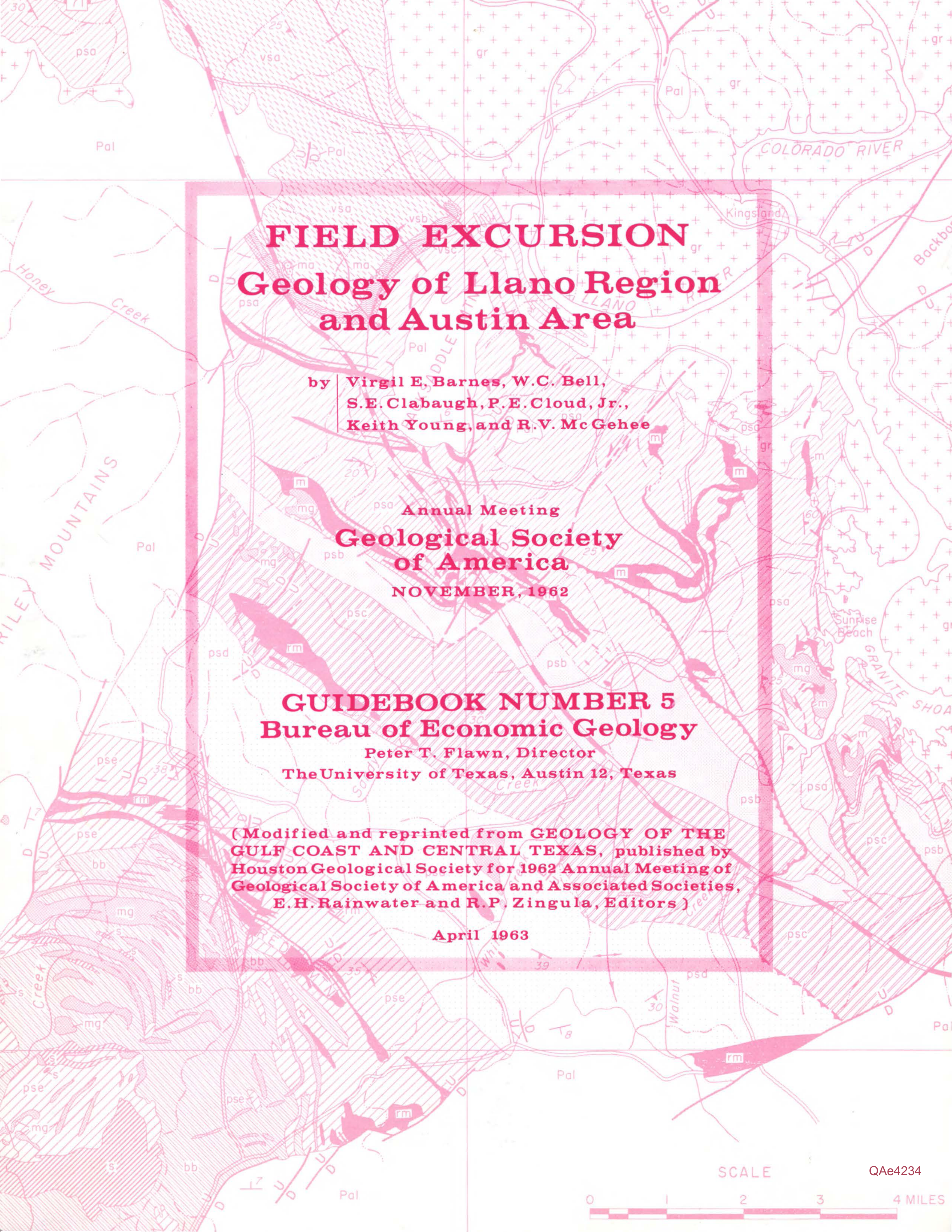

FIELD EXCURSION

Geology of Llano Region and Austin Area

by Virgil E. Barnes, W.C. Bell,
S.E. Clabaugh, P.E. Cloud, Jr.,
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Annual Meeting

Geological Society of America

NOVEMBER, 1962

GUIDEBOOK NUMBER 5

Bureau of Economic Geology

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(Modified and reprinted from GEOLOGY OF THE GULF COAST AND CENTRAL TEXAS, published by Houston Geological Society for 1962 Annual Meeting of Geological Society of America and Associated Societies, E.H. Rainwater and R.P. Zingula, Editors)

April 1963

FOREWORD

This Guidebook is a reprinting (with minor modifications) of Field Trip No. 1 from "Geology of the Gulf Coast and Central Texas," published by the Houston Geological Society for the 1962 Annual Meeting of The Geological Society of America and Associated Societies. The reprinting is in response to strong local interest in the geology of the Llano region and the Austin area and the needs of geology students and faculty engaged in study of this classic region. Cooperation of the Houston Geological Society is gratefully acknowledged. For convenience of reference, the page numbers of the original publication have

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GEOLOGY OF LLANO REGION AND AUSTIN AREA
Field Excursion, November 10-11, 1962

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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 participants on this excursion with the diversity of rock types and the range of stratigraphic section available for study in the Llano region and Austin area. Purposely omitted is a discussion of the Tertiary rocks, which are also tributary to Austin, because these rocks are the subject of other excursions held concurrently or subsequently.

The listing of geologic units recognized in the Llano region and Austin area, the "Schematic section, central Llano County to eastern Travis County" (fig. 2), and the résumé "Geologic History of Central Texas" are included so that participants can more readily integrate the geologic features seen at each locality into the geologic history of the region as a whole.

Geologic units recognized are listed as follows:

Cretaceous (<u>see</u> Young, p. 99, for formations and members)
- Upper Cretaceous
  - Navarro Group
  - Taylor Group
  - Austin Group
  - Eagle Ford Group
  - Woodbine Group
- Lower Cretaceous
  - Washita Group
  - Fredericksburg Group
  - Trinity Group

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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

Ordovician
- Upper Ordovician
  - Burnam Limestone

- Lower Ordovician
  - Ellenburger Group
    - Honeycut Formation
    - Gorman Formation
    - Tanyard Formation (part)
      - Staendebach Member
      - Threadgill Member (part)

Cambrian and Ordovician
- Threadgill Member (part)
- Wilberns Formation (part)
  - San Saba Member (part)

Cambrian
- Upper Cambrian
  - 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)

Upper and Middle Cambrian
- Cap Mountain Limestone Member (part)
- Hickory Sandstone Member (part)

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. 64, for subdivisions)
  - Packsaddle Schist
  - Valley Spring Gneiss

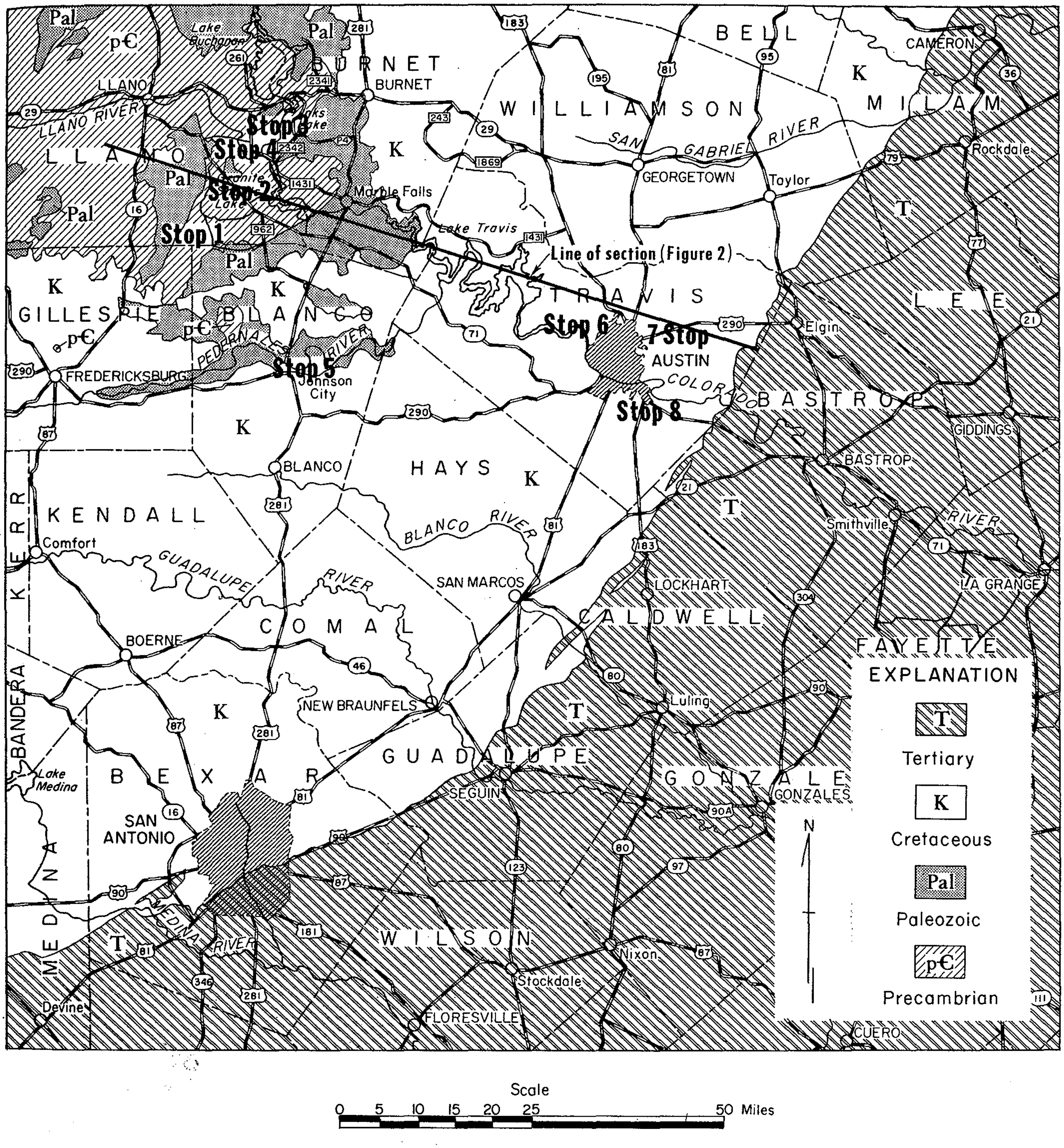

Figure 1. INDEX MAP SHOWING EXCURSION ROUTE AND LOCALITIES.

