Carbonate Facies in the Pueblo Formation—Lower Permian, Eastern Shelf; Transgressive Phylloid Algal Biostromes

By
M.L. VanDerLoop-Avary
Monsanto Co., Midland
and
M.K. Nestell
Department of Geology
University of Texas at Arlington

ABSTRACT

The Pueblo Formation is a repetitive sequence of thin limestones alternating with thicker shales and sandstones in the cratonic setting of the Eastern Shelf of the West Texas Permian Basin. It is early Wolfcampian (Permian) in age and is a member of the Wichita Group.

The formation is comprised of five members in ascending order: Saddle Creek Limestone, Camp Creek Shale, Stockwether Limestone, Coon Mountain Sandstone Lentil, Salt Creek Bend Shale, and Camp Colorado Limestone (subsurface terminology Noodle Creek Limestone).

The limestone members are thin persistent transgressive sediments which have seven distinct facies: 1) **Tubiphytes** phylloid algal biomicrudite (low energy algal bank - open marine shelf); 2) sparse biomicrite (low energy - open marine shelf); 3) crinoid biomicrite (low energy bank - open marine shelf); 4) fusulinid biomicrite (low energy - open marine shelf); 5) crinoid-brachiopod-bryozoan biomicrite (low energy - interdistributary marine bay); 6) foraminiferal algal biomicrite (high energy - open marine shoal); 7) "**Osagia**" coated grain biomicrite (high energy intertidal) with varying amounts of quartz sand and silt.

Facies 1, 2, 4, 6, and 7 are closely interrelated and may develop an idealized sequence in ascending order 7, 4, 1, 6, 7. This sequence defines a transgressive cycle throughout algal biostrome deposition.

INTRODUCTION

This report concerns only the outcrop of the limestone members of the Pueblo Formation in Coleman, Brown, Eastland and Stephens counties, Texas. Eighty miles west of the outcrop area in the subsurface of Nolan, Fisher and Kent counties, the uppermost member of the Pueblo, the Camp Colorado (Noodle Creek) Limestone, is oil productive.

Although this report concerns only the outcrop, study of the Camp Colorado Limestone may lead to an understanding of the oil productive subsurface facies, and to a predictive model for oil exploration. This report provides a basis for future subsurface work in the Noodle Creek Limestone and similar carbonate units.

Lithofacies described in this study are known from Lower Wolfcampian rocks all around the Permian and nearby basins. Depositional systems resulting in these characteristic lithofacies scattered over a wide geographic area must be indicative of paleoenvironmental and paleogeographic conditions that were very similar and very widespread in early Wolfcamp time.

GEOLOGICAL SETTING AND LOCATION

During early Middle Pennsylvanian through late Permian time, a relatively stable platform persisted on the eastern shelf of the West Texas Permian Basin, which had developed on the early Pennsylvanian Concho platform (Cheney and Goss, 1952). Thousands of feet of sediments were deposited on this stable shelf as it tilted gradually westward in response to sediment loading and the deepening of the Midland Basin through Pennsylvanian and Permian time. East of the shelf lay the Ouachita Mountains and exposed Fort Worth Basin piedmont; north of the shelf was the Wichita structural system in southern Oklahoma; and southward the shelf sediments apparently deflected around the Llano structural complex (Figure 1) (Brown, 1969a). A repetitive sequence of thin persistent limestones interstratified with thicker cratonic delta deposits accumulated on the eastern part of the shelf.

The limestones coalesced to build up a thick carbonate sequence on the prograding western edge of the shelf 90 miles west of the study area (Wermund, 1974).

