gray with an olive-gray cast. The basal 2 inches is yellowish gray and contains sand grains. Bedding is irregularly lenticular from almost fissile to 6 inches thick. Except for the lower 2 feet the rock is mostly cherty; the chert, translucent to subtranslucent in upper part, ranges downward to opaque in lower part, brownish to grayish, and occurs as irregular lenses and false joint fillings.

The Ives Breccia Member of the Houy Formation, about 18 inches thick, is composed mostly of angular chert fragments and a small amount of phosphatic limestone matrix. The rounded pieces of chert in the Ives appear to be unbroken chert nodules rather than water-worn chert pebbles. The predominance of angular pieces may be due to disintegration of the chert along incipient fractures. It seems likely that the Ives at this point is an accumulation, essentially in place, of the insoluble constituents of the Stribling Formation. Conodont- and bone-bearing phosphatic and calcareous beds are associated with the Ives in several places in the eastern part of the Llano region. Such an occurrence was exposed here by the record-breaking flood of 1952. At locality 2-42I, north of the river, a bed a few inches thick composed almost entirely of conodonts is weakly radioactive.

The Chappel Limestone is present at only a place or two in this area. The best exposure is south of the fence and west of the drain that marks the southwestern end of the bluff. It is only about a foot thick, is brownish gray and crinoidal, the crinoid columnals being mostly smaller and less distinct than in the overlying biohermal unit of the Marble Falls.

The flood of 1952 exposed Barnett Formation about 2 miles downstream in the bed of Pedernales River. Prior to that time the nearest exposure of shale of the Barnett Formation was several miles to the northeast at Elm Pool. Exposed here at Honeycut Bend at the time of the 1952 flood is a pocket of glauconitic material in the Stribling Formation similar to the basal few inches of the Barnett in the exposures just mentioned. Dr. W. H. Hass, then with the U. S. Geological Survey, obtained conodonts from the upper faunal zone of the Barnett Formation in a quarter-inch crack-filling in the basal beds of the Stribling Formation. Some of the numerous crack-fillings in the Ellenburger may also be from the Barnett Formation.

The lower biohermal unit of the Marble Falls Limestone is composed of bioherms of limestone interspersed with distinctly bedded limestone and black shale and a 21-inch black shale bed at the base, which has considerable lateral persistence. A thin phosphatic zone is at the base of the shale. Fossils from the biohermal unit collected about 1946 by Barnes and Cloud in company with Dr. G. A. Cooper, U. S. National Museum, are regarded by Cooper as of Morrow age. This unit crops out for about 1.5 miles northeastward but only in limited outcrops beyond.

The overlying spiculite unit is dark gray and calcareous; in thin section it is seen to be

Mileage
Total Interval

a mat of spicules in a calcareous groundmass. Where leached at the outcrop, it ranges in color on fresh breaks from white to yellowish gray or even yellowish orange or darker depending on the amount of iron.

The Stribling and Honeycut rocks are truncated by the overlying Mississippian and Pennsylvanian rocks, and at least 100 feet of truncation can be demonstrated within the map area (fig. 14). All of the Paleozoic units described are truncated within a short distance by flat-lying Cretaceous rocks. The immediately overlying unit of the Cretaceous is the Cow Creek Limestone, which wedges out against Honeycut rocks within the map area. From here westward mostly Hensel Sand and rarely Glen Rose Limestone rest directly on the Paleozoic rocks. No more Cow Creek Limestone is present.

The Hensel Sand Member of the Shingle Hills formation forms the bench of the parking area. The Hensel Sand is mostly poorly sorted and composed of a wide variety of materials including cobbles, pebbles, granules, sand, silt, clay, variously mixed, and, in addition, an appreciable amount of calcareous material, which becomes more abundant upward until the Glen Rose Limestone is reached. The basal part of the Hensel is reddish, the color rising stratigraphically westward toward the ancient shore. The top part of the Hensel is gray, and the boundary between the two color phases forms an irregular lateral as well as vertical transition. The Hensel Sand is a shoreward facies of the Glen Rose Limestone; eastward it disappears; westward the top of the Hensel rises higher and higher until no Glen Rose Limestone remains. The base of the Hensel also becomes younger as it climbs the Llano uplift westward.

The Glen Rose Limestone is an alternating series of hard, but mostly impure, limestone beds with softer, marly, shaly, or sandy beds. This alternation of soft and hard beds causes the characteristic stairstep topography of the Glen Rose. The basal bed of the unit forms a bench a short distance south of the road. A thickness of several hundred feet of Glen Rose beds crops out between here and the divide a mile or so to the south. Westward the Glen Rose Limestone thins as beds at its base grade to terrigenous material toward the ancient shore. A bed to the south near the middle of the Glen Rose is characterized by the fossil *Corbula;* westward at Hye the *Corbula* bed becomes the basal bed of the Glen Rose and a short distance beyond the Gillespie County line it disappears, being replaced by Hensel Sand. Near Cross Mountain at Fredericksburg, only 55 feet of Glen Rose remains and 5 miles north of Cross Mountain it has graded entirely to Hensel Sand.

61.6 5.1 Retrace route to U. S. Highway 281 and turn right (north).

63.0 1.4 Pedernales River bridge. Pedernales River drains much of Gillespie and Blanco counties. Its upper reach is on the Edwards Plateau, it traverses Lower Cretaceous sand in central and eastern Gillespie County passing in front of President Johnson's LBJ Ranch residence, it traverses Cambrian and Ordovician rocks to Honeycut Bend and Devonian, Mississippian, and Pennsylvanian rocks to the foot of Pedernales Falls 4 miles downstream from Honeycut Bend; at this point it passes into a canyon rimmed by massive Cow Creek Limestone. The Pedernales arm of Lake Travis occupies the downstream end of this canyon, and several miles of the canyon below Pedernales Falls are within the newly established Pedernales Falls State Park. From the Gillespie County line to Lake Travis the river has a steep gradient and presents a spectacular sight when in flood.

From the Pedernales River to Round Mountain the route traverses mainly Lower Cretaceous rocks and some Ordovician and Cambrian rocks. The Bureau of Economic Geology has issued several 7.5-minute geologic quadrangle maps using U. S. Geological Survey topographic maps for a base and has others in preparation covering much of the route of travel in the Llano region for STOPS 1–7. Published quadrangle maps include Yeager Creek and Monument Hill along U. S. Highway 290 west of Henly; Johnson City; Rocky Creek, Hye, Stonewall, and Cave Creek School west of Johnson City (these four cornering on the LBJ Ranch); and Blowout. Manuscript quadrangle maps include Pedernales Falls (STOP 1);

Mileage		
Total	*Interval*	
		Round Mountain and Howell Mountain (covering route to STOP 2); Click (STOP 2); Dunman Mountain (Stop 3); and Kingsland (Stops 4 and 5). Quadrangles on which mapping has been completed but not compiled include Marble Falls (STOP 3), Longhorn Cavern (STOP 6), and Spicewood (STOP 7).
73.6	10.6	Round Mountain. Turn left (west) on Ranch Road 962. The route traverses Lower Cretaceous and Cambrian rocks, the latter faulted against Precambrian rocks just before leaving Ranch Road 962.
81.4	7.8	Turn left (west) on unpaved county road. Along the county road can be seen low ridges of Red Mountain Gneiss exposed on the right (north) side of the road. The low hills to the left are Paleozoic rocks southeast of the same high-angle fault crossed on the highway.
82.3	0.9	Cross unconformable contact of Cambrian sandstone (Hickory Sandstone Member of Riley Formation) resting on Packsaddle Schist. The sandstone is well exposed along Walnut Creek a short distance ahead.
85.4	3.1	Cattleguard followed by intersection of county roads. Continue straight ahead (west), leaving the Cambrian sandstone and passing back onto Precambrian rocks. In the distance across the lowlands to the right, Packsaddle Mountain may be seen on Precambrian rocks. Ahead is Cedar Mountain, a down-faulted block of Paleozoic limestone and sandstone which continues northward into the Riley Mountains.
87.1	1.7	Cross White Creek. Hornblende schist is exposed in the creek to the right.
89.5	2.4	Intersection of county roads; turn right (north). Ahead and slightly to the right is Red Mountain, a prominent ridge of gneissic granite.
91.9	2.4	Cross Comanche Creek.
92.6	0.7	STOP 2. Park near entrance to the A. D. Hardin ranch. Continue east on foot down Hardin's road to Comanche Creek where Packsaddle Schist is in fault contact with augen gneiss (Big Branch Gneiss which has undergone strong potassium metasomatism). The geology of this area is shown on figure 4 and described in the discussion of the Red Mountain Gneiss (pp. 14-15). Return to parking place and continue ahead (north).
94.0	1.4	On the left is a prominent ridge of gneissic granite, the westward continuation of the main sill of Red Mountain Gneiss. It has been offset northward by a Precambrian strike-slip fault with a displacement of about 600 feet. The fault produced a wide breccia zone lying approximately under the road being travelled.
94.5	0.5	Cross Sandy Creek and stop beside road beyond crossing. To the left (west) is a low hill underlain by another thick sill of Red Mountain Gneiss. To the right are low knobs of breccia, some of which exhibit cylindrical holes in which Indians ground corn. About 0.4 mile north of Sandy Creek the road crosses a small stream valley in which a blastoporphyritic mafic igneous rock is exposed west of the road.
95.3	0.8	Intersection of county roads; turn sharply right (east). Cross Sandy Creek 1.5 miles ahead. Coarse cordierite-biotite gneiss crops out in the creek bank about a thousand yards downstream.
98.2	2.9	Crossing Rough Ridge, an elongate hill of gray quartz-feldspar rock with subordinate hornblende and mica. About 0.5 mile ahead is Green Mountain on the right (south) side of the road. This is a large hill of amphibolite, a metamorphosed gabbro or diorite.
101.9	3.7	Intersection of county road and State Highway 71. Turn left (northwest). The bridge ahead spans Sandy Creek and the road cut beyond the creek exposes weathered hornblende schist.
103.2	1.3	Turn right on road to Sunrise Beach.
106.0	2.8	The road crosses layers of marble in this vicinity. Boulders of marble containing tremolite are abundant at the roadside.
107.7	1.7	Cattleguard and entrance to Sunrise Beach. Take right fork and proceed south to resort area. Little Sandy Mountain is the small hill directly to the left (east) and Sandy Mountain lies straight ahead. Both are composed of leptite (fine-grained quartz-feldspar rock)

Mileage		
Total	*Interval*	
		in nearly vertical layers.
108.4	0.7	Sunrise Beach office on left. Follow the road that curves to the right.
108.9	0.5	STOP 3. Porphyroblasts of tourmaline and andalusite are abundant in the graphitic schist on the hill to the right. A geologic map (fig. 5) and a more detailed description of the geology are given on pages 17-18. Continue to the Sunrise Marina 1.5 miles ahead. If time is available a brief stop can be made on the return to examine metagabbro and a pegmatite with mica pseudomorphs after topaz. Upon returning from Sunrise Marina, take the loop road around the south side of Sandy Mountain. At the high point on the road, brecciated leptite, which locally contains both sillimanite and andalusite, is being crossed. A short distance farther the contact of the leptite with granite is well exposed. Return to State Highway 71 over the same road by which Sunrise Beach was reached. Turn left (southeast) toward Austin.
120.5	11.6	On left, Ranch Road 2147 to Marble Falls.
121.3	0.8	Highway cut in brecciated Ordovician limestone in fault contact with Precambrian rocks to the west. The displacement is in excess of 2,000 feet. From here to a mile south of Marble Falls the route is over Gorman and Honeycut rocks of the Ellenburger Group.
127.5	6.2	Highway intersection; turn left (north) on U. S. Highway 281.
130.8	3.3	To the right (east) along Flat Rock Creek, a 20-foot unit of pure limestone in the Ellenburger has been quarried along the valley floor and is being mined underground. This operation is the direct result of the Bureau's publication of Report of Investigations No. 17, "High purity Marble Falls Limestone, Burnet County, Texas."
131.9	1.1	Colorado River bridge at south edge of Marble Falls. The limestone exposed at the edge of Marble Falls Lake, upstream and downstream from the bridge, constitutes the type section which is now mostly beneath lake level. The Marble Falls is composed mostly of limestone and spiculite, and downstream about 1 mile a thick reef of pure limestone can be seen to advantage from directly across the river. It can also be viewed from the south end of Starcke (formerly Marble Falls) Dam (fig. 16).
132.8	0.9	Turn left (west) on Ranch Road 1431. The excursion route passes over Marble Falls Limestone and Smithwick Shale, the latter largely masked by alluvial and colluvial materials.
133.9	1.1	High-angle fault between Marble Falls Limestone to the east and Town Mountain Granite to the west. The displacement is in excess of 3,000 feet. The excursion route is over Town Mountain Granite for most of the distance to STOP 7.
134.6	0.7	STOP 4. Texas Granite Corporation, Granite Mountain operation. A geologic map (fig. 6), a description of the granite, and a history of the operation are given on pp. 17-19.
139.4	4.8	Entrance to jetty-stone quarry of Texas Construction Material Company. This rounded dome of granite, known as Hog Mountain, stands about 50 feet above the surrounding rather flat country. The granite is coarse grained and is free of aplites, pegmatites, and inclusions. The granite takes a good polish, is of excellent grade, and is suitable for all purposes for which a coarse-grained granite can be used. Texas Construction Material Company opened the Hog Mountain quarry in January 1964 and during the next 4 years produced one-half million tons of granite for use in repair and construction of jetties on the Gulf Coast.
143.4	4.0	STOP 5. Hoover Point of Backbone Ridge (fig. 17). Cambrian rocks, including Cap Mountain Limestone, Lion Mountain Sandstone, Welge Sandstone, and Morgan Creek Limestone, are beautifully exposed in the vertical cut along the eastern side of the highway. The Welge Sandstone and Morgan Creek Limestone are well above road level, but large blocks of these formations, as well as of the Lion Mountain Sandstone, can be seen along the river side of the parking area. In fact, the three-dimensional view of bedding features is much better displayed in these blocks than in the vertical face and furthermore