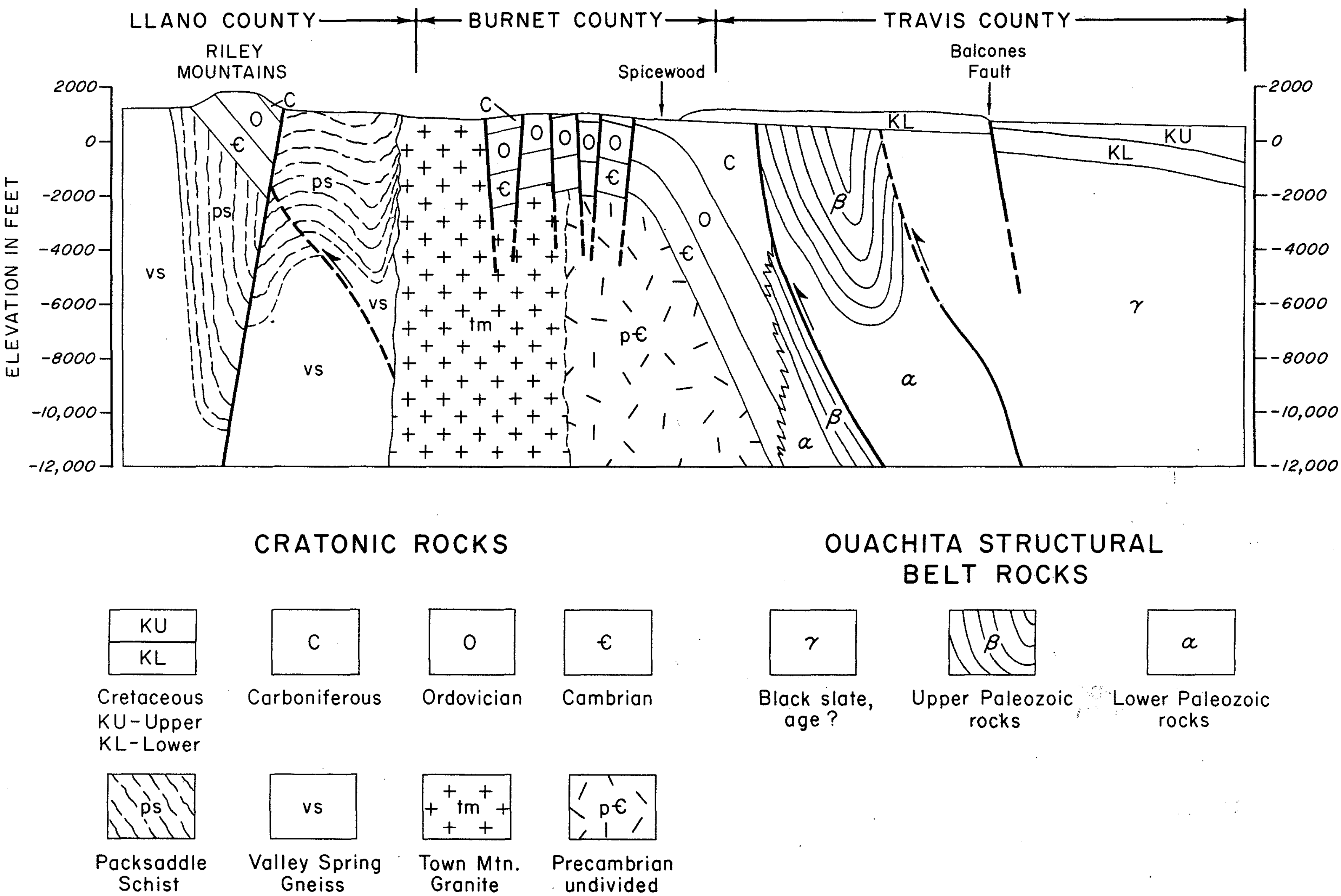

FIGURE 2. SCHEMATIC SECTION CENTRAL LLANO COUNTY TO EASTERN TRAVIS COUNTY, TEXAS.

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. 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

EXPLANATION (Fig. 3 on facing page)

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-feldspar-mica gneiss

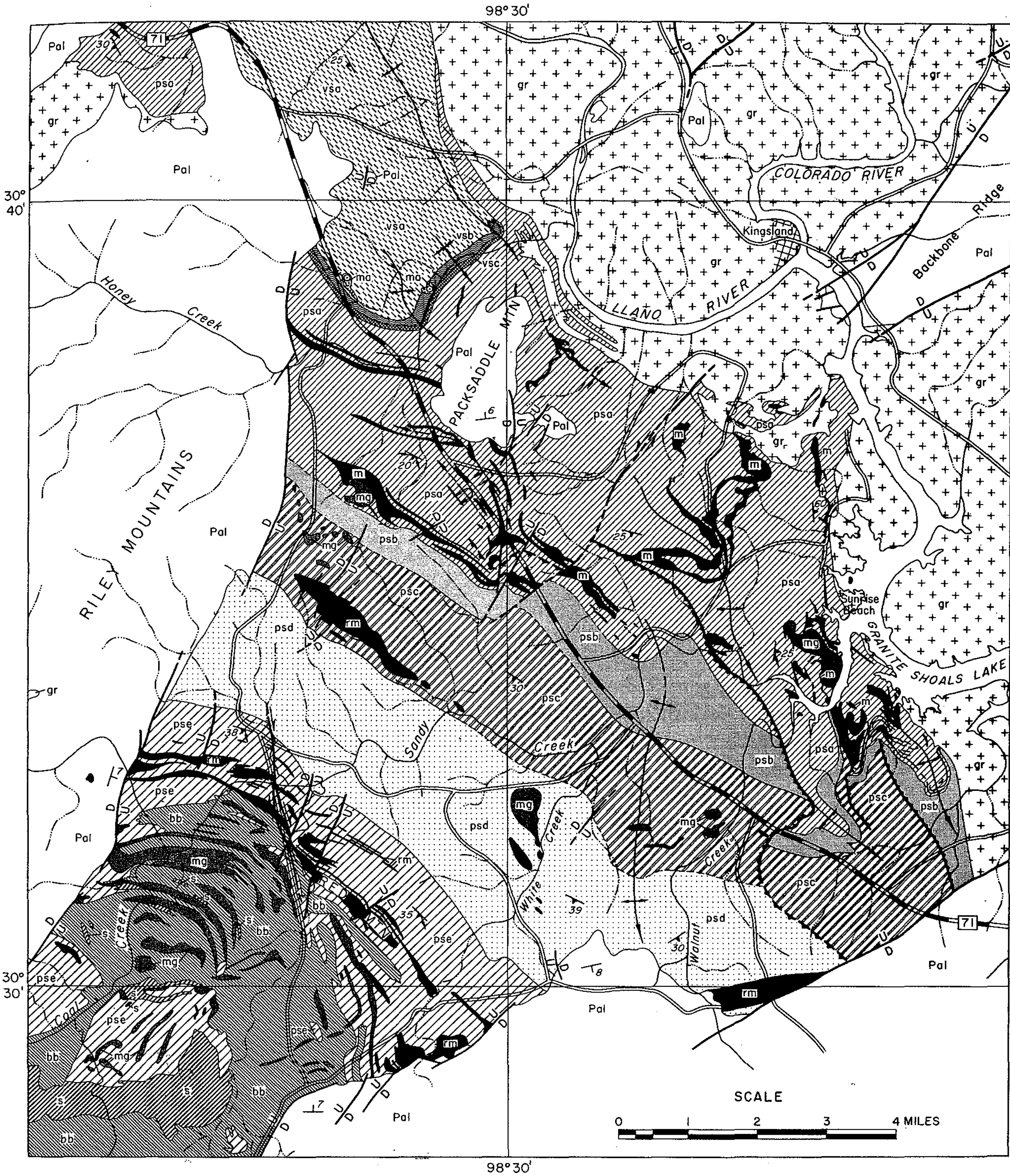

FIGURE 3. GEOLOGIC MAP OF PRECAMBRIAN ROCKS IN SOUTHEASTERN LLANO COUNTY, TEXAS (EXPLANATION ON FACING PAGE).

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 Texas 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 lie 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 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 lip-like 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 in 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 dike-like 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 a while under the trade name of opaline granite.

Age Determinations

Age determinations on minerals from the Llano region were summarized by Flawn (1956, table 4). They include a 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 $1,070 \pm 25$. No age determinations have yet been reported for the metasedimentary rocks.

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 10 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 on the field trip 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 where stops will be made.

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 McGehee and 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 (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.

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,

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)

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. 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. Non-carbonaceous 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 co-workers. 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 non-uniform. The quartz in some

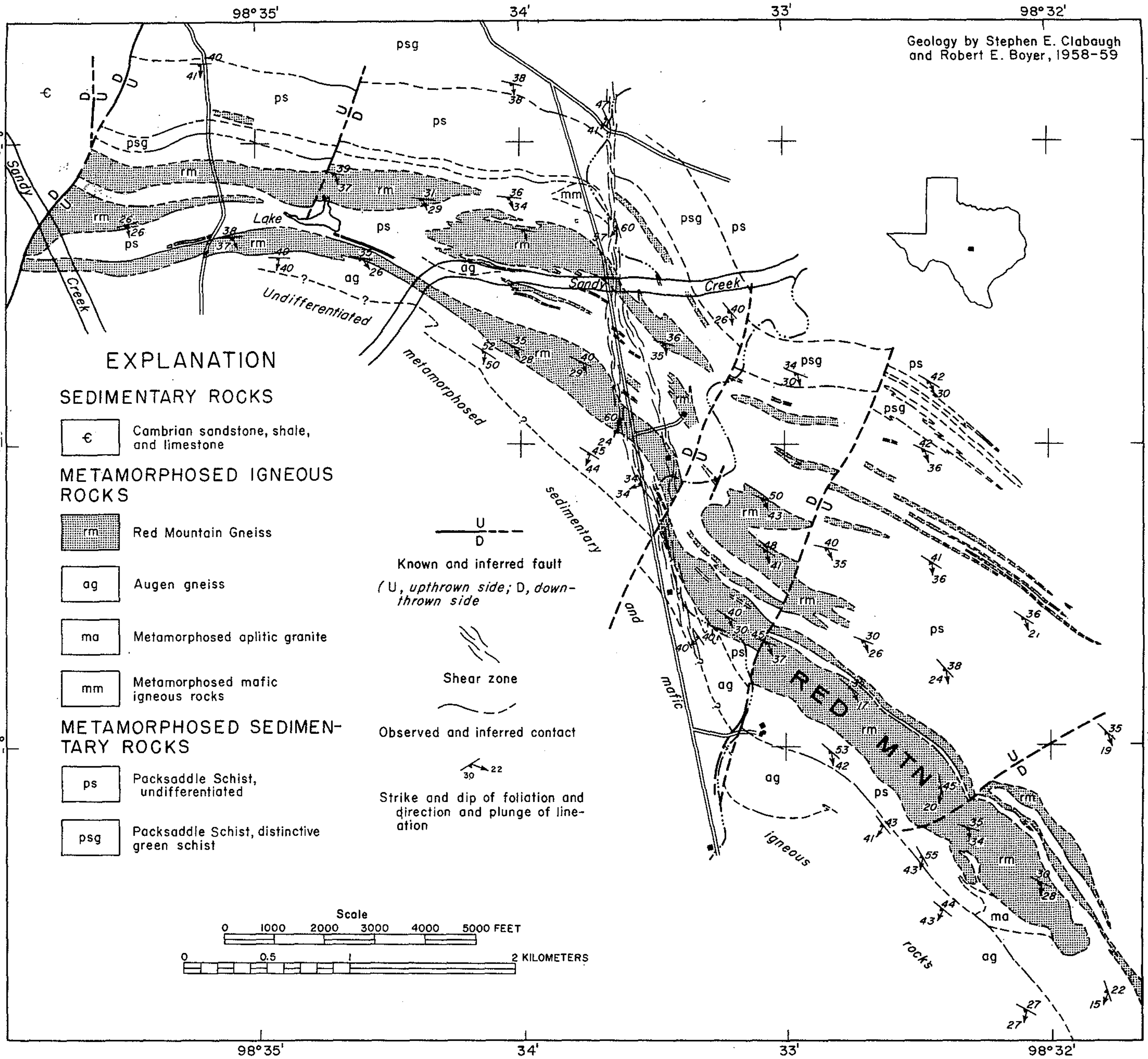

FIGURE 4. GEOLOGIC MAP OF RED MOUNTAIN AREA, SOUTHEASTERN LLANO COUNTY, TEXAS.

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 generall 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 regiona 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 separatio along several exceeds 2,000 feet.

Metamorphism

The maximum grade of regional metamorphism attained by the Precambria 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 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

The two areas in which stops will be made to examine Precambrian rocks are the Red Mountain area (fig. 4) and the Sunrise Beach area (fig. 5). At Red Mountain it will be possible to examine the granite gneiss, the Big Branch Gneiss, and cordierite schist.

Sunrise Beach is an area beside Granite Shoals Lake and Sandy Creek currently being developed as a summer resort. It is underlain by Packsaddle Schist in its central and western parts and by Town Mountain Granite in the eastern part. 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 or diorite 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 pegmatities 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.