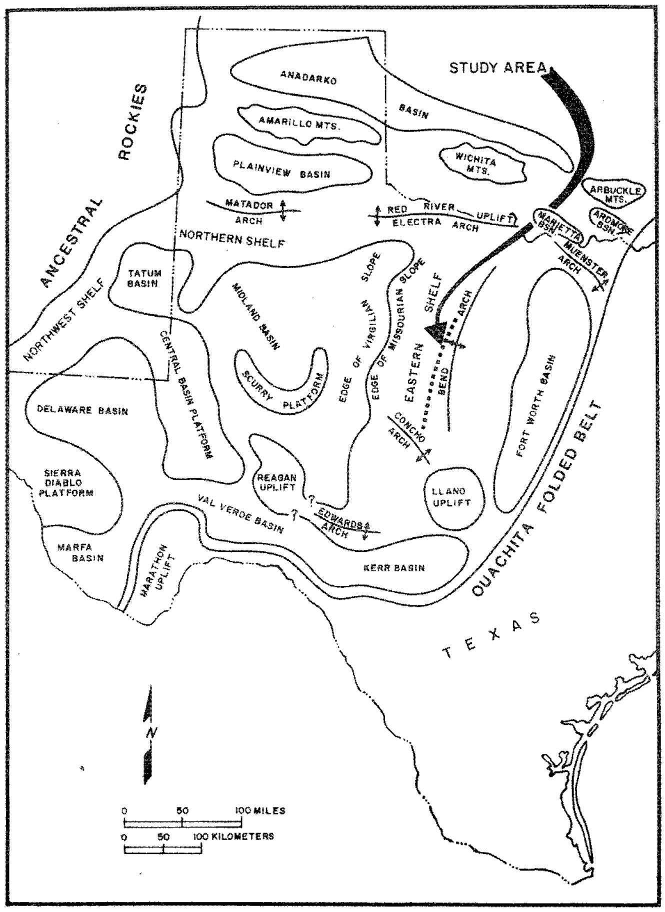


Figure 1. Tectonic elements of Upper Pennsylvanian deposition in north central Texas. Modified from Brown, 1969a.

Each of the sequences displays an orderly vertical arrangement of facies (Brown, 1969a, p. 25). The facies sequence consists of, in ascending order: 1) thin persistent limestone beds; 2) clay shale facies with marine fossils at the base and silty unfossiliferous shale at the top; 3) elongate (east-west) sandstone bodies, laterally equivalent to shale facies, with limestone lenses, coals and lenticular sandstone bodies; 4) shale facies with sheet sandstones and coals and 5) basal limestones of the overlying sequence. There are many local variations on this theme. The Pueblo Formation is one such sequence deposited on this stable shelf.

Cretaceous and Recent erosion has exposed a north northeast-south southwest trending outcrop belt of westward dipping Pennsylvanian and Permian sediments, unconformably onlapped by Cretaceous rocks (Figure 2). A Cretaceous outlier, the Callahan Divide, separates the Pennsylvanian-Permian outcrop belt into the Colorado River Valley and Brazos River Valley segments (Figure 2). Correlation problems persist because of the differences in character of the outcrops between the Brazos and Colorado River valleys.

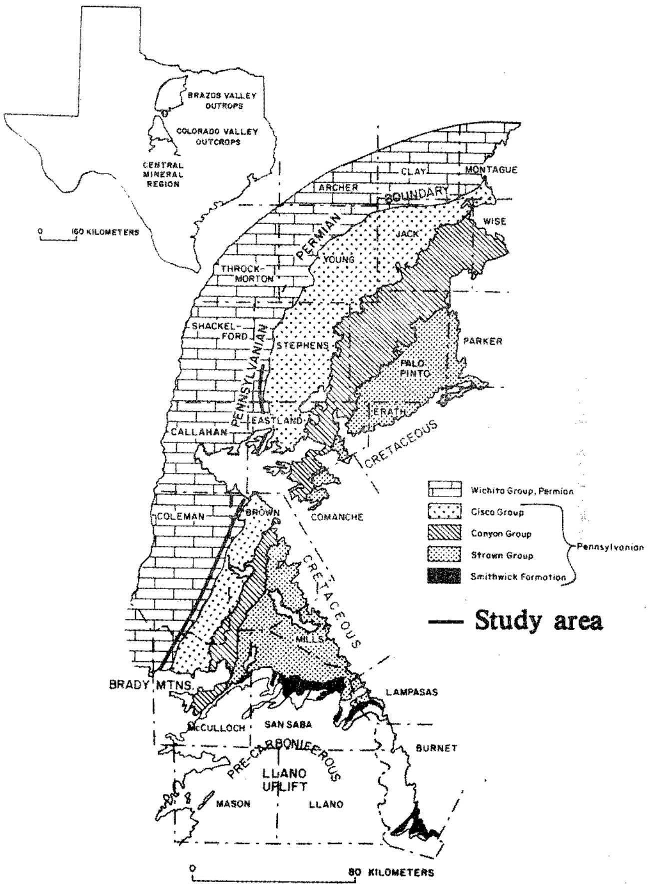


Figure 2. Location map of Pennsylvanian and Permian outcrops in north central Texas. Modified from Kier, Brown, and McBride, 1980.