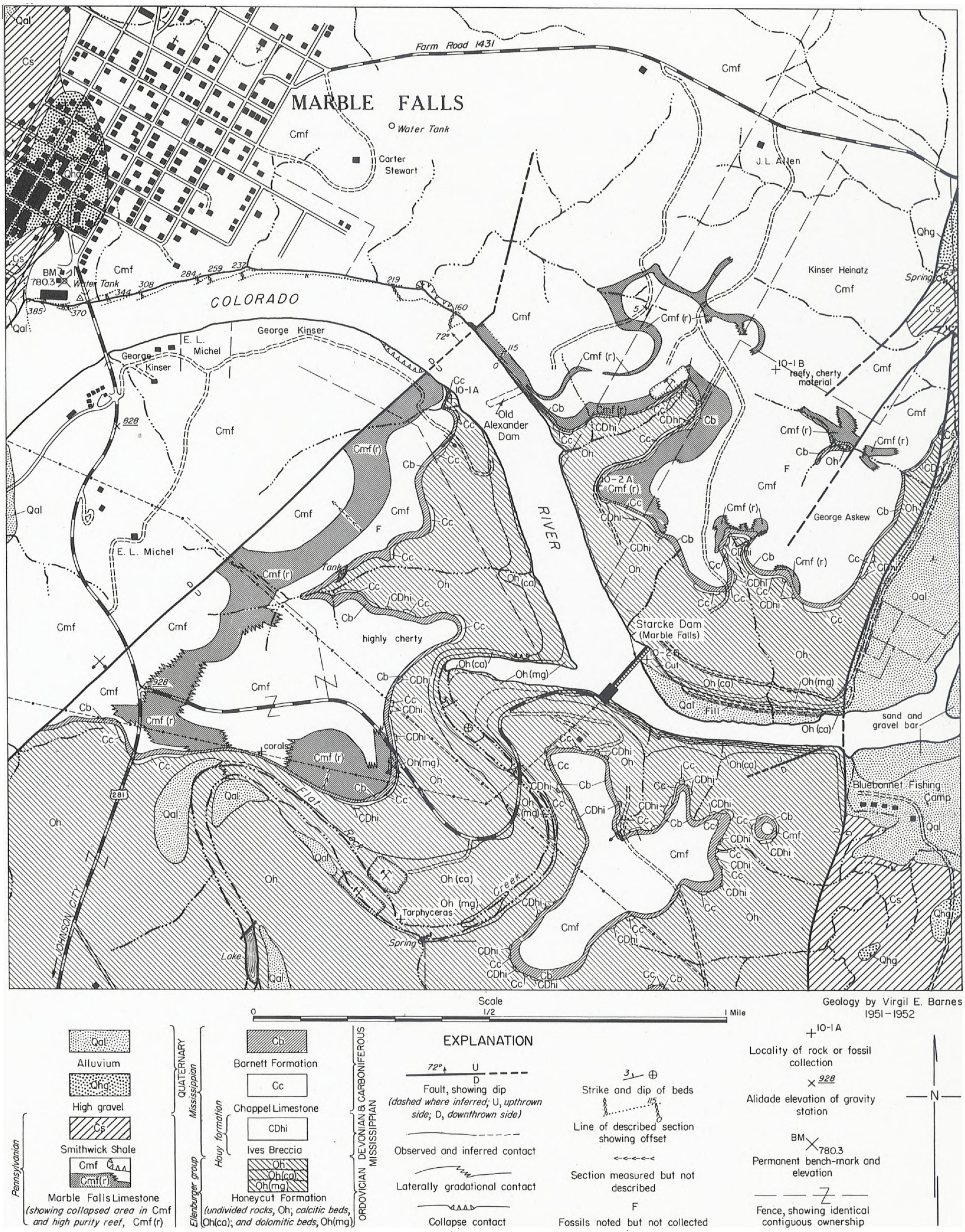


FIG. 16. Geologic map of an area in vicinity of Marble Falls, Burnet County, Texas.

EXPLANATION. The geologic units mapped are shown by the following letter symbols: Quaternary deposits—alluvium, Qal, and colluvium, Qc. Ordovician rocks—Tanyard Formation showing Staendebach Member, dolomitic facies, Ots(mg), and Threadgill Member, dolomitic facies, Ott(mg), and calcitic facies, Ott(ca). Cambrian rocks—Wilberns Formation showing San Saba Member, dolomitic facies, €ws(mg), and calcitic facies, €ws(ca), Point Peak Member, €wpp, showing *Plectotrophia* bed, €p, Morgan Creek Limestone Member, €wm, and Welge Sandstone Member, €ww; and Riley Formation showing Lion Mountain Sandstone Member, €rl, Cap Mountain Limestone Member, €rc, and Hickory Sandstone Member, €rh. Precambrian rocks—Town Mountain Granite, tm. Base from U. S. Department of Agriculture, Soil Conservation Service, aerial photographs flown by Park Aerial Surveys, Inc., 1939-1940. Geology by Virgil E. Barnes and Lincoln E. Warren, 1945; revised by Barnes, 1960.

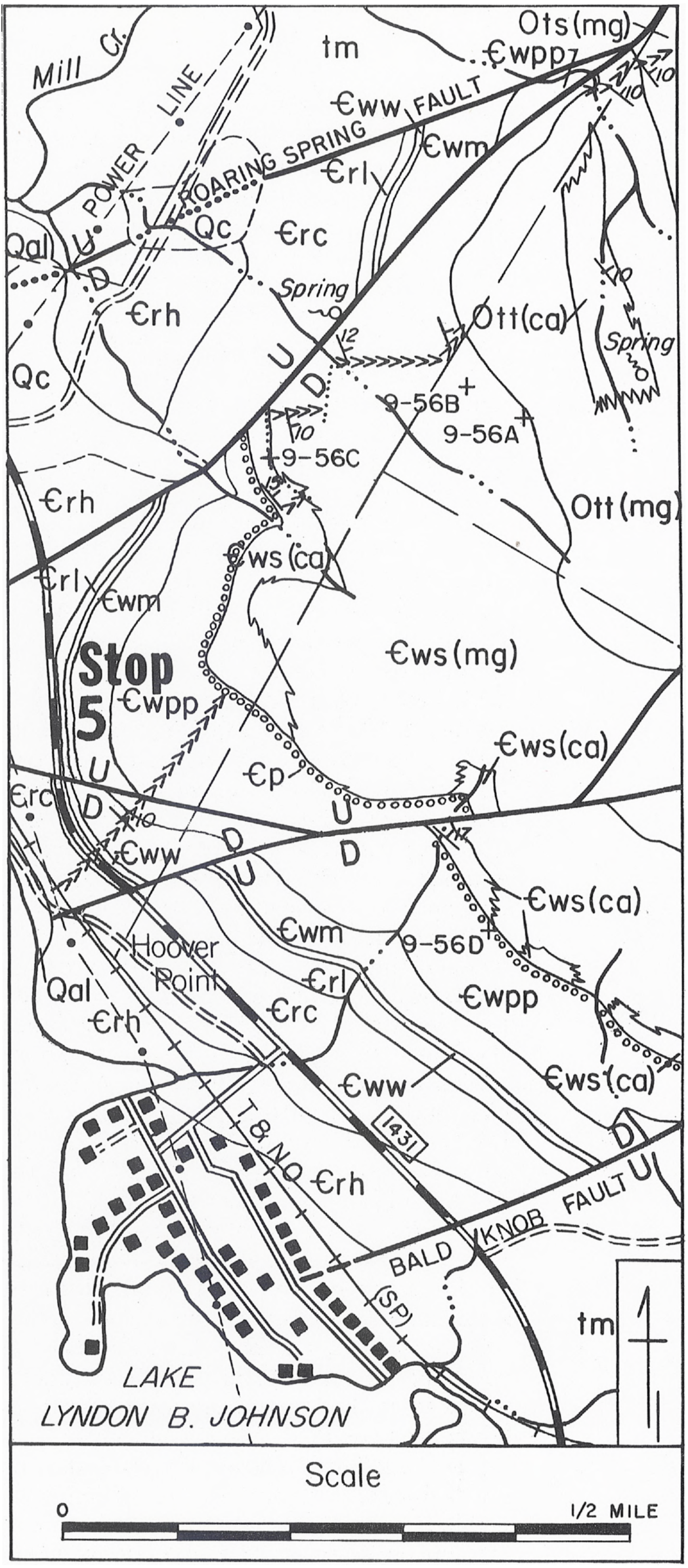


FIG. 17. Geologic map of Hoover Point area, Backbone Ridge, Burnet County, Texas.

Mileage
Total Interval

is in a much safer viewing place. The uppermost beds of the Cap Mountain Limestone can be seen below the parking area to the edge of bluff as well as north of the fault along the west side of the highway. The Lion Mountain Sandstone is a greensand high in glauconite and contains white lenses of trilobite coquinite. It is characteristically cross-bedded. The Welge is a light brown sandstone in part weathered yellowish brown. The portion of the Morgan Creek Limestone exposed is pink, characteristic of this portion of the member throughout the Llano region.

144.5 1.1 Turn right (north) on Ranch Road 2342 passing Buckner's Boys School. To the east is Backbone Ridge consisting of Ordovician rocks in this portion of the ridge.

148.9 4.4 Turn right (east) on Park Road 4.

151.7 2.8 Longhorn Cavern State Park and picnic area. Longhorn Cavern developed in the upper calcitic facies of the Gorman Formation. The entrance to the cavern at the bottom of a sink behind the concessions buildings can be viewed by descending the steps provided. The massive character of the limestone is well displayed.

153.8 2.1 STOP 6. "Wedge" section (Cloud and Barnes, 1948, pp. 288-289). A good view can be obtained from the lookout at the top of the section. Walk down through section along Park Road 4 to intersection of Park Road 4 and Ranch Road 2342. Refer to figure 18, "Geologic map of a fault wedge 2 miles west of Longhorn Cavern, Burnet County, Texas."

The "wedge" section is so named because of its location in a wedge-shaped fault block situated along Roaring Spring fault, one of the major faults in the Llano region. This fault block, which is west of Longhorn Cavern and south of Inks Dam, is along the northwestern side of Backbone Ridge. The block is tilted about 25° to the northeast, and all the units of the Upper Cambrian and of the Lower Ordovician up to and including most of the calcitic facies of the Gorman Formation are exposed in it. There are few areas in the Llano region where so much Cambrian and Ordovician section is exposed in such a short distance, and this is probably the most favorably situated section from which to obtain a quick view of these units. However, it is not suited for detailed measurement and description because numerous small faults are present and in places exposures are poor.

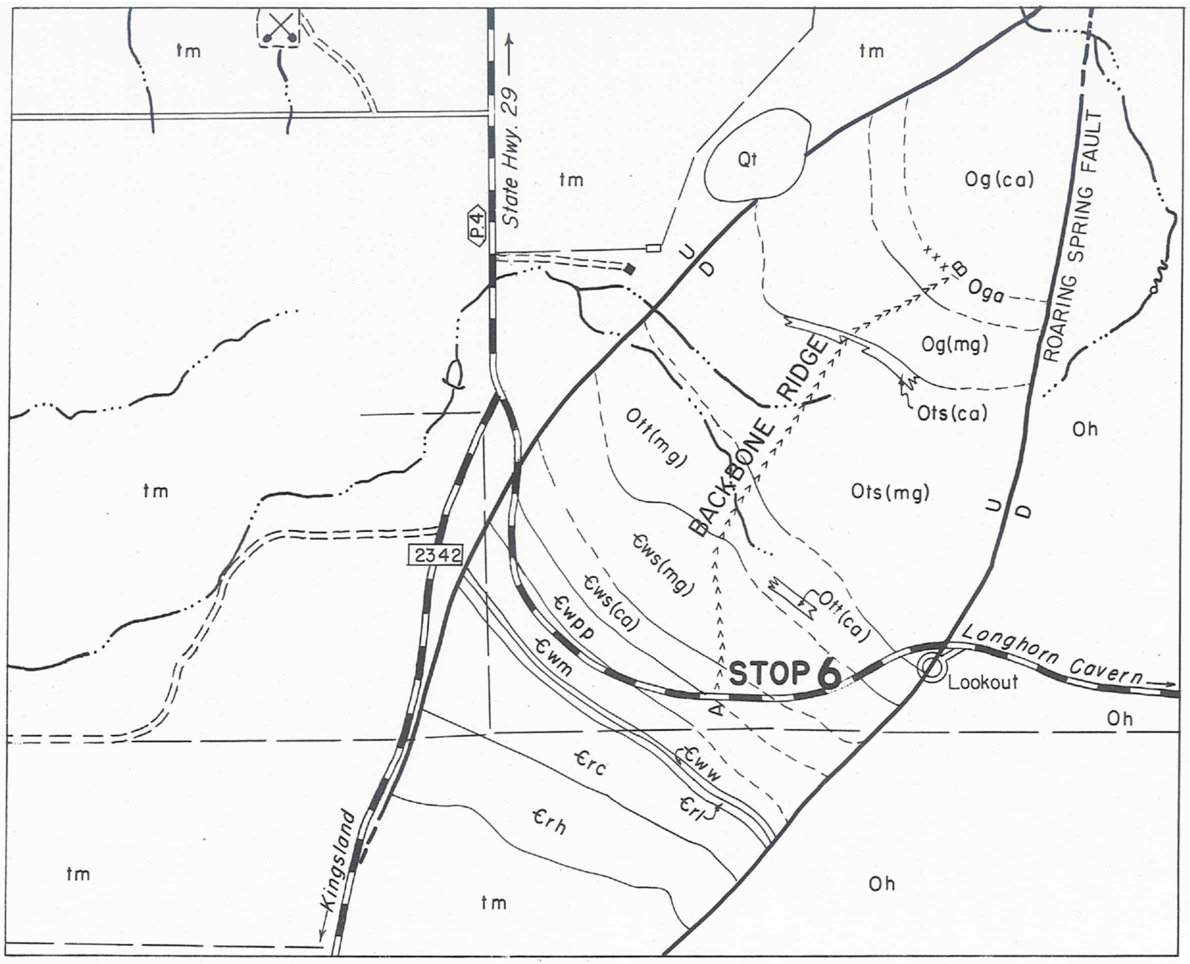
Of the many units in the "wedge" section, only a few may be seen on this stop, namely, the upper part of the Morgan Creek Limestone Member, the Point Peak Member, the calcitic and dolomitic facies of the San Saba Member of the Wilberns Formation, and the Threadgill Member and part of the Staendebach Member of the Tanyard Formation of the Ellenburger Group. Honeycut rocks crop out on the flat east of Roaring Spring fault.