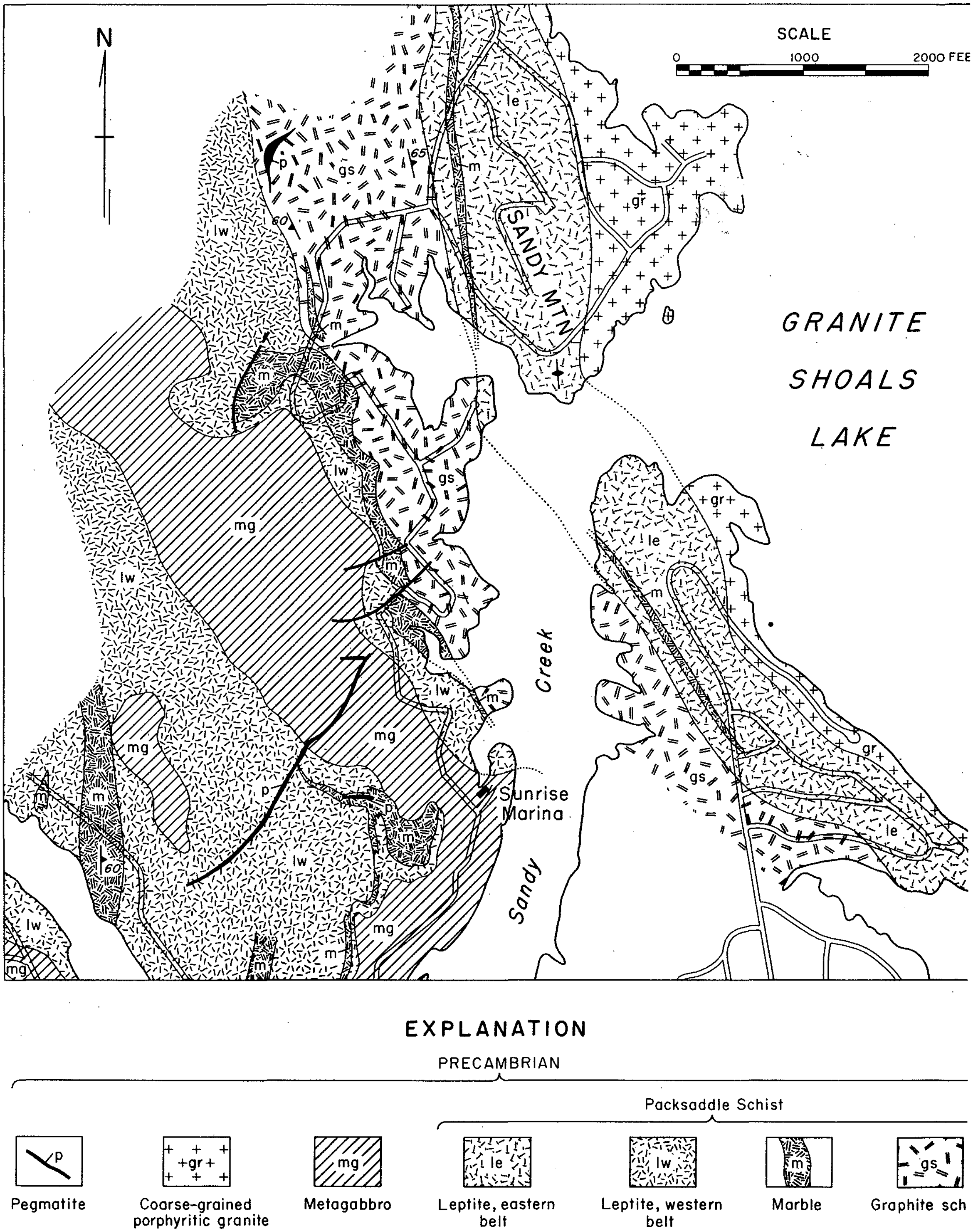

FIGURE 5. GEOLOGIC MAP OF SANDY MOUNTAIN-SUNRISE BEACH AREA, EASTERN LLANO COUNTY, TEX

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 sediments were a thick accumulation of arkosic sandstone, siltstone and shale derived from a nearby granite highland and deposited rapidly in a sinking trough. At least briefly the water was shallow and deposition of terrigenous debris was slow enough to permit development of a thin sheet of impure limestone near the top of the pile of arkosic sediments. Above the arkoses was deposited a great variety of sediments: 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 and 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.

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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. 6). These fossils occur above sandstone which is barren except for Lebensspuren, such as Cruziana, Climactonites, and various other forms. The Cambrian sea spread northward (fig. 7) 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 nonconformity 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. 7) 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. 7). 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

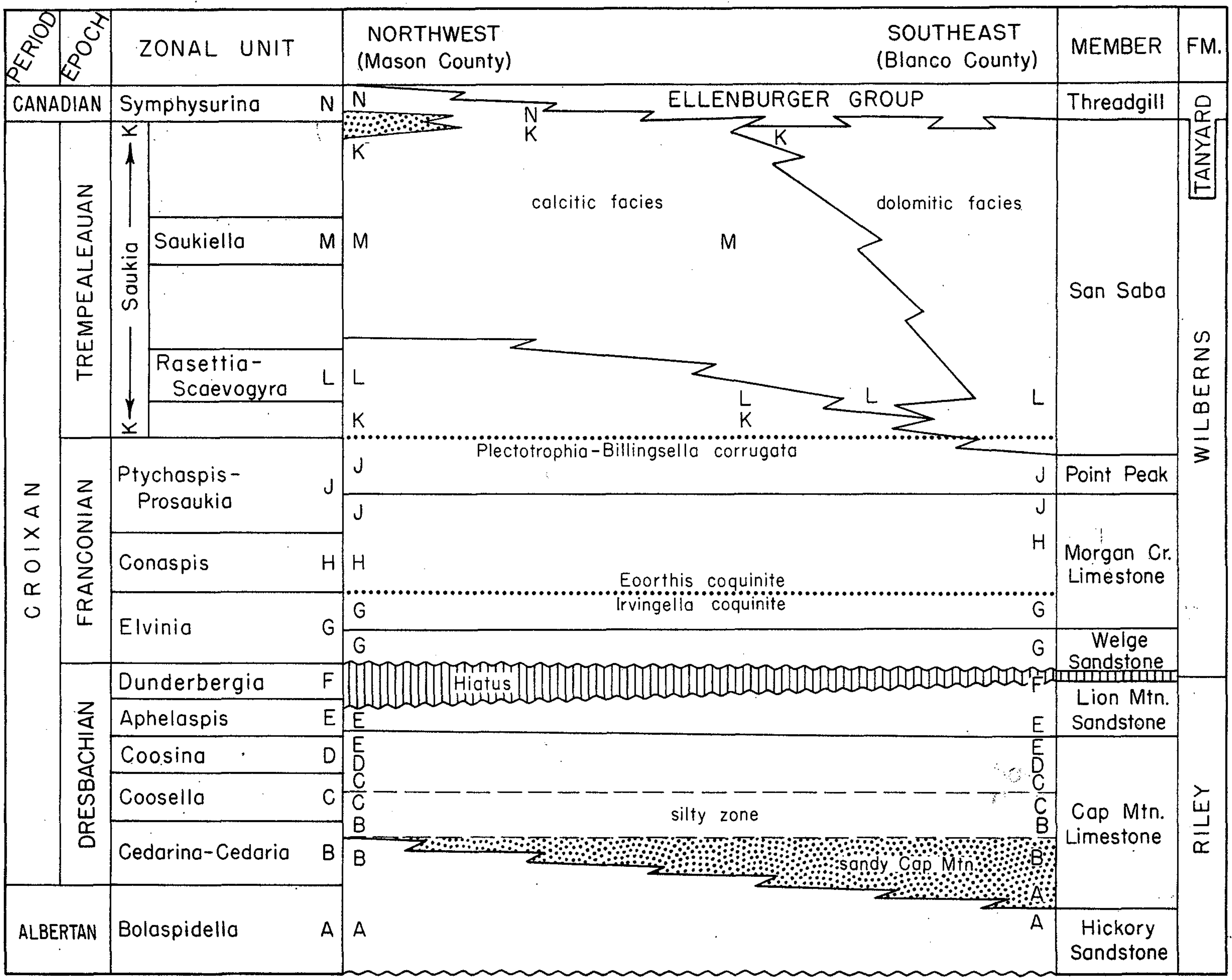

FIGURE 6. CORRELATION OF CROIXAN SERIES IN LLANO REGION, TEXAS.

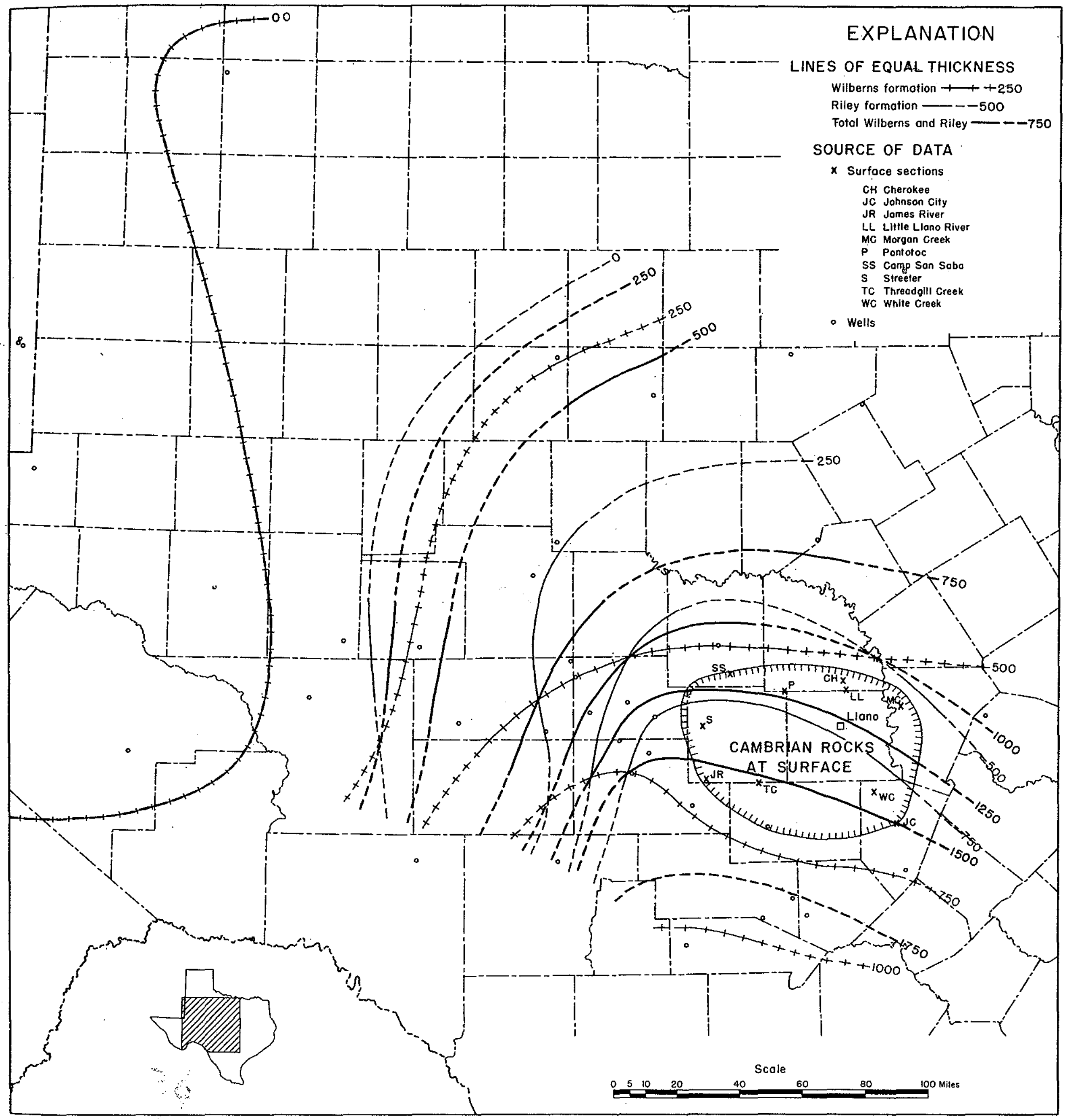

FIGURE 7. ISOPACH MAP OF RILEY AND WILBERNS FORMATIONS IN CENTRAL TEXAS

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.

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 Plectotrophia-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 Plectotrophia 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.

