Stratigraphy and Depositional Framework of the Stanton Formation in Southeastern Kansas

Philip H. Heckel

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Cover photograph of South Bend Limestone Member near Timber Hill (see Figure 10).

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By

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PHILIP H. HECKEL*

Stratigraphy and Depositional Framework of the Stanton Formation in Southeastern Kansas

ABSTRACT

All five members of the Stanton Formation extend southward across east-central Kansas into northern Montgomery County, where the three limestone members are developed as phylloid-algal mound complexes. South of the Elk River Valley, the Stanton Formation grades from predominantly limestone to predominantly terrigenous detrital rocks, as the mound complexes thin and disappear, and the two intervening shale members thicken substantially. The Stoner Limestone Member in the middle pinches out into shale just south of the Elk River, the Captain Creek Limestone Member at the base is traced definitely about 8 miles farther south, and the South Bend Limestone Member at the top is traced 18 miles southward to the Oklahoma border. The Eudora and Rock Lake Shale Members are defined as far south as the southernmost intervening limestone bed (Bolton) is traced; southward, a Eudora-Rock Lake interval is defined between the basal bed (Tyro) below and the South Bend Member above. Within the Stanton, south of the disappearance of the Stoner Member, three distinctive newly named limestone beds and one quartz siltstone bed lie at different stratigraphic horizons, none definitely equivalent to the Stoner Member. They are, from north to south, 1) the Timber Hill siltstone bed, 2) the Rutland limestone bed, an algal-invertebrate calcarenite, 3) the Bolton limestone bed, an invertebrate calcarenite, and 4) the Tyro oolite bed. The Timber Hill, Rutland, and Bolton beds arbitrarily separate the Eudora and Rock Lake Members; the Tyro bed marks the base of the Stanton south of the disappearance of definite Captain Creek, to which it is probably equivalent. Substantial thicknesses of quartz sandstone dominate the Rock Lake Member and the Eudora-Rock Lake interval where they constitute most of the Stanton Formation in southern Montgomery County.

The South Bend Member and Tyro oolite bed have been traced across the state border into Washington County, Oklahoma, where both had been mapped as Birch Creek Limestone by Oakes (1940a); probably only the South Bend is correlative with type Birch Creek, and the post-"Birch Creek" (= post-Tyro) detrital beds of northeastern Washington County belong to the Eudora-Rock Lake interval within the Stanton. The stratigraphy of this region seems best delineated by including the Birch Creek Limestone and Torpedo Sandstone as members of the Wann Formation, which then can be recognized as the Oklahoma equivalent of the Lane through the Stanton Formations in Kansas. In addition, the Tyro bed divides the Wann into upper and lower portions in the Kansas-Oklahoma border region.

Algal-mound complexes characterizing all three limestone members in northern Montgomery County represent a broad carbonate shoal where proliferation of calcareous algae produced enough sediment to compensate for subsidence and maintain very shallow water depths. Southward, the terrigenous detrital regime included a marine environment in which the turbid mud influx restricted the biota somewhat in the Eudora; this was succeeded by quartz sand influx in nearshore, shoreline, and probably deltaic environments of the Rock Lake. Carbonate environments that periodically became established within this dominantly detrital regime included 1) agitated open shoals where the Captain Creek and Tyro oolites formed, 2) organism-rich shoals to open lagoons where the Rutland and Bolton beds were deposited, 3) quiet open lagoons where sponge-rich calcilutite formed in the upper Captain Creek and top of the South Bend, and 4) shoreline complexes where stromatolites and oolitic to shelly quartz sandstones, locally with shale pebbles, formed at certain horizons in the Rock Lake. Following regressive sand deposition in the Rock Lake, a transgression of the sea is recorded in the fossiliferous, polymictic conglomeratic, coarse quartz sandstone that marks the base of the South Bend throughout this region.

INTRODUCTION

General Setting

The Stanton Limestone forms the top of the Lansing Group (Fig. 1) and thus is the youngest formation of the Missourian State in its type region in mid-continent United States. It overlies the Vilas Shale and underlies the Weston Shale Member of the Stranger Formation (Douglas Group, Virgilian Stage). The outcrop of the Stanton Limestone extends from

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SERIES	STAGE	GROUP	FORMATION
UPPER PENNSYLVANIAN	VIRGILIAN	WABAUNSEE	several limestone & shale formations
		SHAWNEE	3 more limestone & 3 shale formations
			OREAD LIMESTONE
		DOUGLAS	LAWRENCE FORMATION
			STRANGER FORMATION
	MISSOURIAN	LANSING	STANTON LIMESTONE
			VILAS SHALE
			PLATTSBURG LIMESTONE
		KANSAS CITY	BONNER SPRINGS SHALE
			WYANDOTTE LIMESTONE
			LANE SHALE
			IOLA LIMESTONE
			CHANUTE SHALE
			4 more limestone & 3 more shale formations
		PLEASANTON	3 formations

FIG. 1.—Position of Stanton Limestone in Upper Pennsylvanian sequence (after O'Connor, 1963; Zeller, ed., 1968).

the Platte River Valley of eastern Nebraska through southwestern Iowa, northwestern Missouri and eastern Kansas to the Oklahoma border. Continuous exposures are limited mainly to Kansas south of the limit of Pleistocene glaciation (Fig. 2).

Like most other Missourian limestone units, the Stanton exhibits the regional pattern of facies belts described by Heckel (1968) and Heckel and Cocke (1969, p. 1069). Where the Stanton is developed in the northern tidal-shoreline and open-marine facies belts throughout the northern three-quarters of its outcrop as far south as east-central Kansas (Fig. 2), the formation is readily divisible into five members: three limestones separated by two shales. In southeastern Kansas, the Stanton enters the algal-mound facies belt where the three limestone members thicken into phylloid algal-mound complexes (Heckel and Cocke, 1969), while the shale members become thin and rarely exposed. Approaching the Oklahoma border in central Montgomery County, Kansas, the Stanton passes into the terrigenous detrital facies belt, where the limestone members thin abruptly and wedge out over various distances within the thickening sequence of quartz sandstone and shale. Thin limestone beds occur within the Stanton sequence in the detrital facies belt, and several do not seem to be continuous along outcrop with the familiar named members of the north.

Purpose

Because wide traceability along outcrop of thin, named rock units has been shown for several Upper Pennsylvanian formations and members in the Midcontinent, continuity along outcrop has been generally assumed for many others. Such an assumption might be expected to result in a certain amount of miscorrelation. Detailed field work since 1966 has shown that misapplication of names and a certain amount of confusion have been introduced into the previous stratigraphic literature with respect to several thin limestone beds in the Stanton Formation[1] in the detrital facies belt of Montgomery County, Kansas and adjacent Washington County, Oklahoma. The purpose of this report, therefore, is (1) to corroborate and update the general stratigraphic framework of previously named members across southeastern Kansas, (2) to establish a more detailed stratigraphic framework of both the previously named members and newly recognized beds in the detrital facies belt at the southern extent of the Stanton Formation, (3) to trace and correlate this portion of the Upper Pennsylvanian sequence into northernmost Oklahoma where different names are in use, (4) to present general petrographic descriptions of the limestone beds that are marker units across this southern region of many diverse rock types, and (5) to describe generally the depositional regime responsible for the various units and facies. Establishing the stratigraphy, general petrography and depositional significance of identifiable Stanton units in this region provides a framework for future detailed paleontologic investigation of the well-preserved fossil assemblages in this area and for more exact interpretation of depositional environments of individual units and facies. Both procedures are necessary for further testing of suggested depositional models relating subsidence and sedimentation.

Finally, this report presents general geologic information that can be investigated in more detail by those involved in developing specific economic resources of the region. For example, it shows where lenticular sandstones and thin limestones, which often provide reservoirs and marker beds in the search for petroleum, can be studied on outcrop in order to

[1] Although officially named Stanton Limestone where limestone predominates throughout most of eastern Kansas, the name Stanton Formation is permissible for units of this rank and is preferable for this unit where limestone is subordinate and shale and sandstone predominate in southern Montgomery County, Kansas.

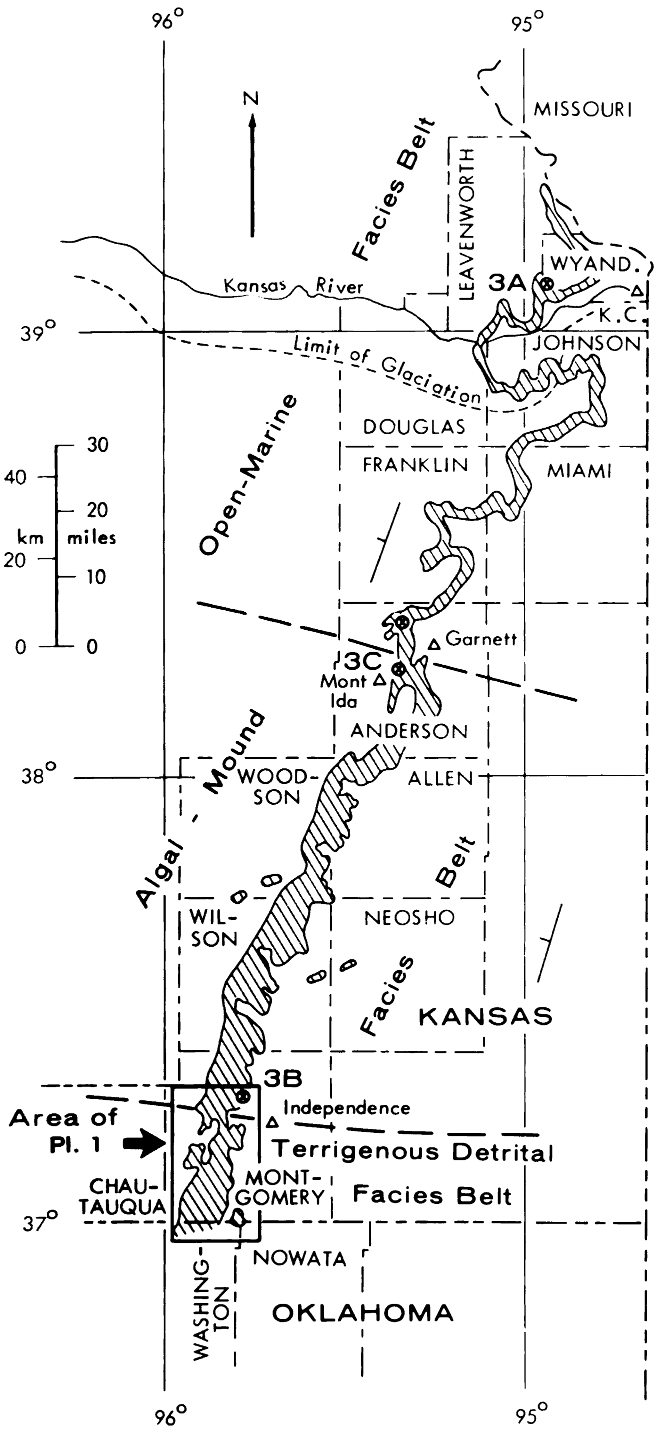

Fig. 2.—Outcrop trace of Stanton Limestone (lined) in eastern Kansas (highly generalized north of Allen County), adapted and modified from State Geological Map (1964). Although boundary separating Terrigenous-Detrital Facies Belt from Algal-Mound Facies Belt is sharp (nearly coinciding with valley of Elk River at outcrop), boundary separating Algal-Mound Facies Belt from Open-Marine Facies Belt is transitional, thus only generally located. More northern Tidal-Shoreline Facies Belt does not extend into Kansas. Circled X symbols labeled 3A, 3B, 3C mark locations of measured sections in Fig. 3.

evaluate their probable nature when encountered in the subsurface.

TYPICAL STANTON LIMESTONE IN EASTERN KANSAS

In the open-marine facies belt throughout northeastern Kansas, the members of the Stanton Limestone are relatively uniform laterally. Distinctive characteristics of the five members in this region are summarized from Newell (1935), Moore (1949), Ball (1959), and personal observations, and are illustrated by a standard section measured along the Kansas Turnpike west of Kansas City (Fig. 3A). Most members undergo moderate lateral change southward in the algal-mound facies belt which extends from Anderson to northern Montgomery Counties (Fig. 2); these changes are summarized from Heckel and Cocke (1969, p. 1073) and personal observations. Although the members there locally vary laterally more than they do northward, they are illustrated by a standard section measured in a 1965 roadcut northwest of Independence (Fig. 3B). Because this is the best-exposed complete section known in the algal-mound facies belt and is located near the detrital facies belt, it affords an excellent section with which to correlate the units recognized in the detrital belt. The members are described in ascending order.

Captain Creek Limestone Member

At the base of the Stanton, the Captain Creek Member is a 4- to 6-foot-thick ledge of medium-bedded, skeletal calcilutite in northeastern Kansas where it carries a marine fauna of brachiopods (with conspicuous *Enteletes*), echinoderm pieces, fenestellid bryozoans, molluscs, fusulinids, phylloid algae, and osagia encrustations.

Southward the Captain Creek thickens through 12 feet in Anderson County to about 45 to 50 feet in northern Montgomery County, where it holds up the prominent escarpment and the outlier of Table Mound northwest of Independence. Coincident with this thickening is an increase in the amount of phylloid algae, which greatly dominates the biota where the unit forms a phylloid-algal mound complex throughout most of southeastern Kansas. Internal structure of most of the phylloid algae has been obliterated by recrystallization, but both green codiaceans (*Anchicodium*) and red ancestral corallines (*Archaeolithophyllum*) have been identified locally. Separating discrete buildups within the complex in Woodson and Wilson counties are contemporaneous channels at least 12 to 22 miles long and 0.5 to 1 mile wide (Heckel 1966; 1972a, p. 589). Where it can be differentiated within these channels, the Captain Creek

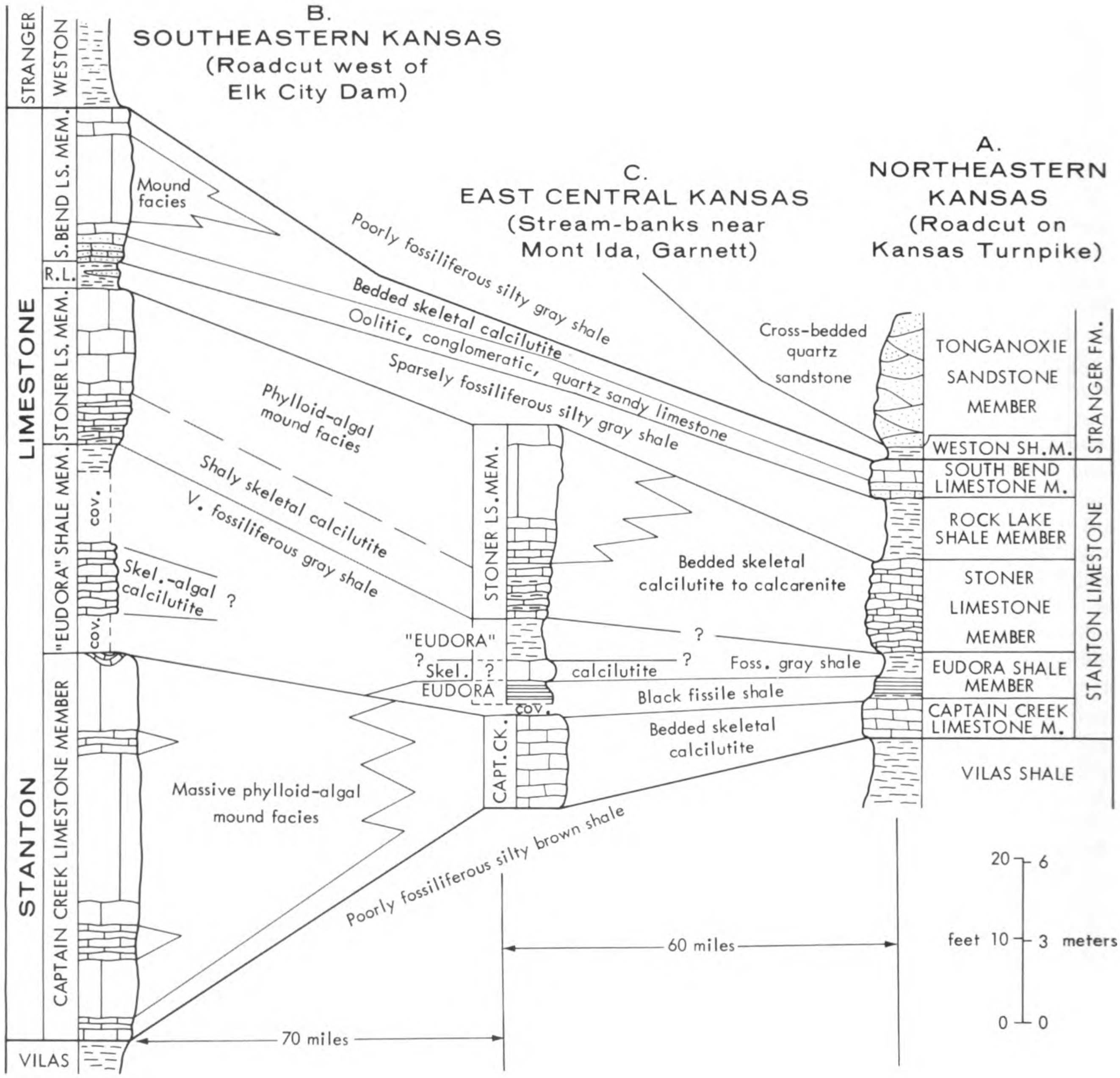

FIG. 3.—Measured sections of Stanton Limestone in eastern Kansas (located on Figure 2) showing both subdivision into five named members that are recognized from Nebraska to southeastern Kansas and their generalized component facies in Kansas; A. Standard section in northeastern Kansas on north side of Kansas Turnpike, 1.2 mile west of Bonner Springs interchange (sec. 18, T11S, R23E, Wyandotte Co.); B. Standard section in southeastern Kansas, on north side of road about 1 mile west of Elk City dam (south of ctr N half 7-32-15, Montgomery Co.); C. Section near Mont Ida in east-central Kansas in west bank of Cedar Creek just north of Missouri Pacific Railroad trestle (NW-SE-NE 17-21-19 Anderson Co.); Captain Creek Member measured in north bank of Pottawatomie Creek (ctr NE-NE 5-20-19) about 5 miles northwest of Garnett, Anderson County.

is thinner, less algal, and several tens of feet lower topographically than in the adjacent buildups. Within the buildups the Captain Creek displays "mound" facies which typically appears massive and vuggy on outcrop. Mound facies consists largely of sparry algal calcilutite in which algal blades shelter spar-filled voids from complete infilling by lime mud through the umbrella effect described by Harbaugh (1960, p. 204).

Throughout the south end of the buildup in northern Montgomery County, much of the upper one-half is algal sparite with extremely coarsely crystalline, brownish and whitish calcite and greatly subordinate calcilutite. At the standard section (Fig. 3B), thinner-bedded layers of skeletal calcilutite occur at the base and intercalated at two horizons within the mound facies. In the top of the buildup in this region are small channels, 8 to 12 feet deep, containing thin-bedded skeletal calcarenite and calcilutite, in places intercalated with fossiliferous shale.

Eudora Shale Member

Overlying the Captain Creek, the Eudora Shale Member averages about 7 feet thick in northeastern Kansas. Its most distinctive feature is the presence of several feet of black fissile shale that contains phosphorite nodules and occupies most of the lower one-half of the unit. The black shale carries mainly conodonts, fish scales, and orbiculoid brachiopods. The remainder of the member is gray shale that carries scattered snails, clams, articulate brachiopods, and conularids. Although thinning locally to less than 1 foot in northern Anderson County, the black shale in the Eudora seems continuous southward to the vicinity of Mont Ida in central Anderson County where about 3 feet is exposed (Fig. 3C), and perhaps into northern Allen County where Miller (1969, p. 15,16) reports about 2 feet of gray shale with lenses of black fissile shale in the base. Southwest of these localities, in the algal-mound facies belt, black shale is found at the Eudora horizon only within the large contemporaneous channels in Woodson and Wilson counties.

Elsewhere in this region above the Captain Creek algal buildups, a horizon of fossiliferous gray shale and thin-bedded limestone is exposed in places separating the massive Captain Creek from the next higher limestone member (Stoner). This shaly horizon has been called Eudora by previous writers (e.g. Newell, 1933, p. 80 ff.; Wagner, 1954, 1961). Five feet of similar shale occurs at the Mont Ida section grading upward into thin-bedded shaly limestone of the Stoner (Fig. 3C). Although this gray shale lies above definite black Eudora, it is separated from it by a 2.5-foot ledge of skeletal calcilutite. Thus, the fossiliferous gray shale could be considered to lie within the lower part of the Stoner, but because it constitutes the only marker unit between Captain Creek and definite Stoner in this region of thick limestone members, this gray shale is referred to as "Eudora" until its exact stratigraphic placement is better delineated (no quotes are used, however, if black shale accompanies the gray shale). In the few places where it is exposed in Wilson County, the gray "Eudora" consists of one to several feet of fossiliferous soft clayey shale intercalated with thin layers of skeletal calcilutite and calcarenite. The lowest shale lies with sharp contact, locally marked by small phosphorite nodules, upon the Captain Creek. Fossils are predominantly brachiopods (including productids, *Composita, Neospirifer,* and *Hustedia*), fenestellid and cylindrical bryozoans, echinoderm pieces, and less commonly, fusulinids and horn corals.

Southward, at the standard section (Fig. 3B), on the south edge of the algal-mound facies belt, the Eudora interval is largely covered. About 24 feet above the top of the Captain Creek, a 3-foot exposure of typical "Eudora" soft gray-green fossiliferous shale grades upward through shaly limestone into typical Stoner. In the interval below the shale, several feet of thin-bedded invertebrate-rich calcilutite, distinct from the generally massive Captain Creek algal mound are included in the "Eudora" interval. On the basis of lithology, the shalier portion of fill in the minor channels at the top of the massive Captain Creek mound might also be considered "Eudora."

Stoner Limestone Member

Above the Eudora Shale lies the Stoner Limestone Member, which, along with the two overlying members of the Stanton, was named from Nebraska. In Kansas, the Stoner was formerly termed Weaver (Newell, 1933) and Olathe (Moore, 1936) before correlation with Nebraska was established. In northeastern Kansas, the Stoner ranges from 11 to 15 feet of wavy, thin to medium-bedded skeletal calcilutite grading upward to calcarenite. Fossils include brachiopods of several types, echinoderm debris, bryozoans and fusulinids.

The Stoner maintains these characteristics southward to northern Anderson County. At the Mont Ida section (Fig. 3C), it is thickened to about 25 feet, with the lower 8 feet transitional downward to "Eudora" gray fossiliferous shale, and the upper 12 feet developed as a massive phylloid-algal limestone typical of the algal-mound facies belt. Although it is difficult to obtain a complete section of the Stoner southward across this belt, thickness seems generally to exceed 15 feet, and as much as 40 feet has been estimated in the Elk River Valley of northwestern Montgomery County, west of the standard section. Throughout most of the algal-mound facies belt, much of the Stoner is algal calcilutite of the mound facies. In contrast to the massive, vuggy Captain Creek in this facies belt, however, Stoner mound facies tends to be thin to medium-bedded in layers that weather less vuggy. Algal blades tend to be smaller, more like small potato chips, and other less algal rock types are more common than in the Captain Creek. The lower few feet tend to be shaly and rich in invertebrate fossils in the downward transition to the "Eudora." Along both the mound buildup rim and the major channels in Woodson and Wilson Counties, the Stoner Member is mostly abraded-grain skeletal calcarenite.

At the standard section (Fig. 3B), the Stoner is only 20 feet thick. The lower portion is thin-bedded and shaly, with a biota dominated by marine invertebrates. Bedding becomes thicker in the middle, where algae become more common, and fusulinids are abundant. The upper several feet are massive and dominated by phylloid algae that shelter spar-filled voids. The codiacean *Eugonophyllum* has been identified here, and the ancestral coralline *Archaeolithophyllum* was found nearby.

Rock Lake Shale Member

Overlying the Stoner Limestone with a sharp contact everywhere, the Rock Lake Shale Member was previously referred to in Kansas as Wolf Creek (Newell, 1933) and Victory Junction (Moore, 1936). In northeastern Kansas, the Rock Lake ranges from 3 to 14 feet thick. Although it consists mainly of light brown, silty, micaceous shale at the standard section (Fig. 3A), it is the most heterogenous member of the Stanton; elsewhere in this region it contains various amounts of clay shale, impure platy limestone, and reddish-brown sandstone that in places dominates the member. Fossils consist chiefly of plant fragments, tracks, trails and burrows, but pelecypods are locally abundant.