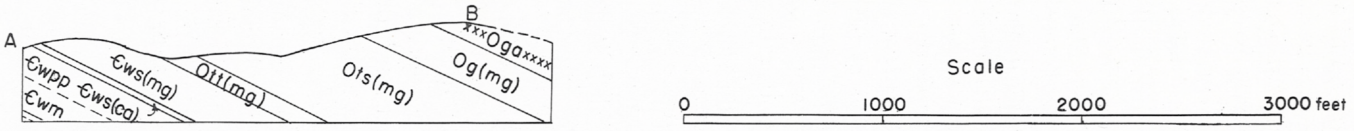
The Morgan Creek Limestone Member is distinctly bedded with thick, coarse-grained, glauconitic, stylolitic, mostly light greenish-gray limestone beds alternating with very thinly bedded, nodular, silty, very shaly, greenish-gray limestone zones and a few thin zones which are essentially silty, calcareous shale. The contact between the Morgan Creek Limestone and the overlying Point Peak Member is gradational.

The Point Peak Member is mostly thinly bedded, argillaceous, glauconitic siltstone and fine-grained, argillaceous, glauconitic limestone with thin shale partings. In the lower part of the upper half, much stromatolitic, very light grayish-green, aphanitic limestone and some granular limestone have accumulated between the reef heads. Intraformational conglomerate is common in the upper half, especially in the zone of gradation to the overlying San Saba Member. The contact between the Point Peak and San Saba Members is placed at the base of the lowest fairly continuous sequence of granular limestone. The boundary is marked by a change in vegetation readily mapped on aerial photographs.

The San Saba Member in this section consists of a lower calcitic facies and an upper, much thicker, dolomitic facies. The lower part of the calcitic facies contains some thinly bedded shaly zones, intraformational conglomerate, oolitic limestone, and upward grades into aphanitic to very fine-grained, yellowish-gray girvanella-bearing limestone mottled by

EXPLANATION. The geological units mapped are shown by the following letter symbols: Quaternary deposits—travertine, Qt. Ordovician rocks—Honeycut Formation, Oh; Gorman Formation showing *Archaeoscyphia* zone, Oga, calcitic facies, Og(ca), and dolomitic facies, Og(mg); and Tanyard Formation showing Staendebach Member, calcitic facies, Ots(ca), and dolomitic facies, Ots(mg); and Threadgill Member, dolomitic facies, Ott(mg), and calcitic facies, Ott(ca). Cambrian rocks—Wilberns Formation showing San Saba Member, dolomitic facies, Ꞓws(mg), and calcitic facies, Ꞓws(ca), Point Peak Member, Ꞓwpp, Morgan Creek Limestone Member, Ꞓwm, and Welge Sandstone Member, Ꞓww; and Riley Formation, Lion Mountain Sandstone Member, Ꞓrl, Cap Mountain Limestone Member, Ꞓrc, and Hickory Sandstone Member, Ꞓrh. Precambrian rocks—Town Mountain Granite, tm. Base from U. S. Department of Agriculture, Soil Conservation Service, aerial photographs flown by Park Aerial Surveys, Inc., 1939-1940. Geology by Virgil E. Barnes and Lincoln E. Warren, 1945.





Modified from The University of Texas Publication No. 4621

FIG. 18. Geologic map of a fault wedge 2 miles west of Longhorn Cavern, Burnet County, Texas.

Mileage *Total*	*Interval*	
		yellowish-brown dolomite which weathers in relief. The calcitic and dolomitic facies at this point appear to be in contact along a small fault. The dolomitic facies of the San Saba is fine grained, mostly light gray with purplish mottles; in the lower part spherical cavities suggest that girvanella have been removed by weathering. The dolomite is somewhat cherty toward the top.
		The contact between the Wilberns and Ellenburger in this section, best seen south of the road, is placed at the contact of the fine-grained dolomite of the San Saba Member and the coarse-grained, very light gray dolomite of the overlying Threadgill Member. The Threadgill Member along the road is all dolomite but laterally to the northwest in part grades into aphanitic limestone; it is essentially noncherty.
		The overlying Staendebach is fine grained and cherty. The chert is mostly white and dolomitic. Only a small part of the Staendebach is crossed before reaching Roaring Spring fault, which is marked by a zone of jumbled rock and reddish-weathering products. To the east of the fault alternating beds of dolomite and limestone of the Honeycut Formation are rather poorly exposed. The rock guard-walls along the road are built of limestone slabs from the Honeycut Formation. Many of these slabs display shallow-water features such as intraformational conglomerate, mud cracks and, rarely, ripple marks. The limestone is aphanitic, yellowish gray to almost white, in part cherty, and in part fossiliferous. A drive-around lookout just south of the road, situated about on Roaring Spring fault, is a good vantage point for viewing the northeastern part of the Llano basin with its fault blocks of Paleozoic rocks forming mountains.
154.5	0.7	Keep right (north) on Park Road 4. A conical mass of travertine can be seen to the east on the side of the fault wedge.
155.8	1.3	Peters Creek. Town Mountain Granite forms an irregular contact with the Packsaddle Schist in this area, and just north of the bridge a hill of Packsaddle Schist includes marble bands. The boundary between Valley Spring Gneiss and Packsaddle Schist is just around the hill where Park Road 4 starts up grade. The entrance to Inks Lake State Park is near the top of the grade opposite Inks Dam.
159.9	4.1	Spring Creek.
160.1	0.2	STOP 7. Valley Spring Gneiss in Inks Lake State Park. A geologic map (fig. 7) and a description of the geology are given on pages 20-21.
161.9	1.8	Turn left on State Highway 29.
163.6	1.7	Colorado River bridge over Inks Lake. Picturesque arch construction of Buchanan Dam can be seen upstream to right.
164.8	1.2	Entrance to Buchanan Dam; turn right. White marble in the Packsaddle Schist crops out just north of entrance. Valley Spring Gneiss crops out along the highway a short distance in either direction.
164.9	0.1	Parking lot at end of Buchanan Dam. Retrace route toward Burnet.
177.1	12.2	Highlander Inn, Burnet.

STOPS 8-14

VIRGIL E. BARNES, PETER U. RODDA, AND KEITH YOUNG

In this portion of the route, Devonian and Mississippian rocks will be seen at STOP 8 (figs. 19-20); Lower Cretaceous rocks will be seen at STOPS 9 through 15 (figs. 21-28); and Upper Cretaceous rocks will be seen at STOPS 16 and 17 (fig. 29).

DEPART FROM HIGHLANDER INN, BURNET.

Mileage		
Total	*Interval*	
0.0		Go east on State Highway 29.
0.2	0.2	Turn right (south) on U. S. Highway 281.
13.3	13.1	Junction of U. S. Highway 281 and Ranch Road 1431; continue south on U. S. Highway 281.
14.2	0.9	Colorado River bridge.
18.6	4.4	Turn left (east) on State Highway 71.
21.4	2.8	STOP 8. Houy Ranch supplementary section along Doublehorn Creek (Cloud, Barnes, and Hass, 1957, p. 807):

> The Devonian-Mississippian transition outcrops of Central Texas are assigned to the Houy Formation. The beds included are mainly Upper Devonian but partly Lower Mississippian. Locally, a basal fraction may be Middle Devonian. Although the deposits included are diverse and their associations complex, the maximum surface thickness so far known is only about 17 feet.
>
> The principal subdivisions, in their usual ascending order, are the Ives Breccia Member (Plummer *in* Bullard and Plummer, 1939), the Doublehorn Shale Member (new), and a thin unnamed phosphoritic interval. Commonly, however, one or more of these members is absent, and rocks not assigned to any member are present. The Ives Breccia Member includes lag deposits of detrital chert of varied age and source. The Doublehorn Shale Member includes black, fissile, spore-bearing shale of Late Devonian age which in a few exposures grades upward into shale of Early Mississippian age. The phosphatic beds are partly Late Devonian and partly Early Mississippian. Remnants of the Doublehorn Shale Member have been found only along the eastern side of the Llano region, but the other units are more widely distributed, and rocks assignable to the Houy Formation are to be looked for between Ordovician and Upper Mississippian deposits anywhere around the Llano region.
>
> Although most abundant in the upper beds, phosphatic inclusions occur locally throughout the Houy Formation. This gives a stamp of unity to the sequence and distinguishes it from the immediately underlying beds as well as from the overlying Chappel Limestone of later Early Mississippian age. The Houy is also a unit of more than average radioactivity and is readily detected in the subsurface by radioactive drill-hole logging.
>
> It correlates with the Late Devonian and earliest Mississippian black shale sequences of other Midcontinent and midwestern areas. Four of the six conodont zones (Hass, 1947, 1956a, 1956b) in deposits of this age in Ohio, Tennessee, Oklahoma, and Arkansas are recognized also in Central Texas.

At locality 6-44A (figs. 19 and 20) the following section is partially exposed (Cloud, Barnes, and Hass, 1957, pp. 815-816):

Mississippian

Barnett Formation (16 feet ±, lower 7 feet well exposed)—dark brown to gray petroliferous shale and gray calcareous shale with thin chert beds, small turbinate rugose corals in calcareous shale about a foot above the base, compressed *Leiorhynchus carboniferum* Girty and *Orbiculoidea* sp. on bedding surfaces of chert, and Middle Mississippian (Meramec) conodonts in the shale (Hass, 1953).

Chappel Limestone (2 feet)—medium to dark gray inequigranular limestone with scattered pelmatozoan columnals, small rare brachiopods and trilobites, and conodonts of Kinderhook (Chouteau) age.