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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 8 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

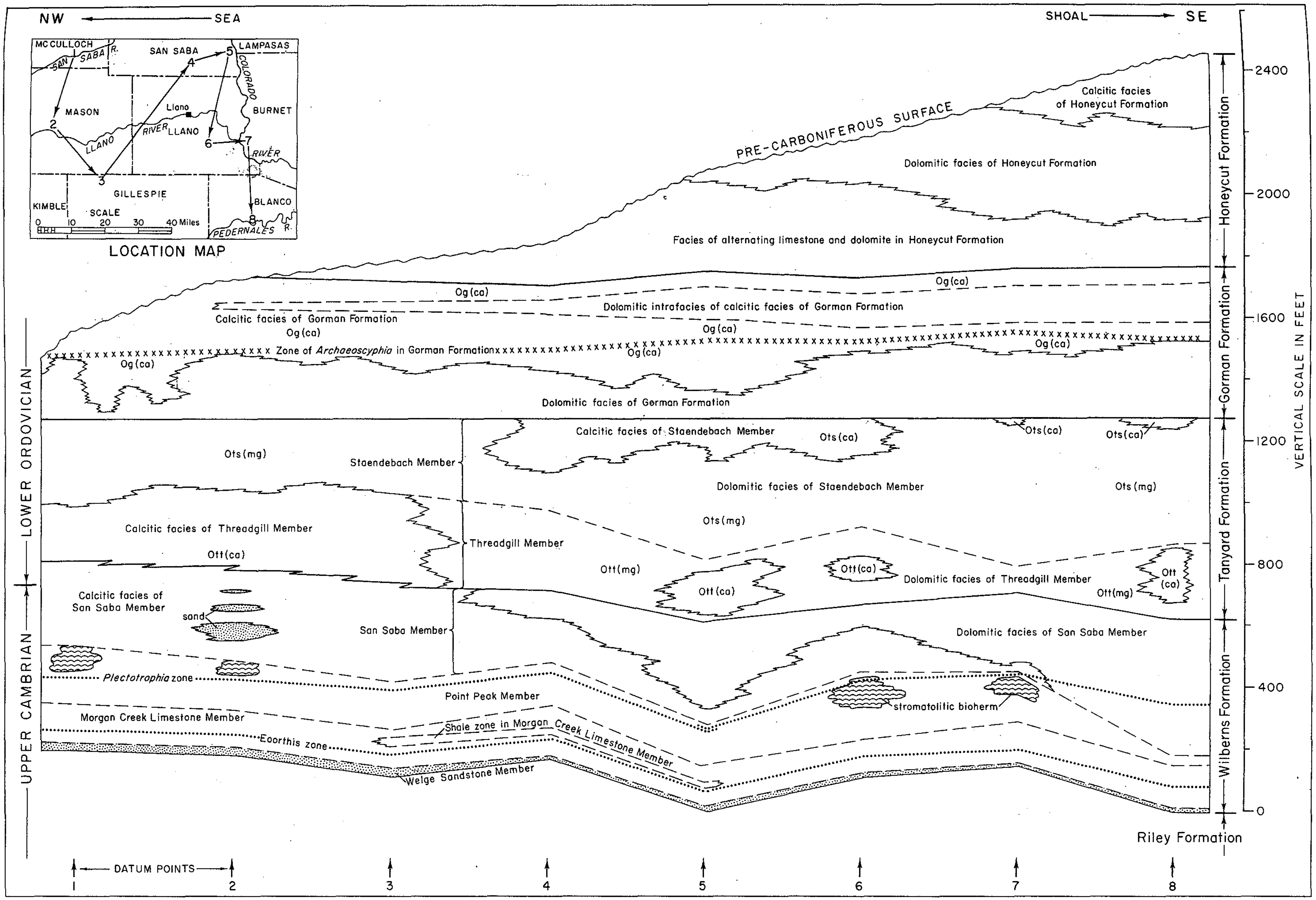

FIGURE 8. DIAGRAMMATIC REPRESENTATION OF THE ELLENBURGER GROUP AND WILBERNS FORMATION IN THE LLANO REGION OF CENTRAL TEXAS.

Threadgill in containing compact cherts that weather smooth and shiny white. Much of this 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 uppermos limestones unusually pure and thickly bedded. The chert of the Gorman Formati 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 occu in Ellenburger rocks of the Llano region, it constitutes 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 faci above from the dolomitic facies below.

Figure 9 is an isopach map showing a general westward thinning of the combined Tanyard and Gorman time-equivalents (from Barnes, 1959, p. 40). Thi map also shows the area where post-Ellenburger erosion has partly removed thes equivalents, and the area far from the Llano region where the Tanyard and Gorm equivalents lap onto the Precambrian. The great distance from the shore here indicated of the Llano region 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 th Llano region.

The upper third of the surface Ellenburger sequence, essentially corre tive 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

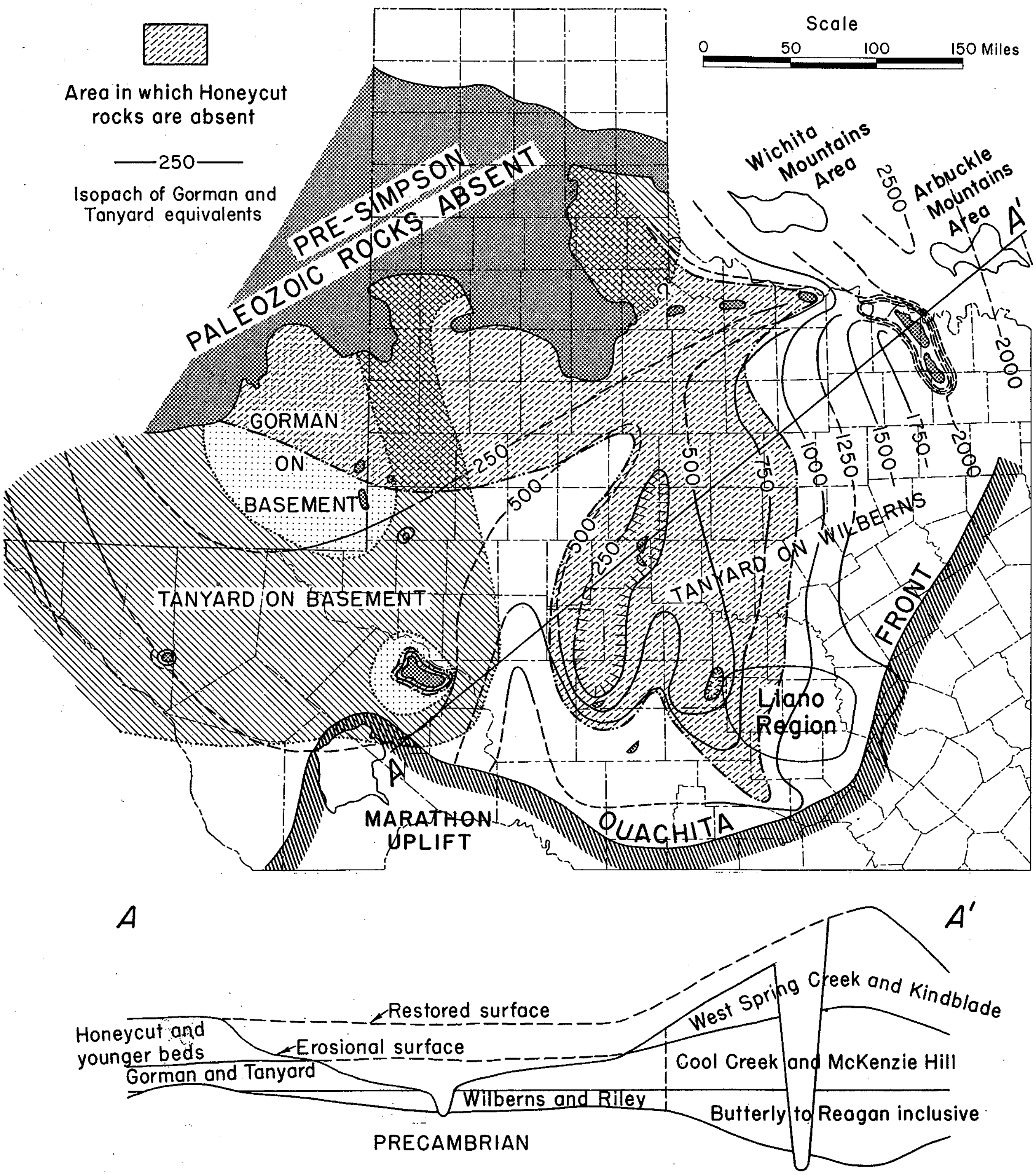

FIGURE 9. ISOPACH MAP OF TANYARD AND GORMAN EQUIVALENTS IN TEXAS, SOUTHEAST NEW MEXICO, AND SOUTHERN OKLAHOMA.

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 Archaeoscyphia. Trilobites are commoner 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 10 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 U.S. Departure from prevailing conditions (thermal, depth, chemical) of the ancient waters at any particular time are suggested by the nature, persistence, and frequency of penecontemporaneous dolomitization.

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, is considered to be correlative with some part of the Cincinnatian, possibly the Richmond Group. The Burnam is exceptionally

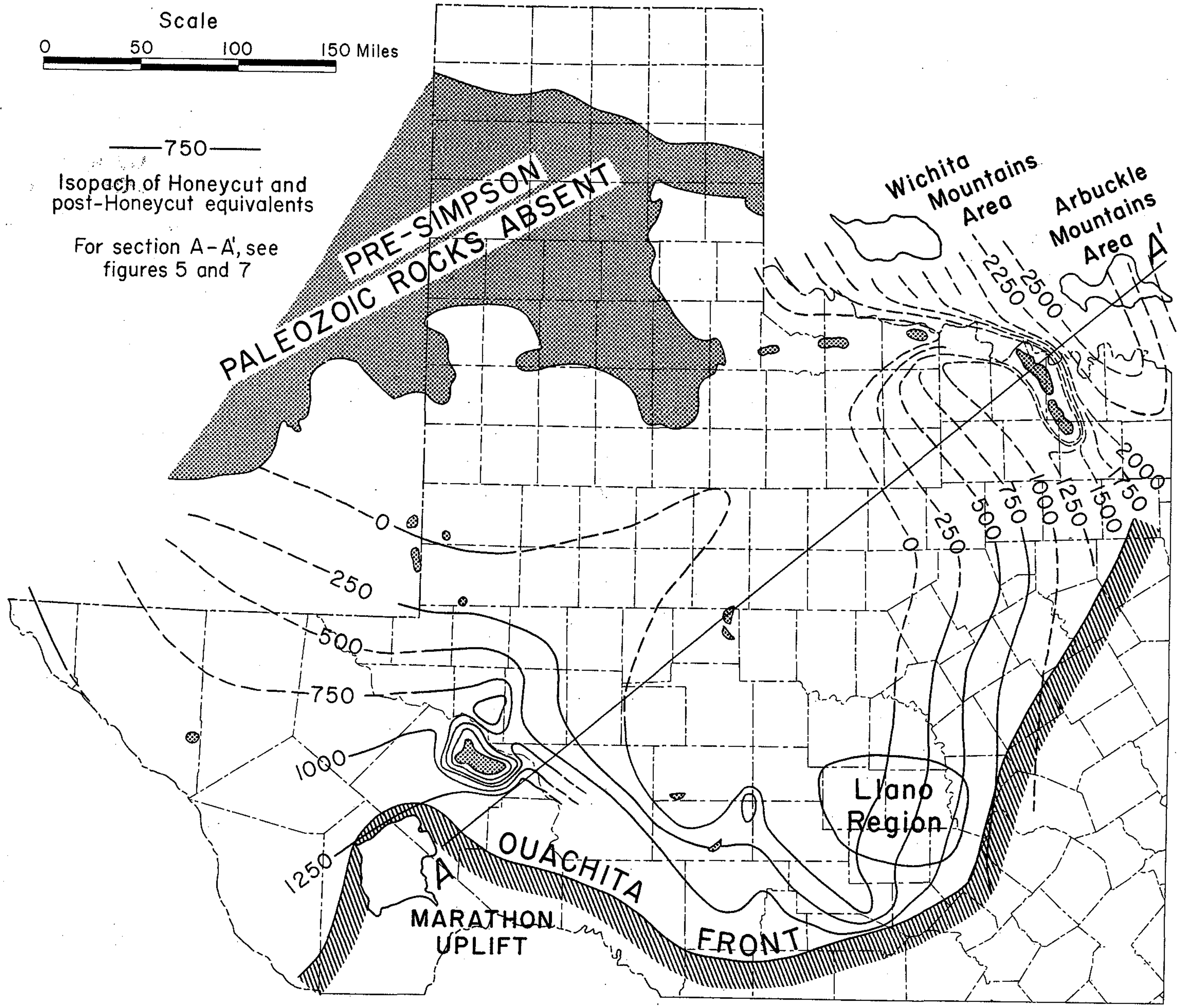

FIGURE 10. ISOPACH MAP OF HONEYCUT AND POST-HONEYCUT EQUIVALENTS IN TEXAS, SOUTHEAST NEW MEXICO, AND SOUTHERN OKLAHOMA.