The Pueblo Formation of this study crops out in a narrow belt one half to three miles wide extending from the Brady Mountains in McCulloch County northeast through Coleman, Brown, Eastland (where it is onlapped by Cretaceous rocks) and Stephens counties. It is overlain by the Moran Formation (Permian) and underlain by the Harpersville Formation (Pennsylvanian) (Figure 3). The formation dips west-northwest at less than 1 degree, and strikes N 10 degrees E (Brown, 1969b).

The age of the Pueblo Formation was a subject of controversy for many years. It is considered in this article to belong to the Lower Permian Wolfcampian Series as a member of the Wichita Group.

SYSTEM	SERIES	GROUP	FORMATION	MEMBER	LENTIL
PERMIAN	WOLFCAMPIAN	WICHITA	PUTNAM	COLEMAN JUNCTION LIMESTONE SANTA ANNA BRANCH SHALE	
			MORAN	SEDWICK LIMESTONE SANTA ANNA SHALE GOULDBUSK LIMESTONE WATTS CREEK SHALE	
			PUEBLO	CAMP COLORADO LIMESTONE SALT CREEK BEND SHALE STOCKWETHER LIMESTONE CAMP CREEK SHALE SADDLE CREEK LIMESTONE	COON MOUNTAIN SANDSTONE
		CISCO	HARPERSVILLE	WALDRIP SHALE	WALDRIP LS. III WALDRIP LS. II WALDRIP LS. I
PENNSYLVANIAN	VIRGILIAN			CHAFFIN/CRYSTAL FALLS LIMESTONE QUINN CLAY	
			THRIFTY	BRECKENRIDGE LIMESTONE AVIS SANDSTONE	
			GRAHAM	GUNSIGHT LIMESTONE NECESSITY SHALE BUNGER LIMESTONE GONZALES CREEK SHALE	
		CANYON	HOME CREEK	HOME CREEK LIMESTONE	

Figure 3. Stratigraphic column, north central Texas study area.

PREVIOUS WORK

The previous work in this area can be characterized by three different approaches to the region. Early studies attempted to describe, correlate and classify the rock sequence because of the known presence of coal beds and later oil and gas fields (Cummins, 1891; Drake, 1893; Plummer, 1919; Plummer and Moore, 1921). Classifications were refined in a second major phase (1930-1960) which included a controversy over where to place the base of the Permian in the rock sequence (Roth, 1931; Lee, Nickell and Henbest, 1938; Cheney, 1940; Gupta, 1975). Present work in the area (1960 to date) has primarily centered on description and interpretation of the depositional environments of the rocks, with intent to predict stratigraphic relationships and possibly thereby predict methods of finding hydrocarbons (McGowen, 1964; L.F. Brown, 1969a, 1969b; Galloway and Brown, 1972; Erxleben, 1975; Wermund, 1975).

METHODS USED IN THIS STUDY

Sections to be measured were selected using the Geologic Atlas of Texas, Abilene and Brownwood sheets, topographic quadrangles, and by walking the outcrop belt. From January to June, 1980, nine complete measured sections, 12 partial measured sections and 10 localities were measured using a meterstick and handlevel. This study intersects McGowen's (1964) study in Stephens County to the north, and extends south 90 miles along the narrow outcrop belt to the Colorado River on the south, where Cretaceous rocks of the Brady Mountains overlie the Pueblo Formation (Figure 4). The sections are almost all in river beds, creek valleys or roadcuts. Numerous photographs were taken and some appear in this study. For the detailed measured sections and localities referred to in this study, see VanDerLoop, 1983.