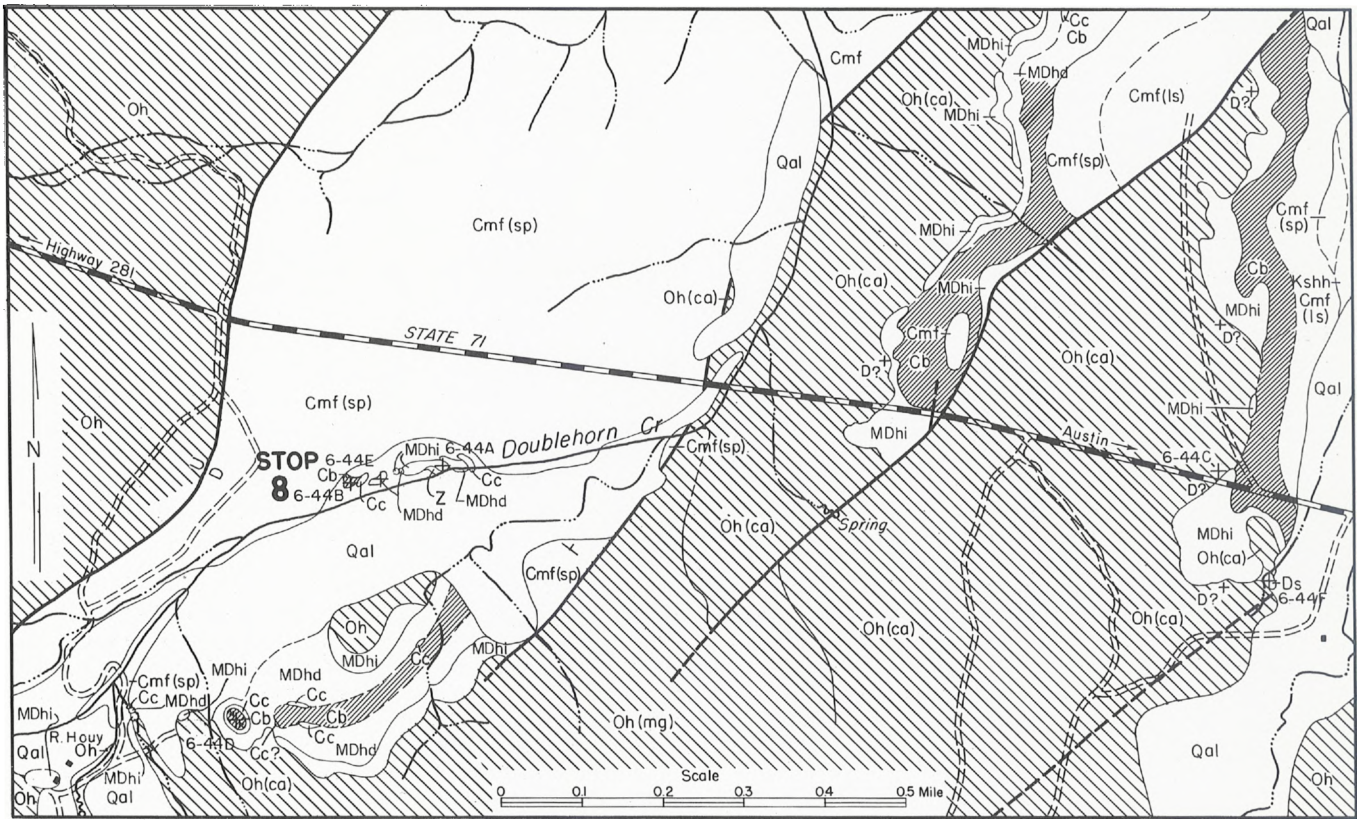
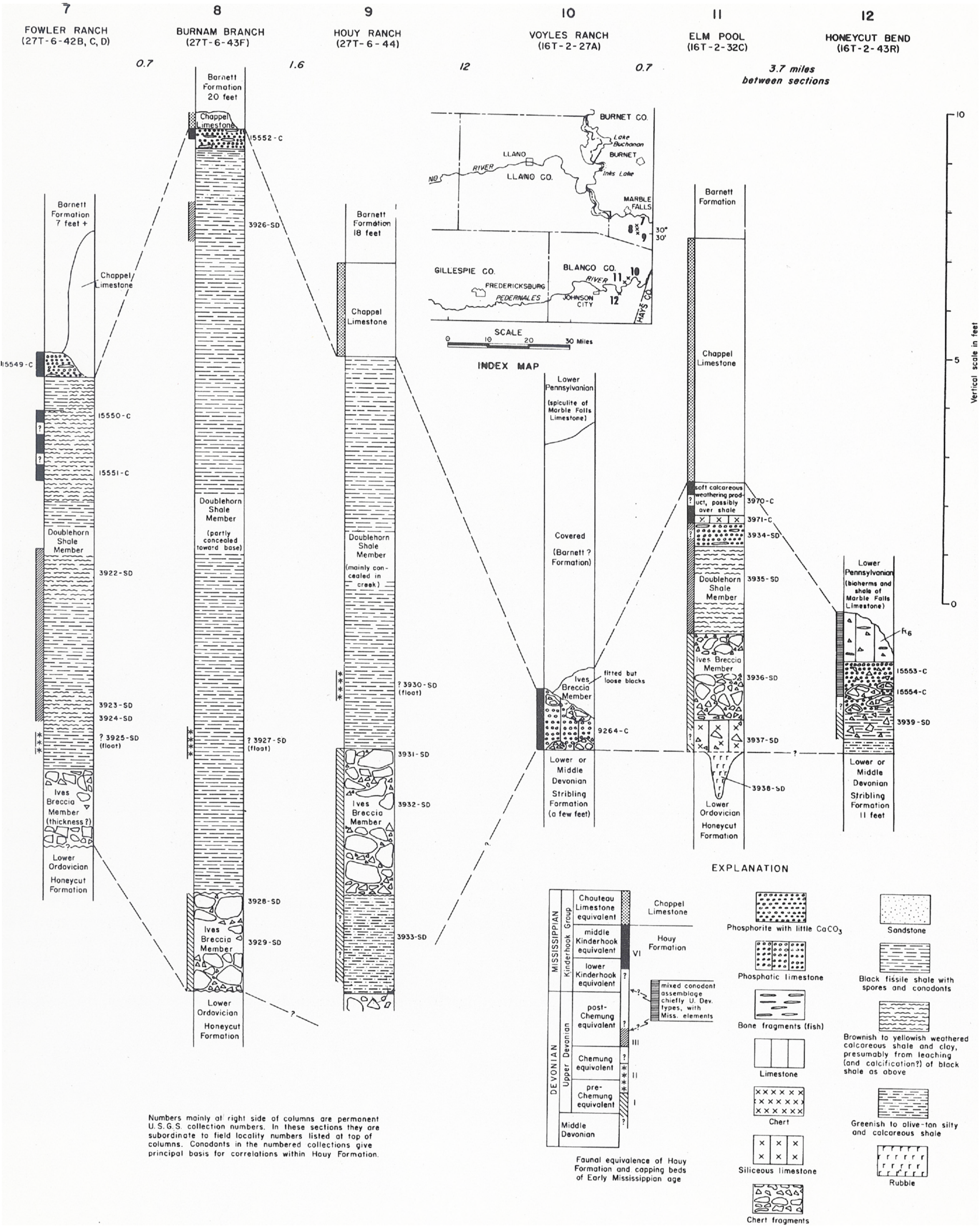


FIG. 19. Geologic map of an area along Doublehorn Creek, Burnet County, Texas.

The geologic units mapped are shown by the following letter symbols: Quaternary deposits—alluvium, Qal; Cretaceous rocks—Hensel Sand, Kshh; Pennsylvanian rocks—Marble Falls Limestone, spiculiferous portion, Cmf(sp) and massive limestone portion, Cmf(ls); Mississippian rocks—Barnett Formation, Cb, and Chappel Limestone, Cc; Mississippian and Devonian rocks—Houy Formation, Doublehorn Shale Member, MDhd, and Ives Breccia Member, MDhi, showing an inclusion of shale, Z; Devonian rocks, crack fillings, D?, and Stribling Formation, Ds; and Ordovician rocks—Honeycut Formation, calcitic facies, Oh(ca), dolomitic facies, Oh(mg), and undivided, Oh. The symbol +6-44A indicates the location of a fossil collection. Base from U. S. Department of Agriculture, Soil Conservation Service, aerial photographs flown by Park Aerial Surveys, Inc., 1939-1940. Geology by Virgil E. Barnes and A. R. Palmer.



Numbers mainly at right side of columns are permanent U. S. G. S. collection numbers. In these sections they are subordinate to field locality numbers listed at top of columns. Conodonts in the numbered collections give principal basis for correlations within Houy Formation.

FIG. 20. Key sections of the Houy Formation, Burnet and Blanco counties, Texas (Cloud, Barnes, and Hass, 1957).

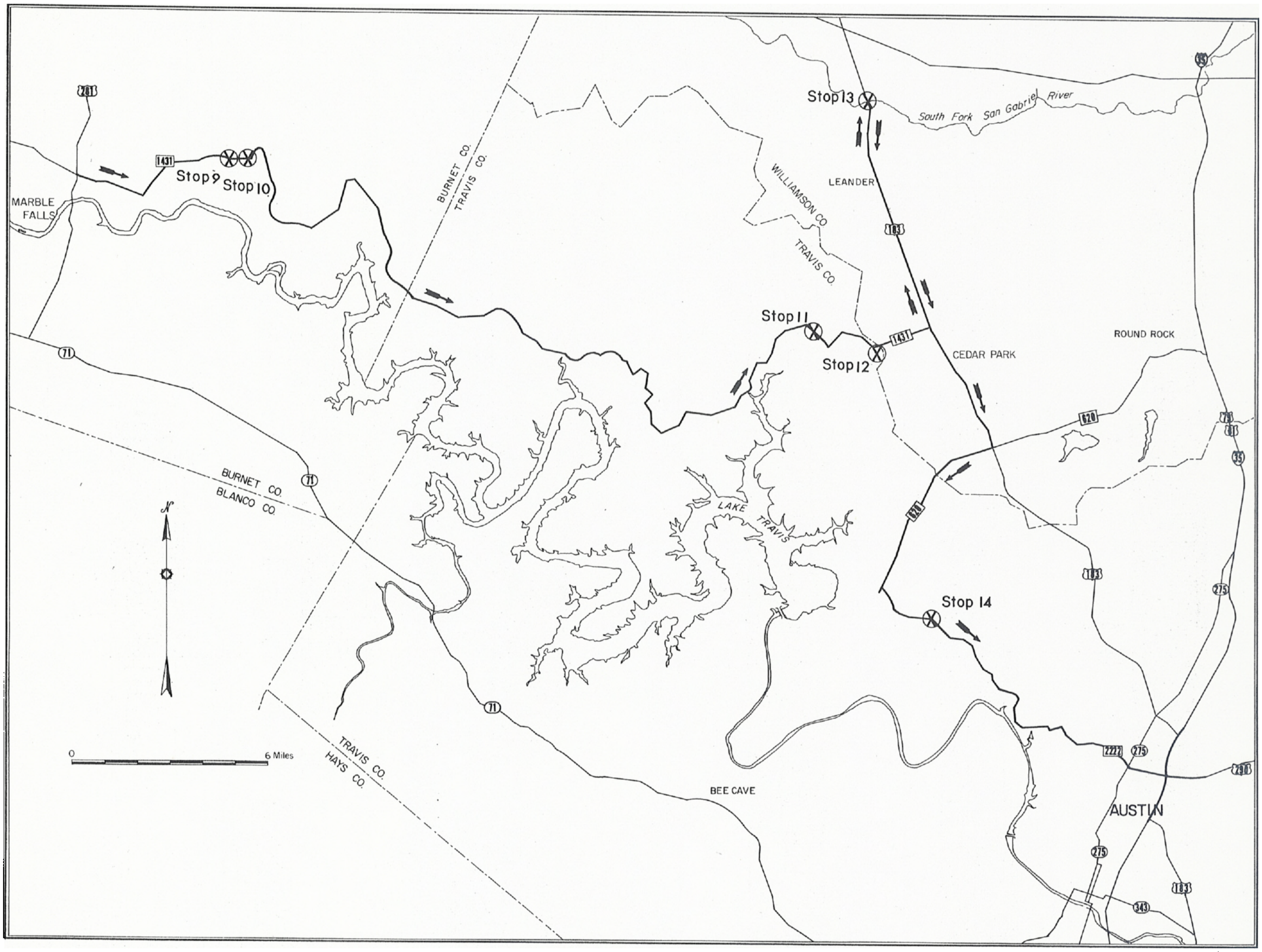


FIG. 21. Route map for Cretaceous rocks (STOPS 9-14).

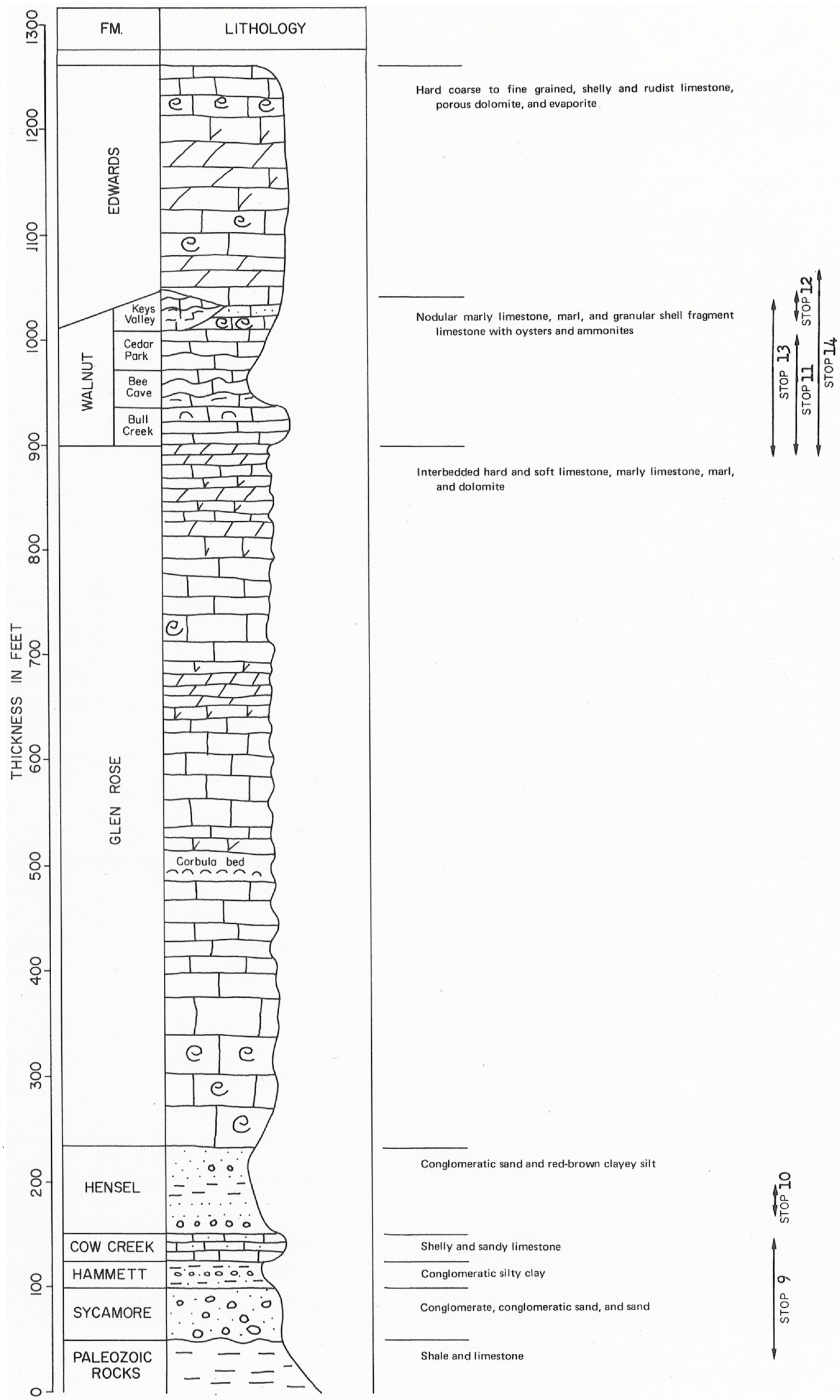


FIG. 22. Generalized columnar section for Cretaceous rocks of field trip area (STOPS 9–14).