Southward, the Rock Lake Shale is thin and poorly exposed over most of the algal-mound facies belt. Where exposed above mound facies of the Stoner from central Anderson to northern Montgomery Counties, it is typically 1 to 2 feet of nearly unfossiliferous[2] light gray shale. At places the Rock Lake is missing, and the overlying limestone member (South Bend) rests directly upon the Stoner with a sharp contact. Within the major channel in Woodson County, however, the Rock Lake occurs as channel fill as much as 70 feet thick and consisting of reddish-brown weathering, friable quartz sandstone interbedded with subordinate gray shale. Exposures of the Rock Lake in this channel have been mapped previously as post-Stanton Weston Shale (Wagner, 1961) and Stranger Formation (Geologic Map of Kansas, 1964), although Miller (1969, p. 16) identified the sandstone exposures in westernmost Allen County correctly as Rock Lake. Within the major channel in Wilson County and associated minor channels cutting into the Stoner mound, the Rock Lake appears as a few to perhaps 10 feet of reddish-brown weathering, cross-bedded, friable quartz sandstone. An undetermined but substantial thickness of more massive reddish-brown sandstone exposed over about 1 square mile northeast of Elk City in northern Montgomery County also belongs in the Rock Lake. At the standard section (Fig. 3B) the Rock Lake consists of about 2 feet of unfossiliferous blocky gray shale overlain by 1.5 feet of laminated buff sandy shale and lenticular quartz sandstone carrying scattered pelmatozoan fragments.

[2] One locality in northern Anderson County, however, yields a remarkable assemblage of land plants and brackish-water to marine invertebrates (Moore *et al.*, 1935).

South Bend Limestone Member

The uppermost member of the Stanton is the South Bend Limestone, formerly known in Kansas as the Kaw (Newell, 1933) and the Little Kaw (Moore, 1936). Characteristic of the South Bend is a twofold lithologic subdivision, which is recognizable along most of the Kansas outcrop and greatly aids in distinguishing this member from those below. The upper part is a relatively uniform, dark-brown to bluish-gray, medium to thick even-bedded skeletal calcilutite which contains a marine biota of fusulinids, echinoderms, brachiopods, bryozoans, molluscs, and scattered corals; algae are rare. The lower part is heterogeneous, ranging from hard, calcareous, coarse quartz sandstone and sandy calcilutite to cross-bedded oolite and conglomerate that contains calcilutite and shale pebbles in a quartz sandy matrix. The brachiopod *Meekella* and large pelecypods are locally common in this part.

Thickness of the South Bend is 4 to 5 feet in northeastern Kansas and changes little southward across most of the algal-mound facies belt from Anderson through Wilson Counties. The upper part remains a nearly constant 2 to 4 feet of calcilutite the entire distance from northeastern Kansas, whereas the heterogeneous lower part ranges from missing in places to several feet of the various sandy, oolitic and conglomeratic rock types. Tracing of the distinctive thin South Bend over the top of the thick sandstone and shale sequence in the Woodson County channel allowed assignment of this channel fill to the Rock Lake

Member. In the Wilson County channel where less Rock Lake is developed, however, the South Bend provides fill, as much as 15 feet thick, of fossiliferous, cross-bedded, conglomeratic, calcareous gray quartz sandstone with locally well-preserved trace fossils.

Only in northern Montgomery County does the South Bend thicken into a buildup characteristic of the algal-mound facies belt. At the standard section (Fig. 3B), the member is 20 feet thick with 5 feet of oolitic quartz sandstone and sandy calcilutite in the base; derbyid and productid brachiopods and crinoid columnals are locally common in this part. The upper part is 15 feet of thick-bedded calcilutite with invertebrates and phylloid algae. Westward along the Elk River Valley, this portion thickens to at least 26 feet and becomes more algae-rich with local zones of crinoidal calcarenite.

The basal contact of the South Bend is sharp over shale of the Rock Lake (or limestone of the Stoner), but locally seems transitional downward from hard calcareous sandstone to friable, less calcareous sandstone of the Rock Lake. The upper contact of the South Bend is sharp nearly everywhere with unfossiliferous buff to gray shale of the overlying Weston Member of the Stranger Formation. At places in northeastern Kansas, the upper contact is erosional beneath another member of the Stranger, the Tonganoxie Sandstone. Similar post-Stanton erosion is not observed to affect the South Bend in southeastern Kansas, however.

STANTON FORMATION IN THE DETRITAL FACIES BELT OF MONTGOMERY COUNTY

Previous Work

Early investigations recognized that the Stanton Formation grades southward from a sequence consisting mainly of thick limestones into two or more thin beds of impure limestone intercalated with thick sandstone and shale in central and southern Montgomery County, Kansas. Schrader (1908, referring to the Stanton as the Piqua), mapped two discrete zones of limestone across this area. Newell (1933, p. 88) recognized the lower zone as the Captain Creek Member. Both writers implied that the upper zone represented one horizon inasmuch as they equated the limestone at Tyro (now termed the Tyro bed) with that dipping beneath the floodplain of Little Caney Creek at Caney (now known to be the South Bend Member); as a result, a large portion of the sandstone and shale within the Stanton were mapped as the overlying formation (Schrader, 1908; Geologic Map of Kansas, 1937; see also Oakes, 1940a). Nevertheless, measured sections by Newell and a correlation cross section, all published in Moore (1937, p. 46-47), show that as many as three layers of limestone were recognized at this time as partially equivalent to the upper two limestone members of the Stanton.

More recently, Wilson (1957a, 1957b) correlated all the named members into the detrital facies belt. He traced the South Bend through Wayside and Havana to Caney and recognized it as stratigraphically well above the limestone at Tyro. He also applied the name Stoner Member to outcrops of two limestone beds (Rutland, Bolton) and a quartz siltstone bed (Timber Hill), all now known to be discontinuous with definite Stoner along outcrop. He considered the limestone at Tyro to be part of the Captain Creek Member, whereas both Schrader (1908) and Newell (1933) had placed this bed above the Captain Creek.

Immediately subsequent work generally follows that of Wilson. Harbaugh (1962) also considered the limestone at Tyro as probably equivalent to the Captain Creek, but previously he (1960, p. 224-226) correlated limestone now known to be Captain Creek in T33S to the Plattsburg. O'Connor (1962) mapped no distinction between the levels of the Captain Creek and Tyro at the base of the Stanton and along with Ball (1964), recognized and mapped most of the South Bend at the top and placed more of the intervening sandstones and shales into the Stanton Formation, as is shown on the more recent Geologic Map of Kansas (1964).

Present Stratigraphic Framework

Aided by the availability of accurate 7.5-minute topographic mapping (1959-1962), by suggestions from previous workers, and by field assistance mainly of J. M. Cocke, I have carried out a program of detailed facies mapping and bed tracing along the Stanton Limestone outcrop intermittently since 1966. The results of this work show that Stanton stratigraphy in the shale and sandstone-dominated sequence of the detrital facies belt of central and southern Montgomery County is best described within the framework of the three previously named limestone members, plus three new informally named limestone beds, a quartz siltstone bed, and several less well delineated limy horizons and quartz sandstone bodies (Plate 1; Fig. 4,5).

Members

Of the three limestone members, the Stoner can be traced less than a mile into the terrigenous detrital facies belt, definite Captain Creek can be traced several miles across it, about halfway to the Oklahoma border, and the South Bend can be traced across it as far as the Oklahoma border. The two shale members,

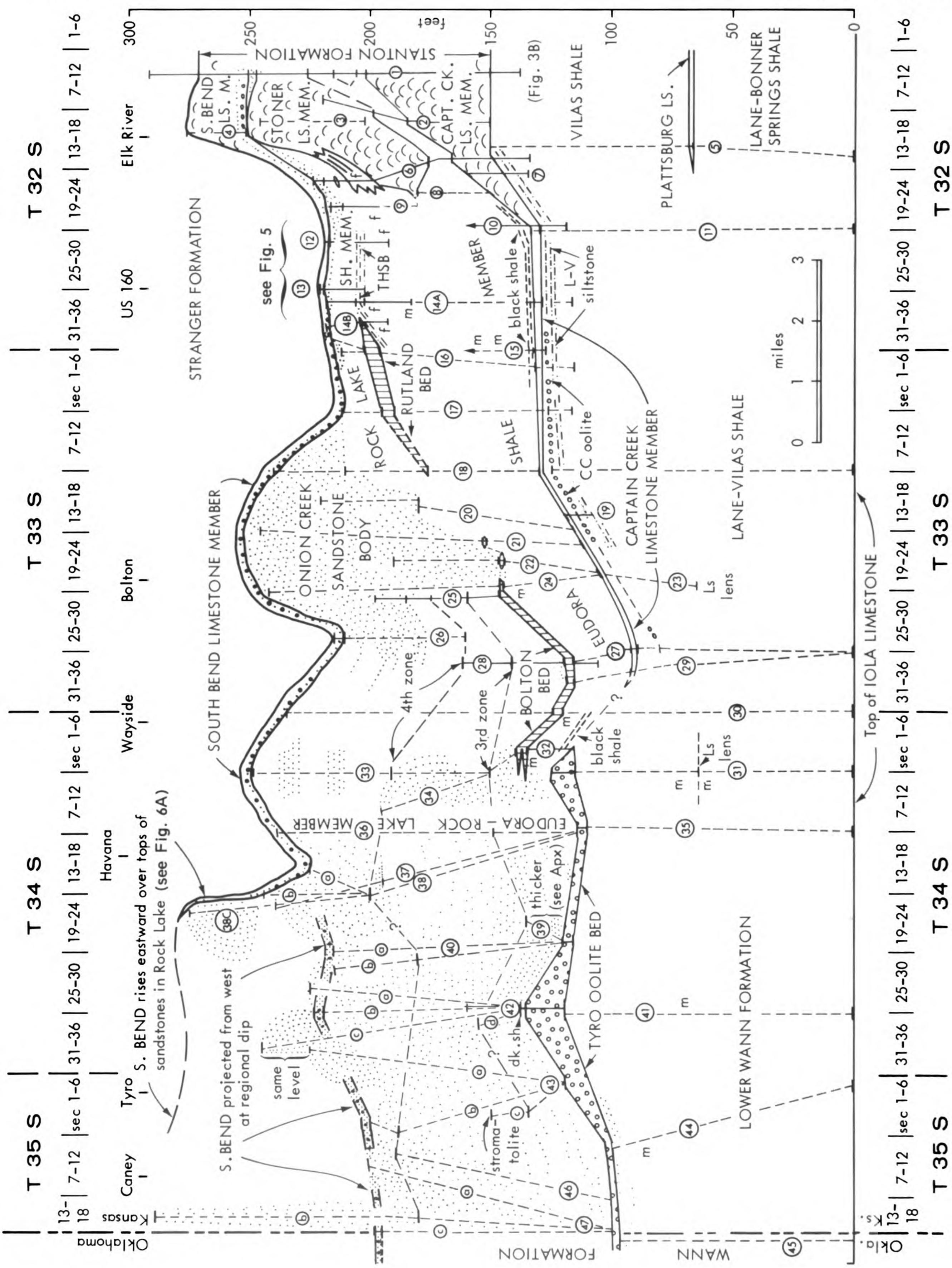
T 32 S
T 33 S
T 34 S
T 35 S
Elk River
US 160
Bolton
Wayside
Havana
Tyro
Caney
Oklahoma
Kansas
feet
STANTON FORMATION
S. BEND LS. M.
STONER LS. MEM.
CAPT. CK. LS. MEM.
(Fig. 3B)
VILAS SHALE
PLATTSBURG LS.
LANE-BONNER SPRINGS SHALE
STRANGER FORMATION
see Fig. 5
SH. MEM.
THSB
MEMBER
black shale
L-V
siltstone
LAKE
RUTLAND BED
ROCK
SHALE
CC oolite
CAPTAIN CREEK LIMESTONE MEMBER
miles
LANE-VILAS SHALE
SOUTH BEND LIMESTONE MEMBER
ONION CREEK SANDSTONE BODY
Ls lens
EUDORA
4th zone
3rd zone
BOLTON BED
black shale
Top of IOLA LIMESTONE
EUDORA - ROCK LAKE MEMBER
S. BEND rises eastward over tops of sandstones in Rock Lake (see Fig. 6A)
thicker (see Apx)
TYRO OOLITE BED
S. BEND projected from west at regional dip
same level
dk. sh.
stroma-tolite
LOWER WANN FORMATION
WANN FORMATION
Okla.
Ks.

FIG. 4.—North-south cross section along strike of Stanton Formation and underlying units in central and southern Montgomery County, Kansas. Primary datum is top of Iola Limestone which is frequently exposed to east (Plate 1), well-defined Stanton units (especially Captain Creek and Tyro) serve as secondary datums between measurements up from Iola. East-west cross-section in southern T32S is given in Fig. 5. Solid vertical lines indicate field measurement with hand level; dashed vertical lines indicate estimation of thickness from outcrop elevations on 7.5-minute topographic maps (10-foot contour interval) with correction made for 30 feet per mile regional dip to west. Both types of measured sections are located by number in Appendix 1. Greater than regional westward dip of South Bend Member off west sides of thick Rock Lake standstone bodies (illustrated in Fig. 6) causes westernmost exposures of South Bend to project eastward to within Eudora-Rock Lake interval at places from southern T33S through T35S. Regional dip of 30 feet/mile is verified on Captain Creek exposures on Table Mound and bluffs to west, north of Elk River; on Tyro exposures in quarry northeast of Tyro and at either end of Hafer Run inlier; and on South Bend exposures along U.S. Rte. 75 between Wayside and Havana (see Plate 1).

Symbols are standard except:

Convex-upward arcs—phylloid algal mound facies

Vertical lines—skeletal calcarenite

Blank in limestone unit—calcilutite, sponge-rich in Captain Creek and in South Bend in southern T33S and northern T34S

Abbreviations:

f—bryozoan-brachiopod-dominated diverse assemblage in Eudora and Stoner

m—mollusc-dominated assemblage in Eudora and lower Wann

THSB—Timber Hill siltstone bed

L-V siltstone—siltstone in top of Lane-Vilas Shale

Eudora and Rock Lake, can be separated about halfway to the Oklahoma border, and a generalized Eudora-Rock Lake interval can be carried along with the South Bend and a newly named basal limestone bed (Tyro) up to the Oklahoma border.

Captain Creek Limestone Member.—From a known exposed maximum of 50 feet at the standard section (Fig. 3B; Fig. 4, meas. sec. 1) north of the Elk River, the Captain Creek thins southwestward in 2 miles through about 12 feet in the low escarpment south of the Elk River (Fig. 4, meas. sec. 7) to less than 5 feet in another 2 miles to the roadcut on U.S. Rte. 160 (Fig. 4, meas. sec. 14A). Mound facies of phylloid-algal calcilutite, in which large algal blades shelter spar-filled voids, dominates the rock type across this region of thinning and is apparent in the roadcut exposure. Invertebrates such as brachiopods,

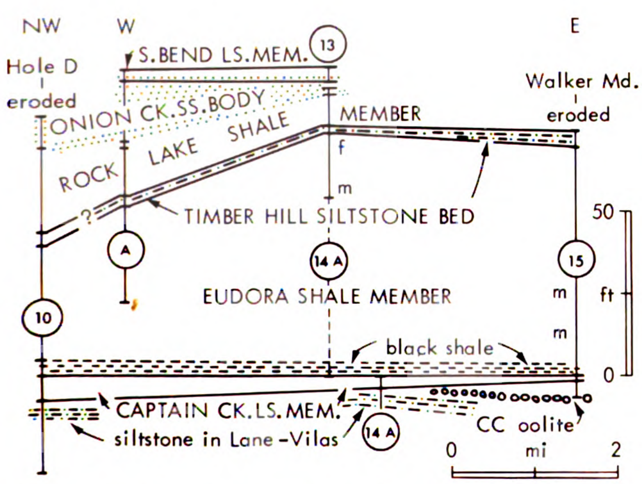

FIG. 5.—East-west cross section of Stanton Formation essentially along U.S. Rte. 160 at northern end of terrigenous detrital facies belt in southern T32S and northern T33S, showing thickness variations not shown on Fig. 4. Measured sections numbered as on Fig. 4 are located in Appendix 1; section A was measured along north side of U.S. Rte. 160 in road ditch west of Coon Creek in SE 28-32-14. Basic datum is top of Captain Creek Limestone Member; secondary datum is base of South Bend Limestone Member between sections 14A (13) and A. Correlation of Timber Hill siltstone bed questioned between sections A and 10 because chips from "hard layer" in drillhole D (section 10) are lost, and probable siltstone lithology cannot be substantiated in laboratory.

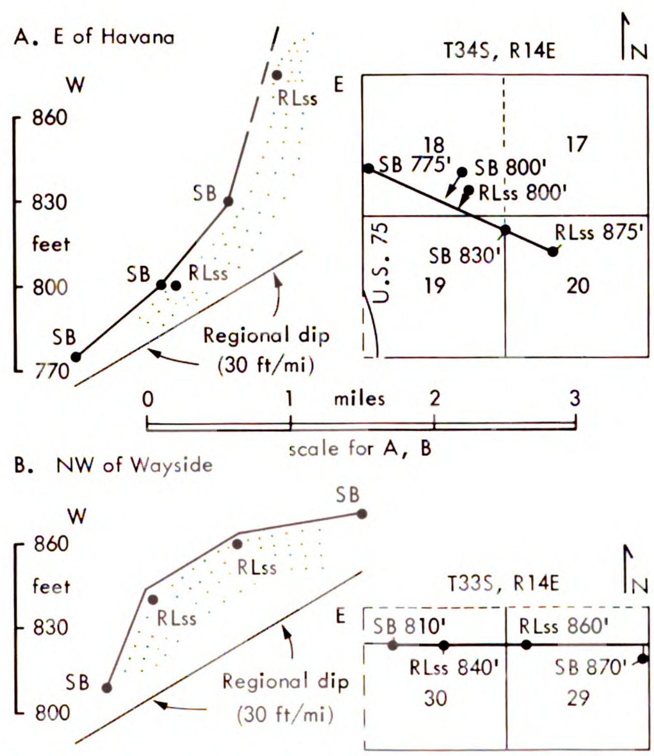

FIG. 6.—Two east-west cross sections, down dip, of upper part of Stanton Formation in southern Montgomery County, Kansas, showing greater than regional westward dips of South Bend Member (SB) off west sides of thick underlying sandstone bodies in Rock Lake Member (RLss). Datum is mean sea level obtained from 7.5-minute topographic maps with 10-foot contour interval.

FIG. 7.—Surface of block of Captain Creek sponge calcilutite facies showing characteristic abundance of conspicuous beaded and cylindrical calcisponges. Blade of hammer visible is 10 cm long. From Patterson's hog farm, NE-NE 23-33-14.

echinoderm pieces, and particularly sponges[3] become more noticeable southward and dominate some of the calcilutite in the roadcut exposure.

South of the U.S. 160 roadcut, the Captain Creek forms a low irregular escarpment that swings eastward around the foot of Walker Mound then south and westward toward Bolton (Plate 1). Throughout this portion of outcrop, the member averages 5 to 7 feet thick and consists of two 1- to 2-foot-thick layers of limestone separated by one to several feet of fossiliferous sponge-rich calcareous shale which is rarely exposed. The upper ledge is a distinctive dull orange to yellowish-brown weathering calcilutite dominated by small cylindrical and beaded calcisponges (Fig. 7) and containing various amounts of echinoderm debris, brachiopods, bryozoans, large irregular algal-invertebrate mats and encrustations (Fig. 8), and individual encrusting foraminifers. The lower ledge is an orangish-weathering oolite that contains scattered echinoderm, bryozoan, and brachiopod debris, most of which is oolitically coated. Quartz grains are present as nuclei, but are greatly subordinate to carbonate grains (pellets and skeletal pieces) in this function. Wilson (1957a) considered this oolite to be laterally equivalent to siltstone exposed to the north in the top of the underlying Vilas (= Lane-Vilas) Shale, but occurrence of oolite above siltstone in ditches along the east-west road bisecting the south one-half of section 17, T33S, R15E (Fig. 4, meas. sec. 19), along with scarcity of quartz nuclei in the northernmost exposures of the oolite, argue against this correlation.

West and south of Bolton, resistant sandstones higher in the Stanton hold up the hills[4] that mark an irregular escarpment, and the Captain Creek is exposed only in certain creek beds and gullies on the lower slope. The oolite lenses out westward in less than 2 miles from Walker Mound as it is replaced by shale carrying small stromatolitic nodules (along W line near NW cor 6-33-15). Its southwestward gradation around Bolton (in SE 13-33-14) consists of less than 1 foot of slightly oolitic skeletal-pelletal calcarenite beneath the sponge-rich calcilutite. Its southernmost known exposure in SE-SW 25-33-14 along U.S. Rte. 75 southwest of Bolton (Fig. 4, est. sec. 27) contains abundant quartz nuclei and stromatolitically (osagia) coated fossils and lithoclasts. The layer of orangish-weathering sponge-rich calcilutite that dominates the Captain Creek throughout the region south of Walker Mound is traced definitely as far south as an outcrop exposure in the road ditch

[3] Most of these are the familiar small cylindrical and beaded calcisponges; a few are represented by fragments of spicular mats, many of which have the appearance of small elongate combs on random cuts.

[4] The hill less than 1 mile northwest of Bolton, however, is held up by siltstone in the top of the Lane-Vilas Shale.

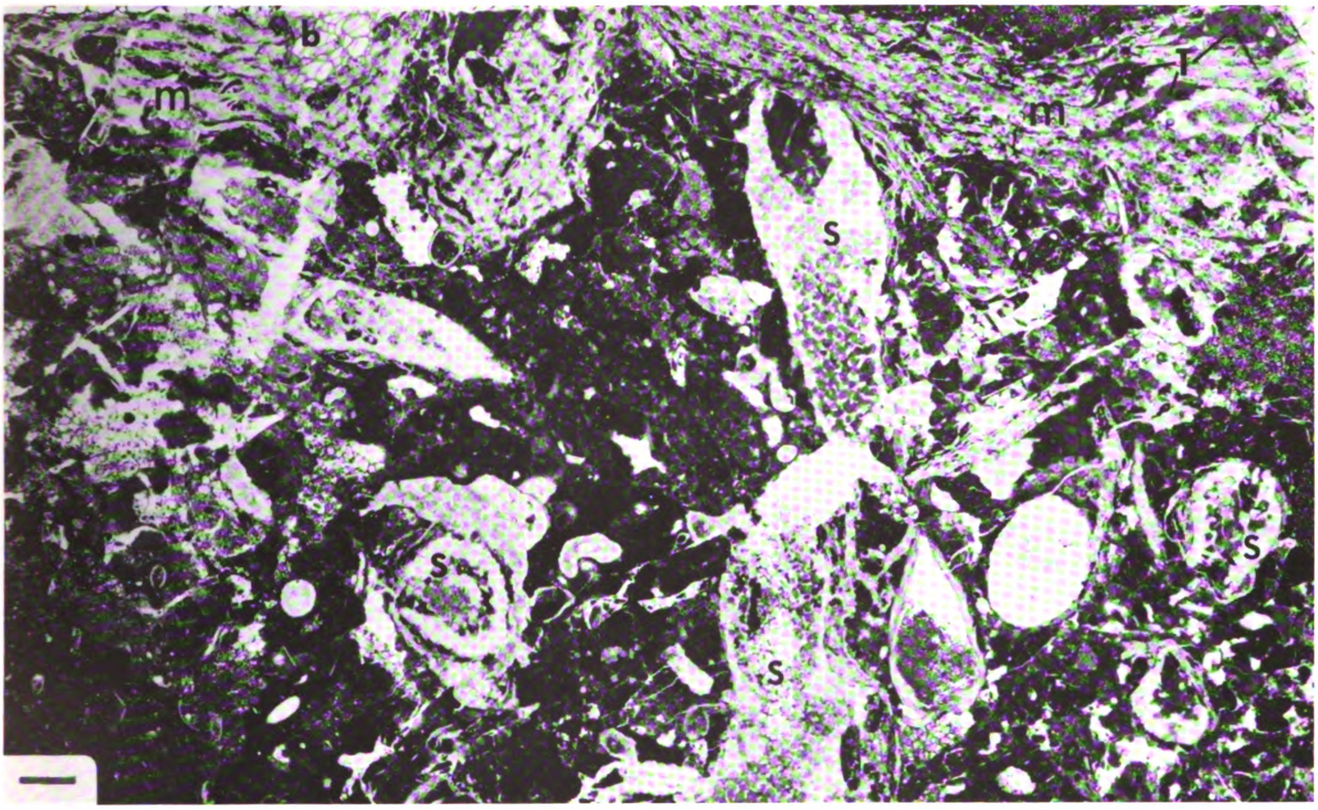

FIG. 8.—Thin section of Captain Creek sponge calcilutite facies showing conspicuous calcisponges (s) with probable algal-invertebrate mat (m) encrusting both sponges and mud surface; mat may possibly be considered "Ottonosia" in sense of Henbest (1963, p. 37) and consists largely of thin recrystallized layers, perhaps of archaeolithophyllid algae, alternating with thinner dark, generally micritic laminae, possibly of blue-green algal origin, augmented in places by encrusting foraminifers, fistuliporid bryozoans (b), and probable *Tubiphytes* (T). Scale in lower left is 1 mm long. From creek bed in SE-NW-SW 24-33-14.

along U.S. Rte. 75 (near ctr N half NW 36-33-14) southwest of Bolton (Fig. 4, est. sec. 27), and with caution to the sponge-bearing argillaceous calcilutite blocks lying in the road ditch along W line NW 31-33-15 (Fig. 4, est. sec. 29).