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.

Silurian and Devonian

The stratigraphic record of the Llano region between Late Ordovician and Early Mississippian time is a complex of formerly extensive units, the remnant of which have been described piecemeal as they have been discovered. Rocks of Silurian age have not, so far, been found. However, in the great area of yet unexplored Ellenburger contiguous to rocks of Devonian and Carboniferous age the possibility exists that Silurian rocks will be found in crevices, collapse structures, or possibly in normal stratigraphic sequence.

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 Onondaga 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 authors 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.

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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 75 years. Outcrops in the area have served as the basis for such names as Bend, Lampasas, Atoka, 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, currently I am in the embarrassing position of disbelieving most previously published interpretations, because of too many data, but being as yet unable to propose an integrated alternative, because of too few data.

Carboniferous strata in the Llano region are in large part exposed in three non-contiguous areas, some of which have been investigated at least in part by my students and myself in recent years whereas others have not. 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. Its investigation is partly completed. It contains the type section (385 feet thick and now mostly under water) of the Marble Falls limestone, described by Barnes (1952), and the conformable type Smithwick, whose sedimentology has been described by Kimberly (1961). About all that can be said about the Marble Falls is that its character changes laterally from its type section, and that its stratigraphy in the Marble Falls area is not known.

According to Kimberly (1961, p. 87) 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." "Type" Smithwick and "Smithwick" of San Saba County and the sub-surface 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 virtually unknown, 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. Its investigation by Donald Winston is in progress as this is written. This is the area of the "rose" Chappel and Barnett "limesand" of Cloud and Barnes (1948, p. 49-59); neither unit is being investigated currently.

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 not divisible into mappable members. Facies patterns are complex. This is the "Big Saline" of recent Texas literature, but whether the name is necessary or useful has not been determined.

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. Six M.A. theses have been completed under my direction; Tom Freeman's investigation of the Brady area is in progress as this is written, but there are several gaps in mapping and many unanswered stratigraphic questions.

Chappel crinoidal limestone (type section near San Saba) is discontinuously present and a foot or two thick throughout the area. Apparently its presence is 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. My personal opinion is that there is evidence for winnowing and by-passing but none for unconformity, and that much more sedimentologic and paleontologic data are necessary before any positive statements are justified. From the standpoint of mapping the interval belongs in the Barnett.

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, but regional lithofacies patterns have not as yet been reconstructed. These sequences, as mappable units, have not heretofore been recognized in Texas literature. Southwest of San Saba, the "type" Sloan and south of Bend the "type" Aylor constitute part or all of the lower map unit; southwest 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 some adjacent fault blocks are not yet 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 western San Saba County and eastern McCulloch County. No other unconformities at the base, within, or at the top of the Marble Falls have been recognized by me or by any of my students.

The Brady and Long Valley areas in McCulloch County include the most northwesterly exposures of Marble Falls strata in the Llano region and as this is being written are being investigated by Tom Freeman. 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 the Marble Falls is quite different than it is in western Lampasas County.

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, and the only published observations sufficiently dependable that they can contribute to future interpretations are by Cloud and Barnes. My personal opinion is that any interpretation based on data presently available would constitute premature wishful thinking.

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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

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
				Hensell	0- 40
			Cow Creek		0- 80
			Hammett		0- 30
			Sycamore		0-550
Precambrian, Paleozoic, or Jurassic					

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 different 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 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 off shore 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) but 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 of 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 deposition. Inequalities in tilting of the Llano area resulted in lower 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

TABLE 3. Correlation of Central Texas Cretaceous Formations with Stages

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

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 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 formations, 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.

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FIELD TRIP ROAD LOG

Stops 1 and 2

S. E. Clabaugh and R. V. McGehee

DEPART FROM VILLA CAPRI MOTOR HOTEL

2630 Interregional Highway, Austin.

Mileage Total	Interval	
0.0		Proceed south on access road of Interregional Highway to East 19th Street.
0.5	0.5	Turn right (west) on East 19th Street, passing, to the left, the "Little Campus," which houses the Bureau of Economic Geology, the Division of Extension, and several other branches of the University of Texas. The main campus of the University lies ahead and to the right, centered about the conspicuous tower. In a small park on the north (right) side of East 19th Street is an unusual and appropriate monument, an old oil well rig brought here from the first producing well--Texon Oil Company No. 1 Santa Rita--drilled on University land in the western part of the State. The University system now possesses an endowment of about a third of a billion dollars obtained chiefly from oil leases and royalties on land grants. Income from the endowment helps operate Texas A. and M. College and its branches, several medical schools, Texas Western College, and the main University in Austin.
1.9	1.4	Turn left (south) on Lamar Boulevard.
3.2	1.3	Bridge over the Colorado River; continue straight ahead on South Lamar. 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.

Mileage		
Total	Interval	
9.9	6.7	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 the land ahead is used for ranching, whereas much of that to the southeast is farmland.
11.2	1.3	Highway intersection; keep to the right on State Highway 71.
23.7	12.5	Two small landslides have occurred here in sandy marl where roadcuts weakened the hillside. Both are still active and debris must be removed from the road at intervals of a few months. We have been traveling through hills cut in Glen Rose Limestone. As the Llano region is approached, where granite and metamorphic rocks were being eroded in Cretaceous time, the Glen Rose Limestone becomes more sandy and marly, finally giving way to near-shore sediments consisting of sandstone, shale, and reef limestone.
25.6	1.9	View of Lake Travis on the right (north) in the valley of the Colorado River.
28.8	3.2	Pale Face store on right and Pedernales River bridge ahead. The river is actually an estuary of Lake Travis at this place. The cliffs bordering the river are reef limestone (Cow Creek Limestone) through which the stream had incised its course into underlying shale. The Pedernales River has recently attained minor fame as the site of Vice-President Lyndon Johnson's ranch, located about 20 miles upstream (southwest). The name of the river is the Spanish word for nodules of flint or chert, which are abundant along the stream. It was a favorite haunt of Indians for at least the last 7,000 years, as shown by radiocarbon dating of charcoal associated with artifacts and bones in shelters in the limestone cliffs near the bridge.
35.3	6.5	Ahead lies a small area of farmland in which the small town of Spicewood is situated. A few beds of Glen Rose Limestone crop out in low hills to the left, but the farms are located on outcrops of Hensel and Sycamore sandstones, the near-shore Cretaceous sandstones. This isolated patch of fertile (but semi-arid) farmland is part of a discontinuous belt of outcrop of sandstone on the southern margin of the Llano region. It

Mileage		
Total	Interval	
		is also a strip of country which German colonists wisely selected for intensive settlement more than a century ago, and the present residents are nearly all of German extraction.
37.4	2.1	The two-story house clearly visible to the left on a low hill is typical of the dwellings built by the German colonists throughout this region. Continuing northwest along Highway 71, we pass rapidly out of the sandy farmland to rocky ground on lower Paleozoic formations.
44.6	7.2	Intersection with U.S. Highway 281. Continue straight ahead on Highway 71. The town of Marble Falls and a major granite quarry are located about 5 miles to the north. The quarry supplied granite for the Texas Capitol building, the Los Angeles County Courthouse, the Leif Erickson Memorial in Iceland, and a multitude of other structures. Marble Falls takes its name from outcrops of unmetamorphosed, siliceous Pennsylvanian limestone in the bed of the Colorado River.
48.9	4.3	In this vicinity Granite Shoals Lake may be glimpsed to the north in the valley of the Colorado River.
50.8	1.9	Roadcut in brecciated Ordovician limestone followed by outcrops of Precambrian metamorphic rock. The two are in contact along a high-angle fault with more than a thousand feet of vertical displacement.
52.8	2.0	On the left side of the road is Mesquite Hill, a low knob underlain by metamorphosed gabbro, now an amphibolite composed chiefly of hornblende, diopside, and plagioclase as calcic as An_{70}.
53.8	1.0	Intersection of State Highway 71 with Ranch Road 962. Turn left (south) on ranch road.
56.8	3.0	Turn right (west) on unpaved county road. As you proceed along the county road you will see 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 we crossed on the highway.
57.7	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.

Mileage		
Total	Interval	
60.7	3.0	Cattleguard followed by intersection of county roads. Continue straight ahead (west), leaving the Cambrian sandstone and passing back onto Precambrian rocks. In the distance to the right Packsaddle Mountain may be seen across the lowlands on Precambrian rocks. Ahead is Cedar Mountain, a down-faulted block of Paleozoic limestone and sandstone which continues northward into the Riley Mountains.
62.4	1.7	Cross White Creek. Hornblende schist is exposed in the creek to the right.
64.8	2.4	Intersection of county roads; turn right (north). Ahead and slightly to the right is Red Mountain, a prominent ridge of gneissic granite.
67.2	2.4	Cross Comanche Creek.
67.9	0.5	STOP 1. Busses will stop 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. 70 to 72. Return to busses and continue ahead (north).
69.1	1.4	On the left is a prominent ridge of gneissic granite, the west-ward 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 we are traveling.
69.5	0.4	Cross Sandy Creek and stop beside road beyond crossing (if time permits). 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.
70.3	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.

Mileage		
Total	Interval	
73.2	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.
76.8	3.6	Intersection of county road and State Highway 71. Turn left (northwest). The bridge ahead spans Sandy Creek and the roadcut beyond the creek exposes weathered hornblende schist.
78.1	1.3	Turn right on road to Sunrise Beach.
80.9	2.8	The road crosses layers of marble in this vicinity. Boulders of marble containing tremolite are abundant at the roadside.
82.6	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) in nearly vertical layers.
83.3	0.7	Sunrise Beach office on left. Follow the road that curves to the right.
83.8	0.5	STOP 2. 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 pp. 73 to 75. Return to busses and continue to the Sunrise Marina 1.5 miles ahead. Busses will turn around here, and if time is available a brief stop will be made to examine metagabbro and a pegmatite with mica pseudomorphs after topaz. Upon returning from Sunrise Marina, you will take the loop road around the south side of Sandy Mountain. At the high point on the road you are crossing brecciated leptite which locally contains both sillimanite and andalusite. 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 you reached Sunrise Beach.
93.1	9.3	Turn right (northwest) on State Highway 71. The next 5 miles will take you past a few exposures of hornblende schist, muscovite schist, and marble. Packsaddle Mountain lies east of the road. It is chiefly Upper Cambrian sandstone and limestone resting unconformably on the Precambrian metamorphic rocks.

Mileage		
Total	Interval	
98.1	1.6	The contact of the Packsaddle Schist with the underlying Valley Spring Gneiss crosses Highway 71 near the Click road intersection. In the small creek valley to the right of the highway are excellent exposures of small bodies of metamorphosed aplitic granite which were intruded into the Valley Spring Gneiss.
100.6	0.9	Contact of Valley Spring Gneiss with overlying Hickory Sandstone. The Cambrian sandstone is well exposed in a roadcut 1.4 miles ahead.
102.6	2.0	Turn right on unpaved county road to Kingsland. For the next few miles the road traverses Valley Spring Gneiss.
105.6	3.0	Margin of granite pluton. From here to Stop 3 the road remains on granite.
107.7	2.1	Llano River crossing. The hill ahead is an outlier of Hickory Sandstone on granite.
109.2	1.5	Intersection of county road with Ranch Road 1431. Turn right (south).
110.2	1.0	Kingsland, Texas. One suspects today that the name of the town is an old Indian work meaning "land where many real estate agents speak with forked tongue."
112.4	2.2	Bridge over Colorado River. To the right may be seen the drowned mouth of the Llano River joining the Colorado from the northwest.
112.6	0.2	Intersection of Ranch Road 1431 with Ranch Road 2342. Turn left (north) on 2342 through the Buckner Boys' Ranch (Baptist orphanage).
117.1	4.5	Intersection of Ranch Road 2342 with State Park Road 4. Turn right (east) on Park Road 4.