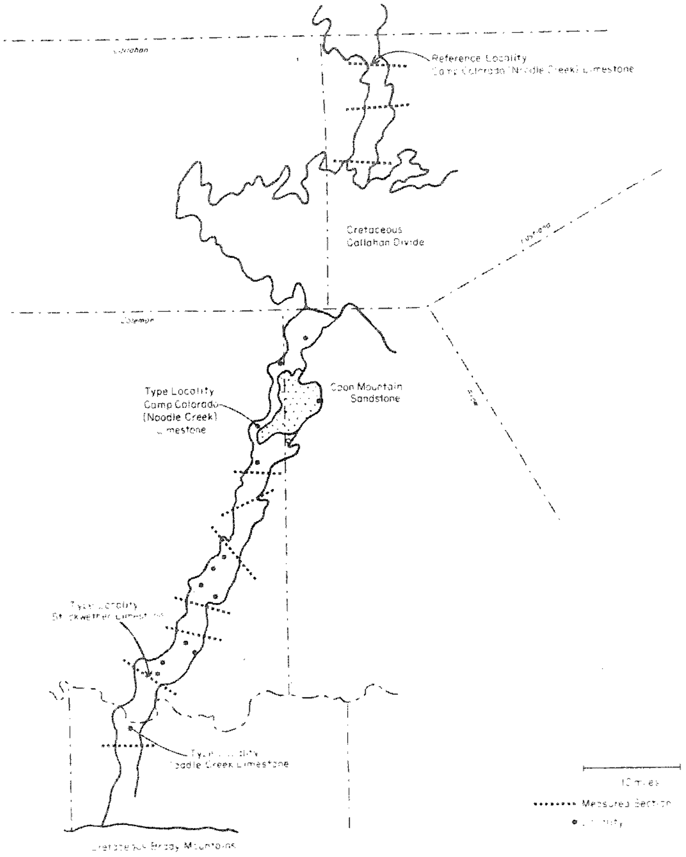


Figure 4. Location map of outcrop belt, measured sections and localities.

Over two hundred eighty-five carbonate rock samples were collected during the course of this study. This represents a density of one sample every 23 centimeters (9 inches) of limestone measured. About 70% of these were slabbed and 36 samples were polished. One hundred fifty-seven samples were selected and thin sections were made. Forty photomicrographs of selected thin sections were made.

STRATIGRAPHIC LOCATION

The Pueblo Formation consists of, from bottom to top, the Saddle Creek Limestone Member, the Camp Creek Shale Member, the Stockwether Limestone Member, the Salt Creek Bend Shale Member and Camp Colorado Limestone Member. The Coon Mountain Sandstone Lentil is present in northwestern Brown County and is a lateral equivalent to the Salt Creek Bend Shale, the Stockwether Limestone, the Camp Creek Shale, and replaces eroded portions of the Saddle Creek Limestone in that area.

Resistant layers form a series of low relief cuestas dipping to the west at about 50 feet per mile (Figure 5).

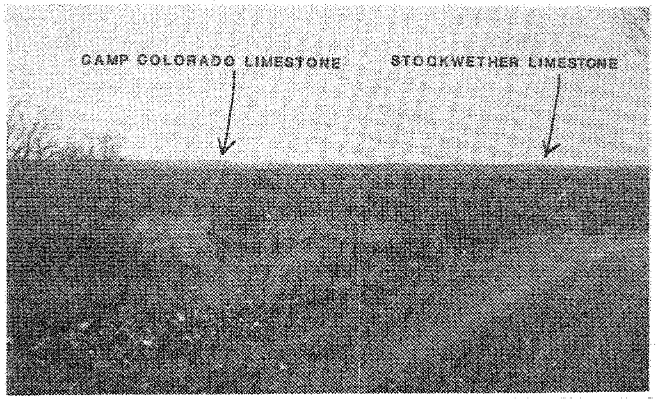


Figure 5. Camp Colorado and Stockwether Limestone cuestas, southern McCulloch County, Texas.