About 1.2 mile south of this, across a region of poor exposure of this horizon, the Tyro oolite bed appears at or near the stratigraphic level of the Captain Creek. This probable correlation is indicated by the occurrence of the black shale facies of the Eudora (see later section) just above the Tyro in the road along the S line of NE-SW 6-34-15. The Tyro bed is considered a separate stratigraphic entity because it is not known to be definitely continuous with either facies of the Captain Creek along outcrop. Even though the Tyro is petrographically similar to the Captain Creek oolite, the latter is last seen grading southward into stromatolitic rock along U.S. Rte. 75; furthermore, it is separated from the black shale facies of the Eudora at Walker Mound by the sponge-rich calcilutite and several feet of calcareous shale, whereas the Tyro directly underlies the black shale in section 6-34-15.

The sponge-bearing limestone lenses exposed in SE-NE-SE 6-34-15 and at the bend in the road on S line SW-SW-SW 5-34-15, around the base of the hill west of Jefferson (Fig. 4, est. sec. 31), were originally correlated to the Captain Creek by Schrader (1908), Newell (1933), and for a time by myself. But these lenses are about 50 feet below the projected level of the Captain Creek as determined by the black shale at the base of the Eudora, and thus they lie within the Lane-Vilas sequence. Along with a similar exposure of sponge-bearing calcilutite about 40 feet below the Captain Creek (Fig. 4, est. sec. 23) in a road ditch west of Bolton (ctr S line SW 19-33-15), these limestone lenses in the Lane-Vilas may possibly correlate with the Plattsburg Limestone. The black shale reported by Newell (in Moore, 1937, p. 50) above these lenses at the base of the hill west of Jefferson (SW 5-34-15), which determined my earlier correlation with the Captain Creek, was not found in a recent visit (summer, 1974) after severe thunderstorm erosion had cleanly exposed the gray shale sequence for some distance above the limestone horizon.

FIG. 9.—South Bend Limestone Member consisting of skeletal calcilutite (behind hammer handle) grading downward into coarse quartz sandy calcilutite (around hammer head), which grades downward into less calcareous quartz sandstone, probably featheredge of Onion Creek sandstone body (Rock Lake Member) with small channel fill (lower right) overying shale of Rock Lake Member. Roadcut on east side of Timber Hill near ctr W line NW 25-32-14.

Stoner Limestone Member.—Although only 20 feet thick at the standard section (Fig. 3B), the Stoner thickens southwestward in 2 miles to 40 feet or more of phylloid algae-dominated mound facies in the bluffs along the north side of the Elk River (Plate 1; Fig. 4, est. sec. 3). About one mile to the south, across the river, in a gully extending eastward from Card Creek to the new north-south road ascending the north prong of Timber Hill, a little over 20 feet of thick-bedded Stoner mound facies is exposed, though with the base badly slumped (Fig. 4, meas. sec. 6). This is overlain (in the road ditch) by 11 feet of thin-bedded calcilutite containing phylloid algae and invertebrates intercalated with calcareous shale containing echinoderm debris, brachiopods, fenestellid, rhomboporid and fistuliporid bryozoans, and scattered corals. About 0.25 mile to the east the Stoner crops out along a nearly disused north-south dirt road. At the north end (near NW-NW-NE 23-32-14) several feet of Stoner mound facies overlie "Eudora" fossiliferous shale. A little less than 0.4 mile to the south, on the west side of the road, Stoner limestone, packed with large blades of phylloid algae in a mud to spar matrix, pinches out into a sequence of shale that carries a diverse assemblage of invertebrates about 20 feet above the limestone pinchout (Fig. 4, est. sec. 9).

It is thus apparent that the Stoner Limestone Member passes southward abruptly into fossiliferous shale with gradation evident in the upper one-third of the gully-road ditch section (Fig. 4, meas. sec. 6) and presumably also in the lower beds (as indicated in the standard section, Fig. 4, meas. sec. 1). Limestone at or near the Stoner horizon is absent for at least 2 miles southward, and that which does appear (Rutland bed) displays a distinctly different rock type from any seen in the Stoner. Moreover, the siltstone (Timber Hill bed) that is exposed at places along U.S. Rte. 160 and was considered a probable or possible equivalent to the Stoner by Wilson (1957a) and Harbaugh (1962) is neither known to be continuous with the Stoner nor is lithologically compatible with it; therefore, it should be considered nothing more than a lens within the shale sequence to the south. All limestones within the Stanton south of the Stoner pinchout are given new informal names as beds, or left unnamed,

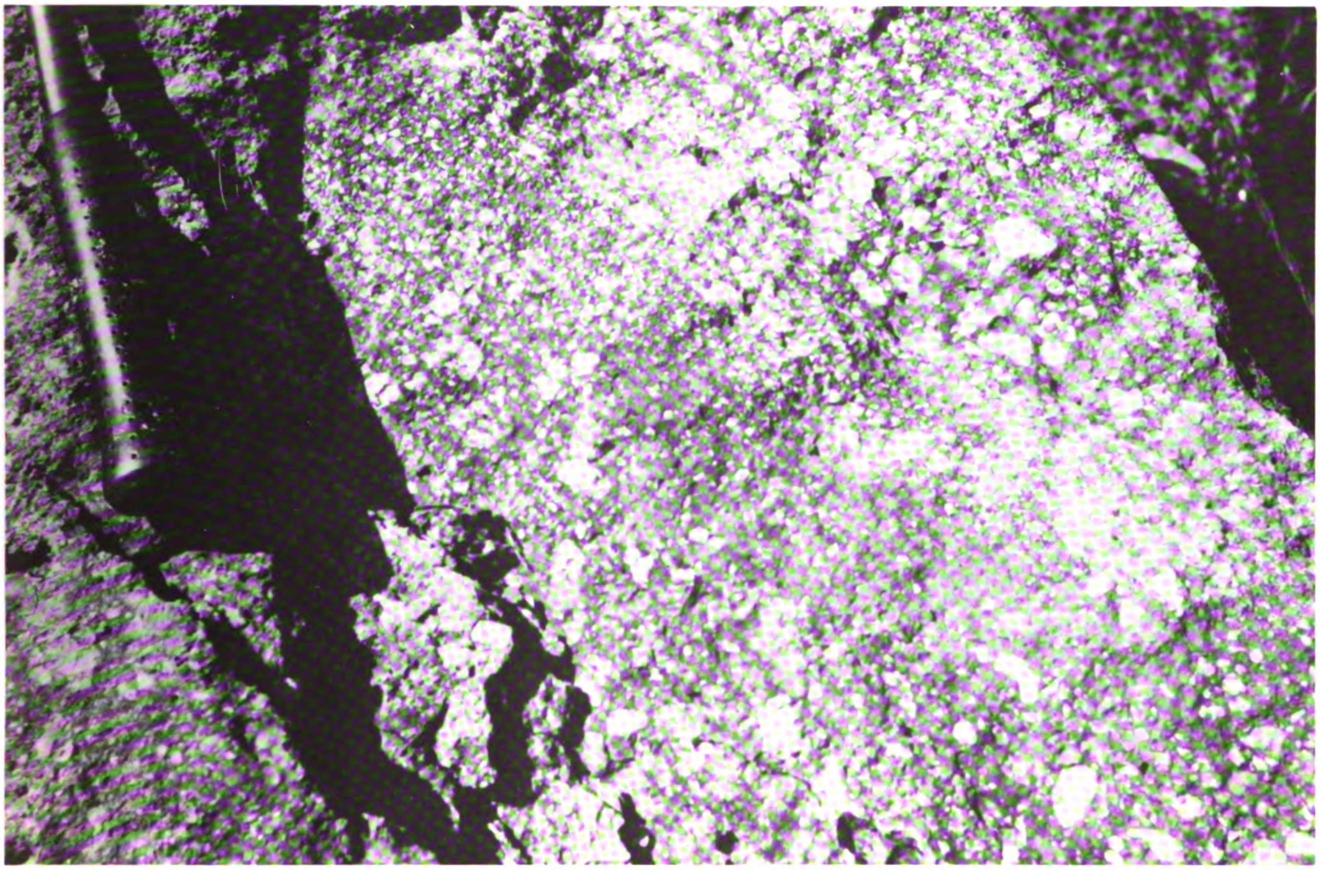

FIG. 10.—Conglomeratic coarse quartz sandstone that characterizes base of South Bend Member in many places; pebbles here are mainly calcilutite (white) and shale (gray). End of hammer in picture is 12 cm long. Blocks along road south of ctr W line SW 36-32-14.

in order to emphasize the lack of continuity along outcrop between them and the Stoner Member.

South Bend Limestone Member.—From its thickest development of 24 to 30 feet along the Elk River just south of Elk City, the South Bend Member thins abruptly southward. Some of the thinning can be observed in the quarry along U.S. Rte. 160 just south of the river (Plate 1, Fig. 4, meas. sec 4). The lower portion of the member, consisting of thin- to medium-bedded calcilutite alternating with quartz sandstone which is conglomeratic at the base, averages about 5 feet in thickness around the entire quarry. In contrast, the upper portion consists of about 20 feet of massive phylloid-algal calcilutite and echinoderm-rich calcarenite in the north wall but thins, in about 300 feet across the quarry, to 13 feet of medium-bedded skeletal calcilutite with subordinate algae in the south wall.

Farther southward and eastward in exposures around Timber Hill and along U.S. Rte. 160 (Plate 1), the South Bend consists of about 4 to 5 feet of yellowish to orangish-weathering skeletal calcilutite containing abundant echinoderm debris, with brachiopods, bryozoans, some phylloid algae, and calcisponges. The lower 1 to 2 feet carry abundant coarse quartz sand grains, locally oolitically coated, either scattered through the calcilutite or sufficiently concentrated to form a basal sandstone (Fig. 9). In many places conglomeratic sandstone (Fig. 10) characterizes the base of the South Bend (SW 36-32-14; NE and SW 11-33-14; and commonly southward). Pebbles in the conglomerate (Fig. 11) are mainly calcilutite, but include shale, siltstone, muddy sandstone, wood fragments and chert. Skeletal material ranges from whole brachiopods and large echinoderm pieces down to sand-size fragments of the above groups and of bryozoans, molluscs and foraminifers. Thus the two-fold lithologic subdivision characteristic of the South Bend in the north is apparent also south of the algal-mound facies belt and allows the member, only 2 to 4 feet thick, to be traced easily southward, marking the top of the Stanton Formation up to the Oklahoma border southwest of Caney.

The lower contact of the South Bend is variable. It is sharp where the coarse-grained limy conglomeratic sandstone overlies shale, such as along U.S. Rte. 75 southwest of Wayside, but seems less abrupt and

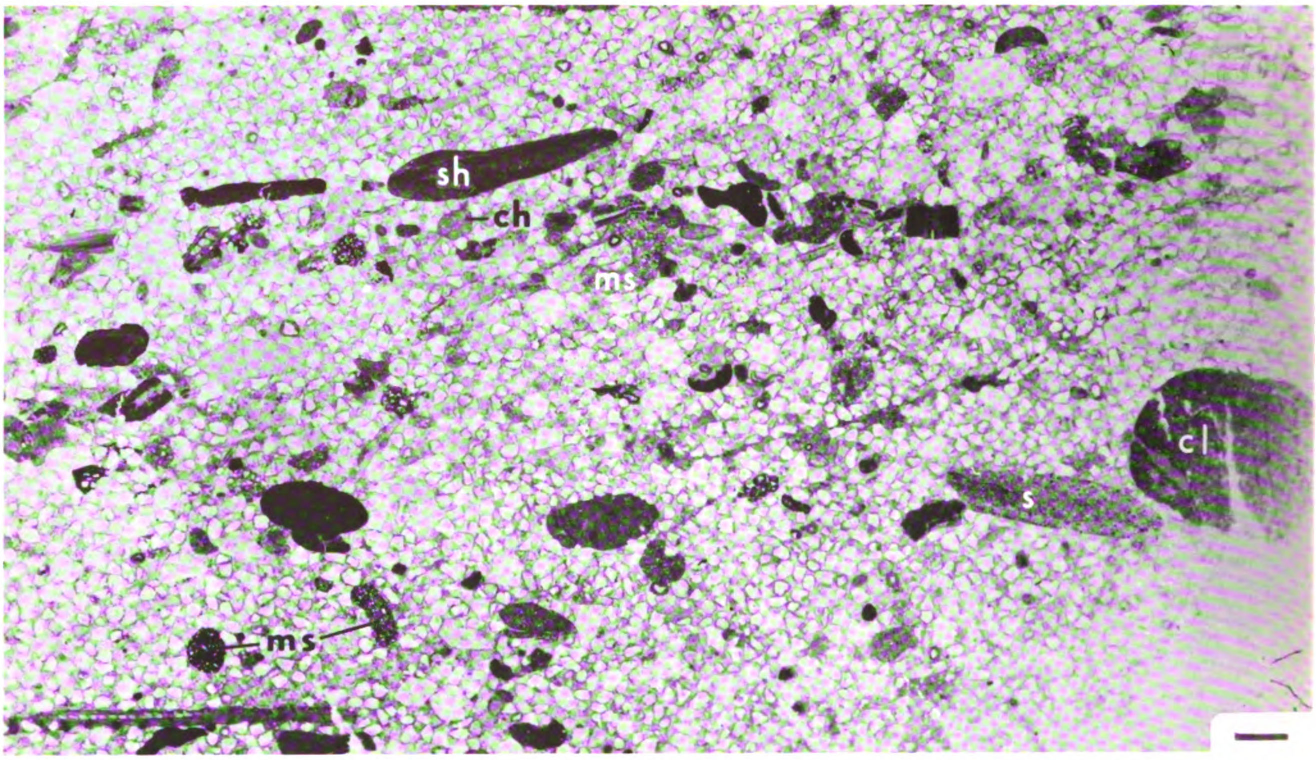

FIG. 11.—Thin section of conglomeratic coarse quartz sandstone characterizing base of South Bend Member; pebbles here include calcilutite (cl), siltstone (s), shale (sh), muddy sandstone (ms) and chert (ch). Also present are fragments of bryozoans, echinoderms, molluscs, etc. Scale in lower right is 1 mm long. From exposure near NW cor 31-34-14.

locally gradational where the South Bend overlies several feet of sandstone such as in exposures along U.S. Rte. 160 and around parts of Timber Hill (Fig. 9). Sandstone underlying the South Bend is reddish-brown, friable, much less calcareous, and in zones is markedly cross-bedded. It is generally distinct from the duller brown to yellowish, harder, calcareous, often fossiliferous, oolitic and/or conglomeratic sandstone marking the base of the South Bend. Quartz grains tend to be much coarser in the South Bend averaging about 0.3 to 0.5 mm and frequently exceeding 1 mm in size (Fig. 11) compared to an average of about 0.1 to 0.2 mm, rarely exceeding 0.4 mm in sandstone immediately below.

The two-fold subdivision characteristic of the South Bend is not observed in all exposures. For example, in the eastward facing line of outcrop north of Wayside (Plate 1), mainly the basal coarse fossiliferous and/or conglomeratic sandstone is apparent at the summit of a minor, only locally developed escarpment, presumably because the limestone is eroded back and covered by soil on the dip slope. Likewise, the upper limestone portion is exposed more often where the outcrop is cut into the dip slope such as northwest and southwest of Wayside. In the region between Wayside and Havana and along the Coon Creek watershed, the upper 1 foot or so of yellowish-weathering calcilutitic limestone carries a biota dominated by cylindrical and beaded calcisponges and including bryozoans, echinoderms, and brachiopods, with largely recrystalized algal?-foraminiferal encrustations around larger grains; it thus resembles markedly the Captain Creek Member at the base of the formation.

The outcrop trace of the South Bend Member, which generally follows the west side of the broad Stanton outcrop belt through most of the algal-mound facies belt, swings eastward around Timber Hill south of the Elk River (Plate 1) where the two thick underlying limestone members thin southward and are replaced by shale. Farther south, the South Bend swings westward again around the thick underlying Onion Creek sandstone body in the Rock Lake Member, then trends to the south-southeast as this sandstone thins just east of Wayside. Southward, more thick sandstones enter the Stanton interval, and the South Bend outcrop once more swings southwestward leaving only a few outliers east of the main trend. Most outliers are capped by younger sandstones. One, however (in SW-SE-NW 19-34-14; Fig. 12), lies upon the west slope of an underlying sandstone body that

FIG. 12.—South Bend Member with prominent conglomeratic quartz sandstone in lower part (particularly in ledge above hammer) overlying unfossiliferous, finer-grained quartz sandstone (foreground) of Rock Lake Member which rises eastward to form hills mapped previously as Douglas Group. Creek bed in SW-SE-NW 19-34-14.

forms hills eastward nearly as high as those formed by overlying sandstones to the south-southwest. These similarities in elevation had caused portions of the underlying sandstone to be mapped previously as a post-Stanton unit.

Approaching the Oklahoma border, much of the outcrop trace of the South Bend is covered by alluvium in the valley of Little Caney River. On the west side of the valley in the southwestern corner of Montgomery County, however, about 1 foot of coarse sandy South Bend Limestone, containing shale pebbles, crinoid debris and brachiopods, was traced from Kansas (SW-NW-SW 14-35-13) into Oklahoma.

Eudora and Rock Lake Shale Members.—Inasmuch as the two shale members of the Stanton Formation are separated by the Stoner Limestone Member, they join to form one continuous terrigenous detrital unit (Fig. 13) for a short distance south of the pinchout of the Stoner in section 23, T32S, R14E. Certain limestone beds and a quartz siltstone bed that appear between the Captain Creek and South Bend Members were used to separate the Eudora and Rock Lake in central and southern Montgomery County by Wilson (1957a) and this practice is followed herein with the Timber Hill, Rutland, and Bolton beds. Nevertheless, it must be recognized that, because these beds first appear above the level of the main mass of the Stoner, then occur at slightly different stratigraphic levels southward, this boundary between the two shale members takes on different time values from place to place (Fig. 4). Where these beds are absent, the entire detrital interval between the Captain Creek (or Tyro) and the South Bend is referred to as Eudora-Rock Lake. Although shales are poorly exposed and were not emphasized in this study, some brief statements can be made concerning the nature of the two shale members.

The **Eudora Member** ranges from about 30 feet thick beneath the south end of the Stoner in section 23 (Fig. 4, est. sec. 8) to 70 or 75 feet above thinned Captain Creek southward in Walker Mound and near the roadcut on the north side of U.S. Rte. 160 (Fig. 4, 5, est. secs. 14A, 15). In these thicker sections the Eudora is capped by a quartz siltstone (Timber Hill bed) which overlies shale that probably is equivalent to the top of the Stoner on the north prong of Timber Hill, so that much of the upper portion of the thicker Eudora shale sequence represents the southward gradation of the Stoner Limestone (Fig. 4). To the south, the Eudora thins southward from 40 feet to 18 feet thick beneath the Bolton bed. South of the disappearance of the Bolton bed, the Eudora is inseparable from the overlying Rock Lake Member. Most of the thicker Eudora in Townships 32 and 33 south is shale, but at least 10 feet of rippled, thin to medium-bedded sandstone appears at the top, 2 miles south-

FIG. 13.—Part of shale sequence dominating Stanton Formation in terrigenous detrital facies belt just south of algal-mound facies belt, showing mostly top of Eudora Member: person standing in lower left marks position of molluscan fauna; person seated marks position of diverse fauna; person above stands on position of Timber Hill siltstone bed which lenses in to left in several tens of feet; brush-covered slope above is shale of Rock Lake Member, and fence line at top rests on featheredge of Onion Creek sandstone body below South Bend Member. Roadcut on north side of U.S. Rte. 160 just north of ctr W line NW 36-32-14, about 6 miles west of Independence. (See also Fig. 4, 5, meas. sec. 14A.)

west of Bolton (NE 35-33-14). Brown sandstone recurs southward near this horizon in the Eudora-Rock Lake interval, not far above the Tyro oolite bed, and caps most of the east-facing escarpment in Townships 34 and 35 south.

Marking the base of the Eudora, about 1 to 2 feet of black fissile shale, locally with phosphorite nodules, has been observed above thin Captain Creek at Walker Mound, in a drillhole at the U.S. 160 roadcut (Wilson, 1957a, p. 45), in drillhole D, 3 miles to the west-northwest (Fig. 4, 5, meas. secs. 15, 14A, 10 respectively), southwest of Bolton (inferred by Wilson, 1957a, p. 14), above the Tyro oolite bed in the road (along S line NE SW 6-34-15) west of the hill west of Jefferson, and above the westernmost Tyro exposure along Hafer Run (Wilson, 1957a, p. 14). Furthermore, about 1 to 2 feet of dark gray, more easily disaggregated, clayey shale overlies the Tyro oolite at the Tyro Quarry (NW-SW-SE 30-34-15). Conodont faunas recovered from this and other exposures, presently under study by R. H. Wood, strongly suggest equivalence of this dark gray shale and the black shales at the base of the Eudora elsewhere in Montgomery County. This apparently extensive horizon of black to dark gray shale forms the basis of correlation of the lower Stanton throughout this region.

Gray to brown shales higher in the Eudora tend to be more noticeably fossiliferous than do higher levels of the Stanton. The fauna generally is dominated by molluscs, particularly snails and clams, but locally carries ammonoids, nautiloids, brachiopods, and crinoids (Fig. 4, symbol m). The upper part of the Eudora, where it represents the southward gradation of the Stoner limestone across about 2 miles from northeast to southeast of Timber Hill (Plate 1), is characterized by a rich, diverse fauna (Fig. 4, symbol f) dominated by fenestellid bryozoans, brachiopods, echinoderms, and, locally, sponges and large ramose bryozoans, which distinguish it from the mollusc-dominated fauna occurring below it. Both faunas can be observed in the U.S. Rte. 160 roadcut (Fig. 4, meas. sec. 14A; Fig. 13).

The Rock Lake Member thickens from a few feet of sandy shale (or missing entirely) above thicker portions of the Stoner mound southward to 10 to 12 feet above the siltstone overlying the Eudora along the east side of Timber Hill, then thickens further to 35 feet westward along U.S. Rte. 160 (Fig. 5). In this region it is largely unfossiliferous, silty, tan to gray shale with scattered earthy calcareous nodules, and includes from less than 1 to nearly 20 feet westward of friable, reddish-brown, unfossiliferous, cross-bedded to even-bedded quartz sandstone (part of the Onion Creek body) at the top, which locally seems transitional upward to the South Bend Member. Much of the westward thickening along U.S. Rte. 160 is in the sandstone at the top, but the underlying shale also increases westward from 10 or 12 feet in the east to 17 feet at Coon Creek and 26 feet in drillhole D (Fig. 5). Complementarily, the underlying Eudora thins westward from 70 or 75 feet southeast of Timber Hill to 40 feet in drillhole D to maintain a relatively constant interval for the entire Stanton in this region (Fig. 5). Southward, the Rock Lake encompasses much greater amounts of quartz sandstone and attains about 100 feet in thickness in the vicinity of Onion Creek. South of Onion Creek several calcareous zones, from oolitic sandstones to fossiliferous horizons and stromatolites, appear in the Rock Lake. Several of these seem traceable and are described further in a later section.

South of the disappearance of the Bolton bed, the Rock Lake is inseparable from the underlying Eudora. The southward thinning of the Eudora beneath the Bolton bed combined with the position of the two major calcareous zones in the Rock Lake (Fig. 4), however, suggests that the great majority, perhaps as much as the upper seven-eighths, of the Eudora-Rock Lake interval of southern Montgomery County consists of strata equivalent to the Rock Lake Member. Thickness of the entire interval is at least 150 feet and may reach as much as 200 feet in the vicinity of Cheyenne Creek, 3 miles northeast of Caney, where 150 feet of relief occurs in strata exposed somewhere between the Tyro and the South Bend in section 33, T34S, R14E. Throughout this region, thin-bedded to massive, gray to brown sandstone, locally with shale pebbles, dominates the Eudora-Rock Lake; certain delineated sandstone bodies are described briefly in a later section. Shale is sandy and subordinate, at least in exposures. Although the top of the Rock Lake is typically sandstone, several feet of shale underlie the South Bend Member along U.S. Rte. 75 for at least 2 miles southwest of Wayside.

Beds

Three beds of limestone and one of quartz siltstone are sufficiently distinct that they can be traced over several miles of outcrop with enough confidence to warrant naming them for ready reference. On account of the multitude of formal member names already applied to more extensive Pennsylvanian rock units in Kansas, I propose naming these new units in the southern end of the Stanton formation informally as beds, using the names Timber Hill, Rutland, Bolton, and Tyro from local geographic features. The former three beds have previously been regarded as Stoner (even though the Timber Hill is a siltstone), whereas the latter is correlated with the Captain Creek. In addition, other limestones or limy horizons mainly within the Rock Lake are either more local in occurrence or less definitely traceable, and thus are only briefly discussed without being geographically named. Finally, several sandstone bodies in the Rock Lake Member and Eudora-Rock Lake interval are roughly delineated, and one is given the informal name Onion Creek, pending more detailed work.