Devonian

Houy Formation (10–13 feet ±)

Doublehorn Shale Member (type section of new unit)—black, fissile, spore-bearing shale (mainly covered) of which a random sample was determined by James Schopf of the USGS to have 0.008 percent equivalent uranium. USGS coll. 3930-SD, from float, contains Late Devonian (zone II) conodonts . . . . 5–8 feet ±

Ives Breccia Member

Massive lag-breccia consisting mostly of locally derived large (several inches) fragments and unbroken nodules of chalcedonic and microgranular chert such as is typical of the Stribling Formation. Large angular blocks of Lower Ordovician dolomite of the Honeycut Formation are locally included within or surrounded by the chert breccia. USGS colls. 3931-SD and 3932-SD, from sparse matrix of phosphatic-siliceous debris, contain early Late Devonian (zone I) conodonts . . . . 3 feet

Yellowish-green to greenish-gray shale with inarticulate brachiopods and rare *Polygnathus linguiformis* Hinde (USGS coll. 3933-SD). Exposed by digging into stream bed beneath breccia . . . . 2 feet

Chert similar to that above the shale, except that it is altered to a depth of nearly an inch and in part is coated by travertine. This unit normally is beneath water level and has been seen out of water only by Barnes on September 21, 1956, when Doublehorn Creek was completely dry. Bottom not exposed . . . . ?

Mileage *Total*	*Interval*	
24.3	2.9	Retrace route to U. S. Highway 281; turn right (north) on U. S. Highway 281.
28.7	4.4	Colorado River bridge.
29.6	0.9	Turn right on Ranch Road 1431. Traveling over Marble Falls Limestone.
30.5	0.9	Descending into Pleasant Valley. Quaternary alluvial deposits overlie Smithwick Shale (Pennsylvanian) which has been faulted against underlying Marble Falls Limestone (Barnes, 1958).
31.9	1.4	Crossing Hamilton Creek.
32.4	0.5	Slopes on either side of road are on Smithwick Shale.
33.3	0.9	Road cut in Smithwick Shale.
33.6	0.3	Crossing Sycamore Creek.
33.8	0.2	STOP 9. Road cut. Park and walk uphill. Cut exposes Smithwick Shale (fig. 23) unconformably overlain by basal Cretaceous clastics: Sycamore, Hammett, and Cow Creek Formations (in ascending order). This is the type area for the Sycamore. Slumping has obscured the Smithwick-Sycamore contact, and the Hammett Shale is poorly exposed on slopes between the lower and upper cuts. Top of cut is approximate top of the Cow Creek; broad bench above cut is on the Hensel Sand.

The basal Cretaceous sequence in Travis and southern Burnet counties as originally designated, based on sections described by Taff (1892) and units proposed by Hill (1901, pp. 131, 140-144), included (in ascending order): Sycamore Sand, Cow Creek beds, and Hensel Sand, collectively designated as the Travis Peak Formation (Hill and Vaughan, 1898, p. 219; Hill, 1890, p. 118) (*see* Fisher and Rodda, 1966, table 1 and fig. 6). Barnes (1948) restricted the name Travis Peak Formation to include the Sycamore and Cow Creek Members and proposed the name Shingle Hills Formation to include the Hensel Sand and Glen Rose Limestone Members (Fisher and Rodda, 1966, table 2). Lozo and Stricklin (1956) suppressed the name Travis Peak, elevated the included rock units to formation rank, and recognized an additional rock unit (in ascending order): Sycamore Sand, Hammett Shale, Cow Creek Limestone, and Hensel Sand (Fisher and Rodda, 1966, table 2 and fig. 6). On the basis of rock sequence and stratigraphic relations along the eastern side of the Llano uplift, Lozo and Stricklin proposed a revised concept of the Trinity Division (Hill, 1901) as a physically defined time-stratigraphic unit.

The Sycamore Sand consists of a coarse basal conglomerate of several pre-Cretaceous rock types of the Llano area and grades vertically to a mixture of sand, pebbles, silt, and clay. The Sycamore generally is about 100 feet in thickness on outcrop and laps out

Mileage *Total*	*Interval*	
		against the Llano uplift. The overlying Hammett Shale is about 60 feet of dark to buff shale and includes fossiliferous dolomitic limestone in the upper part. It grades upward and laterally to the Cow Creek Limestone which consists of massive coarse-grained molluscan limestone, sandy and dolomitic limestone, and crossbedded coarse-grained limestone with rounded shell fragments and quartz sand. The Cow Creek laps out against the Llano uplift and has a maximum thickness of about 75 feet. The Hensel Sand is a marginal facies of the Glen Rose Formation and consists mostly of crossbedded sand, silt, clay, and pebble- and cobble-conglomerate. It is disconformable above the Cow Creek Limestone and is about 40 to 100 feet thick. The cyclical onlapping of these units on the southeastern Llano uplift has been described by Cloud and Barnes (1948, Pl. III), Barnes (1948), and by Lozo and Stricklin (1956). Barnes (1948) mapped Sycamore Sand, Cow Creek Limestone, and Hensel Sand along Lake Travis at the Burnet-Travis County line and mapped (1958) all the basal Cretaceous sequence below the Glen Rose in the vicinity of Burnet as Hensel Sand.
		For the next 15 miles travel will be mainly on Hensel Sand with lower units exposed in the deeper valleys and the overlying Glen Rose Formation forming the higher topography to the north and east.
34.4	0.6	STOP 10. Road cuts expose sandstone and silty clay of the Hensel Sand (fig. 23). Park at top of cut and walk down hill and back. Typical exposure of crossbedded and channeled, conglomeratic sand and underlying red-brown silty clay.
35.1	0.7	Camp Creek. Prominent ledges are Cow Creek Limestone.
36.0	0.9	Hensel Sand in road cut. Slope above cut is on Glen Rose Formation.
36.5	0.5	View to north. Stairstep topography developed on alternating hard and soft limestones of the Glen Rose Formation.
39.7	3.2	Hammett Shale exposed in cut on south side of road.
41.1	1.4	Smithwick Church.
41.4	0.3	Smithwick Cemetery. Hensel Sand in road cuts.
42.5	1.1	Hickory Creek. Prominent ledges are Cow Creek Limestone.
45.7	3.2	Typical Glen Rose stairstep topography to the north from 43.2 to 45.7.
46.6	0.9	Road cut. Excellent exposure of crossbedded and channeled Hensel Sand.
47.7	1.1	Burnet-Travis County line. Road cut exposes Hensel Sand below and Glen Rose Formation above.
48.6	0.9	Traveling on Glen Rose Limestone.
49.2	0.6	View point. Ridge on eastern skyline is composed of Glen Rose, Walnut, and basal Edwards Formations in ascending order.
52.2	3.0	On Hensel Sand from 50.7 to 52.2.
52.2	0.0	Cow Creek bridge. Prominent knob to the north is Travis Peak. The type areas for 3 basal Cretaceous units are in this vicinity. The creek gave its name to the Cow Creek Limestone; the Hensel Sand was named from the Hensel ranch on Cow Creek; the name Travis Peak Formation was taken from the prominent knob and the old Travis Peak Post Office. (*See* Barnes, 1948; Lozo and Stricklin, 1956; and Fisher and Rodda, 1966, for discussion of these units.)
53.7	1.5	View south of Cow Creek arm of Lake Travis. At low lake levels an excellent outcrop of Cow Creek Limestone is exposed in the bed of Cow Creek.
54.0	0.3	Base of Glen Rose Formation. For the next 12 miles travel will be over Glen Rose limestone, marl and dolomite. Generally, the Glen Rose of this area has been divided into an upper and a lower unit on the basis of a thin, widespread bed, or series of beds, containing an abundance of the small, elongate clam *Corbula harveyi* (Hill). More recently, in the Austin area the Glen Rose has been subdivided into 5 informal, mappable members based mainly on the concentration of dolomite beds at certain levels (Rodda et al., 1970). The 5 members persist, but thin, to the west up the Colorado Valley.

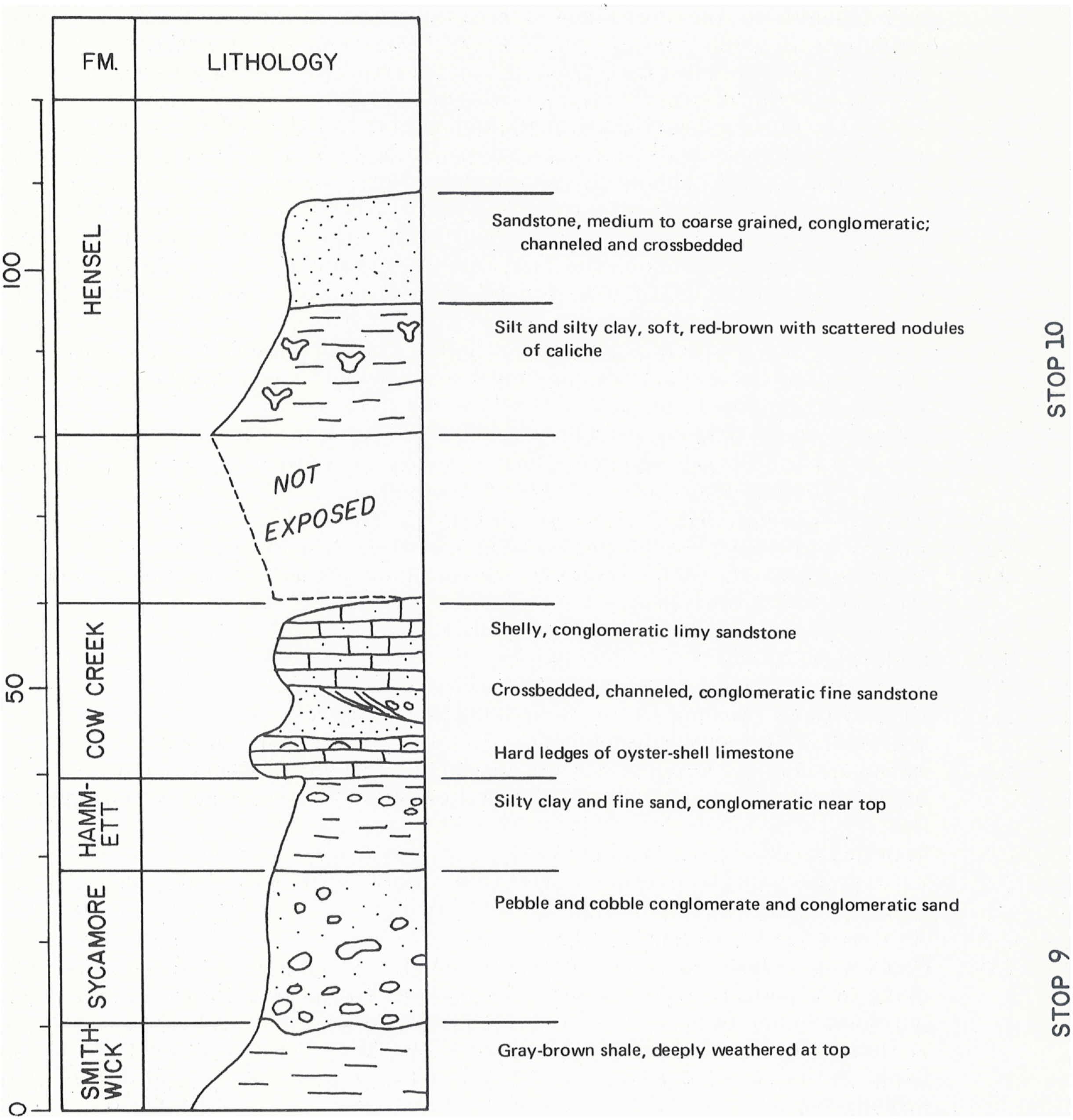


FIG. 23. Stratigraphic section at STOPS 9 and 10. STOP 9 is road cut on Ranch Road 1431, 0.2 mile east of Sycamore Creek crossing. STOP 10 is road cut on Ranch Road 1431, 0.6 mile east of STOP 9.