Stops 3 to 5

W.C. Bell, P.E. Cloud, Jr., and Virgil E. Barnes

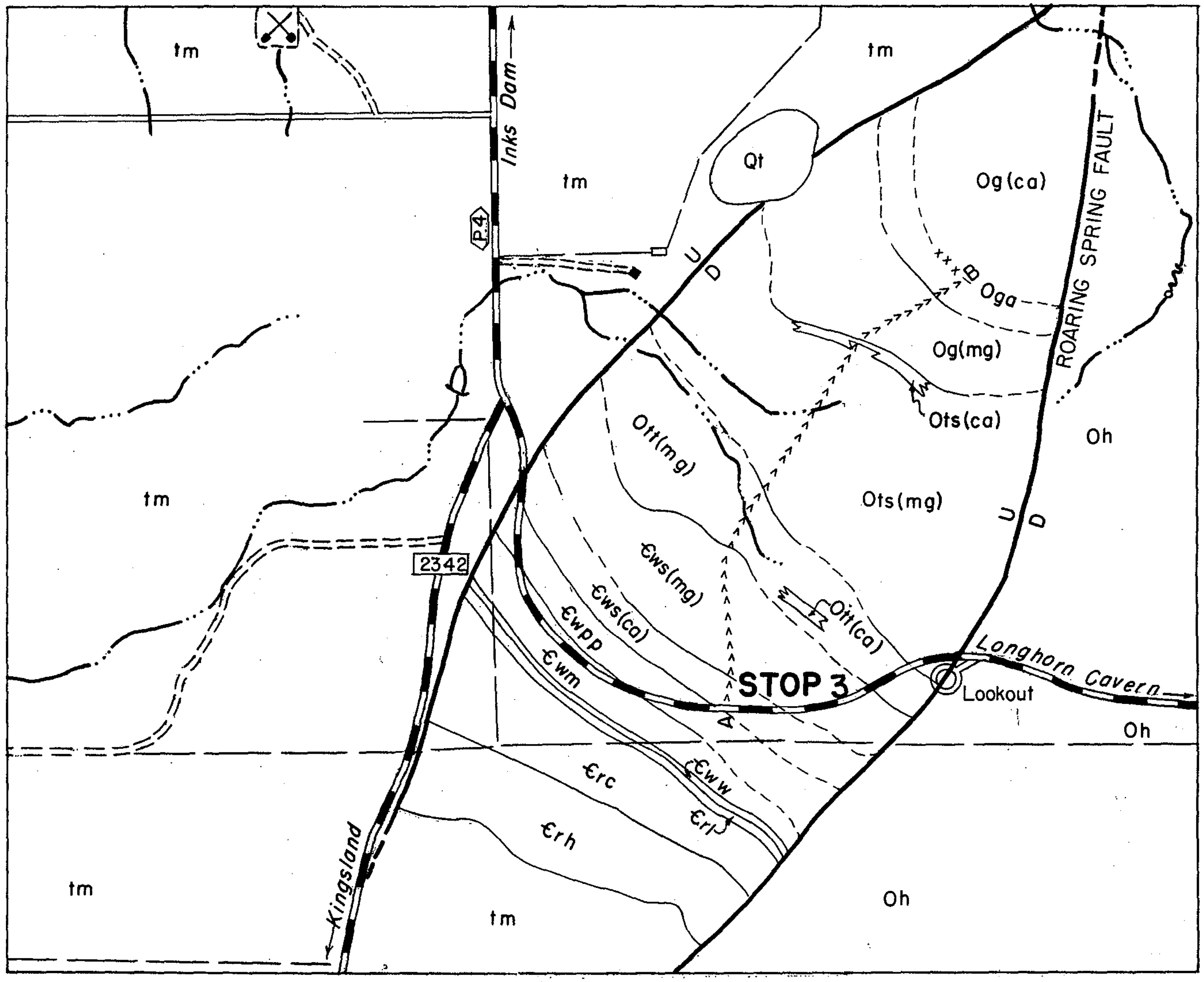
Mileage		
Total	Interval	
117.5	0.4	STOP 3. "Wedge" section (Cloud and Barnes, 1948, pp. 288-289). Walk up through section along Park Road 4; rejoin vehicles at "Lookout" parking area at top of hill. Refer to figure 11, "Geologic map of a fault wedge 2 miles west of Longhorn Cavern, Burnet County, Texas."

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 will 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.

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.



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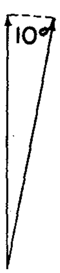
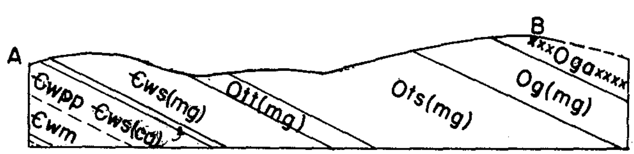




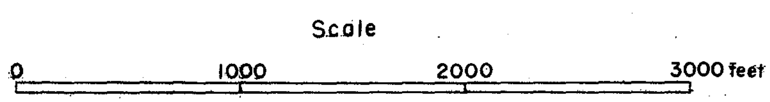


Figure 11. GEOLOGIC MAP OF A FAULT-WEDGE 2 MILES WEST OF LONGHORN CAVERN, BURNET COUNTY, TEXAS.

Mileage

Total	Interval

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 has some granular limestone 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 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 non-cherty.

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

Mileage		
Total	Interval	
		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.
117.5		Pick up mileage at base of "wedge" section; travel down hill.
117.9	0.4	Turn left (south) on Ranch Road 2342.
118.2	0.3	Roadcut on left; Hickory Sandstone in contact with weathered granite.
122.2	4.0	Turn left (east) on Ranch Road 1431.
123.2	1.0	STOP 4. Exposures of Cap Mountain Limestone and Lion Mountain Sandstone in roadcut (fig. 12). This stop exhibits two roughly east-west-trending, south-facing, vertical roadcuts separated by a faulted zone at the crest of a hill. The western cut exposes upper Cap Mountain Limestone transitional into overlying Lion Mountain Sandstone. In the upper half of the cut, interbedded with typical Cap Mountain Limestone, are 6-inch to 2-foot beds of highly glauconitic silty strata reminiscent of the Lion Mountain. Some of the glauconitic beds at the eastern end of the cut are steeply and erratically cross-laminated, another characteristic of typical Lion Mountain. All strata in the western cut would be mapped as Cap Mountain Limestone. The eastern cut, separated from the western one by a down-to-the-east fault, exposes 20-25 feet of fresh Lion Mountain Sandstone below a fence. Notice cross-laminated tangential calcitic lenses distributed through the highly glauconitic sandstone. The Lion Mountain (Riley)--Welge (Wilberns) unconformity is in the soil at the top of the cut, and the vertical 10-foot cliff beyond the fence is Welge Sandstone. This section has not been investigated paleontologically, but the top of the Coosina (Crepicephalus) zone should be low in the western cut, the top of the Aphelaspis zone low in the eastern cut, and the top of fossiliferous strata of the Dunderbergia zone should be about 10 feet below the top of the eastern cut. Continue east on Ranch Road 1431.

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, Ꞓws(mg), and calcitic facies, Ꞓws(ca), Point Peak Member, Ꞓwpp, showing Plectotrophia bed, Ꞓp, Morgan Creek Limestone Member, Ꞓwm, and Welge Sandstone Member, Ꞓww; and Riley Formation showing 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; revised by Barnes, 1960.

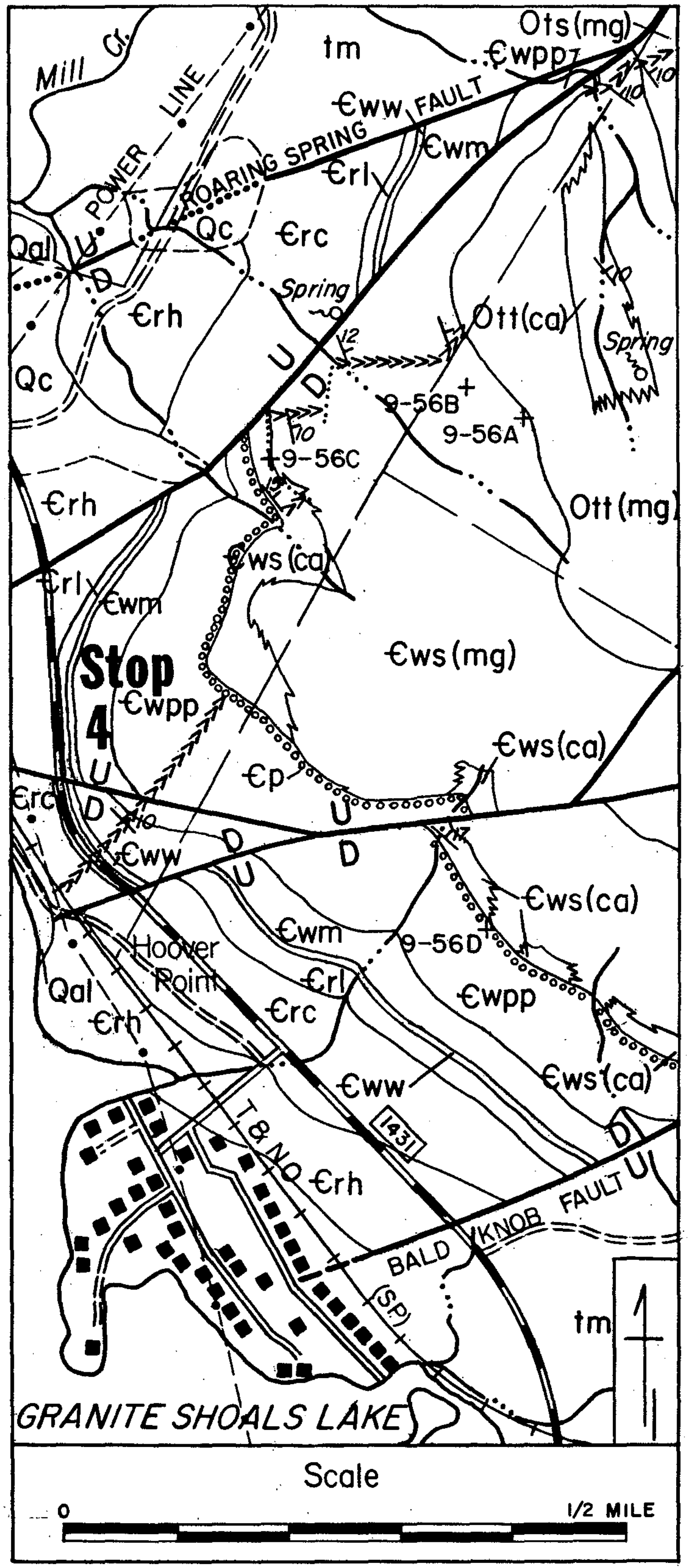


Figure 12. GEOLOGIC MAP OF HOOVER POINT AREA, BACKBONE RIDGE, BURNET COUNTY, TEXAS.

Mileage		
Total	Interval	
131.8	8.6	Entrance to quarry in Granite Mountain, from which was quarried rock for the State Capitol.
133.5	1.7	Turn right (south) on U.S. Highway 281 near north edge of Marble Falls.
134.3	0.8	Colorado River bridge. The type section of the Marble Falls Limestone extends for nearly a mile downstream (left).
138.6	4.3	Intersection with State Highway 71; continue south on U.S. Highway 281.
154.7	16.1	Pedernales River bridge rests on Tanyard Formation of Ellenburger Group.
156.0	1.3	Turn left (east) in Johnson City on U.S. Highway 290.
156.6	0.6	Turn left (east) on graded road.
161.2	4.6	STOP 5. Park vehicles and walk a quarter mile to outcrops along Pedernales River.

Please refer to "Geologic map of Honeycut Bend area, Blanco County, Texas" (fig. 13), and "Pennsylvanian, Mississippian, Devonian, and Ordovician rocks, Honeycut Bend, Blanco County, Texas" (fig. 14). Stay west of fence along western side of Archer ranch. Walk north toward Pedernales River, cross east-west fence, and follow fence eastward to bluff along river.