Timber Hill siltstone bed.—Separating shale of the Rock Lake Member from shale of the underlying Eudora in the southern half of T32S, is a thin bed of tan-weathering, light-gray quartz siltstone ranging from 2 to 4 feet thick. It is well exposed in cuts along the east side of Timber Hill, from which it is named, and the roadcut near center W line NW 25, T32S, R14E is chosen as type section. The siltstone lenses out abruptly eastward, at least locally, within the U.S. 160 roadcut in SE-NE-NE 35-32-14. Here it overlies shale containing the diverse bryozoan-brachiopod-dominated assemblage, which occurs northward above the pinchout of the Stoner Member in section 23 (Fig. 4, meas. sec. 14A, 9). Westward, the Timber Hill siltstone is exposed along Coon Creek at the U.S. Rte. 160 highway bridge (Fig. 5, meas. sec. A). Southward, it occurs near the top of the north slope of the hill just north of ctr. E line SE 35-32-14, where it is overlain by the north end of the Rutland limestone bed and underlain by shale containing the diverse bryozoan-brachiopod fauna (Fig. 4, meas. sec. 14B). Eastward it is eroded away, but apparently occurs in an outlier as the capping siltstone ledge, 5 feet thick, on top of Walker mound (Fig. 5, est. sec. 15).

Lithologically, the Timber Hill is wavy thin-bedded to massive hard quartz siltstone with grains ranging from 0.03 to 0.12 mm and averaging about 0.05 to 0.06 mm in size. Muscovite is a subordinate constituent; matrix is sparry calcite. Irregular thin shaly partings separate the siltstone layers in some places. Where well exposed, contacts with both overlying and underlying shales seem conformable and gradational.

The Timber Hill bed so far has proved to be poorly fossiliferous. On top of Walker Mound, however, it contains rare pinnid and nuculid clams, gastropods, and the brachipod *Linoproductus;* a thin section from the type exposure reveals small pelecypod and rare echinoderm fragments.

Rutland limestone bed.—The first limestone to appear between the Captain Creek and South Bend Member south of the Stoner pinchout (Fig. 4) is a calcarenite bed named from the Township of Rutland. The main portion of known outcrop is in the southern halves of sections 35 and 36, T32S, R14E and adjacent

FIG. 14.—Rutland bed at type section showing well developed cross-bedding dipping to north or northwest. Quarried ledge in NE cor 2-33-14.

portions of section 1 and 2 in T33S (Plate 1). The most easily accessible exposure, designated the type section, is an old quarried ledge just south of the driveway in the northeast corner of section 2, T33S, R14E (Fig. 14; Fig. 4, est. sec. 16). An outlier is known in the northeast corner of section 12, T33S, R14E, and another is inferred from scattered blocks near the southeastern corner of the same section.

The north end of the Rutland bed (near ctr. E line SE 35-32-14; Fig. 4, meas. sec. 14B) lies upon the Timber Hill siltstone bed, which overlies upper-Stoner-equivalent Eudora shale and separates the Rock Lake from Eudora along the east side of Timber Hill. Thus the Rutland bed not only is separated from the Stoner laterally along outcrop by a little over 2 miles of shale and siltstone, but also it overlies the siltstone that lies above the fossiliferous shale that overlies the Stoner pinchout (Fig. 4). These relations suggest that the Rutland bed is stratigraphically higher than most, if not all of the Stoner Member.

Thickness of the Rutland bed ranges from about 1 foot at its north end to at least 8 feet in its westernmost known exposure in the farmyard in NW-NE 2-33-14. Where well exposed, the unit exhibits large-scale cross-bedding (Fig. 14). It seems variable in thickness from place to place and perhaps is lenticular in nature within its outcrop extent, which may account for its spotty distribution.

Lithologically, the Rutland is a tannish to dull orangish-brown, coarse-grained bioclastic calcarenite with darker oatmeal-like plates of algae conspicuous over much of the weathered surface. Most skeletal grains are fragmental, and many are relatively well abraded. Small ooids (generally 0.2 to 0.5 mm) are scattered through the rock in the more northern outcrop and form an appreciable proportion of thin layers of the rock in the southeastern outliers. Oolitic nuclei are mainly small skeletal fragments, nondescript carbonate grains, and less commonly quartz. Small 1 to 2 mm calcilutitic intraclasts occur scattered throughout the rock, and only a few of the larger of these display osagia-type internal structure. Matrix is generally fine-grained to coarse-grained calcite spar with substantial replacement by small strained blocky crystals of dolomite.

Red and green algae constitute the most conspicuous and perhaps the most numerous elements of the biota (Fig. 15). Red algae consist mainly of fragments of *Archaeolithophyllum* with internal structure often exquisitely preserved, but include one fragment of a solenoporid identified as *Parachaetetes* (Heckel, 1975). Green algae are represented by fragments of the dasyclad *Epimastopora* and nondescript sparry grains, which probably are phylloid codiaceans that lack preserved internal structure. Invertebrate material comprises a diverse assemblage of echinoderm debris (including crinoid calyces and a possible sieve plate), fenestellid and rhomboporid bryozoans, mollusc and brachiopod fragments, scattered fusulinids and other foraminifers, small calcisponges, and small corals.

Bolton limestone bed.—About 1.5 miles south of the disappearance of the Rutland bed, another bed of calcarenite, the Bolton bed, appears. It crops out across an arc of about 4 miles midway up the irregular low escarpment capped by higher sandstones west

Fig. 15.—Thin section of Rutland bed showing fragmented and fairly well abraded grains of algae, including well preserved red *Archaeolithophyllum* (A) and dasyclad *Epimastopora* (E); most lighter grains are poorly preserved *Archaeolithophyllum;* other grains include several types of bryozoans, echinoderms, fusulinids, mollusc and brachiopod fragments, and ooids; matrix is spar that is largely replaced by small Fe-stained crystals of dolomite. Scale in lower right is 1 mm long. From ledge in farm yard in NW-NE 2-33-14.

Fig. 16.—Bolton bed at type section on north side of railroad cut near ctr S half NW-NW 36-33-14, with overlying Rock Lake shale and ledge of sandstone carrying shale pebbles exposed above shoulder level.

and south of the settlement of Bolton, from which it is named (Plate 1). The type section is chosen in the Santa Fe railroad cut about 2 miles southwest of Bolton (just N of ctr. S half NW-NW 36-33-14) where the bed is well exposed along with immediately adjacent strata (Fig. 16). Other easily accessible good exposures occur in roadcuts along the driveway in SE-SE-SW 24-33-14; along the road in SE-SW-SE 26-33-14; and especially along the paved highways at S line SW-SW-SW 31-33-15, and W line SW-NW-SW 6-34-15.

The northeast end of the Bolton bed (in SE-SW-NW 24-33-14, just north of the small pond) is 1.5 miles and 2.5 miles south of the southernmost known loose blocks and in-place exposures, respectively, of the Rutland bed in section 12 of the same township. No exposure of limestone was found, despite a search, in the nose of escarpment extending from section 14 into section 13 (Plate 1). Thus the Bolton bed is not connected along outcrop with the Rutland bed. Although the possibility exists of connection in the subsurface, some evidence suggests that the Bolton bed lies at a slightly lower stratigraphic horizon than the Rutland bed. The Rutland lies about 45 to 65 feet above the Captain Creek whereas the Bolton lies about 20 to 40 feet above the Captain Creek in the northern 3 miles of outcrop closest to the Rutland outcrop. Most of these figures are only estimates from topographic maps allowing for regional dip, however, and may not be accurate enough for a definite determination of horizon. The limy horizon exposed near the top of the small hill in NW-SE 13-33-14 about 30 to 40 feet above the Captain Creek and nearly midway between the limiting Rutland and Bolton exposures is mainly fossiliferous quartz siltstone with a lens of stromatolite, unlike the rock type of either of the two named beds. Furthermore, the northeasternmost exposure of the Bolton bed is a lenticular layer less than 1 foot thick that appears to lens out northward on outcrop; it is overlain by 2 feet of shale that is capped by about 0.2 feet of similarly lenticular oolitic limestone; these are relations that would be expected at the limit of a limestone unit. Elevations suggest that the ledge of skeletal-oolitic calcarenite in the bed of Onion Creek near W line NW-NW 23-33-14 is the northwesternmost known exposure of the Bolton bed.

Thickness of the Bolton bed ranges generally between 1 and 2 feet and attains 4.5 feet near the south end (SW-NW-SW 6-34-15), where 1 foot of shale occurs in the middle. Thickness is quite variable in short distances along outcrop, as is shown near the base of the north side of the hill northeast of Wayside (NE 35-33-14), where the bed thickens in a short distance from less than 2 up to 3 feet in a sort of megaripple form. Nearby, it apparently thins to zero inasmuch as the bed was not found at the expected elevation in the sandy sequence exposed just to the south between the railroad and U.S. Rte. 75 (SE-NE 35-33-14). Thus, it is possible that the Bolton bed consists of a series of closely spaced lenses, some of which might be at slightly different levels as suggested by the shale layers between limestone ledges at the north and south ends. Nevertheless, the lithologic character of the exposures is similar enough across a well-defined line of outcrop to treat these limestones as a named unit.

Lithologically, the Bolton bed is a yellowish-orange to yellowish-gray weathering, dominantly skeletal calcarenite in which several kinds of invertebrates are conspicuous on weathered surface. Petrographically, limestone in the Bolton ranges from skeletal calcarenite to mixed skeletal-oolite calcarenite in which many skeletal pieces are not oolitically coated. Skeletal pieces appear less fragmented and less abraded (Fig. 17) than those in the Rutland bed (Fig. 15). Scattered osagia-like coatings (see below) range from very thin around some smaller grains up to 0.5 and 1.0 mm thick around certain larger skeletal grains. Very few calcilutitic intraclasts without osagia structure were noted. Ooids are concentrated in certain layers; their sizes range generally from about 0.4 to 0.8 mm with coatings ranging from superficial to substantial around all sizes of nuclei, which include quartz grains as well as skeletal fragments. Quartz sand is scattered throughout the bed but is especially abundant in samples from both its north and south ends which suggests that the unit may grade laterally into sandstone. The matrix to the grains throughout the Bolton bed is mainly sparry calcite cement, although limonitic mud is apparent in places.

The osagia-like coatings consist of layers of micrite that contain zones of tiny encrusting foraminifers. The micrite layers supposedly result from blue-green algae (Henbest, 1963, p. 35), but no diagnostic blue-green algal structure is preserved in Stanton specimens. Only a few preserved algae represented by fragments of red *Archaeolithophyllum* were noted in the Bolton bed. A diverse group of invertebrates dominates the biota (Fig. 17) and includes echinoderm pieces, fenestellid, rhomboporid, and fistuliporid bryozoans, brachiopods, less commonly snails, ostracodes, nonfusulinid foraminifers, calcisponges, and rare cephalopods and trilobite pieces.

Tyro oolite bed.—The bed of oolite that can be traced southward at least 9 miles from the north end of T34S across the border into Oklahoma is named from the village of Tyro on U.S. Rte. 166 where it

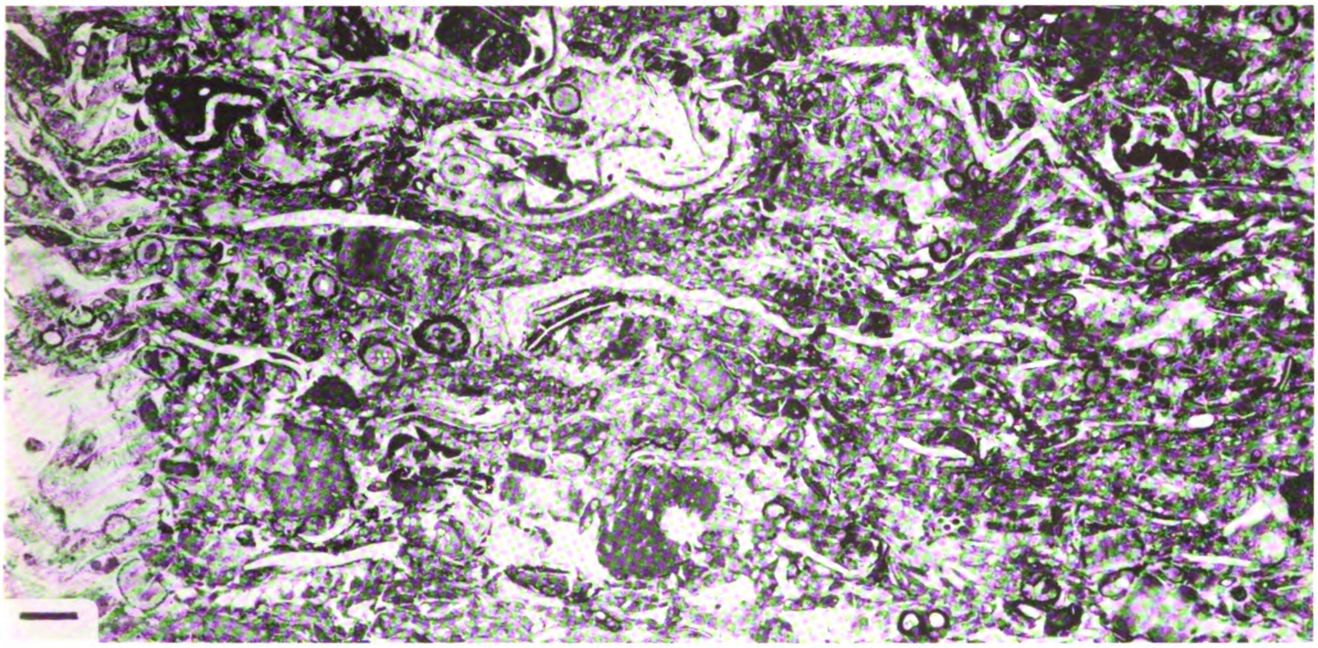

FIG. 17.—Thin section of Bolton bed showing relatively unfragmented and unabraded skeletal material consisting of a diverse group of invertebrates, including most conspicuously, several types of bryozoans, brachiopods, and mollusc and echinoderm debris; dark rims on some grains are osagia-like micritic coatings containing tiny encrusting foraminifers; ooids also are present. Scale in lower left is 1 mm long. From lower ledge exposed in roadcut along W line NW-SW 6-34-15.

crosses the outcrop trace (Plate 1). The Tyro oolite[5] occurs at or near the top of a relatively continuous escarpment from Tyro north and is encountered as an outlier about midway up the irregular mass of hills to the southeast in T35S, R15E. Southwest of Tyro, the outcrop descends to the plain at the base of the escarpment and was traced across the Oklahoma border just west of the southeast corner of section 15, T35S, R14E. Reconnaissance in Oklahoma indicates that the southeastern outlier of the Tyro crops out around the remainder of the hills in the north part of T29N, R14E, and that the main trend extends southwestward toward an exposure on the road along the west line NW 27-19-13; this is a small outlier according to Oakes (1940a, plate 1) and is the southernmost exposure of Tyro presently known. The type section is chosen in the abandoned quarry northeast of Tyro, west of Stony Point (in NW-SW-SE 30-34-15). The only good exposures easily accessible by road are near the ctr. E line NE 7-35-15, and the state border locality near the SE corner 15-35-14. Other good but less accessible exposures include the top of the hill west of Jefferson at the juncture of sections 5,6,7, and 8, T34S, R15E; near the crest of the hill northwest of Fawn Creek Cemetery in SE 19-34-15 (Fig. 18); along the railroad tracks just east of Tyro near ctr. N line, NW 6-35-15; and in an inlier west of Tyro in the west bank of Hafer Run near ctr. NE-NE 4-35-14.

The Tyro is traced west-northwestward from the hill west of Jefferson (SW corner 5-34-15) to a poor exposure in the road ditch along west line NW-SW 6-34-15. Because black shale typical of the base of the Eudora farther north overlies the Tyro in the road exposure (S line NE SW 6-34-15) in between, the Tyro seems equivalent to the Captain Creek Member (which disappears southward about 1.2 miles to the north). Nevertheless, stratal continuity is not proven, and lithologic transition between the two units is unknown. Thus, the Tyro bed is a distinct lithologic entity that marks the base of the Stanton in the southern two townships in Kansas and the northernmost township in Oklahoma.

The Tyro overlies a substantial thickness of gray shale that constitutes the Lane-Vilas Formation. Layers of sandstone appear just below the Tyro in T35S, and are best exposed in the outlier hills southeast of Tyro. The Lane-Vilas locally carries a mollusc-dominated fauna including snails, nuculid, pectinid and other claims, leiorhynchid brachiopods and occasional crinoids and cephalopods, which resembles both the fauna of the stratigraphically higher Eudora to the

[5] This name was first mentioned by Strimple and Cocke (1969).

FIG. 18.—Tyro oolite bed exposed on southeast side of hill northwest of Fawn Creek Cemetery (NW-SE-SE 19-34-15) showing consistently westward to southwestward dipping cross-beds emphasized by thin zones of echinoderm fragments (white spots); similar consistent southwestward dips of cross-beds were measured by Harbaugh (1962, p. 58) and illustrated by Hamblin (1969, p. 8) from type section of Tyro bed in Tyro Quarry, 1 mile to south.

north and that of much of the Wann Formation farther south in Oklahoma.

The elevation of the west end of the Tyro inlier along Hafer Run (795 feet above sea level) is extensively exposed along Cheyenne Creek a little over one mile along strike to the north (Plate 1), but no oolite was found; this suggests either that the Tyro lenses out to the northwest between the two localities, or that it dips more northerly and perhaps more steeply in this local area. It is known that the Tyro dips more steeply westward across section 6-34-15, at nearly 70 feet per mile (from top at 905 feet in SE corner to 837 feet along W line; Appendix 1, est. secs. 31,32) and across section 7-34-15 at about 50 feet per mile (from 880 feet to 850 feet in 0.6 mile; see Appendix 1, est. secs. 35, 36), and perhaps also farther south (see note in Appendix 1, est. sec. 39).

Thickness of the Tyro ranges from about 1 or 2 feet in several places to as much as 15 feet at the type section where the base is not exposed. Thickness can be observed to vary in an undulatory manner by a foot or so in a short distance along a good exposure, imparting to the Tyro the sort of megaripple form that occurs in the Bolton bed. Also, thinning of the Tyro eastward across NW-NE 13-35-14 to disappearance in exposures along the north-south road indicates that the Tyro is locally lenticular within its outcrop belt.

Lithologically, the Tyro is a cross-bedded oolite everywhere with local zones carrying substantial abraded fossil debris (Fig. 18). At the three localities where measurements were made, cross-beds dip consistently to the west to southwest (Tyro Quarry; hill west of Jefferson; hill northwest of Fawn Creek Cemetery). In various exposures the rock weathers yellowish to orangish-brown or light gray. Most distinctively, in the Tyro Quarry it weathers light gray and is marked by rusty-brown "leopard" spots and "tiger" stripes resulting from oxidation of localized patches and streaks of ferroan dolomite replacement of whole ooids.

Ooids range from about 0.3 to 0.5 mm in size with relatively thin coatings around mainly quartz nuclei in the north, to 0.6 to 0.9 mm in size with relatively thick coatings around both quartz and carbonate nuclei around Tyro. When present, larger skeletal grains (up to 2 and 3 mm) typically have a thinner oolitic coating (Fig. 19). In places toward the south, smaller

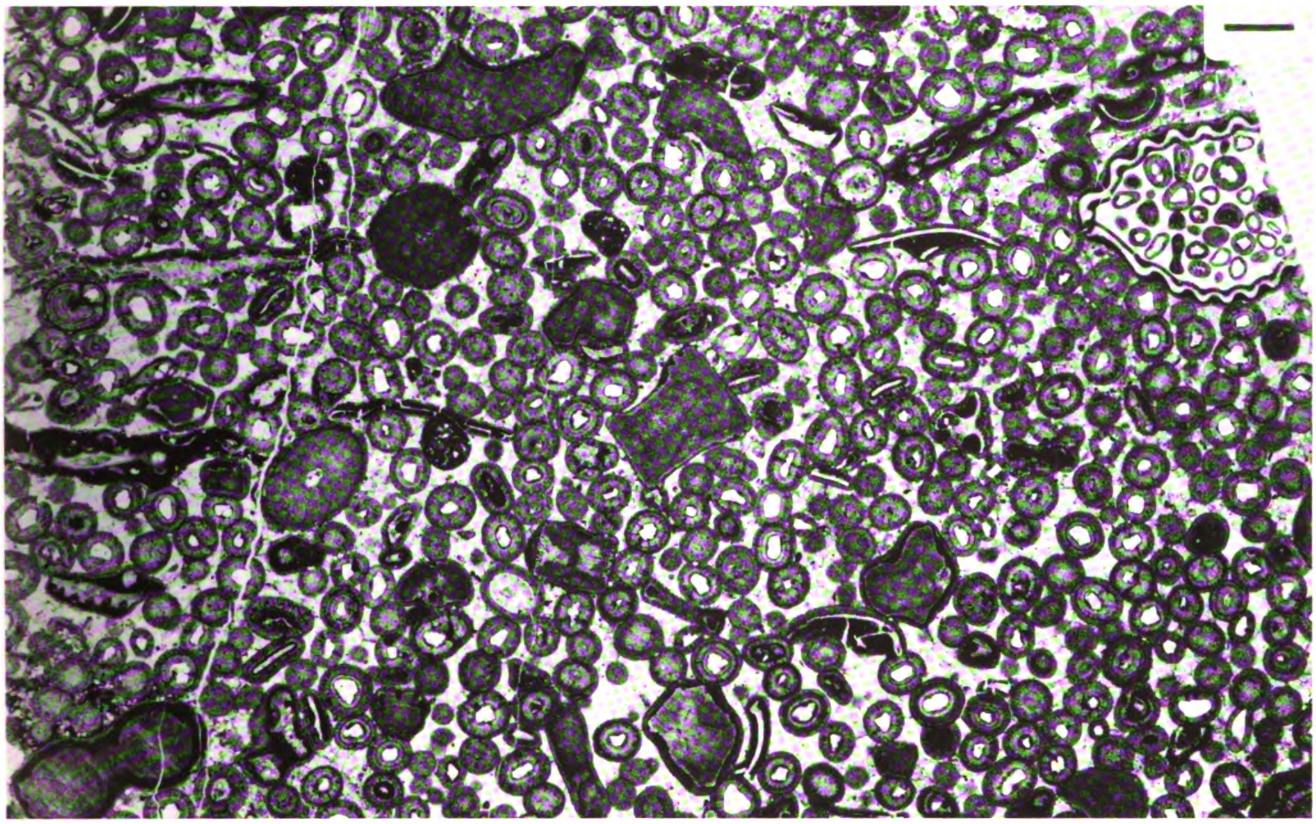

Fig. 19.—Thin section of Tyro oolite bed showing both thickly coated small ooids, mainly with quartz nuclei (white spots), and more thinly coated large ooids nucleated around skeletal fragments (mainly echinoderm pieces, but also bryozoan and brachiopod fragments); shell of brachiopod in upper right became closed around ooids in earlier stage of development. Scale in upper right is 1 mm long. From hill northwest of Fawn Creek Cemetery, SE 19-34-15.

ooids are interbedded with larger ones. At the Hafer Run exposure, ooids average about 1.2 mm in size with thick coatings around nuclei of quartz and small carbonate grains. Intraclasts are rare in the Tyro, but a calcareous quartz sandstone pebble several mm in diameter and with a thin osagia-like coating was collected in the oolite near the north end. Matrix to the ooids is almost entirely spar throughout the bed. Both interstitial calcite spar and particularly the ooids have undergone a wide variety of patterns of diagenetic replacement, especially by ferroan dolomite.

Skeletal material scattered through certain zones in the Tyro consists predominantly of echinoderm debris, with a number of bryozoan, brachiopod, and mollusc fragments. Whole fossils occur typically in shaly partings, and consist mainly of the above named groups.

Calcareous horizons in the Rock Lake Member. —The occurrence of at least two higher levels of impure limestone above the Bolton bed within the Rock Lake Member is shown in the small hill north of U.S. Rte. 75, about 2 miles northeast of Wayside, near ctr. NE 35-33-14 (Plate 1; Fig. 4, meas. sec. 28). Here the Bolton bed is exposed several feet above creek level on the north side of the hill. About 24 feet above the Bolton bed is a one-foot layer of oolitic quartz sandstone. At the top of the hill, 16 to 20 feet higher, is a 4-foot thickness of fossiliferous oolitic quartz sandstone containing brachiopods, bryozoans, and shale pebbles. These limy horizons are referred to informally as the third and fourth oolitic zones, respectively, from their position above the lower oolitic horizons. Although lateral continuity of these poorly exposed calcareous horizons is only conjectural, similar rocks are found at approximately the right elevations at enough places in Townships 34 and 35S and southernmost T33S that they can be joined locally into probable outcrop traces shown by broken lines on Plate 1 and Figure 4.

The most laterally traceable exposures are assigned on the basis of elevations to the **third oolitic zone.** These consist of sporadically fossiliferous oolitic sandstones, locally with mud pebbles, around the watershed of Cheyenne Creek in south to east-central T34S, R14E. Also assigned to the third zone are outcrops of oolitic and shelly sandstones 10 to 25 feet above the Bolton bed in adjacent sections 1 and 6, T34S, Ranges 14 and 15E, and 10 feet above the Bolton in SW 25-33-14. Two outcrops of skeletal to oolitic sandstone with mud pebbles in section 4, T35S, R14E are assigned with caution to the third zone because they lie perhaps as little as 15 feet stratigraphically above the exposure of Tyro oolite along Hafer Run in the northeast corner of section 4; their horizon is close to that of the Bolton bed, but is 6.5 miles southwest of the nearest known Bolton exposure.