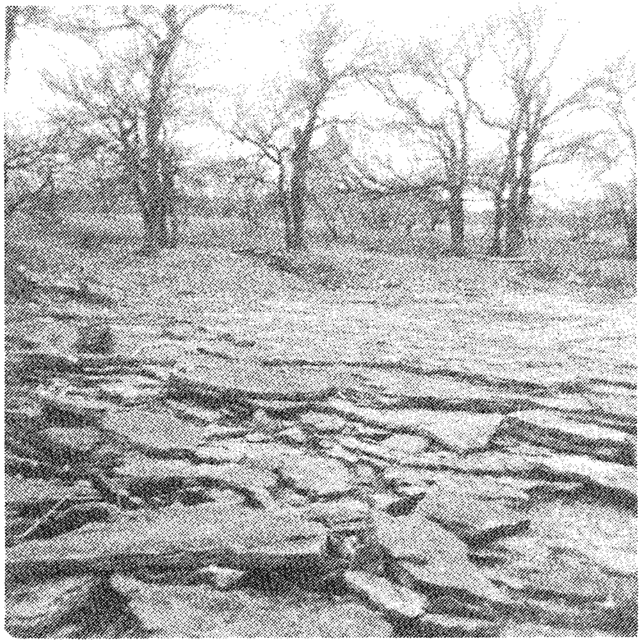


Figure 6. Saddle Creek Limestone, Locality D, bed of Bull Creek, southern Coleman County, Texas.

SADDLE CREEK LIMESTONE MEMBER

The Saddle Creek Limestone was named by Drake (1893) for outcrops near the junction of Saddle Creek and the Colorado River. The type locality, designated by Moore (1949b) is in McCulloch County, Texas, along an east-west gravel road six miles west-northwest of Fife and one mile north of FM 765, on bluffs on the eastern side of Saddle Creek, just south of the Colorado River.

Across the study area from northern McCulloch to southeastern Stephens County, the Saddle Creek Limestone is a persistent and mappable unit. It is primarily a light gray weathering, flaggy-bedded to thick-bedded limestone which forms subdued escarpments and ledges. The best exposures are in road cuts, creek banks and creek beds. The limestone unit is 1.5 meters (4.9 feet) thick at the type locality in McCulloch County, and thins to 0.5 meters (1.6 feet) thick in southeastern Coleman County, where it lies just two to six meters (6.5 to 20 feet) above the Waldrip Bed No. 3 Formation. Just south of Jim Ned Creek, in northwestern Brown County, the Saddle Creek Limestone is exposed at the top of a clay pit quarry seven miles southwest of Grosvenor along FM 5687, where it is underlain by the buff to red variegated Harpersville sediments, containing Waldrip Limestone Beds No. 3 and No. 2 (Figure 7).

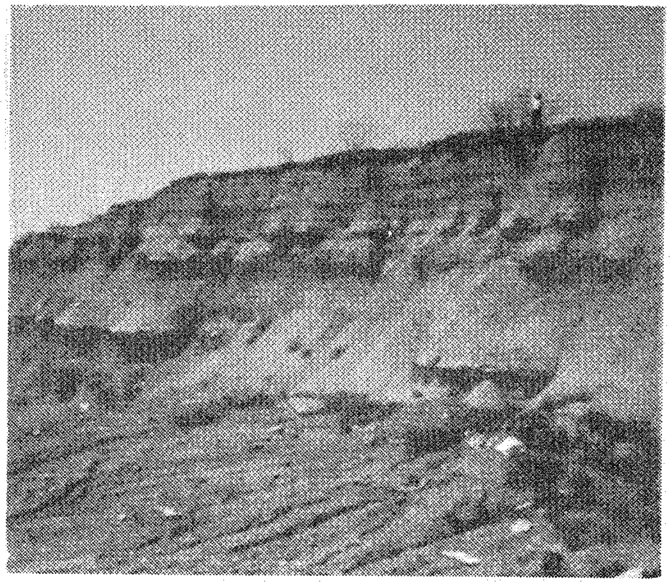


Figure 7. Locality M: Saddle Creek Limestone overlying Harpersville Formation, Waldrip Shales and Waldrip Limestones No. 3 and No. 2.

Waldrip Limestone Bed No. 3 is present in the southern part of the study area and contains the stratigraphically lowest known incidence on the Eastern Shelf of the fusulinid genus **Schwagerina**. The base of the Permian System thus has commonly been considered to be in the upper part of the Harpersville Formation, below Waldrip Limestone Bed No. 3. Winslow (1983) reported **Schwagerina [Pseudofusulina** of some authors) from a limestone lens in the upper part of the Harpersville Formation between Cisco and Breckenridge in Stephens County, Texas.