The following stratigraphic units crop out in this area:

Cretaceous
- **Lower Cretaceous**
  - **Upper Trinity (Shingle Hills Formation)**
    - **Glen Rose Limestone Member**
    - **Hensell Sand Member**
  - **Middle Trinity**
    - **Cow Creek Limestone Member**

Pennsylvanian
- Lower Pennsylvanian
  - Marble Falls Limestone
    - Spiculite facies
    - Biohermal limestone and shale facies

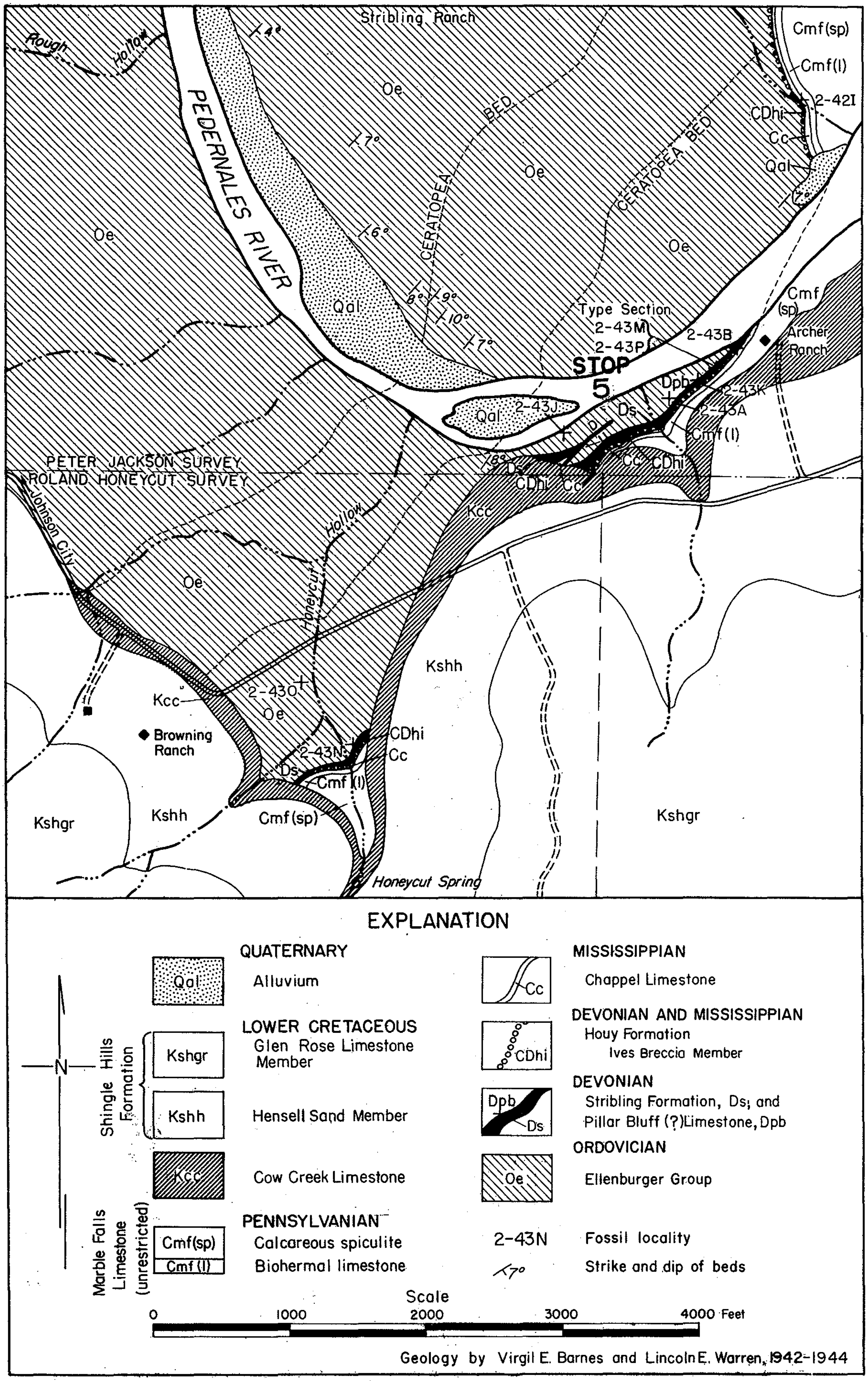
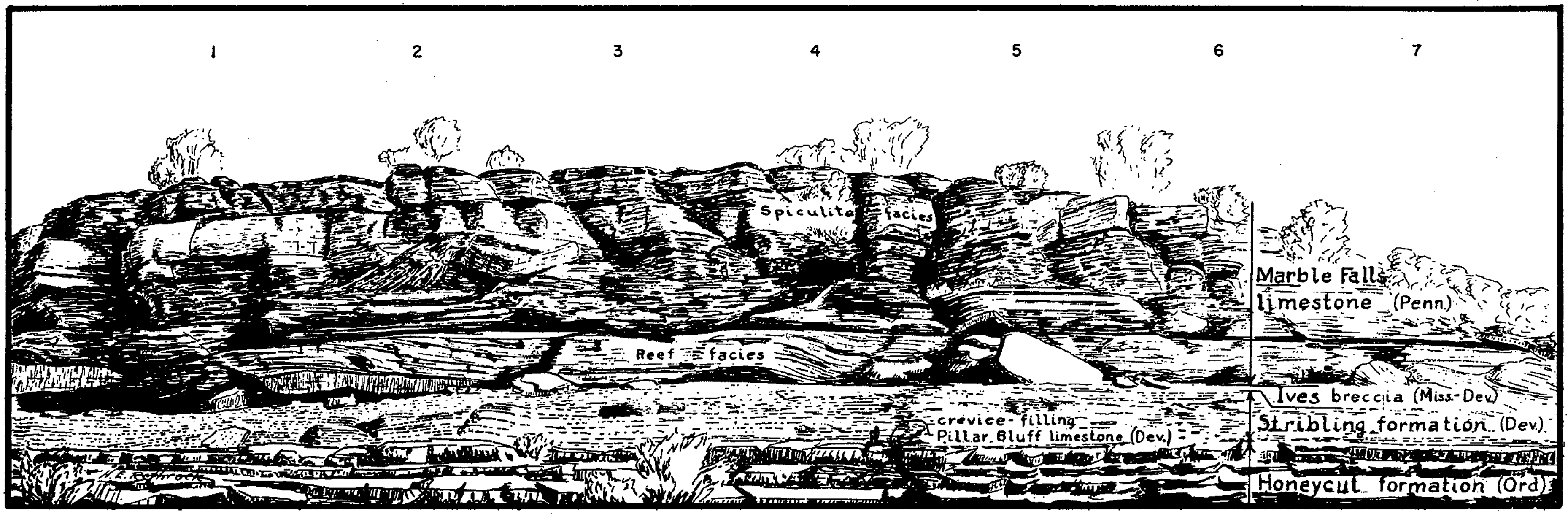


Figure 13. GEOLOGIC MAP OF HONEYCUT BEND AREA, BLANCO COUNTY, TEXAS.



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

Figure 14. PENNSYLVANIAN, MISSISSIPPIAN, DEVONIAN, AND ORDOVICIAN ROCKS, HONEYCUT BEND, BLANCO COUNTY, TEXAS.

Mileage

Total	Interval

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
Honeycut Formation (upper part of Ellenburger Group)

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 will 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., Ceratopa cf. C. tennesseensis Oder, and Orospira sp. In places the top ledge is a coquinite of Hormotoma, mostly unsilicified.

A pocket of impure yellowish-brown limestone enclosed by the Ellenburger strata has been assigned to the Pillar Bluff (?) Limestone. The evidence of the fossils alone is equivocal, and the rock could be Helderberg, Oriskany, Onondaga, or even Silurian age, but the Stribling Formation is early Onondaga. 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. Moreover, there is little resemblance between the fauna of the pocket and that of the Stribling Formation itself, so it is unlikely that the pocket filling represents Stribling rocks. Therefore,

Mileage

Total Interval

one can infer that the filling sediments were deposited in the pocket before Stribling time. The only pre-Stribling Devonian so far known in central Texas is the Pillar Bluff Limestone, and the fossils from the pocket are compatible with assignment to the fauna represented by those contained in the Pillar Bluff Limestone at the type locality.

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 across the fence on the Archer ranch between the foot of the bluff and where the cars are parked. 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.

Until the flood of 1952 the nearest exposure of shale of the Barnett Formation was several miles to the northeast at Elm Pool. Now there is an exposure about 2 miles downstream in the bed of the Pedernales River. Exposed here at Honeycut Bend at the same time is a pocket of glauconitic material in the

Mileage

Total	Interval

Stribling Formation similar to the basal few inches of the Barnett in the exposures just mentioned. Dr. W.H. Hass, U. S. Geological Survey, reports obtaining conodonts from the upper faunal zone of the Barnett Formation in a quarter-inch-crack-filling in the basal beds of the Stribling Formation. 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 collected 16 years ago from the biohermal unit are regarded by Dr. G.A. Cooper, U.S. National Museum, 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 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. 13). 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 Hensell Sand and rarely Glen Rose Limestone rest directly on the Paleozoic rocks. No more Cow Creek Limestone is present.

The Hensell Sand member of the Shingle Hills Formation forms the bench on which the cars are parked. The Hensell 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 Hensell is reddish, the color rising stratigraphically westward toward the ancient shore. The top part of the Hensell is gray, and the boundary between the two color phases forms an irregular lateral as well as vertical

Mileage		
Total	Interval	
		transition. The Hensell Sand is a shoreward facies of the Glen Rose Limestone; eastward it disappears; westward the top of the Hensell rises higher and higher until no Glen Rose Limestone remains. The base of the Hensell 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 Hensell 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 Hensell Sand.
165.8	4.6	Retrace route westward to outskirts of Johnson City; turn left on U. S. Highway 290; go 48 miles to Austin.

Acknowledgments

Information on pages 113 to the top of page 116 of this road log appeared first in a modified form in a Guidebook of the San Angelo Geological Society (Barnes, p. 13-19, 1956). Both versions were modified from work by Cloud and Barnes (1948, p. 288-290). Figure 12, page 117, is a revision of a part of Plate 11 of Cloud and Barnes (1948). Information on pages 118 to 124 was compiled by Barnes from Cloud and Barnes (1948, p. 308-319) and Barnes, Cloud, and Warren (1945, 1947). This compilation appeared first in the San Angelo Geological Society's 1956 Guidebook and in 1958 in the Bureau of Economic Geology's Guidebook No. 1.

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Stops 6 to 8

Keith Young

DEPART FROM VILLA CAPRI MOTOR HOTEL

2630 Interregional Highway, Austin

Mileage

Total	Interval	
0.0		Villa Capri is on the Dessau Formation of the Austin Division. Head south on access road of freeway.
0.2	0.2	Turn right (west) on East 23rd Street.
0.4	0.2	Turn right (north) on Red River Street, driving on Jonah calcarenite. The University of Texas campus to left is on Vinson Chalk of Austin Division.
1.3	0.9	Turn left (west) on East 38th Street.
1.6	**0.3**	**Waller Creek bridge is on Vinson Chalk (= upper part of "Lower Austin" of Adkins, 1933, p. 407).**
1.8	0.2	Turn right (north) on Duval Street, driving on lower part of Austin Division.
2.4	0.6	Turn left (west) on East 45th Street, driving on lower part of Austin Division.
3.4	1.0	Intersection with Lamar Blvd; continue ahead driving on Austin Division.
3.7	0.3	Intersection with Burnet Road; continue ahead.
3.95	0.25	Intersection with Shoalwood Drive; continue ahead, passing from Atco Formation (lowest part of Austin Division) to Eagle Ford Division.
4.1	0.15	Eagle Ford--Buda boundary.
4.25	0.15	Shoal Creek bridge; Del Rio clay is exposed in creek bottom, and banks are held up by Buda Limestone. The flatter profiles on both sides of the creek are underlain by Eagle Ford.