Exposures assigned to the **fourth oolitic zone** are locally more limy, but generally less laterally traceable than those below. The most extensive horizon is that of shelly oolite to fossiliferous oolitic sandstone not far below the South Bend in the western half of T35S, R14E, east of Caney; the gastropod-dominated sandstone in section 16 of this township may also belong in this horizon. Exposures of fossiliferous oolite with quartz nuclei northeast of Wayside about 1 mile west of the hill capped by the type exposure of the fourth zone were probably continuous with it prior to modern erosion. Isolated outcrops of oolitic skeletal calcarenite in NW corner 12-34-14 and of quite pure oolite on the S line, SW 17 of the same township are included because of appropriate elevations. Definitely above the third zone, but less certainly assigned to the fourth, are two layers of brachiopod-dominated sandstones north and west of Tyro (W line NW 30-34-15; NW-SW 34-34-14). Elevations would suggest inclusion also of the layer of fossiliferous oolitic sandstone near the top of the knob near ctr. E half 12-35-14 south of Tyro, even though the third zone then would be absent throughout this area.

It is possible that some of these limy horizons in the Eudora-Rock Lake interval occur outside the two zones that are delineated in the hill north of U.S. Rte. 75 northeast of Wayside. In any case, all horizons are lithologically unlike the quartz-free skeletal calcarenitic Rutland bed to the north, which is separated from the northernmost reported exposures (Fig. 4, meas. sec. 25) along outcrop by at least 2 miles of noncalcareous sandstone and shale.

A variety of oolitic and skeletal quartz sandstones are the most common rock types in the limy horizons of the Eudora-Rock Lake interval of southern Montgomery County. In addition, three types of purer limestone in this interval: oolite, stromatolite, and sorted-abraded skeletal calcarenite, are worthy of note despite their apparently quite limited outcrop extent.

Slightly oolitic quartz sandstones dominate the horizons mapped as the third oolitic zone, particularly around the watershed of Cheyenne Creek. Petrographically, these rocks range from variants in which most nuclei are only slightly coated to those composed of a mixture of both uncoated quartz grains and thinly to thickly coated ooids (Fig. 20), sometimes segregated into discrete laminae. The thicker oolitic coatings often are replaced by several blocky, strained crystals of dolomite. Quartz grains range from about 0.1 to 0.3 mm and 0.2 to 0.6 mm in size in different samples, and seem fairly well sorted in any one sample. Ooids with quartz nuclei range generally from 0.2 to 0.4 mm in size. Although macrofossils are not common in these rocks, a number of quartz-size or larger grains consist of abraded skeletal debris, including ostracodes and pieces of echinoderms, brachiopods, molluscs, and occasionally bryozoans. Locally, shale pebbles up to 1 or 2 cm long are common (Fig. 20). The matrix to the grains is mostly clear calcite spar, often in crystals large enough (about 1 mm) to encompass several grains. This group of rocks is gradational into the next category.

Skeletal-oolitic quartz sandstones dominate the northern and southwestern portions of the horizons mapped as the fourth oolitic zone, and occur locally in the third oolitic zone. These rocks are characterized by the presence of a substantial number of large skeletal grains, some nearly whole, and by the presence of thin to thick oolitic coatings around nearly all quartz grains and many smaller skeletal grains (Fig. 21). These coatings exhibit both concentric and radial structure, but only minimal replacement by dolomite. Quartz is subordinate enough in some variants of this group that they approach lithologies characteristic of the Tyro and Bolton beds. Macrofossils consist mostly of fragments of echinoderms, brachiopods (including productid spines), and bryozoans (including rhomboporids, fenestellids, and rare fistuliporids); molluscan fragments, small snails, foraminifers (including rare fusulinids), ostracodes, and calcisponges are present in lesser numbers. Locally, some grains have osagia-type coatings. Generally, quartz grains range from 0.1 to 0.4 mm, and ooids range from 0.2 to 0.5 mm in diameter; skeletal debris is typically much coarser, in places exceeding 0.5 cm in thin-section cuts. As in the oolitic sandstones, most of the matrix is clear calcite spar in crystals large enough to encompass several small grains.

Skeletal quartz sandstones differ from the above group by containing mostly uncoated quartz grains and only greatly subordinate ooids. These rocks are

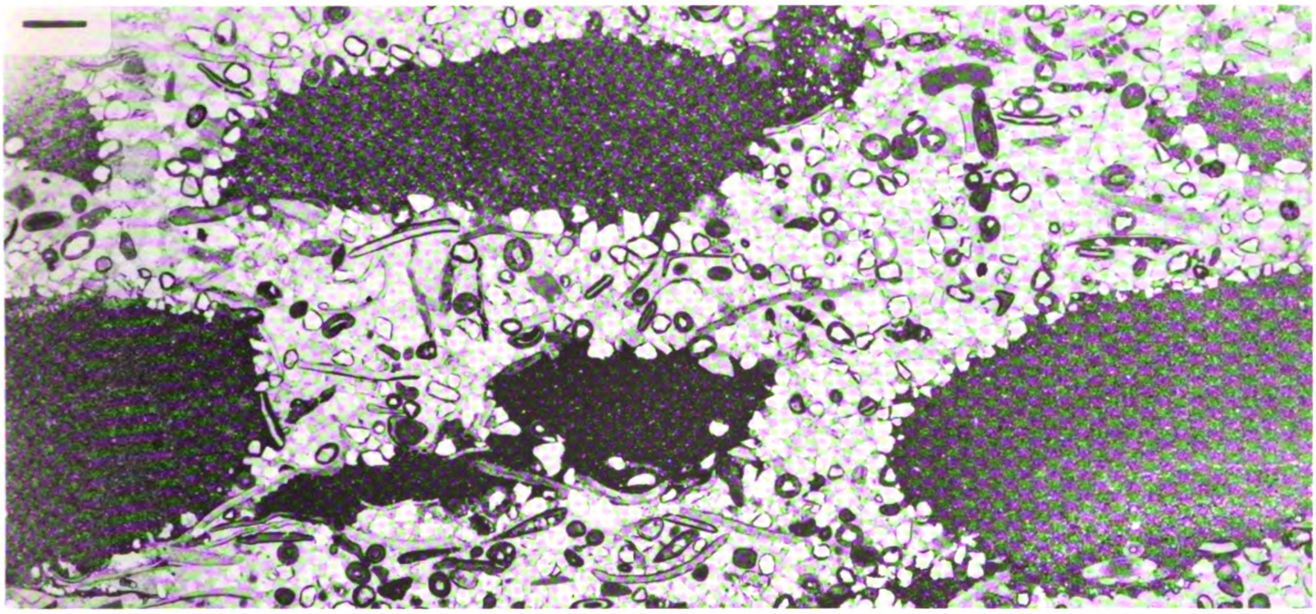

Fig. 20.—Thin section of slightly oolitic quartz sandstone with shale pebbles, and containing enough small skeletal fragments (mostly mollusc and brachiopod, with some bryozoan and echinoderm) to consider rock as gradational to skeletal-oolitic quartz sandstone; scattered ooids range from thinly to thickly coated. Scale in upper left is 1 mm long. From 3rd oolitic zone of Eudora-Rock Lake interval exposed in road ditch near ctr W line 23-34-14.

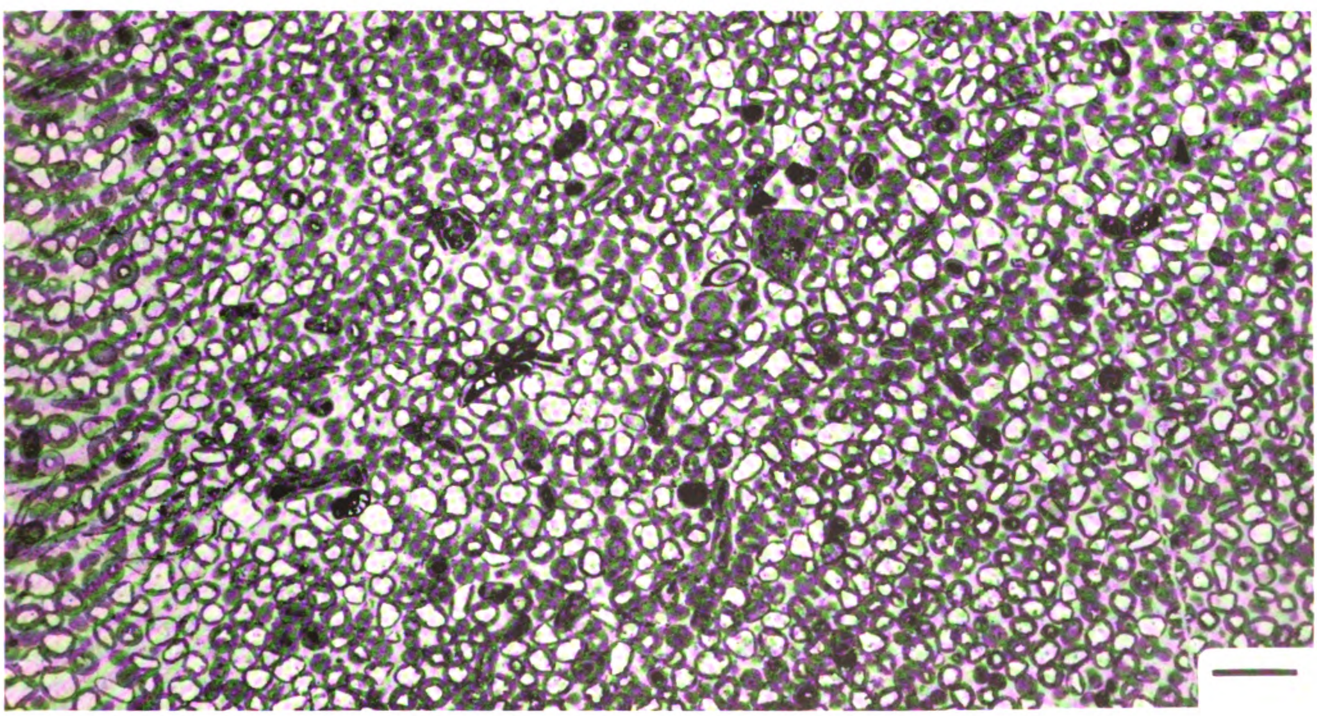

Fig. 21.—Thin section of skeletal-oolitic quartz sandstone showing thin to relatively thick coatings around all quartz grains and small skeletal fragments (mainly echinoderms, some brachiopods and foraminifers); macrofossils typically common in this rock type were not cut in this thin section. Scale in lower right is 1 mm long. From 4th oolitic zone of Rock Lake Member exposed at top of hill northeast of Wayside near ctr NE 35-33-14.

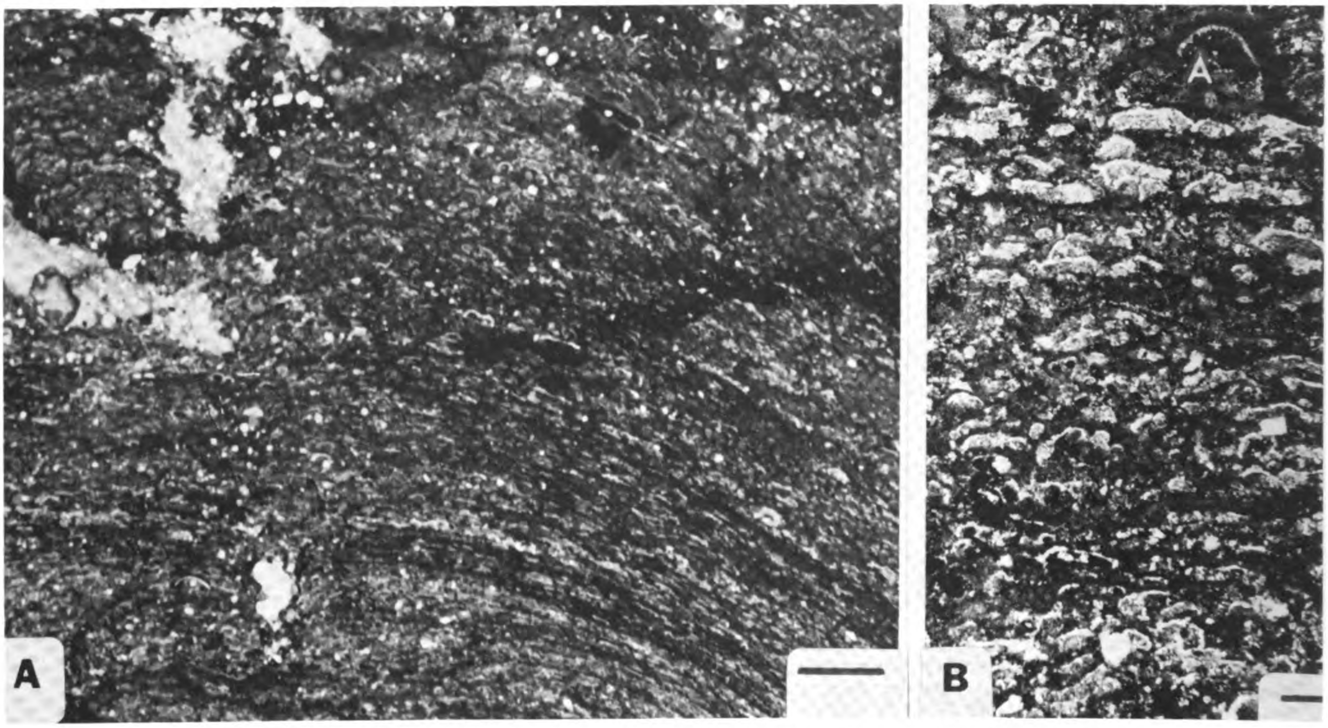

Fig. 22.—Thin section of stromatolite layer in Eudora-Rock Lake interval exposed in gully in SW-SE-NE 4-35-14 near Hafer Run. A. Low-magnification shot showing well-laminated appearance consisting of dark micrite alternating with lighter concentrations of encrusting foraminifers; spar-filled cavities break laminae in upper left. Scale in lower right is 1 mm long. B. High-magnification shot of small portion of lower right center of A showing individual encrusting foraminifers, mostly agglutinated *Minammodytes* (small white irregular semicircles usually surrounding light gray fillings) but with larger calcareous, dark-shelled, probable *Apterrinella* (A) in upper right. Scale in lower right is 0.1 mm long.

generally found in layers of limited lateral extent, but assigned to the fourth zone on the basis of elevation. Quartz grains range from about 0.1 to 0.3 mm in size. Skeletal material includes fragments coarser than the quartz and also a large number of whole shells. Brachiopods, bryozoan (fenestellid, rhomboporid), and echoniderm pieces are common to the group in general. Whole brachiopods characterize beds in NW-SW 34-34-14 and in NW 30-34-15, whereas whole snails of several general (including bellerophontids and probable *Hypsolentoma*, identified by E. Yochelson) dominate the horizon exposed near ctr. SE 16-35-14. Matrix ranges from mud and small calcite crystals in the gastropod-rich layer to large clear calcite crystals in one of the brachiopod-rich layers.

Oolite that is relatively pure forms the bed of the creek in SW SE 17-34-14. Although not traced laterally, this rock seems to lie in the fourth oolitic zone. Quartz grains 0.2 to 0.3 mm in diameter nucleate most of the ooids, which average about 0.6 to 0.7 mm in diameter. Most coatings exhibit several concentric layers within which fine radial structure is visible. Matrix is clear blocky calcite locally containing small (about 0.05 to 0.10 mm) micritic pellets resting in places upon the ooids.

Stromatolites are best known from exposures on a small tributary to Hafer Run in SW-SE-NE 4-35-14, and cannot be definitely assigned to a traceable zone. Two ledges of stromatolitic limestone, each several inches thick, crop out in a shaly sequence about 15 feet above the mud-pebble-rich skeletal-oolitic sandstone assigned with caution to the third zone (Fig. 4, est. sec. 43c). One ledge displays gently undulating stromatolitic laminae in a sequence several centimeters thick, starting on a relatively flat surface (Fig. 22A). The other ledge exhibits warty nodular to digitate protuberances of laminae several millimeters thick around nuclei of whole shells, including brachiopods, bryozoans, and small corals. Laminar microstructure in both growth forms is somewhat similar to that of the osagia coatings around grains in the Bolton bed. It consists of irregular thin zones of dark micrite alternating with thicker zones of small (0.05 to 0.20 mm long) subhemispherical cuts of encrusting agglutinated foraminifers that are composed of tiny quartz grains and that have interiors filled with lighter-

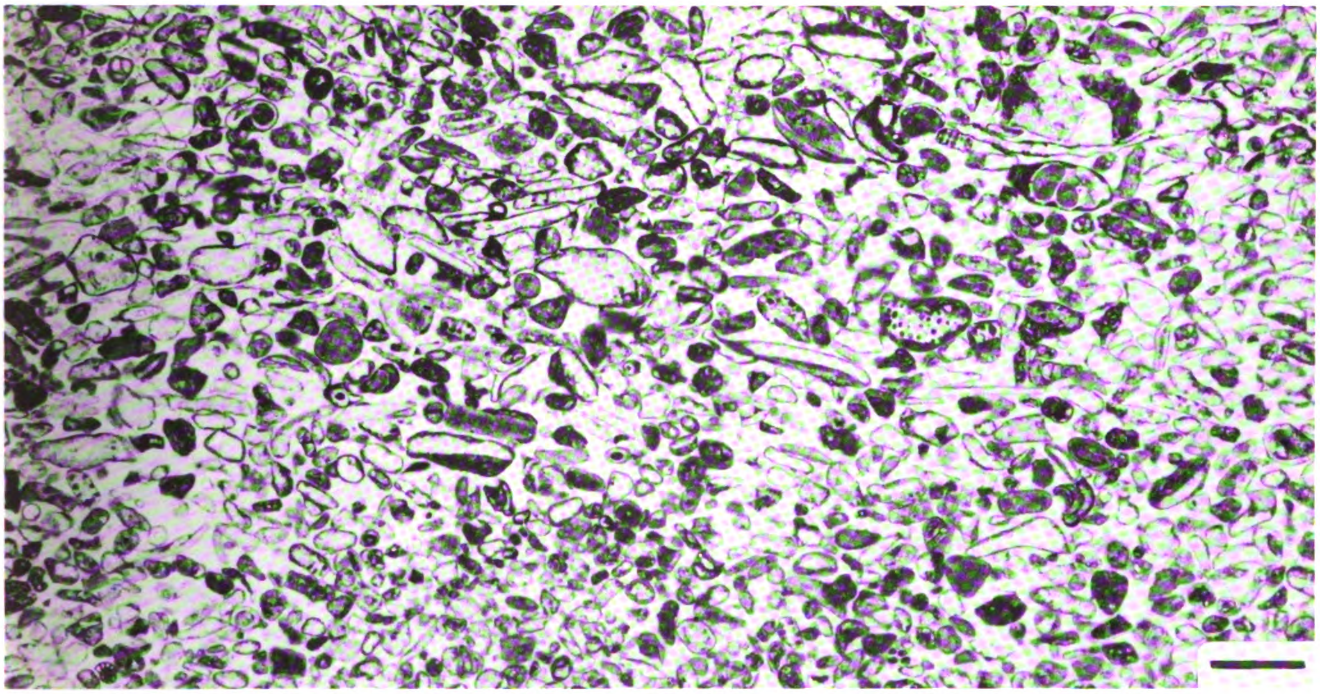

FIG. 23.—Thin section of sorted-abraded skeletal calcarenite layer within Rock Lake Shale Member in north prong of Timber Hill near ctr NW 23-32-14, showing lack of grains over a certain size and well-abraded nature of fragments derived from a wide variety of skeletal groups, including probable phylloid algae, foraminifers, echinoderms, molluscs and ostracodes. Scale in lower right is 1 mm long.

colored mud (Fig. 22B); these foraminifers resemble *Minammodytes* of Henbest (1963). Larger (0.2 to 0.4 mm) subhemispherical, locally multichambered calcareous foraminifers with dense brownish skeletal material, probably *Apterrinella* (D. F. Toomey, pers. commun., 1973), augment the encrustation in places (Fig. 22B). Scattered quartz grains are incorporated into the lamination. Although no remains were detected, the dark micritic laminae are attributed to poorly calcified blue-green algae which leave visible remains of tiny tubules in certain encrusting fabrics elsewhere in Pennsylvanian limestones (but not in the Stanton, as far as known). Another stromatolitic mass containing encrusting foraminifers surrounds a group of small corals in an unassigned fossiliferous siltstone ledge on the side of the hill in NW-SE 13-33-14.

Sorted-abraded skeletal calcarenite constitutes a 0.3-foot ledge of finely graunlar limestone within the 10-foot sequence of shale in the Rock Lake exposed above the southern end of the Stoner Member along the road down the north prong of Timber Hll near ctr. NW 23-32-14 (Fig 4, meas. sec. 6). This ledge has not been found to trace laterally. It may lie at or near the horizon of the Rutland bed, but is separated from it along outcrop by shale that is well exposed at places for nearly 2 miles along the east side of Timber Hill. The rock consists almost entirely of fairly well rounded skeletal fragments, ranging from 0.2 to 1.2 mm in diameter (or length), in a matrix of relatively clear fine-grained calcite spar (Fig. 23); drusy rims are detectable on some grains. The grains are dominantly foraminifers (including encrusting types) and rounded blocky mosaics of calcite that may be recrystallized fragments of phyloid algal blades. Less abundant grains include echinoderm pieces, ostracode valves, and fragments of snails, clams, brachiopods, and dasyclad algae. Osagia-like and oolitic coatings occur on a few grains.

Sandstones in the Rock Lake Member.—Although not studied in detail, a number of quartz sandstone bodies and facies were sufficiently delineated within the Rock Lake Member and Eudora-Rock Lake interval for some general observations on their occurrence and nature.

Along outcrop in T33S, R14E, a thick body of sandstone and shale occupies a large portion of the Rock Lake Member between the Bolton bed and South Bend Member (Plate 1; Fig. 4). It is informally termed the **Onion Creek sandstone body** from its extensive exposure in sections 14, 15, 22, and 23 along Onion Creek and its tributaries. Substantial sandstone first appears as low as the horizon of the Bolton bed, north and east of the house in NW-SW 24-33-14 (Fig. 4, between est. secs. 22 and 24), but southeastward

FIG. 24.—Portion of northern extent of Onion Creek sandstone body (Rock Lake Member) showing even-bedded horizon that may represent beach or offshore bar environment. North side of U.S. Rte. 160 roadcut in SW SE 28-32-14 about 8 to 9 miles west of Independence.

about 0.5 mile, massive sandstone first appears only above what is apparently the northernmost extent of the fourth oolitic zone in a section measured by Newell in 1935 (Fig. 4, meas. sec. 25). Although the base of the sandstone is poorly exposed west of the eastern prongs of escarpment, about 100 feet of dominantly sandstone may be estimated using elevations from the sandstone ledge at 860 feet near the house in NW-SW 24, west-southwestward to the crest of the hill at 925 feet in NW-NW 26, adding 35 feet for regional dip. The Onion Creek body consists mainly of massive to bedded, friable, buff to reddish-brown quartz sandstone with cross-bedding locally conspicuous on the surface; shale occurs at places within the body. Quartz grains range from 0.1 to 0.4 mm and rarely exceed 0.5 mm in size. The Onion Creek body extends westward at least 3 miles through sections 29 and 30 where sandstone of similar nature is exposed below the South Bend in the inlier along Deer and Coon Creeks. It apparently extends northward as well, but thins to 20 feet or less and becomes restricted to the very top of the Rock Lake Member as the reddish-brown, cross-bedded to evenly bedded sandstone (Fig. 24) exposed just below the South Bend Limestone in the southern tributaries of Card Creek from northernmost T33S into the southern sections of T32S (Plate 1; Fig. 5). The southern end of the Onion Creek sandstone body is marked by gradation from more massive sandstone into thin-bedded sandstone alternating with shale and by reduction of the entire Rock Lake Member to perhaps 70 feet in sections 27 and 34 (T33S, R14E) just northeast of Wayside.

Southward in townships 34 and 35 south, a number of sandstone masses are apparent in the Eudora-Rock Lake interval, but are less well delineated than the Onion Creek body. Two major facies types are recognized: 1) massive to thick-bedded sandstone, and 2) thin-bedded sandstone with intercalated shale.

1) Sandstones forming the topographic prominances in this region tend to be thick-bedded to massive, friable, and with cross-bedding visible on some surfaces, like the Onion Creek body. Color ranges from tan to brown and locally red. Three large masses primarily of this type lie northwest and southwest of Tyro (Plate 1), centered respectively in sections 23, 24, 25, and 26, T34S, R14E; sections 20, 21, 22, 28, and 29, T34, R14E; and sections 1, 2, 3, 10, 11, and

12, T35S, R14E; all three may be erosional remnants of the same larger body. Thicknesses of perhaps 50 to 80 feet can be estimated from elevations for the two northern masses. A total of 80 feet is suggested for the southern mass along the road separating the south halves of sections 10 and 11; the amount of covered shale included in these estimates is unknown. Although not field checked, the prominence in section 33, T34S, R14E suggests that much of the 150 feet of relief there is resistant sandstone. Where the two northern masses face Cheyenne Creek, they lie above the third oolitic zone. Part of the eastern mass extends above the brachiopod-rich sandstone mapped as the fourth zone in 30-34-15. Away from Cheyenne Creek, the third oolitic zone is unknown around the eastern and southern masses, which suggests that this zone either has changed facies into, or has been cut out by, the massive sandstones to the southeast. A smaller sandstone body centered in the west half of section 7, T34S, R15E above the Tyro oolite bed apparently replaces both the Bolton bed and the third oolitic zone southward.