Mileage		
Total	*Interval*	
55.3	1.3	Views of Lake Travis to the southeast from 54.3 to 55.3.
59.1	3.8	Entrance to Lago Vista lakeside community.
62.7	3.6	Road cut exposes Glen Rose Limestone.
63.0	0.3	Jonestown community on Big Sandy arm of Lake Travis.
65.2	2.2	Big Sandy Creek.
65.7	0.5	Bloody Hollow.
66.5	0.8	STOP 11. Road cut and slope. Park and walk downhill to Glen Rose—Walnut contact; examine section on way back. Upper Glen Rose, Walnut, and basal Edwards Formations. Rudist bed marks local base of Edwards Formation (fig. 24). The section at this stop, together with that at STOP 12, reflects platform margin deposition intermediate between shallow-shelf basinal facies characterized by relatively thick sections of marly limestone and marl with oysters and ammonites (Comanche Peak and Walnut Formations, STOP 13), and platform facies characterized by rudist limestones, dolomite, and evaporite (Edwards Formation, STOP 14) (Fisher and Rodda, 1969). The two facies are not mutually exclusive; initial Fredericksburg deposits on the platform consist of nodular marly limestone similar to the shelf basinal facies but thinner (fig. 24).
68.7	2.2	Driving on erosional remnant of the Edwards Plateau from 66.7 to 68.7. Topographic surface is approximately top of the Whitestone Lentil (Edwards Formation). Low cuts and hills to north expose Keys Valley Marl (Walnut Formation), Comanche Peak Limestone, and higher parts of the Edwards Formation.
69.0	0.3	Travis-Williamson County line. Turn right (east) on Lime Creek Road.
69.05	0.05	STOP 12. Inactive building-stone quarry of Texas Quarries, Inc. Park beside road. Walk south to quarry edge and down ramp into quarry. Whitestone Lentil (Edwards Formation) and Keys Valley Marl (Walnut Formation). The Whitestone has been quarried for many years as a building stone (Barnes, Dawson, and Parkinson, 1947, pp. 37-38). It is attractive, soft and easily worked, and is used widely in Texas and elsewhere. Two types of stone are quarried: a crossbedded oolite (Cordova Cream) and an underlying shell-fragment oolite with distinctive molds of the bivalve *Trigonia* (Cordova Shell). The building-stone oolite is a local facies within the Whitestone Lentil; elsewhere the Whitestone is an oolitic, shell-fragment limestone containing both oysters and rudists (Moore, 1964; Moore and Martin, 1966; Frishman, 1968; Rogers, 1969). The entire unit, but especially the building-stone facies, is analogous to the modern oolitic sands on the eastern edge of the Bahama Islands (Ball, 1967). As such the unit is more a part of the platform deposition than it is of the shelf basin, and the stratigraphic nomenclature has been modified to reflect this. The Whitestone Lentil was defined as a part of the Walnut Formation, a shelf-basin facies (Moore, 1964). In this guidebook the Whitestone is considered a part of the Edwards Formation; in early geologic descriptions the building-stone facies had been referred to the Edwards (Burchard, 1910; Barrow, 1922; Frishman, 1968). The marly unit (Keys Valley Member of the Walnut Formation) above the Whitestone Lentil in the quarry is a tongue of oyster- and ammonite-bearing, shelf-basin facies that extends southward over the Whitestone Lentil onto the margin of the platform (fig. 25).
69.7	0.7	Whitestone Lime Company (inactive). This small plant utilized the building-stone facies of the Whitestone Lentil as raw material. The Whitestone is one of the purest limestones (99.9% $CaCO_3$) in the State (Rodda et al., 1966).
70.9	1.2	Intersection of Ranch Road 1431 and U. S. Highway 183. Turn left (north).
74.0	3.1	Traveling on Keys Valley Marl (Walnut Formation). Cultivated fields are in the Keys Valley; higher, juniper-covered slopes are Comanche Peak Limestone.
76.2	2.2	Leander community.
77.5	1.3	Railroad crossing. CAUTION.

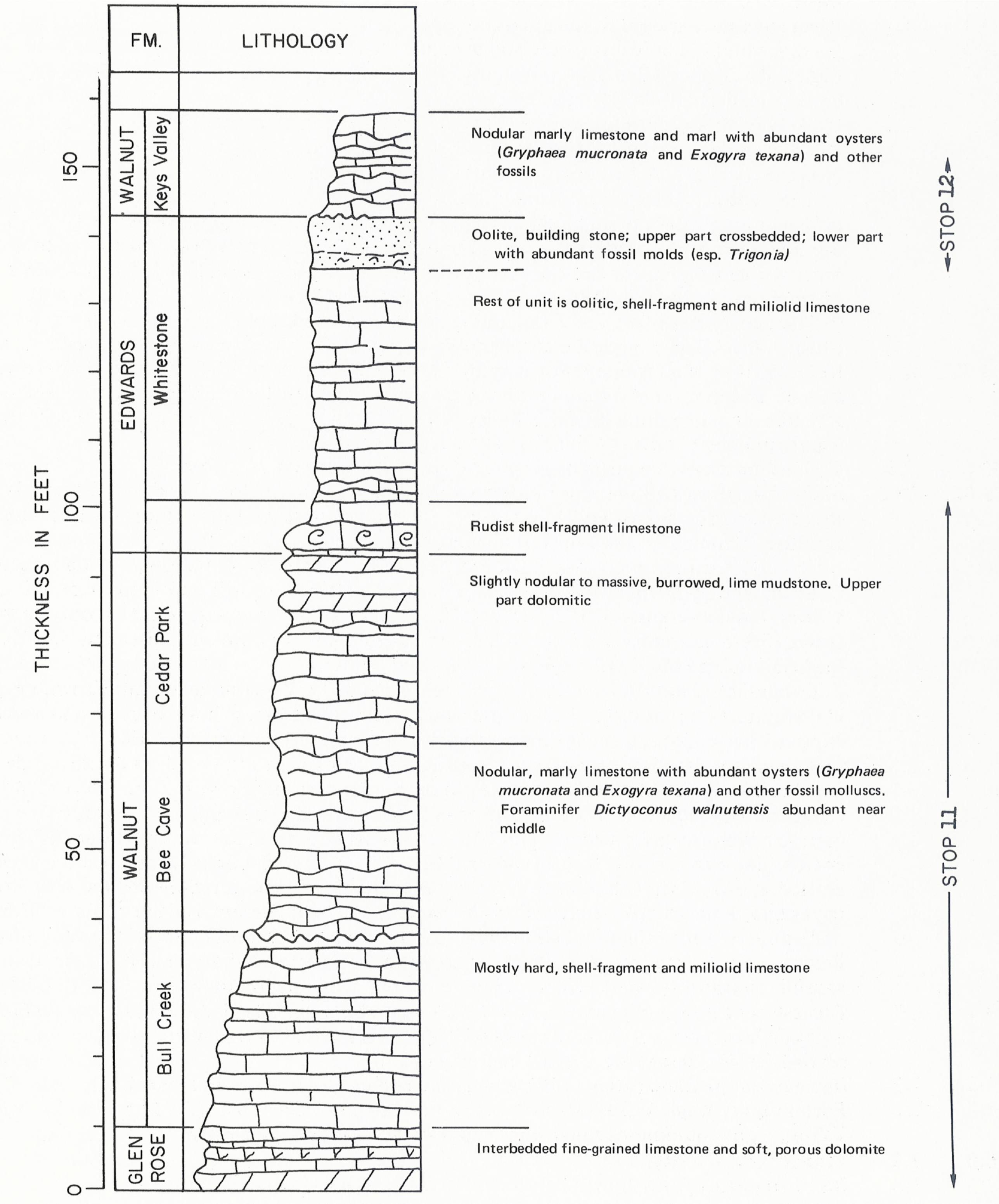


Fig. 24. Stratigraphic section at STOPS 11 and 12. STOP 11 is road cut in Travis County on north side of Ranch Road 1431, 2 miles west of Williamson County line. STOP 12 is inactive quarry of Texas Quarries, Inc., on south side of Ranch Road 1431 at Travis-Williamson County line (modified from Moore, 1964).

Mileage		
Total	*Interval*	
78.5	1.0	Roadside park on left.
79.1	0.6	STOP 13. South Fork of San Gabriel River. Section exposed in river bed and in high bluff upstream from bridge (fig. 26). Upper Glen Rose, Walnut, and Comanche Peak Formations. In river bed the dolomitic upper Glen Rose contains pockets of pale blue celestite (strontium sulfate). Downstream about 100 yards from the bridge, along the north bank, is an excellent exposure of dinosaur tracks on the upper surface of the Glen Rose Formation (*see* Moore, 1964, Pls. 2, 3). The bluff section exposes the Bull Creek, Bee Cave, and Cedar Park Members of the Walnut Formation and at the top, the Comanche Peak Limestone. Whitestone-Edwards facies is not present. Turn around and head back south on U. S. Highway 183.
80.7	1.6	Railroad crossing. CAUTION.
82.2	1.5	Leander community.
86.5	4.3	Intersection with Ranch Road 1431. Continue on U. S. Highway 183.
86.6	0.1	Whitestone community.
87.3	0.7	Cedar Park community.
88.5	1.2	Road cut on right (west) exposes limestone and dolomite of the lower Edwards Formation. For about the next 10 miles travel will be on a slightly dissected remnant of the Edwards Plateau; surface rocks are limestones and dolomites of the lower Edwards Formation. A mixed live-oak, juniper, hackberry vegetation characterizes the Edwards.
90.8	2.3	Intersection. Turn right (west) on Ranch Road 620.
96.5	5.7	Four Points. Intersection; turn left (east) on Ranch Road 2222.
98.4	1.9	STOP 14. Road cuts. Stop at top of cuts and walk down through the cuts. The cuts expose lower Edwards, Walnut, and Glen Rose Formations, in descending order (fig. 27). Compare and contrast this section with sections at STOPS 11-13. This section is on the platform, behind the Whitestone section. The Cedar Park Limestone has thinned by facies change to Edwards lithology and consists of massive, burrowed, slightly dolomitic lime mudstone (micrite). Thinly bedded limestone and dolomitic limestone near the top of the section may correlate with the Whitestone Lentil and Keys Valley Marl. Other Walnut Members (Bee Cave and Bull Creek) persist, but thin, on the platform. The Bull Creek Limestone is poorly exposed in this section but is better exposed in the bar ditch along the old highway about 100 yards north. Top of the Bull Creek is iron stained and case hardened, was bored by Cretaceous clams, and is one of the most prominent bedding surfaces in the Cretaceous rocks of this area. The contact with the underlying Glen Rose Formation is much more obscure. The lower cut exposes limestones and dolomites of the upper Glen Rose Formation.
100.0	1.6	Traveling down west Bull Creek valley. For the next 6 miles surface rocks are limestones and dolomites of the upper Glen Rose Formation (Rodda et al., 1970).

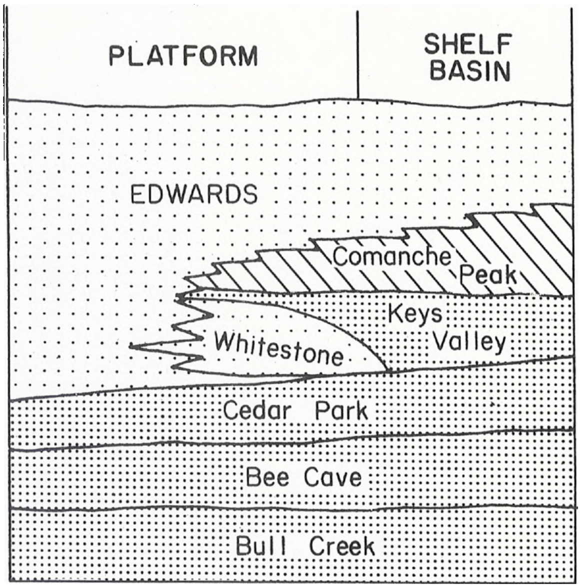
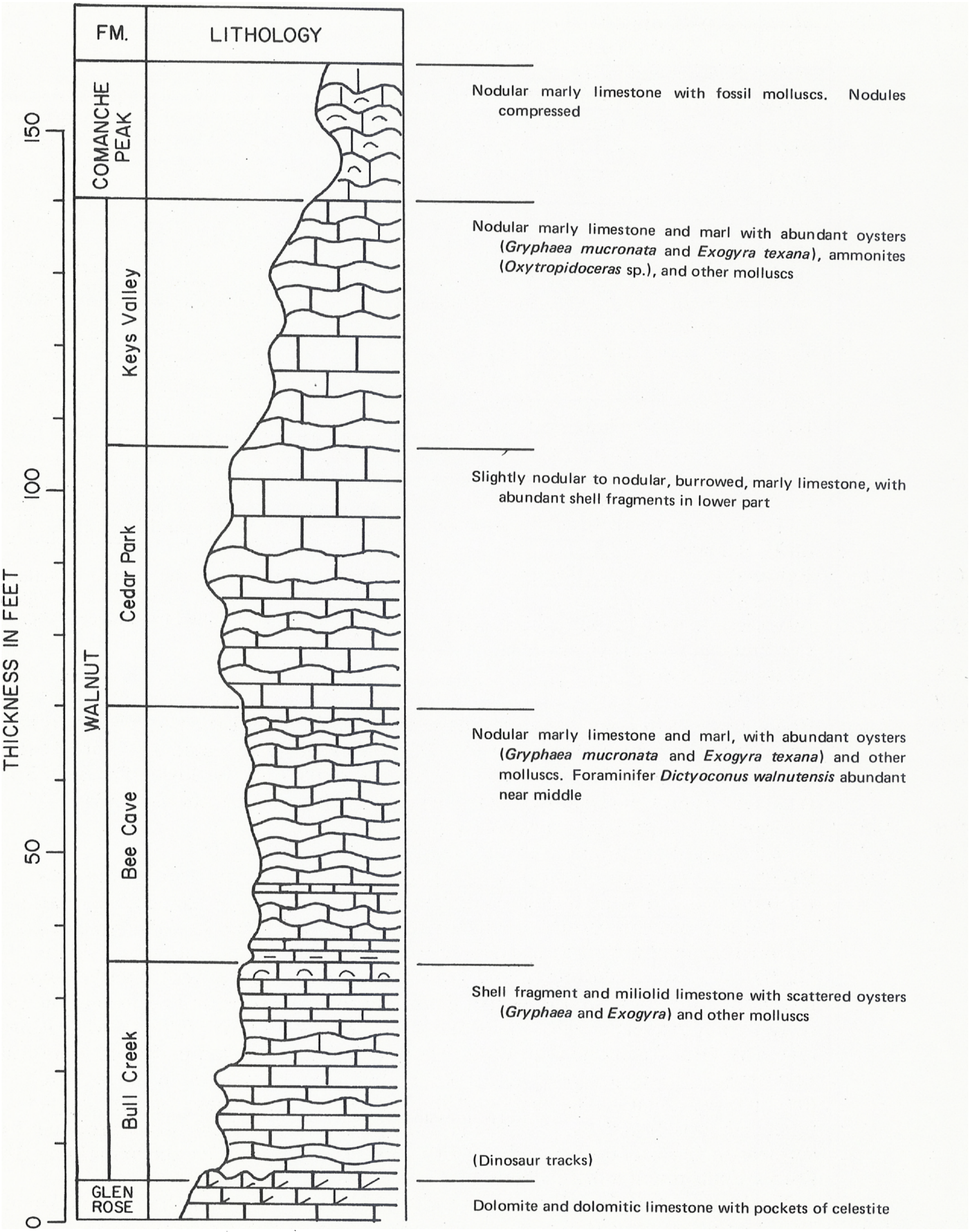