Mileage		
Total	Interval	
4.4	0.15	Intersection with Chiappero Trail; continue ahead, passing from Buda Limestone to Eagle Ford.
4.55	0.15	Intersection with Bull Creek Road; continue ahead.
4.9	0.35	Turn left on Perry Lane.
4.95	0.05	Missouri Pacific railroad crossing, driving on Eagle Ford.
5.5	0.55	Intersection with Shadow Lane near main fault of the Balcones fault system. The fault line scarp is immediately in front of you, and we will drive along the scarp for several miles. At this locality lower Eagle Ford is in fault contact with upper Glen Rose. The stratigraphic displacement is approximately 520 feet; 1 mile south it is 720 feet. We will drive along the fault for several miles beyond Stop 7, and where we leave the fault the stratigraphic displacement is around 400 feet, with Eagle Ford in fault contact with Edwards Limestone.
5.6	0.1	Turn right on Balcones Drive, driving on upthrown side of fault but near the foot of the fault line scarp. The fault trace is approximately 100 yards to your right.
5.9	0.3	Driving on Glen Rose Limestone on upthrown side of fault, Highland Park School to east. The large "sinkhole" (a former quarry) is on the fault. The island of limestone in the school ground is a drag block, caught between Del Rio Shale and Eagle Ford Shale in the fault zone.
6.0	0.1	Intersection with Hancock Drive; continue ahead following Balcones Drive and Balcones Trail.
6.6	0.6	Approximate Glen Rose--Bull Creek boundary.
6.9	0.3	Bee Cave Member of Walnut Formation (Fredericksburg Division) can be seen in small cliffs on left.
7.4	0.5	Turn left to Texas Crushed Stone Quarry.
7.85	0.45	STOP 6. Texas Crushed Stone Quarry. This section (fig. 15) is in the lower part of the Edwards Limestone, which is here partly dolomitized. The one massive bed is a reefoid biostrome containing *Caprinulinoidea* sp., *Toucasia* sp., and colonial and solitary Actinaria. Retrace route out of quarry.

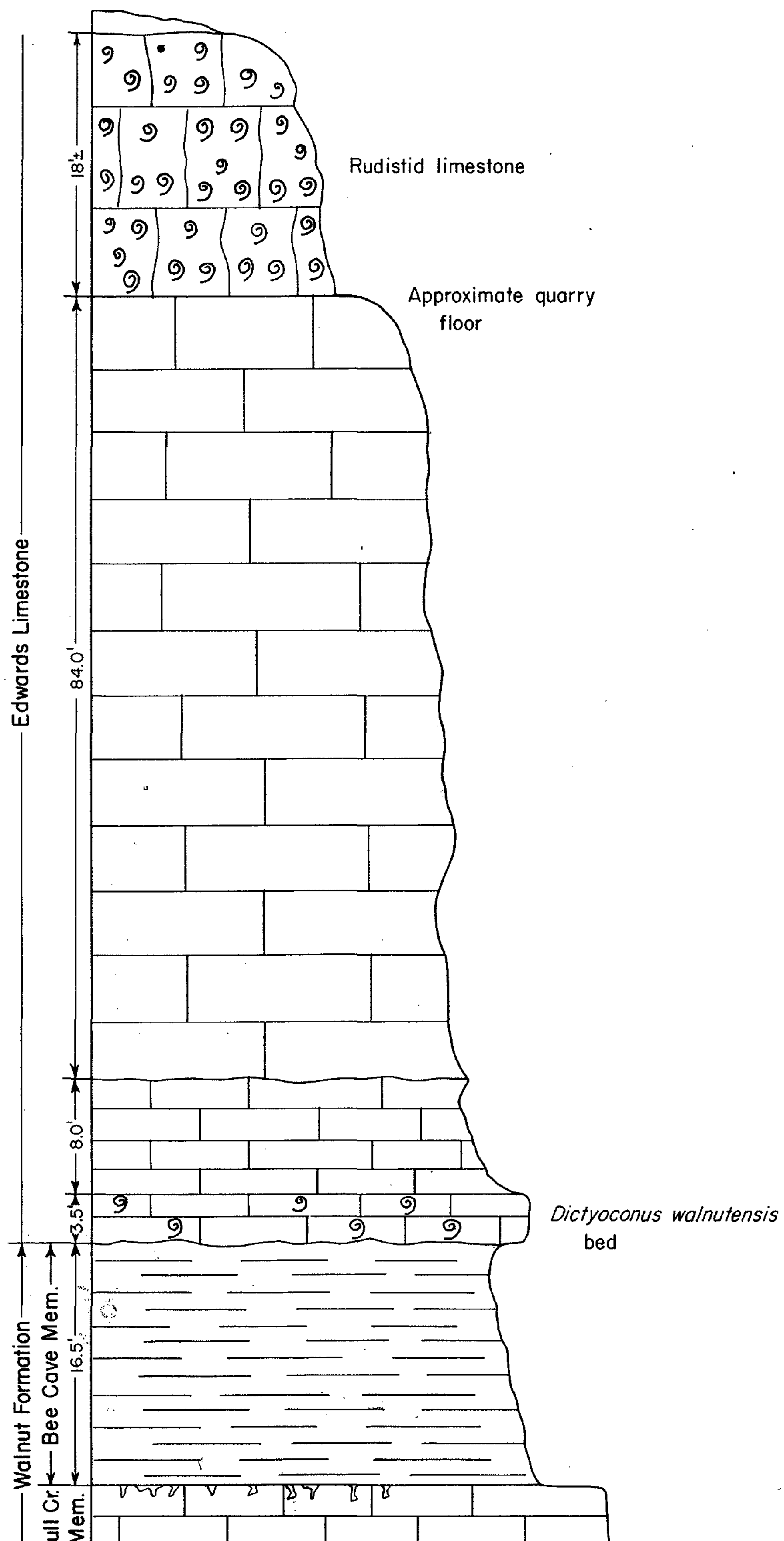

FIGURE 15. UPPER PART OF WALNUT FORMATION AND LOWER PART OF EDWARDS LIMESTONE, TEXAS CRUSHED STONE QUARRY, BALCONES TRAIL, AUSTIN, TRAVIS COUNTY, TEXAS.

Mileage		
Total	Interval	
8.3	0.45	Turn left on Balcones Trail.
10.05	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.
11.0	0.95	Intersection at cloverleaf on Burnet Highway (U.S. Highway 183). Turn left to go right (east). Here we leave the main fault of the Balcones system, Eagle Ford in fault contact with Edwards.
11.35	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 is in the buildings on the left. In addition to research in physics, chemistry, and psychology (this is the home base of Enos and other pre-*Homo* astronauts), there are various geological research facilities. The Bureau of Economic Geology's Mineral Studies Laboratory is located here, as well as its Well Sample Library. The Vertebrate Research Laboratory, in charge of Professors John A. Wilson and E. L. Lundelius, the Basement Rocks Project, in charge of Professor W.R. Muehlberger, and the Micropaleontology Laboratory, in charge of Professor S.P. Ellison, are also housed at the Balcones Research Center.
11.55	0.2	Passing from Eagle Ford to Atco (= lowest formation of Austin Division).
12.15	0.6	Intersection with Burnet Road; continue ahead.
12.85	0.7	Driving on lower part of Austin Division.
14.3	1.45	Turn right on Lamar Blvd.
15.1	0.8	Turn left on Airport Blvd.
16.45	1.35	Turn left on U.S. Highway 290 (toward Elgin), driving on upper part of Austin.

Mileage		
Total	Interval	
18.7	2.25	STOP 7. Austin Archery Club. Exposed here (fig. 16) 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.
20.95	2.25	Turn left on Airport Blvd. (U.S. Highway 183).
22.35	1.4	Underpass at freeway; driving on Burditt Marl and Big House Limestone.
23.05	0.7	Passing Austin Airport. This level area, Airport Terrace, is held up by the gravel of the highest terrace of the Colorado River.
24.45	1.4	Asylum Terrace level. This is the next to the highest terrace of the Colorado River.
24.85	0.4	Sixth Street terrace level. One of the most extensive of the lower terraces of the Colorado River.
25.75	0.9	Katy (M.-Kan.-Tex.) railroad overpass.
26.55	0.8	Highway intersection. First Street Terrace.
26.95	0.4	Colorado River.
28.55	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.
30.35	1.8	Main Gate, Bergstrom Air Force Base (SAC); driving on terrace gravel of Colorado River.
32.25	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.
33.45	1.2	STOP 8. Onion Creek bridge. We will 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

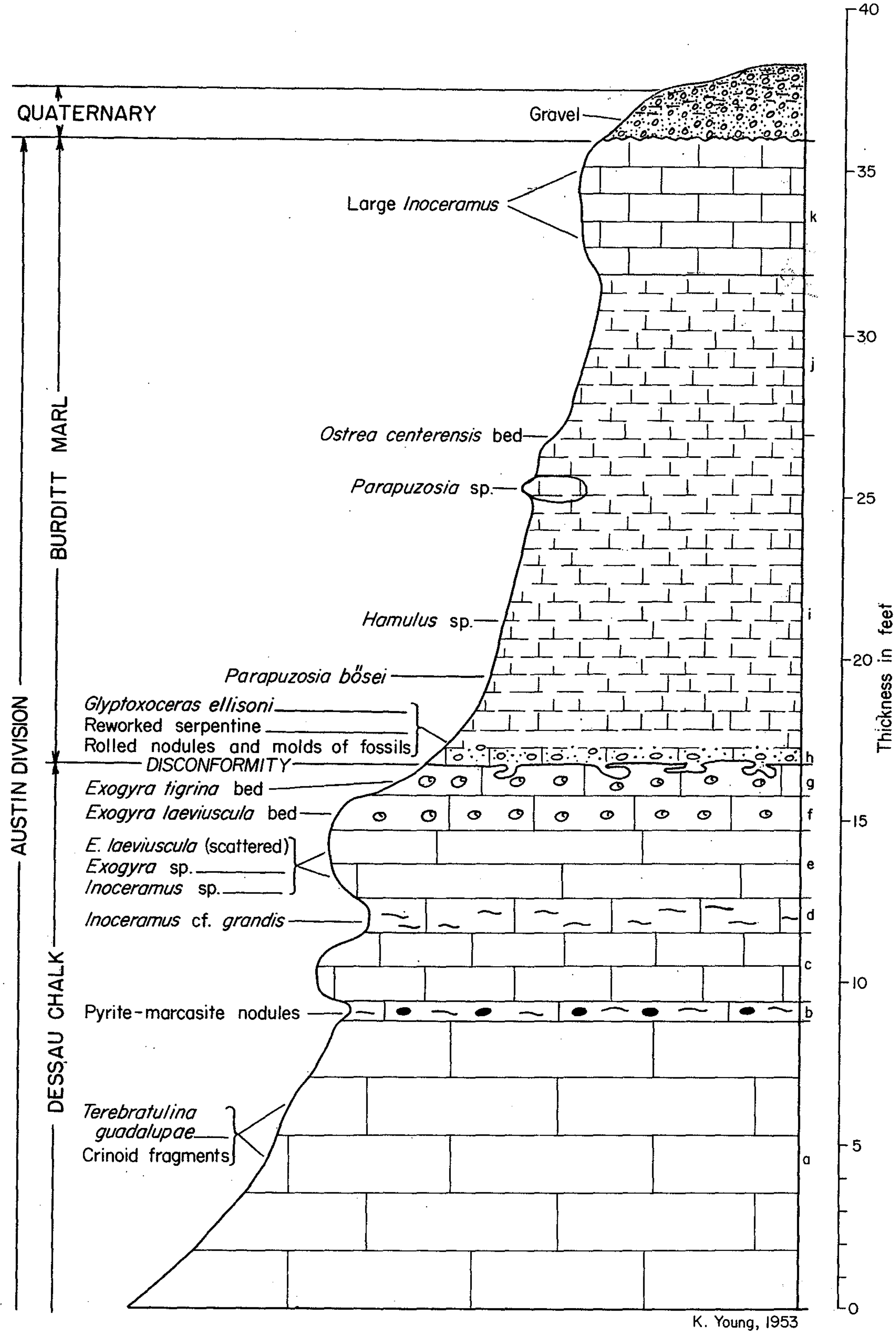

FIGURE 16. PARTIAL SECTION OF DESSAU CHALK AND BURDITT MARL NORTH OF BRIDGE ON WEST SIDE OF LITTLE WALNUT CREEK, U.S. HIGHWAY 290 (AUSTIN-MANOR), TRAVIS COUNTY, TEXAS.

Mileage

Total Interval

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).

Continue ahead on State Highway 71 about 75 miles to Columbus, turn left (east) on U.S. Highway 90 about 73 miles to Houston.

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