Another small massive sandstone body forming the two high hills in sections 16 and 17, T35S, R14E not only lies above shelly sandstone assigned to the fourth oolitic zone, but also reaches 160 feet higher than mapped South Bend in the base of the hill 2 miles to the northwest, yet no South Bend was found in a reconnaissance search of these hills. This suggests that this body is either 1) a Douglas Group sandstone which has cut out the South Bend in this region, or 2) a local thickening of a Stanton sandstone lens, the featheredge of which is found in the thin interval between the fourth oolitic zone and the South Bend in SE 6 and adjacent NE 7-35-14. The latter alternative is preferred because of similar situations to the north, for example N half sec. 30 T33S, R14E and in sections 18, 19, and 20, T34S, R14E, where the South Bend ascends abruptly onto eastwardly thickening sandstones that lie within the Rock Lake (Fig. 6).

2) Thin-bedded sandstones and siltstones are known in the poorly exposed shale sequences that underlie many of the massive sandstones and crop out low on hill slopes or in stream valleys. These sandstone beds range from white and friable to tan or brown and ripple marked. All commonly contain shale pebbles, which are scarce, though present, in the more massive sandstones. Fossils are unknown.

A particularly distinctive type of thin-bedded sandstone facies consists of a rather regular interbedding of shale and very hard sandstone layers, each several inches thick and locally containing abundant mud pebbles. This facies is well exposed above and below the horizon of the third oolitic zone in roadcuts near the northwest and southwest corners of section 23, T34S, R14E and just below the South Bend east of the northwest corner sec. 20 and near ctr. W half sec. 19, T34S, R14E. Grains in at least one layer consist mainly of quartz ranging from a little less than 0.1 to 0.3 mm, but include subordinate plagioclase and potassium feldspar and substantial muscovite. Most distinctively, although the toughness of these layers can lead one to consider them "quartzitic," the matrix is entirely clear calcite spar in immense crystals several millimeters to perhaps centimeters across, each encompassing multitudes of quartz sand grains.

IMPLICATIONS TO STRATIGRAPHIC SUBDIVISION IN OKLAHOMA

Tracing of members and beds of the Stanton Formation across Montgomery County, Kansas, to the Oklahoma border bears significantly on the stratigraphic subdivision utilized in the geologic map of adjacent Washington County in Oklahoma by Oakes (1940a). The following observations are based on the detailed mapping in Kansas along with limited reconnaissance south of the Oklahoma border. Verification of suggested relations of units farther south in Oklahoma awaits availability of accurate 7.5-minute topographic maps of Washington County.

Relationship of Stanton Units to Birch Creek Limestone in Northern Washington County

Oakes (1940a, p. 76, 86) regarded the Birch Creek Limestone as a single stratigraphic horizon. It is obvious from the present study, however, that the Birch Creek as mapped by Oakes (1940a, plate 1) in the northernmost tier of townships in Oklahoma (T29N) represents at least two different stratigraphic levels in the Stanton Formation: 1) the Tyro oolite bed, and 2) the South Bend Limestone Member.

The Tyro oolite has been traced across the border into mapped Birch Creek Limestone in Oklahoma both in the outlier hills in sections 15 and 16 of T29N, R14E and along the main outcrop trend into NW 13, T29N, R13E (Plate 1). I have collected weathered oolite characteristics of the Tyro from the Birch Creek outlier near the northwest corner of section 27, T29N, R13E. Oakes (1940a, p. 88) reports a very sandy oolite from the main line of his outcrop trace in section 21 about 1 mile to the northwest; this seems to resemble more closely the higher oolitic sandstone horizons in Eudora-Rock Lake interval. Thus it appears that all of the Birch Creek mapped by Oakes in T29N, R14E and in at least the eastern and southeastern portions in R13E represent the Tyro oolite bed (as indicated with a dashed line on Plate 1). In addition, mapped Birch Creek in the western part of T29N, R31E may represent one or more horizons above the Tyro, within the Eudora-Rock Lake interval of the Stanton.

The South Bend Limestone Member has been traced across the border into mapped Birch Creek in the northwest corner of section 13, T29N, R12E (Plate 1). This line of Birch Creek outcrop is indicated to extend for a great distance southward along the line of hills west of Caney River. At several localities for a distance of about 35 miles to its type section in T24N, Oakes (1940a, p. 88-90) describes the Birch Creek as a thin, brownish, fossiliferous, sandy limestone to limy sandstone, which seems similar to the South Bend of southernmost Montgomery County, Kansas. Assuming that this limestone horizon has been correctly traced, then the type Birch Creek Limestone correlates to the South Bend Limestone Member of the Stanton Formation in Kansas, as Oakes (1951) and O'Connor (1962, p. 155) have suggested. Nevertheless, evaluations that the Birch Creek represents more than one horizon west of the Caney River in Townships 25 and 26N (e.g. Tanner, 1956, p. 30; Strimple and Strimple, 1968) point up the necessity of field verification.

Of the outliers mapped as Birch Creek by Oakes (1940a, plate 1) in T28N, R13E, the limestone holding up eastern Twin Mound in section 35 is the small phylloid-algal buildup mentioned by Heckel and Cocke (1969, p. 1073) and regarded as a lens in the Wann Formation (see later section); the other outliers were not visited. Considering elevations obtained from the 30-minute Nowata Quadrangle (1914; with contour interval of 50 feet) along with the regional westerly dip of the strata, at least some of the outliers in T28N, R13E may lie below the Birch Creek-South Bend horizon west of Caney Creek, and thus may occur lower within (or even below) the horizon of the Stanton Formation in Kansas.

Relationship of Stanton Units to Torpedo Sandstone

Oakes (1940a, p. 76) considered the Torpedo Sandstone to represent a unique stratigraphic horizon of variable thickness lying unconformably below the Birch Creek Limestone, with or without an intervening shale. Because the Birch Creek mapped by Oakes (1940a, Plate 1) represents at least two different stratigraphic horizons in northernmost Washington County (T29N), it is obvious that the Torpedo Sandstone mapped by Oakes in the same region represents at least two different horizons: 1) directly below the Tyro oolite in T29N, R14E and the eastern half of T29N, R13E, and 2) above the Tyro oolite within the Eudora-Rock Lake interval in T29N, R12E and probably also in parts of the western half of T29N, R13E. It seems likely that the Torpedo as mapped by Oakes represents measurably different stratigraphic levels southward into T28N as well.

Type Torpedo Sandstone occurs about 20 miles south of the Kansas-Oklahoma border west of Bartlesville, in T26N, below Birch Creek Limestone that may be equivalent to the South Bend. Thus type Torpedo and its overlying shale are very likely equivalent to sandstones and shales occurring within the Eudora-Rock Lake interval in southern Montgomery County, Kansas. Oakes (1940a, p. 86) considered the Torpedo Sandstone to be "cut off" at the Kansas-Oklahoma border by a sub-Birch Creek unconformity because he mapped the sandstones lying above the Tyro bed in the northern part of T29N, R13E (Plate 1) as post-Birch Creek, thus equivalent to the post-Stanton strata west of Caney River, when in fact they lie within the Eudora-Rock Lake interval of the Stanton Formation between the horizons of mapped "Birch Creek."

Relationship of Stanton Formation to Wann Formation (as Redefined)

The name Wann Formation was applied by Oakes (1940b, p. 276-277) to the substantial thickness of predominantly shaly strata above the Iola Limestone and below the Torpedo Sandstone, or Birch Creek Limestone where the Torpedo is absent (see also Oakes, 1940a, p. 67). Because the notoriously lenticular nature of sandstone bodies in this part of the sequence nearby in Kansas strongly suggests that both type Torpedo and other sandstones mapped as Torpedo by Oakes (in addition to those now definitely determined to lie below the Tyro oolite) are merely lenticular bodies within a clastic sequence, it is deemed advisable to redefine the top of the Wann Formation at a more consistent stratigraphic horizon.

Therefore I propose (1) that the top of the Wann Formation in Oklahoma be placed at the top of the "type" Birch Creek Limestone as mapped by Oakes along the main outcrop trace west of Caney River and (2) that the Birch Creek Limestone and Torpedo Sandstone be recognized as members within the Wann.[6] (Although this proposal assumes lateral con-

[6] A procedure close to this seems to have been utilized for the Geological Map of Oklahoma (1954) on which the Torpedo is mapped with the Wann without being listed as a separate formation in the explanation; this procedure was adopted by Strimple and Strimple (1968). The Birch Creek had been placed as a member marking the base of the overlying Barnsdall Formation by Oakes (1951), but is more appropriately included in the Wann if it is largely equivalent to the South Bend inasmuch as the Missourian-Virgilian boundary is now recognized at the top of the South Bend, and thus would be at the top of the Wann as herein redefined in Oklahoma.

tinuity of this part of the Birch Creek outcrop trace, which needs verification, it seems a better alternative than using the base of the mapped Torpedo, which is known at this time to lie at a minimum of two different stratigraphic horizons). Assuming that the type Birch Creek and the South Bend Member of the Stanton Formation at the Kansas-Oklahoma border are correlative, then the Wann Formation as redefined in Oklahoma is exactly equivalent to the sequence of six formations ranging from the Lane Shale up through the Stanton Limestone in Kansas (Fig. 25).

In addition to the Stanton, this sequence contains two older limestone formations (Wyandotte and Plattsburg) in northeastern Kansas. As these disappear southward and the adjacent shale formations coalesce, the combined shale sequence customarily is given a hyphenated name formed from the names of the highest and lowest separate shales northward. Thus the Lane-Bonner Springs Shale extending south of the disappearance of the Wyandotte Limestone becomes Lane-Vilas Shale south of the disappearance of the Plattsburg in northern Montgomery County (Fig. 25). The Lane-Vilas can be recognized southward to the disappearance in northernmost Oklahoma of the Tyro oolite bed, which marks the base of the Stanton. Because the Tyro oolite is the only good marker bed within the redefined Wann Formation in the Kansas-Oklahoma border region, and also because it lies near the middle of the formation (Fig. 4), it divides the Wann into subequal lower and upper parts (Fig. 25). The lower Wann encompasses strata equivalent to the Lane, Wyandotte, Bonner Springs, Plattsburg and Vilas Formations, thus is the exact equivalent of the Lane-Vilas Shale, whereas the upper Wann, including the Tyro bed, is the exact equivalent of the Stanton Formation.

The Missourian-Virgilian Boundary

Prior to the 1960's, the boundary between the Missourian and Virgilian Stages of the Upper Pennsylvanian Series was considered to be a widespread erosional unconformity within the thick clastic sequence above the Stanton Limestone. Proof of this unconformity was shown by the demonstrably erosional base of the Tonganoxie Sandstone channel in northeastern Kansas. Largely because of unpublished work of S. M. Ball (1964), who recognized that the unconformity at the base of the Tonganoxie is not laterally traceable, the Missourian-Virgilian boundary in the type area for both stages (eastern Kansas and adjacent Missouri) has been placed at the base of the clastic sequence (Douglas Group as redefined) di-

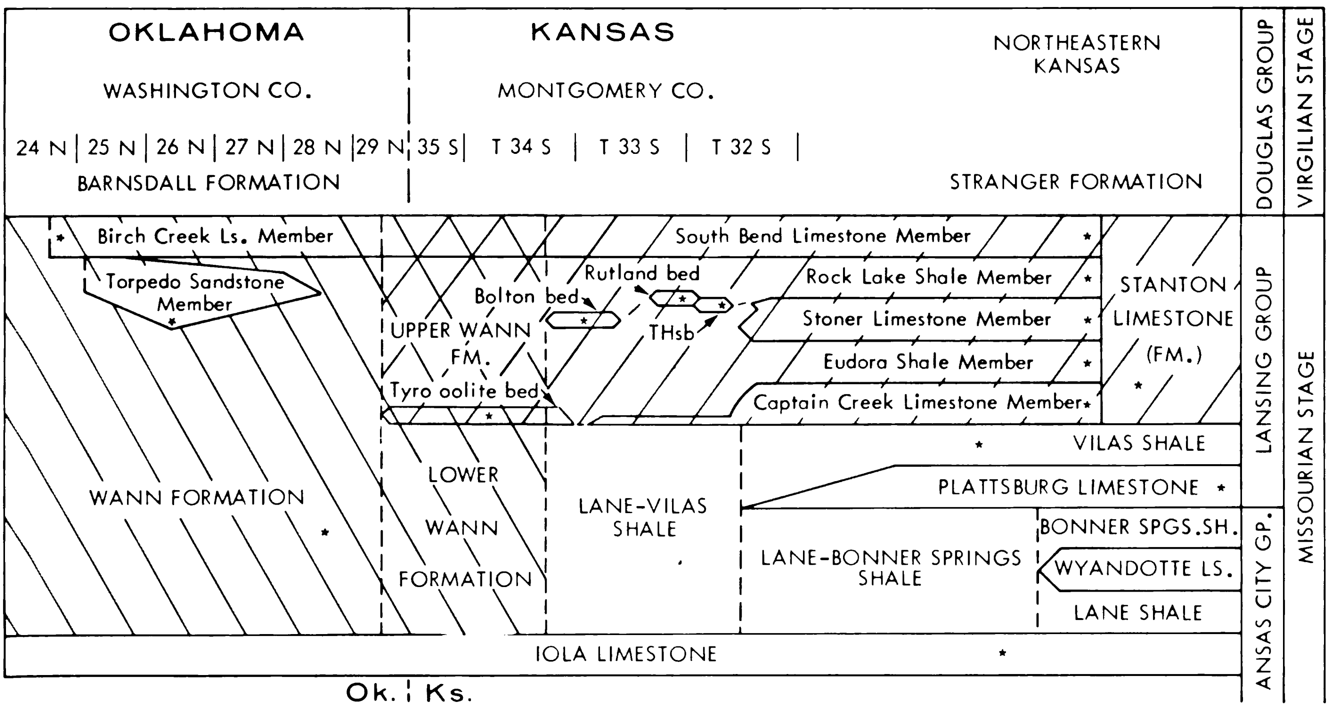

FIG. 25.—Stratigraphic nomenclature for upper Missourian units in eastern Kansas and adjacent portion of Oklahoma (modified from Oakes, 1940a, 1951; O'Connor, 1963; Zeller, ed., 1968): new suggestions involve Stanton and Wann Formations (lined obliquely in opposite directions) in Montgomery County, Kansas, and Washington and adjacent counties in Oklahoma. Formations and groups are in capital letters; members and beds are in small letters. THsb= Timber Hill siltstone bed. Asterisks mark approximate locations of type sections. Distances and thicknesses are not to scale. Note that Lansing Group is a meaningless unit south of disappearance of Plattsburg Limestone in Montgomery County, Kansas.

rectly above the Stanton Limestone (O'Connor, 1963; see also Zeller, ed., 1968).

Thus, the redefined Missourian-Virgilian boundary is traced into Oklahoma at the top of the South Bend Member of the Stanton in the NW corner of section 13, T29N, R12E and should extend southward along the main outcrop trend of the Birch Creek Limestone west of Caney River. This places all post-Birch Creek formations ("Okesa" etc. of Oakes, 1940a; Barnsdall, Tallant of Oakes, 1951) in the Virgilian and points up the desirability of verifying continuity of this portion of the Birch Creek outcrop trace as accurate topographic maps become available.

DEPOSITIONAL SIGNIFICANCE OF STANTON FACIES IN SOUTHEASTERN KANSAS

The following brief consideration of probable environments of deposition of Stanton facies in southeastern Kansas is based mainly on the general lithologic, paleontologic, and stratigraphic observations presented above. A more complete analysis will require more detailed areal study of each facies and its lateral and vertical contacts, particularly in the terrigenous detrital units.

Carbonate Rocks

Carbonate rocks signify voluminous local carbonate production with protection from, or slowdown of, terrigenous detrital influx.

Phylloid-algal mound complexes.—Depositional environment of the greatly thickened limestones composed of phylloid-algal-dominated mound facies that characterizes all three limestone members in northern Montgomery County is treated in Heckel and Cocke (1969, p. 1066-1069). To summarize the significant points, these features are subregional buildups of carbonate sediment resulting from relatively rapid accumulation of the remains of a luxuriant growth of phylloid algae, thereby maintaining their optimum, well-illuminated, shallow-water environment in response to subsidence of the sea bottom. That sedimentation did compensate for subsidence and thus maintain shallow depths during deposition of the limestone members is shown not only by continuation of algae-rich facies up to the top of each member, but also by development of channels at the top of the mounds, implying response to need for tidal drainage of the algae-choked sea bottom, which would occur most likely in very shallow water. Thus, the mound facies can be considered to have developed as the response to subsidence of an algae-covered sea bottom just below sea level. Mound growth probably ceased in different cases because of (1) overwhelming by terrigenous clastics, or (2) a drop in sea level, or (3) a temporarily increased rate of sea level rise beyond that which could be compensated by algal sediment production.

Topographic relief of about 80 to 100 feet has been mapped on the northwest edge of the combined Captain Creek-Stoner mound in northern Wilson County (Heckel, 1972a, p. 590). Similar determinations based on elevations are difficult to make across the Elk River Valley, which has eroded out much of the south ends of the mounds in northern Montgomery County. It is not unreasonable to expect, however, that relief of at least the difference in thickness between mound and offmound facies was developed at the south ends of the buildups in northern Montgomery County. Support for this lies in the lack of intercalated shale in the mound facies, particularly in the upper parts, a situation expected only if the limestone buildups stood substantially above any contemporaneous incoming terrigenous muds, and certainly not expected if muds were being introduced at the same topographic level. Thus the Captain Creek, Stoner, and South Bend mounds probably stood nearly 50, 10 to 30, and 20 feet respectively above offmound facies to the south. In support, the South Bend mound exhibits about 7 feet of relief in 300 feet across the quarry west of U.S. 160 just south of the Elk River bridge.

Skeletal calcarenites.—Three units composed basically of skeletal calcarenite are the Rutland bed, Bolton bed, and the small lens exposed within the Rock Lake Shale on the north side of Timber Hill. Other calcarenites that are directly associated with the algal mounds generally reflect wave and current action in shoal water at the tops of the mound complexes (Heckel and Cocke, 1969, p. 1066-1068), and are not treated further here.

By virtue of its lenticular nature over a small region, conspicuous cross-bedding, and preponderance of abraded grains in a sparry matrix, the **Rutland bed** represents a well-washed, probably wave-swept accumulation of algal and shell debris, apparently in the form of an offshore bar. The dominance of phylloid algal debris, particularly *Archaeolithophyllum* and nondescript codiaceans, both of which are rare outside the mounds, suggests a source in the mounds where these types of algae dominate the biota. The substantial abrasion displayed by many of these grains would support transport from as far as the top of the Stoner mound at least 2 miles away. Dasyclad green algae, on the other hand, are rare in the mound facies; thus their abundance in the Rutland bed suggests another source, perhaps nearly in place, inasmuch as dasyclads characterize shoals associated with reefy buildups throughout much of their history (Wray, 1971). Although the solenoporid fragment is hardly enough for definite interpretation, this type of red algae is found elsewhere in the Stanton only in a similarly well-washed mound-edge calcarenite to the north in Wilson County. The invertebrates in the Rutland bed also point to a source other than the mounds. Aside from the in-place origin suggested by some nearly whole fenestellid bryozoan fronds and crinoid calyces, the rich invertebrate fauna at the top of the underlying Eudora is a possible source for transported material. The scattered ooids and mud clasts suggest even different sources. Thus the Rutland bed represents a cessation or winnowing of terrigenous influx for a time while skeletal debris from a variety of distant and nearby sources was swept into a windrow-like shoal-water bar.

The high degree of sorting, in particular the absence of grains above a critical size (Fig. 23), and its development as a single thin layer, strongly suggest that the **sorted-abraded skeletal calcarenite** lying within the Rock Lake Shale above the south end of the Stoner mound on the north prong of Timber Hill is a storm deposit. Although abrasion would support transport for a large distance, it is more likely inherited from a previous environment of long-term water agitation. Unique to this layer is the predominance of foraminifers along with probable fragments of phylloid algae. Whereas origin of the algal fragments could be attributed to erosion of an exposed unlithified part of the top of the Stoner mound, the foraminifers have no other known area of concentration to serve as their source, unless they represent a winnowed concentrate of nearby unstudied shales.

Although the generally spar matrix and lensing nature along outcrop suggests that wave or current action influenced development of the **Bolton bed,** the greater number of whole shells combined with lesser amounts of grain abrasion indicates less consistent water turbulence than influenced the Rutland bed. A greater abundance of ooids further differentiates the Bolton bed, but the constant water agitation they imply is incongruent with the many larger whole shells present. This, in conjunction with presence of non-oolitic grains of similar size, suggests that the ooids formed in a different area and were subsequently washed into the preserved Bolton environment, where a variety of invertebrates were living. The near lack of phylloid algae undoubtedly reflects greater distance from the mounds. Occurrence of osagia-type encrusting foraminiferal-algal? coatings on many of the larger shells reflects some little understood aspect of biotic succession in many Pennsylvanian marine environments. Presence of such coating on all sides of some shells suggests enough agitation occasionally to overturn the shells, but the generally unequal coatings on most of the shells points to only intermittent agitation of any force. Thus the Bolton bed appears to represent a less strongly wave-washed accumulation of shell debris in a broader, probably deeper area than the Rutland bed, perhaps an open lagoon into which ooids were periodically transported from a more strongly agitated shoal or shoreline.

Oolites.—Dominantly oolitic rocks include the lower layer of the Captain Creek in northern T33S, R15E, the Tyro bed, and most of the third and fourth oolitic zones in the Rock Lake.

Captain Creek oolite, where well developed, is generally poorly exposed, but samples show that it is petrographically similar to much of the Tyro. Westward and southwestward gradations of the Captain Creek oolite layer include stromatolitically coated shells, pebbles, and surfaces, all suggesting a shallow restricted lagoon around this side; the environment of the main part of the oolite to the northeast is probably similar to that of the Tyro bed.

The **Tyro oolite** was considered by Harbough (1960, p. 229) to represent a shallow agitated marine shoal environment similar to that of the Great Bahama Bank, although admittedly with a terrigenous detrital sequence. Certainly the pervasive presence of thick coatings on small grains and thin coatings on larger grains, along with sparry matrix, well-developed cross-bedding and particularly the large-scale thickening and thinning of the bed, are compatible more with a continually agitated, broad open shoal environment like the Great Bahama Bank than with the shoreline or less agitated oolite environments described by Rusnak (1960) and Freeman (1962). Portions of the Bahamian oolite shoals are characterized by parallel sets of huge bars, several feet thick, that thin locally to disappearance in the troughs (Ball, 1967, p. 563, 570). This seems compatible with the apparent geometry of the Tyro bed. Although tidal currents are largely responsible for the agitation of the Bahamian shoals, flood tides in places are stronger than ebb tides toward the interior of the platform, and cross-bedding dip directions show movement predominantly in one direction (Ball, 1967, p. 561). Thus, the consistently westward to southwestward-dipping sets of cross-beds (Fig. 18) measured at three Tyro localities are compatible, at the present state of knowledge, with either tidal or unidirectional currents. A southwestward trend of ooid movement is suggested also by spot samples from other localities: the thinnest oolitic coatings are found in the northeasternmost exposure whereas the thickest coatings (thus the largest ooids) are found in the westernmost exposure on Hafer Run. Although a greater quantity of systematic data will be necessary to substantiate this trend, the suggestion at this point is that oolitic coatings formed progressively thicker as the ooids moved southwestward off an open shoal, just as ooids apparently grew in size to pisolites as they moved off the edge of a thick algal buildup in the Plattsburg Limestone in Wilson County (J. M. Cocke assisted by author; see also Kettenbrink and Manger, 1971, p. 435-436). The west side of such a shoal to the northeast during Tyro deposition is suggested by the substantially steeper westerly dips recorded in the northeasternmost Tyro exposures across section 6-34-15. The skeletal material in the Tyro is mostly oolitically coated (Fig. 19), which shows that it too was rolled about and probably largely transported, with perhaps little indigenous to the shoal environment of unstable substrate, another situation that is compatible with the Bahamian model.

Oolites of the third and fourth zones generally involve various combinations of thinner oolitic coatings, mixtures of uncoated with thickly coated grains, and skeletal grains having osagia coatings. These features would be more characteristic of the shoreline oolite environment described by Rusnak (1960), in which agitation may be constant where the ooids are forming, but near which various associated non-oolitic subenvironments provide places where other grains can avoid oolitic coating and where invertebrates can live on different substrates, some eventually becoming covered by algal-foraminiferal crusts. Presence of shale pebbles at places within these oolitic horizons indicates nearby erosion of mud, perhaps in channels that normally occur in a shoreline regime. The fossiliferous quartz sandstones merely represent variants of such a nearshore regime where no oolitic coating was taking place. The number and type of invertebrate groups present, particularly the stenohaline echinoderms, indicate that nearly normal marine salinites were established within portions of the regime. Because these limy horizons signify times of lessening of the terrigenous detrital influx dominating this portion of the Stanton, if they do lie at only two well defined and fairly traceable zones, they signify times of reduction of detrital influx over a substantial area. If most localities represent different horizons, then the limy deposits formed in different places where detrital influx was reduced at different times. Because the zones that can be mapped do not seem continuous over the entire belt, terrigenous clastics were undoubtedly flooding in continuously in some places, while other areas witnessed development of less diluted, thin impure carbonates.