FIG. 25. Diagrammatic cross section of Fredericksburg rocks, Travis and Williamson counties, Texas (modified from Moore, 1964).



Nodular marly limestone with fossil molluscs. Nodules compressed

Nodular marly limestone and marl with abundant oysters (*Gryphaea mucronata* and *Exogyra texana*), ammonites (*Oxytropidoceras* sp.), and other molluscs

Slightly nodular to nodular, burrowed, marly limestone, with abundant shell fragments in lower part

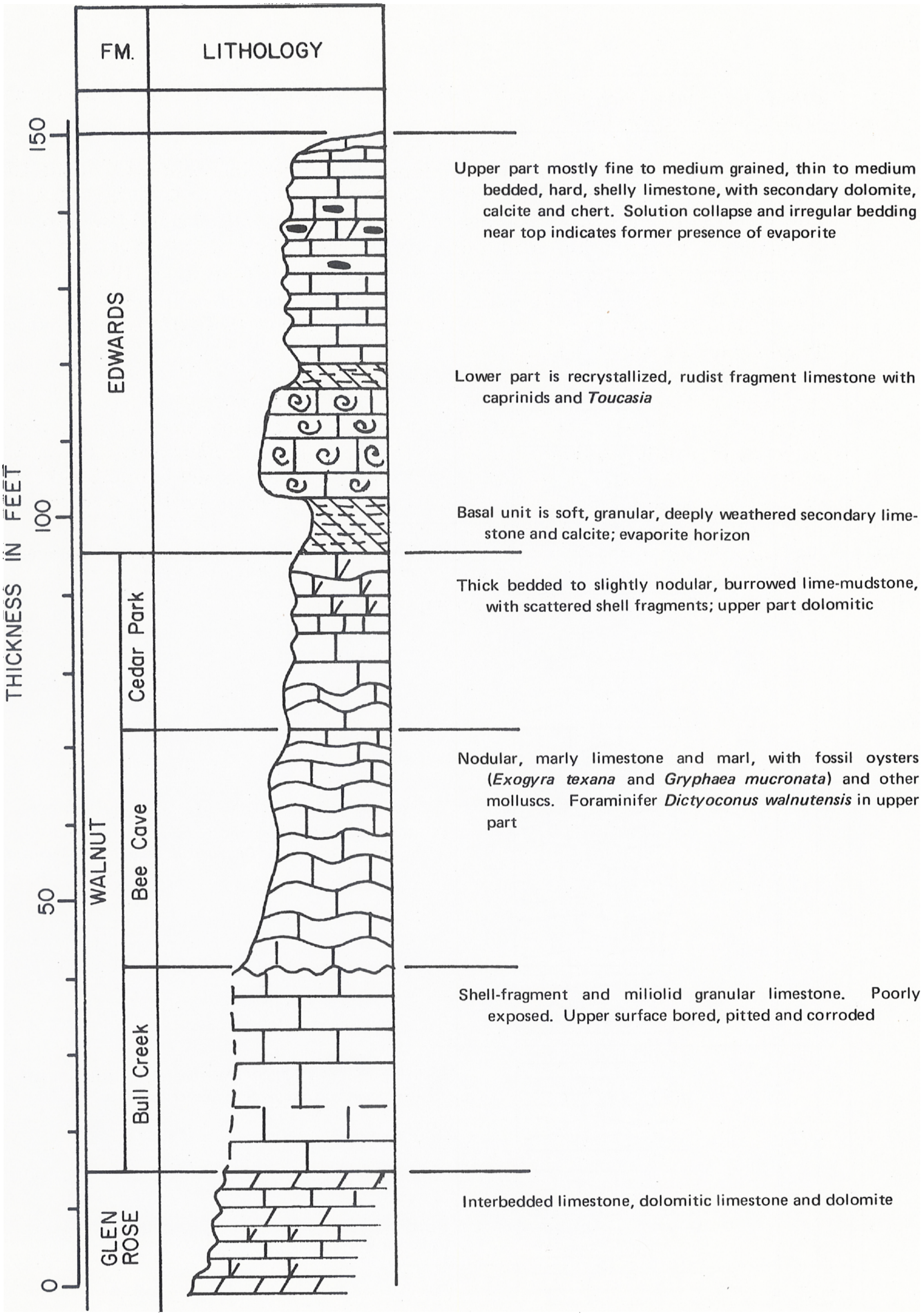
Nodular marly limestone and marl, with abundant oysters (*Gryphaea mucronata* and *Exogyra texana*) and other molluscs. Foraminifer *Dictyoconus walnutensis* abundant near middle

Shell fragment and miliolid limestone with scattered oysters (*Gryphaea* and *Exogyra*) and other molluscs

(Dinosaur tracks)

Dolomite and dolomitic limestone with pockets of celestite

FIG. 26. Stratigraphic section at STOP 13. Bluff on south side of South Fork of San Gabriel River, 3 miles north of Leander, Williamson County (modified from Moore, 1964).



Upper part mostly fine to medium grained, thin to medium bedded, hard, shelly limestone, with secondary dolomite, calcite and chert. Solution collapse and irregular bedding near top indicates former presence of evaporite

Lower part is recrystallized, rudist fragment limestone with caprinids and *Toucasia*

Basal unit is soft, granular, deeply weathered secondary limestone and calcite; evaporite horizon

Thick bedded to slightly nodular, burrowed lime-mudstone, with scattered shell fragments; upper part dolomitic

Nodular, marly limestone and marl, with fossil oysters (*Exogyra texana* and *Gryphaea mucronata*) and other molluscs. Foraminifer *Dictyoconus walnutensis* in upper part

Shell-fragment and miliolid granular limestone. Poorly exposed. Upper surface bored, pitted and corroded

Interbedded limestone, dolomitic limestone and dolomite

FIG. 27. Stratigraphic section at STOP 14. Road cut, Ranch Road 2222, 2 miles east of Four Points, Travis County.

Mileage		
Total	*Interval*	
102.3	2.3	Austin City Park road to right. Type locality of the Bull Creek Limestone is in a road cut ¾ mile west (Moore, 1961).
103.0	0.7	Crossing Bull Creek. Bull Creek road to left.
103.5	0.5	Deep road cut below Cat Mountain exposes the upper limestone unit of the Glen Rose Formation. Slopes above cut are in the upper dolomite unit of the Glen Rose, the Bull Creek and Bee Cave Members of the Walnut, and, at the top, the lower Edwards Formations. Slopes below road, down to Bull Creek arm of Lake Austin, expose middle dolomite and middle limestone units of the Glen Rose (Rodda et al., 1970).
104.3	0.8	View of Lake Austin to southwest.
104.8	0.5	Mount Bonnell road to right (south). Continue on Ranch Road 2222.
105.5	0.7	Traveling up the valley of Dry Creek.
106.0	0.5	Contact of Bull Creek Limestone and Glen Rose Formation.
106.2	0.2	Intersection. Turn left (east) on Ranch Road 2222 (Northland Drive).
106.3	0.1	Intersection of Ranch Road 2222 (Northland Drive) and Balcones Trail. Trace of main Balcones fault (Mount Bonnell fault) at this point is along Balcones Drive. At this intersection Buda Limestone to the east is faulted down against Bull Creek Limestone (Walnut Formation). Net throw is about 500 feet. Turn left (north) on Balcones Drive.
106.5	0.2	Approximate Glen Rose—Bull Creek boundary.
106.8	0.3	Bee Cave Member of Walnut Formation (Fredericksburg Division) can be seen in small cliffs on left.
107.3	0.5	Turn left to Texas Crushed Stone quarry.

STOPS 15-17

KEITH YOUNG

Mileage		
Total	*Interval*	
107.75	0.45	STOP 15. Texas Crushed Stone quarry. This section (fig. 28) is in the lower part of the Edwards Limestone, which is here partly dolomitized. The one massive bed is a reefoid biostrome containing *Caprinuloidea* sp., *Toucasia* sp., and colonial and solitary *Actinaria*. Retrace route out of quarry.
108.2	0.45	Turn left on Balcones Trail.
109.95	1.75	Balcones fault system. For the past mile the road has been following approximately the trace of the main fault of the Balcones fault system. The fault line scarp to the left on the upthrown side of the fault is underlain by untillable Edwards Limestone covered with live-oak, juniper, and other brush typical of the Hill Country. To the right, the downthrown side of the fault, the outcrop consists of Eagle Ford claystone which supports a sparse growth of mesquite and hackberry and is tillable. Although formerly farmed, this land is now too expensive to farm and is awaiting urban development.
110.9	0.94	Intersection at cloverleaf on Burnet Highway (U. S. Highway 183). Turn left to go right (east), leaving the main fault of the Balcones system. Eagle Ford is in fault contact with Edwards.
111.25	0.35	Missouri Pacific railroad overpass. Condensed zone of Eagle Ford exposed at east end of overpass. The Balcones Research Center of The University of Texas at Austin is in the buildings on the left. In addition to research in physics, chemistry, and psychology (this was the home base of Enos and other pre-*Homo* astronauts), there

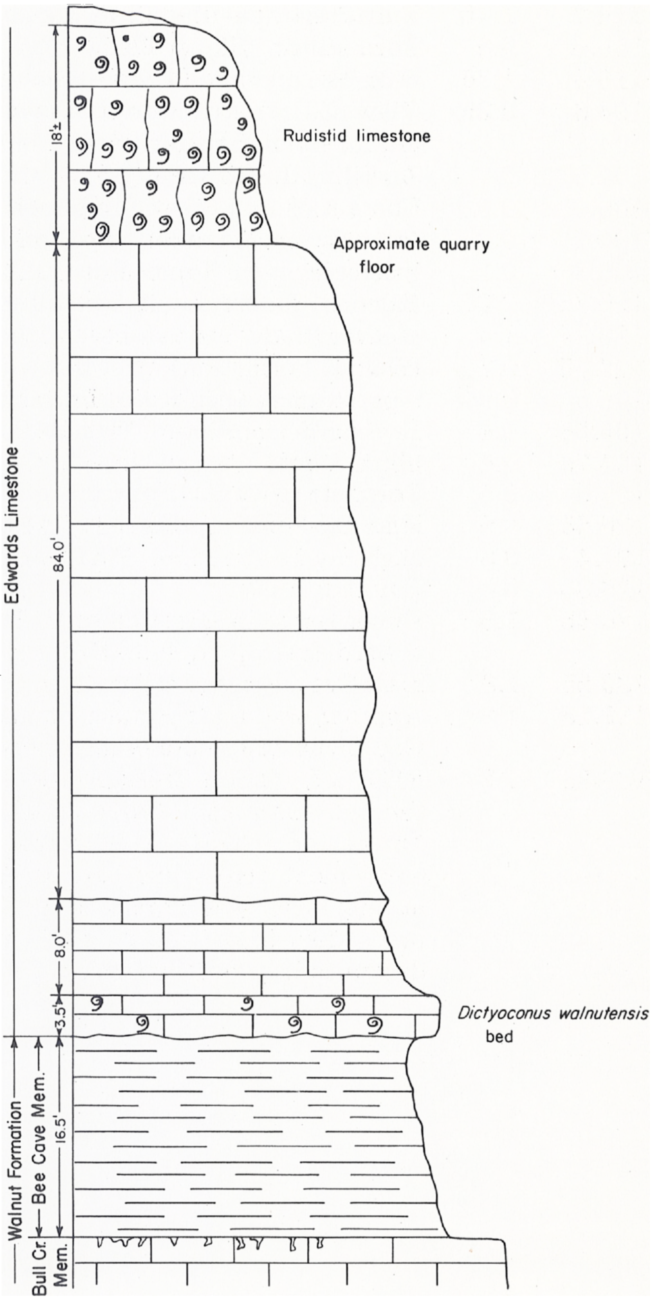


FIG. 28. Upper part of Walnut Formation and lower part of Edwards Limestone, Texas Crushed Stone quarry, Balcones Trail, Austin, Travis County, Texas (modified from Feray, Hazzard, Lozo, and Nunnally, 1949).