Sponge-rich calcilutites.—Presence of calcilutite matrix and several invertebrate groups, including echinoderms, signify a quiet environment with normal marine salinity for this facies in both the Captain Creek and South Bend Members. Dominance of normally subordinate calcisponges suggests some slight modification of the normal open marine regime, and the later complex algal? and invertebrate encrustations on larger organisms and mud surfaces (Fig. 8) suggest perhaps another type of modification of the environment through time. A lagoonal environment suggested by Wilson (1957a, p. 26) seems reasonable only if freely connected with the open sea. Apparently its initial conditions underwent as yet unspecified changes in circulation or other factors, while remaining within the relatively open marine regime.

A similar calcisponge-rich biota characterizes off-mound calcilutites determined to have been deposited in water several tens of feet deeper than the Stanton mound complex in Wilson County to the north (Heckel, 1972a, p. 590). Sponge-rich calcilutites are considered to represent a deeper-water facies also around Middle Pennsylvanian phylloid-algal buildups in the Paradox Basin (Elias, 1963, p. 196). The probably algal-influenced encrustations evident in the southern Montgomery County sponge-rich calcilutites, however, would place a lower depth limit on their place of formation. These encrustations characteristically involve a number of different kinds of foraminifers, thin layers of badly recrystallized, possibly archaeolithophyllid red algae, micrite laminations that may be attributed to poorly calcified blue-green algae, the problematicum *Tubiphytes,* and rare fistuliporid bryozoans (Fig. 8). The presence of a greater diversity of organic components in these encrustations imply more favorable conditions than normally attributed to a stromatolite environment (see below). Thus a quiet open marine lagoon, shallow enough for certain types of algal growth but deep enough that waves did not consistently agitate the bottom seems reasonable for the sponge-dominated calcilutites. This slightly deeper position is supported by best development of the South Bend portion of this facies where the unit overlies shale rather than sandstone, which suggests that compactional sag over the shale formed a slightly deeper embayment between the sandstone bodies that are common elsewhere at the top of the underlying Rock Lake Member.

Stromatolites.—This facies includes those encrustations on shells and surfaces peripheral to the Captain Creek oolite as well as the untraced lenticular horizons within the Eudora-Rock Lake interval to the south. Although resembling closely in hand specimen the familiar stromatolites *sensu stricto* of Logan, Rezak, and Ginsburg (1964), which contain no skeletal remains and thus are attributed wholly to mats of nocalcified blue-green algae, the Stanton stromatolites contain a large number of small agglutinated encrusting foraminifers with some larger calcareous forms (Fig. 22), and thus resemble osagia coatings in microstructure. They are intermediate in biologic composition between stromatolites in the strict sense, which imply very restricted intertidal to supratidal conditions, and the more biologically diverse invertebrate-rich encrustations in the sponge-rich calcilutite facies which imply more favorable conditions in a more open environment. The Stanton stromatolites with osagia microstructure probably developed in a near-shore semi-restricted subtidal to perhaps low intertidal environment. They seem to reflect a deterioration of the more open environment that is represented by the wide variety of shells they encrust, perhaps through restriction of circulation brought about by nearby sedimentation.

Terrigenous Detrital Rocks

These rocks signify access to a terrigenous detrital provenance.

Shales.—Several types of shales are recognized, including fossiliferous and "unfossiliferous" gray to brown varieties, and fissile black shales. Few were delineated in much detail because of poor exposure, and none were studied microscopically.

Many apparently **unfossiliferous light-brown shales** occur in the Rock Lake Member, where they constitute most of the thin northern end of the unit, and underlie, surround and interbed with the sandstones to the south. Inasmuch as other apparently unfossiliferous Pennsylvanian shales in Kansas have turned out under closer examination to contain a variety of fossils (Heckel, 1972b, p. 259), the shales within the southern Stanton should be subjected to more detailed investigation; specifically they should be washed for microfossils in order to determine at least whether they represent marine or nonmarine environments.

Fossiliferous shales, gray to brown in color, occur more commonly in the Eudora interval and carry two distinct macrofossil assemblages: (1) One is a diverse bryozoan-brachiopod-echinoderm-dominated biota best developed near the top of the Eudora above and south of the Stoner Limestone pinchout. This assemblage is somewhat similar to those occurring in the Bolton bed and in higher fossiliferous sandy horizons in the Rock Lake as well as generally in bedded limestones north of the algal mounds. Thus it probably represents a detrital mud-dominated variant of the normal quiet-water open marine environment.

(2) The other assemblage is a molluscan fauna dominated by snails and clams, and containing, in places, ammonoids, nautiloids, brachiopods, and crinoids. This is similar to the so-called Wann fauna, which Newell (1933, p. 142-144) considered "geosynclinal" because of its extensive development in the thicker sequences of Oklahoma. This molluscan fauna appears in Kansas in the Eudora Member at several localities, as well as in the lower Wann Formation below the Tyro oolite. Presence of echinoderms and cephalopods in this assemblage indicates normal marine salinity, but the remainder of the assemblage points to some sort of restriction. Lack of suspension-feeding bryozoans and reduction in numbers and diversity of crinoids and brachiopods suggest that the water may have been quite turbid. The dominance of snails and clams, many of them burrowers, and the shale lithology also are compatible with a turbid-water, soft-substrate, but otherwise nearly normal marine environment that one might expect in the portion of a sea under substantial, but not overwhelming, fine detrital influx.

Black shales are colored by an abundance of organic matter and are characterized by lack of benthonic fossils, which together signify an environment with oxygen-starved (anoxic) bottom water that rendered the subtrate inimical to life. The thin black shale found at the base of the Eudora above thinned Captain Creek (and Tyro) south of the mound complex occupies the same stratigraphic position as the black Eudora of the north, one of several black shales characteristic of this horizon within Missourian and lower Virgilian limestone formations (megacyclothems) in Kansas. Black shale occurs in the Eudora only where the underlying Captain Creek is thin. Because thick Captain Creek consists mainly of the topographically high phylloid-algal facies, the black Eudora is developed only over topographic lows on the Captain Creek. This can be measurably documented where the Eudora is black shale within the major channels in Wilson and Woodson Counties. Thus the anoxic environment responsible for this thin horizon of black shale apparently involved slowdown of deposition combined with bottom stagnation below a certain depth, and it affected only the deeper portions of the sea (Heckel, 1972b, p. 264).

Sandstones.—In general, sandstones signify an influx of quartz sand which may be distributed through a number of environments. These are as yet largely undetermined in the Stanton. Within the mound region, sandstone in the Rock Lake fills in lows developed in places on top of the Stoner mound. South of the Stoner mound, the Timber Hill siltstone bed, which separates the Rock Lake from the Eudora, is a relatively tabular, though lenticular unit for which the scattered brachiopods and particularly the echinoderm remains indicate the marine regime.

Farther southward the two major sandstone facies recognized in the Rock Lake interval can be related provisionally to the deltaic environmental regime, as Wilson (1957b, p. 433) has suggested previously. The thick, massive, laterally restricted sandstones, typified by much of the Onion Creek body, probably represent channels of continual water movement such as rivers or distributaries in the subaerial to submarine environmental transition. The thin-bedded sandstones, particularly those regularly interbedded with thin shales, probably represent quiet areas of intermittent sand influx such as the flood plain and interdistributary marshes and lagoons where intermittent flooding and levee breaching brought sand periodically into a normally muddy environment. The thin sandstones carrying shale pebbles reflect such an environment where cohesive lumps of eroded mud are commonly incorporated into the moving sand. The same general pattern of two similar major facies in the Chanute Formation below the Iola Limestone has been interpreted in this way (Haggiagi, 1970). In the younger Elgin Sandstone, elongate bodies of thick sandstone have been interpreted as bar-finger sands generated by delta distributaries (Brown, 1967). Other environments of sand deposition are probably also represented in various Stanton sandstones. For example, beaches and offshore bars may have been responsible for the thin even-bedded facies occurring in part of the northwestern extent of the Onion Creek body (Fig. 24). More detailed work on geometry and structures is needed to adequately determine origin of most Stanton sandstones.

Conglomeratic sandstone at base of South Bend.— Unlike the Rock Lake sandstone beds that carry only shale pebbles, the conglomeratic sandstone at the base of the South Bend contains pebbles of calcilutite, quartz siltstone and sandstone, wood fragments and chert, as well as shale, along with both whole and fragmented fossils and a concentration of the largest quartz grains (many exceeding 1 mm) in the Stanton (Fig. 11). Furthermore, this basal South Bend horizon can be traced not only over all of southern Montgomery County, but also northward where it maintains its conglomeratic nature, at least locally across the algal-mound facies belt and on into northeasternmost Kansas (Ball, 1964, p. 62). The basal contact is sharp over shales and limestones in Montgomery County, but only locally is sharp over sandstones. The concentration of the coarsest quartz grains in the sequence suggest a well-winnowed lag deposit. The wide variety of sources represented by the pebbles, along with widespread distribution of the deposit and its sharp contact over a variety of rocks that represent environments of different topographic relief, indicate a regional subaerial erosional event of substantial vertical magnitude. The lack of a sharp contact over many sandstones probably reflects mainly the tendency of sand to remain loose and unindurated relative to carbonate or clay-dominated sediment in the subaerial environment. Many fossil fragments may have been eroded out of underlying deposits, or in the case of the wood, derived from trees living on emergent land. Whole marine fossils (and some of those represented by less abraded fragments) may have lived, however, in the earliest marine stages of South Bend deposition.

It is obvious that this erosional event, apparent nearly everywhere between the Rock Lake and South Bend Members, requires regression of the sea during latest stages of Rock Lake deposition, followed by transgression to initiate South Bend deposition. Regression in the Rock Lake is not only suggested locally by the probable deltaic environments developed near the top throughout much of southern Montgomery County, but also is indicated by the assemblage of land plants occurring near Garnett in east central Kansas (Moore *et al.*, 1936), and by a variety of other features reflecting subaerial exposure at a number of places along outcrop in Kansas (Ball, 1959, p. 287) and in Nebraska (Russell, 1972). Furthermore, subaerial exposure at this horizon is compatible with Oakes' (1940a) assertion of a sub-Birch Creek unconformity (although erosion on the scale necessary to explain northward and southward disappearance of the Torpedo Sandstone is unwarranted). Transgression is indicated within the South Bend by the vertical succession of (1) the laterally variable conglomeratic base that represents erosion before, and agitation during, early inundation of an irregular surface, followed upward by (2) the relatively homogeneous marine calcilutite that represents a quiet environment below wave base developed in deeper water relatively uniformly over features of differing topographic relief, including both local thick sandstone lenses in southern Montgomery County and irregularities of the algal-mound complexes father north. The South Bend mound complex occurring locally on the thickest and probably most prominant portion of the Stoner mound represents the main departure from this pattern of uniformity across an area where depths after transgression remained sufficiently shallow for phylloid algae to proliferate.

CONCLUSIONS

Stratigraphic Considerations

1. *Members.*—All five members of the Stanton Formation recognized in northeastern Kansas can be traced through the algal-mound facies belt into northern Montgomery County (Fig. 3). The **Stoner Limestone Member** is the first to disappear southward as its algal-mound development pinches out abruptly into fossiliferous shale at the north margin of the terrigenous detrital facies belt in central T32S (Fig. 4). The **Captain Creek Limestone Member** is traced out of the algal-mound facies belt as a thin sponge-rich calcilutite overlying an oolite in T33S, R15E; it apparently correlates to the Tyro oolite bed which appears in northern T34S and is traced southward across the Oklahoma border. The **South Bend Limestone Member** is traced across the entire extent of the detrital facies belt exposed in Montgomery County as a thin but distinctive conglomeratic limy sandstone overlain much of the way by echinoderm- and calci-sponge-rich calcilutite. The two shale members south of the Stoner pinchout can no longer be separated at a consistent stratigraphic horizon and so are separated arbitrarily by two beds of limestone and one of quartz siltstone, which lie at slightly different horizons within the Stanton interval. Defined in this way, the **Eudora Shale Member** thickens southward and consists mainly of shale that includes diversely fossiliferous strata equivalent to the Stoner near the top; the Eudora contains a mollusc-dominated fauna in the middle and lower parts, and a thin fissile black shale at the base. The **Rock Lake Shale Member** thickens southward into the detrital belt where it contains both great thicknesses of sandstone and thin fossiliferous limy horizons of different degrees of traceability. South of the disappearance of the intervening Bolton bed, the two shale members are inseparable as the Eudora-Rock Lake interval, which constitutes nearly all the Stanton Formation in southernmost Kansas.

2. *Beds.*—One quartz siltstone bed and three thin limestone beds that appear at various positions in the Stanton interval in the detrital facies belt are newly named and described. The **Timber Hill bed** is a thin quartz siltstone that appears about 1 mile south of, and stratigraphically above, the Stoner pinchout. The **Rutland bed,** appearing above the south end of the Timber Hill bed, is a dull-orange-weathering, cross-bedded, abraded-grain skeletal calcarenite in which red- and green-algal debris dominates a diverse group of invertebrate fragments and scattered ooids. Southward and apparently stratigraphically, lower, the **Bolton bed** is a more yellowish-weathering skeletal calcarenite with less abrasion of grains, very little red or green algae, but with some osagia coatings around the dominant invertebrate debris, and a greater though still subordinate amount of ooids. Appearing below the Bolton bed south of the disappearance of typical Captain Creek, and extending across the Oklahoma border, the **Tyro bed** is a largely quartz-nucleated oolite with thickly coated ooids and scattered invertebrate fragments.

Dominance of grain types in the three calcarenite beds trends southward from red and green algae nearest the mound belt through invertebrate debris to ooids with quartz nuclei. The Timber Hill, Rutland, and Bolton beds separate the Eudora and Rock Lake Members. The Tyro bed lies at the stratigraphic horizon of the Captain Creek Member and marks the base of the Stanton in the southern two townships in Kansas.

At least two thin limy zones within the Rock Lake Member and Eudora-Rock Lake interval in southern Montgomery County consist largely of oolitic and fossiliferous quartz sandstone typically with thinner oolitic coatings on a smaller proportion of the grains than in the Tyro. Much of the Rock Lake and Eudora-Rock Lake is characterized by two gross sandstone facies, thin-bedded and massive; one massive unit in T33S and adjacent sections of T32S seems well enough delineated to be termed the **Onion Creek sandstone body.**

3. *Correlation into Oklahoma.*—Of all the distinctive traceable units in the Stanton Formation, only the Tyro bed and South Bend Member (and by definition the intervening Eudora-Rock Lake interval) are traced into Oklahoma, where both limestone beds were mapped as the Birch Creek Limestone and thus assumed to be the same horizon by Oakes (1940a) and ultimately by the Geological Map of Oklahoma (1954). Because the major outcrop trend extending northward from type Birch Creek Limestone west of Caney River on Oakes' map joins directly with the South Bend, that portion of the mapped Birch Creek east of Caney River should be removed from the Birch Creek and placed in the Tyro (in T29N, R14E and eastern R13E) and probably also into higher limy zones in the Stanton (in western T29N, R13E). More importantly, the thick sequence of post-"Birch Creek" (= post-Tyro) strata mapped in northern T29N, R13E belong to the Eudora-Rock Lake interval and should be placed in the Stanton, which is mostly pre-Birch Creek in position. Nevertheless, final establishment of correlation of the South Bend Member of the Stanton to type Birch Creek Limestone should await availability of accurate 7.5-minute quadrangles in Oklahoma for detailed tracing of the horizon.

In the meantime, assuming that the South Bend-Birch Creek correlation is correct, it is suggested that the Wann Formation be redefined to include both the Birch Creek Limestone as a member marking its top and the Torpedo Sandstone as a member within its upper part, instead of picking the upper limit of the Wann at the base of the Torpedo, which probably has been mapped at several different horizons. This allows the Wann to be recognized as the exact Oklahoma equivalent of the Lane, Wyandotte, Bonner Springs, Plattsburg, Vilas, and Stanton Formations, instead of being limited upward at some ill-defined horizon or horizons within or possibly below the Stanton, as it is now. Furthermore, where the Tyro bed is present, it conveniently divides the Wann Formation into two subequal parts: the lower Wann, which is equivalent to the Lane-Vilas Shale, and the upper Wann, which is equivalent to the Stanton Formation.

4. *Sedimentary break at Rock Lake-South Bend contact.*—Occurrence of widespread evidence for regression in the upper Rock Lake, erosion at the contact, and transgression during deposition of the South Bend throughout eastern Kansas marks a significant regional sedimentary break. Attempts should be made to trace the break farther across the Midcontinent Basin. If it has an underlying tectonic cause, the nature of the event it signifies may aid in unraveling the history of mountain-building going on at this time in southern Oklahoma.

The break occurs just below the Missourian-Virgilian boundary as now recognized. If a sedimentary break is considered desirable for a stage boundary, then lowering the boundary to the base of the South Bend would seem appropriate. Such a decision, however, should be left to biostratigraphic investigations. In any case, detailed study of the biotas on either side of the break, particularly of environmentally equivalent biotas in the South Bend and Stoner Limestone Members, is warranted in order to evaluate the time significance of the sedimentary break at the contact.

Depositional Considerations

5. *General sequence of environments.*—In the phylloid-algal mound facies belt of Northern Montgomery County, the sediment surface during deposition of the limestone members was being kept close to sea level by phylloid-algal production of sediment at a rate sufficient to compensate for subsidence of the sea bottom. Only during deposition of shale members did terrigenous detrital influx encroach into this region enough to deposit a few feet of Eudora shale above the Captain Creek mound and a few feet of Rock Lake shale and sandstone, particularly in local lows, above the Stoner mound. Following the regression that closed Rock Lake deposition, the transgression that initiated South Bend deposition stabilized sea level rise at shallow enough depths over the thickest part of the Stoner mound for algal-mound development to continue locally during South Bend deposition.

To the south in the detrital facies belt (Fig. 4), however, too much influx of terrigenous detritus, combined with more subsidence than could be easily compensated by phylloid-algal proliferation, inhibited much growth of phylloid algae. After the detrital influx that dominated earlier deposits lessened, Stanton deposition was initiated in central and southern Montgomery County by local developments of ooids, presumably on small shoals. On the southern shoal, ooids nucleated mainly around quartz sand grains and moved in megaripples southwestward off the shoal, apparently accreting as they moved, to form the Tyro bed. On the northern shoal, ooid formation was succeeded over a broader area by proliferation of calcisponges and other invertebrates in a quiet environment of accumulation of fine detritus that was followed by carbonate mud to form the thin southern end of the Captain Creek Member. Much of this carbonate mud may have been derived from the growing Captain Creek algal mound to the north. While continuing subsidence combined with extremely low detrital influx caused deepening of the sea bottom, an episode of bottom stagnation that affected only deeper water resulted in the thin black shale that marks the base of the Eudora over both the Captain Creek sponge calcilutite and the Tyro oolite. Then fine clastics flooded in again in greater quantities to form most of the Eudora of central Montgomery County. This influx of fine clastics brought about environments of high turbidity and soft substrate like those that had preceded Stanton deposition; they now produced gray shales with a molluscan fauna in the Eudora that is similar to those of the Lane-Vilas Shale, below, and much of the Wann Formation to the south.

While fine clastics dominated the thicker Eudora to the north, greater amounts of quartz sand flooded in over the basal dark shale in the south. This coarser influx advanced northward to the point in northern T34S where invertebrate growth replaced the previous fine detrital influx on a large enough scale to produce the Bolton bed. Farther northward toward the mound edges, fine clastics flooded in throughout deposition of the Stoner mound and ceased only long enough locally for invertebrate and algal debris from various sources to be swept up into the Rutland bed just after a pulse of coarser detritus left the Timber Hill siltstone bed spread over part of the sea bottom. In the meantime, the continuing flood of quartz sand from

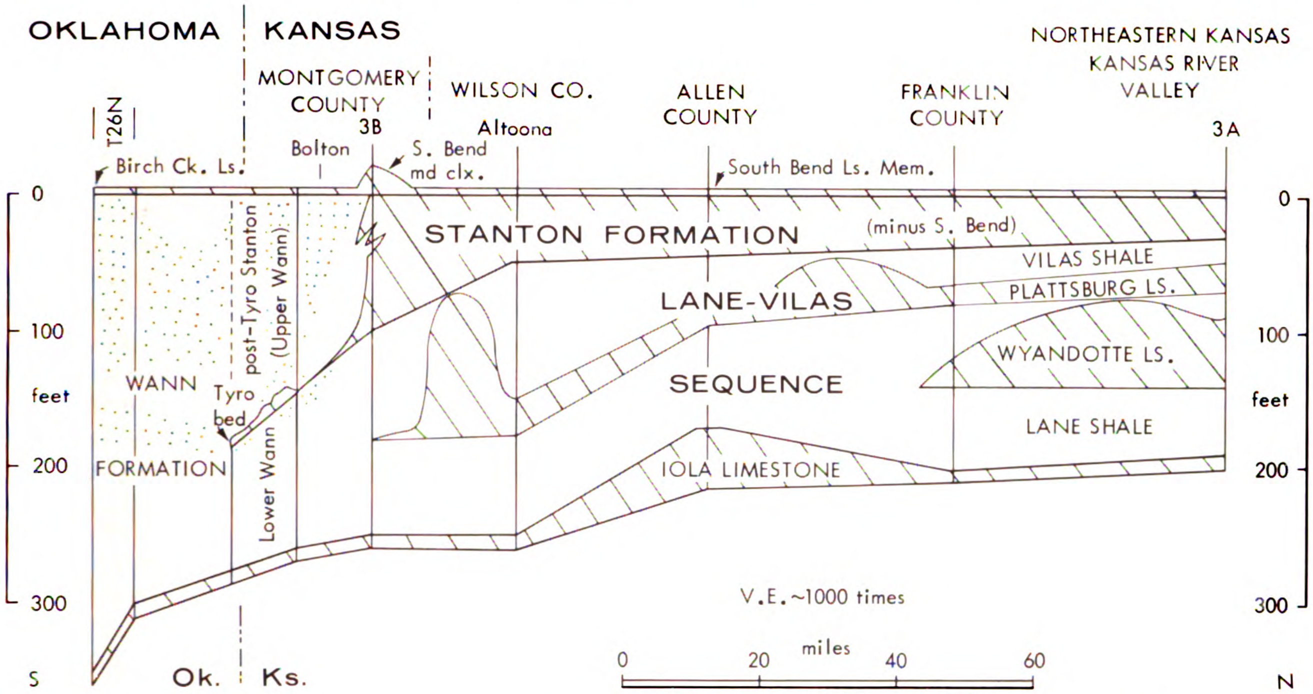

Fig. 26.—Generalized cross section along strike of upper Missourian units from northeastern Kansas to northern Oklahoma showing complementary thickness relations between Stanton Formation and underlying Lane-Vilas sequence. Datum is base of South Bend Limestone Member and probably correlative Birch Creek Limestone. Dominant lithologies are generalized with limestone lined, sandstone dotted, and shale left blank. Thicknesses averaged from ranges obtained from following sources: Kansas River Valley—Crowley (1969), Moore and Merriam (1965, p. 12-13); Franklin County—Ball and others (1963); Allen County—Miller (1969); Wilson County (Altoona)—Wagner (1961); Montgomery County—Figure 4 in this paper; northern Oklahoma—Oakes (1940a, p. 76).

the south more strongly inhibited carbonate formation in the southern region throughout the remainder of Stanton deposition. Only at a few times was detrital influx reduced enough in limited areas to allow the oolitic coating of sand grains and growth of conspicuous numbers of shelled organisms (locally encrusted by osagia-like stromatolites), which formed the discontinuous third and fourth limy zones within the Eudora-Rock Lake interval. In higher parts of the sandy sequence, facies resembling channel and interchannel deposits suggest that deltaic complexes became established in this region. One of these advancing fronts of sand entered T33S at an angle to the present outcrop belt just after the Bolton bed was formed and dominated deposition of the Rock Lake Member in this region as the Onion Creek sandstone body. This body finally advanced northward over the remaining area of fine clastic deposition above the Rutland bed and encroached onto parts of the Stoner mound before a general regression terminated deposition of Rock Lake clastics over much of eastern Kansas.

The ensuing transgression first reworked a variety of eroded and residual materials in a number of microenvironments on the irregular surface to produce the coarse sandy, conglomeratic base of the South Bend. Then deepening of the sea inundated all of the surface, and lime mud was spread uniformly over the sandy conglomerate in the areas that were submerged below wave base. Stanton carbonate deposition was finally ended over the entire outcrop area by the beginning of the immense influx of terrigenous detritus that formed the succeeding Douglas Group.

6. *Significance of the sequence.*—Because the phylloid-algal buildups represent nearly continual near-surface water depths, the thickness of the standard section (Fig. 3B) in northern Montgomery County, which they dominate, provides a fair estimate of the net amount of subsidence undergone by the south end of the algal-mound facies belt during Stanton deposition. This amounts to 120 feet for the entire Stanton and 100 feet for the pre-South Bend-Stanton interval, which was terminated by the regression. Thicknesses of the equivalent stratigraphic interval to the south show that greater subsidence was taking place in the detrital facies belt, on the order of 130 to 140 feet around Bolton and in places as much as 160 to nearly 200 feet south of Bolton for the pre-South Bend-Stanton (Fig. 4, 26). Even if 10 or 20

feet is subtracted from detrital belt thicknesses to account for greater elevation than the algal mounds of a possible subaerial delta near the end of Rock Lake deposition in the detrital belt, this would be more than offset by the greater compaction undergone by shales in the detrital belt compared to what is generally observed for lime muds, which dominate the mound belt.

The great increase in sand upward through the Stanton interval and progressively northward across the clastic belt represents an expected vertical sequence of fine to coarse detrital filling of a basin from the south. Nevertheless, this was not just a simple overwhelming of the subsiding basin by nonmarine clastics in subaerial environments. The presence of relatively diverse marine fossil assemblages at several horizons in the detrital Stanton interval reflects periodic establishment of subtidal, relatively open marine environments and signifies that sedimentation was not keeping up with subsidence continually in the detrital belt. It is also possible that the water was substantially deeper at times within the detrital facies belt than in the algal-mound facies belt. The molluscan fauna that characterizes both the Wann and Eudora has been considered "geosynclinal," and its particular biotic makeup seems to reflect a turbid-water, soft-substrate environment more than a near-shore regime with fluctuating salinity; thus it would be compatible with relatively deep water.[7] Considering both the possible intermittency and localized nature of rapid detrital influxes, deeper water on the order of several tens of feet could have been established periodically during continual subsidence within the detrital facies belt.

It can be shown that sedimentation caught up with subsidence only if subaerial deltas are definitely identified or if the oolite beds represent the areas in which their component ooids were generated. The shoreline environment suggested by the higher oolitic zones is compatible with the channelling suggested by the associated shale pebbles and by the possible deltaic sandstone facies present in this part of the section. On the other hand, the apparently consistent westward to southwestward direction of movement indicated by cross-bedding dips in the Tyro oolite, along with increase in size of the ooids toward the southwest (Hafer Run), suggest the possibility that Tyro ooids were swept continually southwestward off a shoal and that they continued accreting in deeper water. Presence of such a shoal northeast of the Tyro outcrop is suggested by: (1) the substantially greater than regional westward dip of the Tyro in the northeasternmost prong of outcrop (see discussion of Tyro bed) and possibly also to the south (see note in Appendix 1 for est. sec. 39); and (2) the rather abrupt thickness increase in the pre-Tyro (= pre-Captain Creek) Lane-Vilas interval southeastward from southernmost T33S into northernmost T34S (Fig. 4).

7. *Relation between sedimentation and subsidence.* —Thickness data show that the Lane-Vilas sequence of formations maintains an average of about 160 feet[8] from northeastern Kansas southward to northern Montgomery County (Fig. 26), where about 150 feet are measured below the Captain Creek mound complex in Table Mound (Fig. 4, est. sec. 5). The Lane-Vilas then thins unevenly southward to 95 feet below the Tyro oolite at the Oklahoma border. This thinning stands in contrast to the regional trends of southward thickening that are detectable in most underlying Missourian combined clastic-carbonate units and particularly to that of the overlying Stanton interval, which thickens southward from about 35 feet in northeastern Kansas to 100 feet and greater in Montgomery County (Fig. 26). Combining the Lane-Vilas and Stanton thicknesses, however, shows them to be roughly complementary, giving a Lane-Stanton interval thickening somewhat from about 200 feet in northeastern Kansas to 250 feet or so in Montgomery County and to 300 to 350 feet as the Wann Formation (redefined to include the Torpedo and Birch Creek) in T26N in Oklahoma (Oakes, 1940a, p. 76). Thus the entire unit comprising the Wann and its correlatives does reflect the general trend of increasing thickness to the south. The differences in thickness trends of its two major components (Lane-Vilas and Stanton) may be explained by considering possible relationships of rates of subsidence and compensation by influx of terrigenous clastics or by generation of carbonate sediment.

One hypothesis calls for subsidence increasing southward at the same rate at any place throughout the entire Lane-Stanton sequence. In this model, the thin Lane-Vilas sequence of central and southern Montgomery County reflects insufficient sedimentation to compensate for subsidence, thus resulting in deeper water in this region until detrital influx increased enough in the Stanton interval to get ahead of subsidence and finally fill up the basin by the end of Stanton deposition. Compatible with this are the finer

[7] Presence of osagia-like coatings consisting mainly of encrusting foraminifers and micrite on some fossils at one locality (near NW cor 32-34-15) might argue against very deep water because such coatings supposedly are formed largely by blue-green algae; however, as in osagia coatings in many Kansas limestones, no definite remains of blue-green algae are yet apparent in thin section.

[8] It ranges from about 100 to 200 feet, thinning over the Iola algal-mound complex in Allen County.

detritus and Wann-Eudora molluscan fauna suggesting turbid marine and possibly deeper water in the lower part of the sequence which then was followed upward by increasing amounts of coarser clastics with probable delta development toward the top. The Stanton algal mounds also are compatible because they lie upon the thicker (thus higher) part of the Lane-Vilas detrital sequence facing on the south a slightly deeper basin that was trapping the southerly detrital influx in deeper water. The Tyro oolite, however, is not compatible with this hypothesis if it occurs today upon the area where the ooids were generated because it would require a shoal in the part of the sequence where water was supposedly still deep before most of the basin filling occurred. On the other hand, if the Tyro today represents ooids transported off a shoal on the east, it would be compatible. A shoal on the east would require a thicker sequence of pre-Tyro sediments east of the main line of outcrop, which is suggested both in the steeper than regional westward dip of the Tyro off its northeasternmost prong of outcrop and in the local southward thickening of the Lane-Vilas into this area. Such a shoal would indicate that the detrital influx involved lobes of detrital sediment coming in at a variety of directions, which is compatible with the model for Missourian deposition outlined by Cocke (1968).

A hypothesis involving different rates of subsidence at different times, nearly completely compensated by sedimentation would involve less subsidence in the south than in the north for the Lane-Vilas sequence followed by much greater subsidence in the south relative to the north for the Stanton. Both the Tyro oolite remaining upon its shoal of generation, and the stromatolite-rich deposits around the south and west sides of the Captain Creek oolite are more compatible with this hypothesis. The Stanton algal mounds would seem compatible also because their south ends would lie along a hingeline of greater southward subsidence during this phase of deposition. At least the Captain Creek mound, however, is more compatible with the first hypothesis because the lack of shale within the mound indicates a fairly long time when it stood substantially higher than incoming clastics, which implies deeper water to the south that trapped the detrital influx coming from that direction.

It is probable that the interplay of rates of subsidence and amount of compensation by sedimentation lay somewhere between these two models for this sequence of rocks. Thus, further detailed work along with consideration of the roles of compaction and eustatic sea-level change, is needed to more definitely assess the history of sedimentation. Formulating such models as multiple working hpyotheses, however, helps determine along what lines further work might be undertaken.

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APPENDIX 1

Locations of measured and estimated sections used in construction Figures 4 and 5, by number from north to south.

1. Measured in long roadcut west of Elk City Dam, south of ctr N half 7-32-15 (same as standard section, Fig. 3B).
2. Measured in exposures along abandoned road from Captain Creek in NE-SW-NE 14-32-14 northwest into Stoner near ctr W line NW-NE 14-32-14.
3. Estimated as much as 40 to 50 feet of Stoner moundrock from elevation differences mapped within Stoner Member in sections 14, 15 and adjacent parts of 10 and 11, T32S, R14E.
4. South Bend measured in N wall of quarry W of U.S. Rte. 160 S of Elk River bridge in NE-NE-SW 17-32-14; South Bend rests directly on Stoner in quarry about 1.2 mile to E, near ctr W half, SE 16-32-14.
5. Estimated from Iola exposed at 810 ft. in spillway at new road crossing in NE-SW-SW 15-32-15 northwestward to Plattsburg at 870 ft. near ctr W line NW-SW 15, plus 5 ft. regional dip; thence westward to base of Stanton at 950 ft. near top of grade where new road ascends SE part of Table Mound in NW-NE-SE 16-32-15, plus 5 ft. regional dip.
6. Captain Creek and top of Vilas measured when formerly exposed in 1965 at site of dismantled old U.S. Rte. 160 bridge over Elk River in NW-SE-SW 14-32-14; Eudora interval measured southward along Card Creek to ravine in N half NW 23-32-14, up ravine to E through Stoner to new road ascending north prong of Timber Hill; upper Stoner, Rock Lake and sandstone below base of South Bend measured southward in road ditch to point near ctr NW 23-32-14 when exposed in 1966.

7. Upper Vilas and Captain Creek measured in prong of escarpment in NE-NW 24-32-14.
8. Eudora interval estimated from top of Captain Creek at 830 ft. E of ctr W line 24-32-14 westward to Stoner pinchout at 845 ft., W of old road NW of pond, N of ctr 23-32-14 (at junction of Bolton and Table Mound 7.5 minute Quadrangles), plus 15 ft. regional dip.
9. Shale above Stoner pinchout (located in 8, above) estimated southward to richly fossiliferous horizon exposed at 860 ft. just west of site of old oil well; thence measured westward up to sandstone (below S. Bend) capping prong of hill about 875-880 ft. near ctr 23-32-14.
10. Drill hole D (drilled by Leo Reavis for this project in 1966) on S line just E of old house site, in SE-SE-SW 21-32-14; only lower part shown on Fig. 4; complete section on Fig. 6.
11. Estimated from Iola formerly exposed about 780 ft. in creek bank along old U.S. Rte. 160, N line NW-NE 29-32-15 (from section measured by N. D. Newell in 1935 on file at Kansas Geological Survey) to Captain Creek about 840-845 ft., especially brought up around pond in SE-SW 24-32-14, plus 70 ft. regional dip.
12. Complete South Bend (Fig. 9) and portion of underlying shale sequence with Timber Hill siltstone (type section) measured in roadcut of new road along E side Timber Hill near ctr W line NW 25-32-14.
13. Complete South Bend and portion of underlying shale sequence with Timber Hill siltstone measured in roadcut of new road along E side Timber Hill near NW cor 36-32-14.

14A. Upper part measured in shale bank in roadcut on N side U.S. Rte. 160 (Fig. 13), SE corner Timber Hill, N of ctr W line NW 36-32-14; lower Eudora interval including black shale taken from nearby borehole reported by Wilson (1957a, p. 44-45); Captain Creek and underlying shale and siltstone exposed in roadcut along N side U.S. Rte. 160 to E along S line NW-NE 36-32-14. Complete section on both Fig. 4 and Fig. 5.

14B. Measured from top of Eudora Shale through Timber Hill siltstone bed, Rutland bed and Rock Lake Shale Member in road ditch along E line SE-NE-SE 35-32-14 to South Bend conglomerate along road near ctr W line SW 36-32-14.

15. Walker Mound in NE 5-33-15; interval estimated from road ditch exposures of Captain Creek, top about 880 ft., and basal Eudora black shale on NE side of Mound up to base of 5-foot capping siltstone (probably Timber Hill bed) at 950 ft.; this closely matches section measured by N. D. Newell in 1935 on file at Kansas Geological Survey. Only lower part shown on Fig. 4; complete section on Fig. 5.
16. Captain Creek and underlying shale and siltstone exposed in road ditches near ctr NE 1-33-14; Eudora interval estimated from top of Captain Creek about 830 ft. along creek just S of road in SE-NW 1-33-14 to Rutland bed type section (5 ft. thick), base at 885 ft., in NE cor 2-33-14, plus 10 ft. regional dip; Rock Lake interval estimated northward to exposure of South Bend conglomerate and limestone at 905-910 ft. near ctr W line SW 36-32-14; also shale interval estimated from Rutland bed westward to sandstone capping small hill under house at 900 ft.
17. Estimated from basal Captain Creek oolite about 880 ft. with underlying Lane-Vilas siltstone exposed along road on S line SE-SE 5-33-15 westward to Rutland bed capping small hill at 885 to 890 ft. in NE-NE 12-33-14, plus 60 ft. regional dip, giving Eudora interval of 60 ft., allowing 5 ft. for upper Captain Creek; thence 1 mile westward to South Bend conglomerate capping small hill at 875 ft. in NE-NE 11-33-14, plus 30 ft. regional dip, giving Rock Lake interval of 15 ft.
18. Estimated from Iola exposed in creek bank at 790 ft. E of house S of ctr S half 10-33-15 westward to Captain Creek oolite exposed along road at 875 ft. just N of house in NW-NW 16-33-15, plus 40 ft. regional dip; from Captain Creek in creek bed about 845 ft. in SE-SW 7-33-15 westward to probable blocks of Rutland bed on top of rise, estimated originally about 875 ft., plus 15 ft. regional dip; thence westward to base of Onion Creek sandstone at 870 ft. by Oak Ridge School near ctr S line 11-33-14, plus 40 ft. regional dip; thence westward to South Bend at 895 ft. in SW-SE-SW 11-33-14, plus 5 ft. regional dip.
19. Measured from siltstone in top of Lane-Vilas westward through Captain Creek oolite to sponge calcilutite along road near ctr SW 17-33-15.
20. Estimated from blocks of Captain Creek sponge calcilutite brought up from about 820 ft. along E line near NE cor 23-33-14 northward to base of Onion Creek sandstone at 885 ft. along E line NE-SE 14-33-14; thence from same horizon at 880 ft. along N line NE-SE 14-33-14 westward to 905 ft. at top of hill in sandstone in SE-SE-NW 14-33-14, plus 15 ft. regional dip.
21. Estimated westward up valley of Onion Creek from Captain Creek at 815 ft. in creek bed ctr W line NW 24-33-14 to Bolton bed at 825 ft. in creek bed on W line NW-NW 23, plus 30 ft. regional dip; thence to sandstone ridges at 875 ft. along creek in NE 21-33-14, plus 40 ft. regional dip.
22. Estimated from Captain Creek at 825 ft. in creek bed in SE-NW-SW 24-33-14 northward to lens of Bolton bed at 865 ft. N of pond in SE-SW-NW 24; thence westward into Onion Creek sandstone capping hill at 905 ft. near ctr W line 24, plus 5 ft. regional dip.
23. Estimated from limestone lens in Lane-Vilas at 815 ft. in road ditch at ctr S line SW 19-33-15 westward to Captain Creek at 825 ft. in creek bed SE-NW-SW 24-33-14, plus 30 ft. regional dip.
24. Estimated from Captain Creek at 825 ft. in creek bed SE-NW-SW 24-33-14 southeastward to Bolton bed at 870 ft. along and in road in SE-SE-SW 24, minus 5 ft. regional dip; thence westward to highest sandstone at 925 ft. at top of hill in NW-NW 26-33-14, plus 40 ft. regional dip.
25. Section measured by N. D. Newell in 1935 near ctr S line 24-33-14 on file with Kansas Geological Survey.
26. Estimated from 4th oolitic zone at 860 ft. in road ditch on W line SW-SW 26-33-14 westward to South Bend at 895 ft. just south of road near ctr S half 27-33-14, plus 15 ft. regional dip.
27. Estimated from Iola blocks originally about 790 ft., around new pond W of house near ctr N line NW 32-33-15 westward to oolitic, stromatolitic lower Captain Creek exposed at 820 ft. in road ditch on N side of U.S. Rte. 75 in SE-SE-SW 25-33-14, plus 50 ft. regional dip; thence southwestward along highway to upper Captain Creek sponge calcilutite at 825 ft. in NW-NE-NW 36-33-19, plus 5 ft. regional dip; thence southwestward

to Bolton bed (type section) at 845 ft. in railroad cut near ctr S half NW-NW 36-33-14, plus 5 ft. regional dip.

28. Hill northeast of Wayside; measured up northeast side of hill near ctr NE 35-33-14, from Bolton bed about 835 ft. south of creek to 4th oolitic zone capping hill at 880 ft.
29. Estimated from Iola blocks originally about 790 ft. around new pond W of house near ctr N line NW 32-33-15 westward and southward to Captain Creek sponge calcilutite blocks perhaps originally about 840 ft. along road NW-SW-NW 31-33-15, plus 40 ft. regional dip; thence southward to Bolton bed at 865 ft. in road ditch near SW cor NW 31-33-15.
30. Estimated from Iola at 800 ft. in road near ctr S line SW 33-33-15 westward to Bolton bed at 855 ft. capping small rise north of paved road near SW cor 31-33-15, plus 65 ft. regional dip; thence westward to South Bend at 885 ft. along paved road in Wayside near ctr S line SW 34-33-14, plus 85 ft. regional dip.
31. Hill west of Jefferson; estimated from Iola at 800 ft. in road along S line SE-SW-SE 5-34-15 westward to limestone lenses in Lane-Vilas about 845 ft. at first northward bend in road, plus 20 ft. regional dip; thence westward up hill to Tyro oolite capping hill from about 895 to 905 ft.
32. Measured southward up road ditch along W line NW-SW 6-34-15, from Tyro oolite just south of creek, 18 ft. up to Bolton bed in prominent exposure of two limestone layers from about 855 to 860 ft.; Black Eudora shale overlies Tyro oolite in nearby road along S line SE-NE-SW 6-34-15.
33. Estimated from top of Bolton bed about 860 ft. on W line NW-SW 6-34-15 southward to fossiliferous oolitic sandstone of probable 3rd zone at 870 ft. in SE cor 1-34-14; thence westward to oolitic skeletal calcarenitic sandstone blocks of 4th zone around pond at 880 ft. in NW cor 12-34-14, plus 30 ft. regional dip; thence westward to South Bend blocks from about 875 ft. N of road in SW-SE-SE 4-34-14, plus 65 ft. regional dip.
34. Estimated from 3rd zone at 870 ft. in SE cor 1-34-14 southward to top of thick sandstones capping hill at 915 ft. in SE-NE 12-34-14.
35. Estimated from Iola at 800 ft. along road, S line SW-SE 8-34-15 westward to Tyro oolite about 880 ft. in old quarry on side of hill S of house, SW-SE 7-34-15, plus 30 ft. regional dip.
36. Estimated from Tyro oolite at 850 ft. in road ditch along E line near NE cor 13-34-14 westward to slightly fossiliferous oolitic quartz sandstone of 3rd zone at 855 ft. in road ditch along N line near NE cor 14-34-14, plus 30 ft. regional dip; thence westward to South Bend at 850 ft. in road ditch near ctr W line SE-SE 8-34-14, plus 95 ft. regional dip.
37. Estimated from Tyro oolite at 850 ft. in road ditch along E line near NE cor 13-34-14 west-southwestward to sandstone from about 850 to 895 ft. in hill in W half 22-34-14 and adjacent SW quarter 15-34-14, plus 80 ft. regional dip.
38. Estimated from Tyro oolite at 850 ft. in road ditch along E line near NE cor 13-34-14 west-southwestward to oolite of 4th zone at 795 ft. in creek bed N of road near ctr S line SE-SW 17-34-14, plus 140 ft. regional dip; thence, a) northwestward to South Bend at 800 ft. in SE-NW-SE 18-34-14 (north of Havana Lake), plus 20 ft. regional dip; b) westward to South Bend at 830 ft. in road ditch on W line just S of NW cor 20-34-14, plus 10 ft. regional dip, and c) southward to top of hill at 870 ft. in SW-NE-NW 20-34-14 capped by sandstone in Rock Lake Member (see also Fig. 6a).
39. Estimated from Tyro oolite at 900 ft. on side of hill NW of Fawn Creek Cemetery, just SE of ctr SE 19-34-15 westward to fossiliferous shale-pebble-bearing oolitic quartz sandstone of 3rd zone at 830 ft. in road ditch at ctr W line 23-34-14, plus 85 ft. regional dip; (compared to 15 ft. computed above, at least 40, perhaps 55 feet of sandstone and shale are exposed below the 3rd zone in the creek bed to the northwest in SE-NE 22-34-14, which indicates that the Tyro either lenses out westward, or more likely dips westward at greater than regional dip at it does in section 6-34-15 to north along strike; no compensation is made on Fig. 4 for the latter possibility).
40. Estimated from Tyro oolite at 900 ft. on side of hill NW of Fawn Creek Cemetery, just SE of ctr SE 19-34-15, westward: a) to South Bend at 760 ft. along creek in SW cor 24-34-13, plus 235 ft. regional dip; and b) to fossiliferous quartz sandstone probably of 4th zone at 935 ft. in road ditch on W line near NW cor 30-34-15, plus 25 ft. regional dip; thence westward to top of sandstone capping ridge at 940 ft. along W line NW-NW 25-34-14, plus 30 ft. regional dip.
41. Estimated from Iola at 800 ft. in road ditch near ctr S line SW-SE 29-34-15, westward to base of Tyro oolite about 900 ft. in nose of Stony Point at junction of sections 29, 30, 31, 32, plus 20 ft. regional dip.
42. Tyro measured in quarry in NW-SW-SE 30-34-15 (type section) where it is overlain by 2 ft. of dark gray shale followed by 25 ft. + of sandstone with intercalated shale; other sections estimated from top of Tyro at 900 ft. here, westward: a) to Rock Lake sandstone capping hill at 850 ft. in NE -SE 29-34-14, plus 140 ft. regional dip; b) to South Bend at 785 ft. (base) in NW cor 31-34-14, plus 200 ft. regional dip; c) to Rock Lake sandstone capping hill at 890 ft. S of ctr 33-34-14, plus 120 ft. regional dip; d) to slightly fossiliferous oolitic sandstone of 3rd zone at 840 ft. in gully just below road near ctr E line NE-NE 34-34-14, plus 80 ft. regional dip; (comment on estimated section 39 applies here also).
43. Estimated from Tyro oolite at 795 ft. in SW bank of Hafer Run near ctr NE-NE 4-35-14: a) northward to Rock Lake sandstone capping hill at 890 ft. S of ctr 33-34-14, plus 10 ft. regional dip; b) west-southwestward to oolitic, skeletal quartz sandstone of 4th zone at 805 ft. in roadcut on U.S. Rte. 166 near ctr N line NE-NE 7-35-14, plus 60 ft. regional dip, thence northwestward to South Bend at 810 ft. in S nose of hill in NE-SW-SE 6-35-14, plus 5 ft. regional dip; c) south-southwestward to skeletal oolitic quartz sandstone with mud pebbles, possibly the 3rd zone, at about 805 ft. in gully in SW-SE-NE 4-35-14, plus 5 ft. regional dip; thence measured southward up gully to stromatolite horizons about 820 ft.
44. Estimated from top of Iola along U.S. Rte. 166 at 850 ft. just W of ctr E line NE 6-35-15 southward to Tyro oolite at 950 ft. in road ditch along N line, just W of E line SE-NE 7-35-15. [This Iola exposure is higher than one at 830 ft. about 1.2 mi eastward on U.S. Rte. 166 and another at 800 ft. about 1.4 mi to the NNE (located in estimated section 41), apparently because it lies on the north nose of a broad anticlinal structure noted by Oakes, 1940a, p. 75, 100, as the Pleasant View dome centered to

the south in western T29N, R14E, Washington County, Oklahoma; this local departure from regional westward dip also explains why the Tyro oolite lies at or near 950 ft. around most of the outlier hills in eastern section 7, and sections 8, 16, 17, 18, T35S, R15E in Kansas.]

45. Thickness of interval of Iola to "Birch Creek" (which = Tyro oolite near Iola exposures) shown to be about 90 to 95 ft. at the Kansas-Oklahoma border by Oakes (1940a, p. 16). Thickness of Wann Formation reported to be 95 ft. in sec. 13, T29S, R13E, Oklahoma (ibid., p. 76) and thickness of overlying Torpedo Sandstone reported to be 2 ft. in NW corner of same section (ibid., p. 83) where main trace of Tyro outcrop crosses state border. This reported range of 90 to 97 ft. for the Iola to Tyro interval is compatible with that estimated east of the outlier hills in 16-35-15 (Kansas) where the Iola is not exposed but sandstone near top of the Chanute (ctr S line NW-NW 15-35-15) at 890 ft. lies about 100 ft. below Tyro oolite at 960 ft. (NW-SW-NW 16-35-15), adding in 30 ft. for regional dip.

46. Estimated from Tyro oolite at 890 ft. in bank on S side of dirt lane just W of junction with main road near ctr E line NW-NE 13-35-14, northward to fossiliferous oolitic quartz sandstone, probably of 4th zone, exposed at about 980 ft. on W side of road in NW-NE-SE 12-35-14; farther northward along W line NW 7 and SW 6-35-15, sandstone is exposed between 940 ft. and 975 ft.

47. Estimated from Tyro oolite overlying sandstone at 835 ft. in ditch along state line road just west of road junction on S line near SE cor 15-35-14: a) northward to sandstone capping hill at 935 ft. along W line NW-SW 11-35-14; b) westward to fossiliferous oolitic quartz sandstone of 4th zone at 875 ft. in SE-SW-NE 16-35-14, plus 40 ft. regional dip; thence southwestward to top of sandstone capping hill at 980 ft. in E half SW 16-35-14, plus 5 ft. regional dip; c) westward along state border to South Bend at 750 ft. along hill in SW cor 14-35-13, plus 180 ft. regional dip.

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GEOLOGIC MAP OF STANTON FORMATION
IN WEST-CENTRAL AND SOUTHWESTERN MONTGOMERY COUNTY, KANSAS

Kansas Geological Survey

Plate 1

Bull 210
by Phil Heckel
1975