Mileage		
Total	*Interval*	
		are various geological research facilities. The Bureau of Economic Geology's Mineral Studies Laboratory and its Well Sample Library are located here.
111.45	0.2	Passing from Eagle Ford to Atco (= lowest formation of Austin Division).
112.05	0.6	Intersection with Burnet Road; continue ahead.
112.75	0.7	Driving on lower part of Austin Division.
114.2	1.45	Turn right on Lamar Blvd.
115.0	0.8	Turn left on Airport Blvd.
116.35	1.35	Turn left on U. S. Highway 290 (toward Elgin); driving on upper part of Austin.
118.6	2.25	STOP 16. Austin Archery Club. Exposed here (fig. 29) are the Dessau Limestone below and the Burditt Marl above. Both of these formations belong to the upper part of the Austin and with the Big House Limestone comprise the "Upper Austin" of Adkins (1933). These rocks are Lower Campanian and represented here are the zones of *Submortoniceras tequesquitense* below and *Delawarella delawarensis* above. The *Exogyra laeviuscula* biostrome is the top bed of the Dessau Chalk. Retrace route to Airport Blvd.
120.85	2.25	Turn left on Airport Blvd. (U. S. Highway 183).
122.24	1.4	Underpass at freeway; driving on Burditt Marl and Big House Limestone.
122.95	0.7	Passing Austin Airport. This level area, Airport Terrace, is held up by the gravel of the highest terrace of the Colorado River.
124.35	1.4	Asylum Terrace level. This is the next to the highest terrace of the Colorado River.
124.75	0.4	Sixth Street Terrace level. One of the most extensive of the lower terraces of the Colorado River.
126.65	0.9	Missouri-Kansas-Texas (Katy) railroad overpass.
126.45	0.8	Highway intersection. First Street Terrace.
126.85	0.4	Colorado River.
128.45	1.6	Underpass at intersection of U. S. Highway 183 and State Highway 71. Continue eastward toward Bastrop on State Highway 71, driving on terrace gravel of the Colorado River.
130.25	1.8	Main Gate, Bergstrom Air Force Base (SAC); driving on terrace gravel of the Colorado River.
132.15	1.9	Approximate fault contact of Taylor Division with Navarro Division. There is no Pecan Gap Chalk scarp here because this formation is faulted out.
133.35	1.2	STOP 17. Onion Creek bridge. Walk approximately 200 yards downstream to see one of the best outcrops of Corsicana Marl. The embankment is almost 120 feet high. The upper 15 feet or so is Kemp Siltstone, which holds up the embankment and produces a small escarpment across this part of Travis County. The remaining 100 feet or more of rock at this locality is Corsicana Marl. The base of the formation is not exposed but is not many feet below the base of the outcrop. This is the type locality for Foraminifera described by Dorothy Carsey (1926).

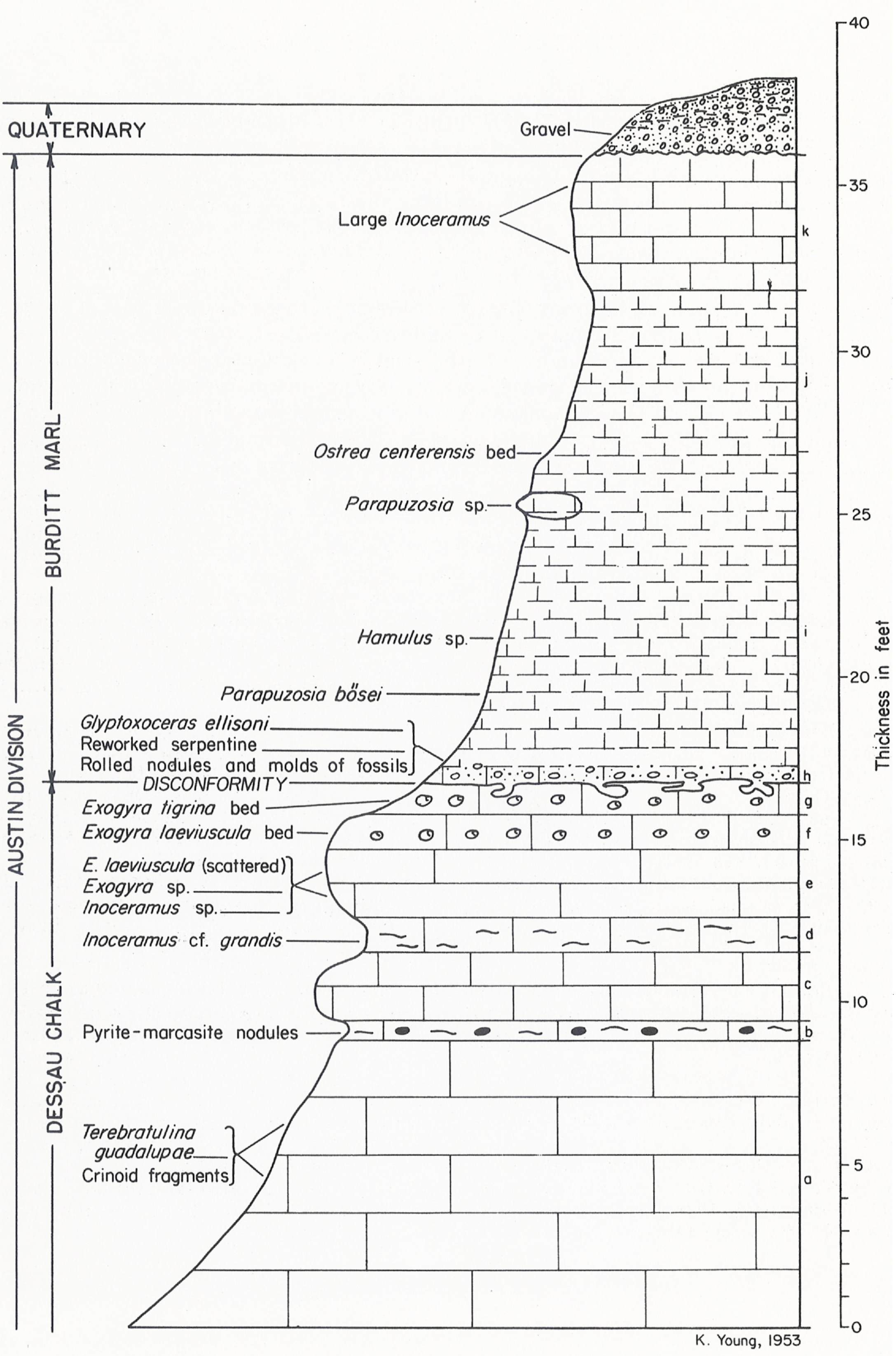


FIG. 29. Partial section of Dessau Chalk and Burditt Marl north of bridge on west side of Little Walnut Creek, U. S. Highway 290 (Austin-Manor), Travis County, Texas.

REFERENCES CITED IN ROAD LOG

ADKINS, W. S. (1933) The Mesozoic systems in Texas, *in* SELLARDS, E. H., ADKINS, W. S., and PLUMMER, F. B., The geology of Texas, Vol. I, Stratigraphy: Univ. Texas, Bull. 3232 (Aug. 22, 1932), pt. 2, pp. 239-518.

BARNES, V. E. (1948) Ouachita facies in Central Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 2, 15 pp.

________ (1958) Field excursion, eastern Llano region: Univ. Texas, Bur. Econ. Geology Guidebook No. 1, 36 pp.

________, CLOUD, P. E., Jr., and WARREN, L. E. (1947) Devonian rocks of Central Texas: Bull. Geol. Soc. America, vol. 58, pp. 125-140.

________, DAWSON, R. F., and PARKINSON, G. A. (1947) Building stones of Central Texas: Univ. Texas Pub. 4246 (Dec. 8, 1942), 198 pp.

BARROW, L. T. (1922) The geology of the building stone of Cedar Park and vicinity: Univ. Texas, Austin, M.A. thesis, 88 pp.

BULLARD, F. M., and PLUMMER, F. B. (1939) Paleozoic section of the Llano uplift: Guide to geologic excursion sponsored by West Texas Geol. Soc., Fort Worth Geol. Soc., Texas Acad. Sci., and Univ. Texas (Nov. 11-12, 1939), 20 pp.

BURCHARD, E. F. (1910) Structural materials available in the vicinity of Austin, Texas, *in* Contributions to economic geology, 1909, Pt. 1, Metals and nonmetals except fuels: U. S. Geol. Survey Bull. 430, pp. 292-316.

CARSEY, D. O. (1926) Foraminifera of the Cretaceous of Central Texas: Univ. Texas Bull. 2612, 56 pp.

CLOUD, P. E., Jr., and BARNES, V. E. (1948) The Ellenburger Group of Central Texas: Univ. Texas Pub. 4621 (June 1, 1946), 473 pp.

________, ________, and HASS, W. H. (1957) Devonian-Mississippian transition in Central Texas: Bull. Geol. Soc. America, vol. 68, pp. 807-816.

FERAY, D. F., HAZZARD, R. T., LOZO, F. E., and NUNNALLY, J.D. (1949) Texas Crushed Stone quarry, Balcones Trail, Travis County, Texas, *in* Cretaceous of Austin, Texas, area: Shreveport Geol. Soc., Guidebook, 17th annual field trip, Plate 7.

FISHER, W. L., and RODDA, P. U. (1966) Nomenclature revision of basal Cretaceous rocks between the Colorado and Red Rivers, Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 58, 20 pp.

________ and ________ (1969) Edwards Formation (Lower Cretaceous), Texas: Dolomitization in a carbonate platform system: Bull. Amer. Assoc. Petrol. Geol., vol. 53, pp. 55-72.

FRISHMAN, S. A. (1968) Depositional environment of the Whitestone Lentil, *in* SCOTT, A. J., Ed., Early Cretaceous depositional environments: Univ. Texas, Austin, Dept. Geol. Sciences, pp. 93-110 (unpublished).

HASS, W. H. (1947) Conodont zones in Upper Devonian and Lower Mississippian formations of Ohio: Jour. Paleont., vol. 21, pp. 131-141.

________ (1953) Conodonts of the Barnett Formation of Texas: U. S. Geol. Survey Prof. Paper 243-F, pp. 69-94.

________ (1956a) Conodonts from the Arkansas Novaculite, Stanley Shale, and Jackfork Sandstone: Guidebook Ardmore Geol. Soc. Ouachita Mountain Field Conf., southeastern Oklahoma, pp. 25-33.

________ (1956b) Age and correlation of the Chattanooga Shale and the Maury Formation: U. S. Geol. Survey Prof. Paper 286, 47 pp.

HILL, R. T. (1890) A brief description of the Cretaceous rocks of Texas and their economic uses: Texas Geol. Survey, 1st Ann. Rept. (1889), pp. 105-141.

________ (1901) Geography and geology of the Black and Grand Prairies, Texas: 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.

LOZO, F. E., and STRICKLIN, F. L., Jr. (1956) Stratigraphic notes on the outcrop basal Cretaceous, Central Texas: Trans. Gulf Coast Assoc. Geol. Socs., vol. 6, pp. 67-78.

MOORE, C. H., Jr. (1961) Stratigraphy of the Walnut Formation, south-central Texas: Texas Jour. Sci., vol. 13, pp. 17-40.

________ (1964) Stratigraphy of the Fredericksburg Division, south-central Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 52, 48 pp.

________ and MARTIN, K. G. (1966) Comparison of quartz and carbonate shallow marine sandstones, Fredericksburg Cretaceous, Central Texas: Bull. Amer. Assoc. Petrol. Geol., vol. 50, pp. 981-1000.

RODDA, P. U., FISHER, W. L., PAYNE, W. R., and SCHOFIELD, D. A. (1966) Limestone and dolomite resources, Lower Cretaceous rocks, Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 56, 286 pp.

________, GARNER, L. E., and DAWE, G. L. (1970) Austin West, Travis County, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map No. 38 (with text).

ROGERS, M. A. C. (1969) Stratigraphy and structure of the Fredericksburg Division (Lower Cretaceous), northeast quarter Lake Travis quadrangle, Travis and Williamson counties, Texas: Univ. Texas, Austin, M.A. thesis, 49 pp.

SEDDON, GEORGE (1970) Pre-Chappel conodonts of the Llano region, Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 68, 130 pp.

TAFF, J. A. (1892) Reports on the Cretaceous area north of the Colorado River: Texas Geol. Survey, 3d Ann. Rept. (1891), pp. 267-379.