North of Jim Ned Creek in northern Coleman County both the Saddle Creek Limestone and Waldrip Limestone Bed No. 3 have been eroded during deposition of the Coon Mountain Sandstone, which represents a fluvial deltaic system correlative to Upper and Lower Tannehill sandstones of the subsurface (Plummer and Moore, 1921; Rothrock, 1961b; Eargle, 1960).

North of the Callahan Divide Cretaceous overlap in Eastland County, Saddle Creek outcrops are again found near Cisco. A traceable Waldrip Limestone Bed No. 3 is not present here (Figure 8). The limestone reported by Winslow (1983) in Stephens County is stratigraphically in the position of Waldrip Limestone Bed No. 3 and occurs 20 feet below the Saddle Creek Limestone but is not continuous. Because the Saddle Creek Limestone is the lowest mappable unit at the base of the Permian System, it therefore is considered the base of the Pueblo Formation for the purpose of this study.

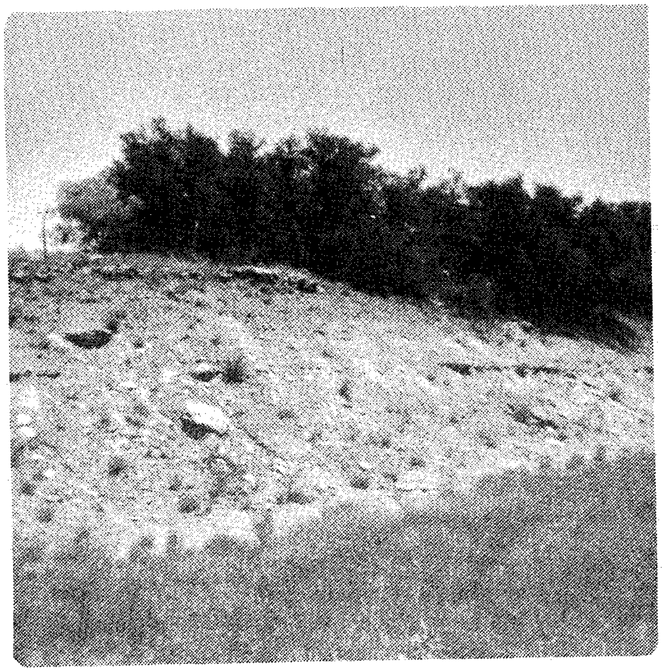


Figure 8. Locality P: Saddle Creek Limestone on old Highway 80, 1 mile west of Cisco in Eastland County, Texas, Saddle Creek caps the roadcut, Waldrip Limestone No. 3 is not present here.

STOCKWETHER LIMESTONE MEMBER

The Stockwether Limestone is the middle member of the Pueblo Formation. It was named by Drake (1893) for outcrops on the Stockwether ranch on Bull Creek, near the junction of Bull Creek and the Colorado River in southern Coleman County, Texas. The type locality is currently the property of Robert See, Coleman, Texas, and is accessible by permission only.

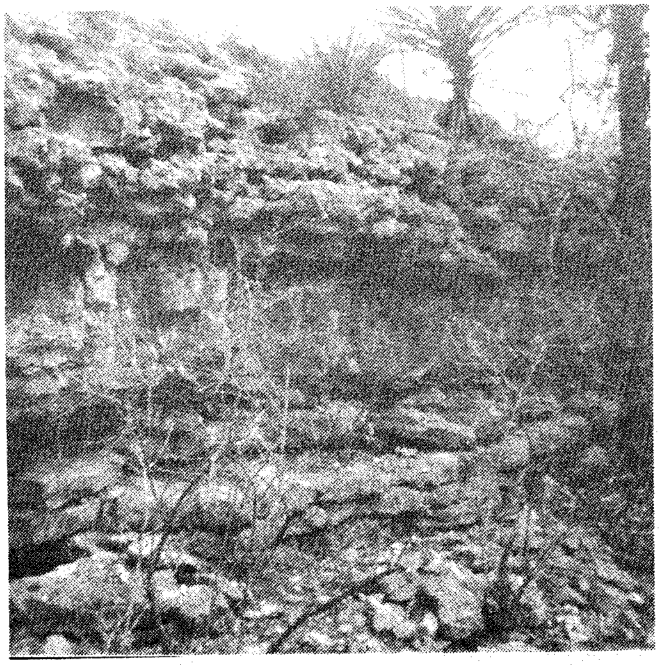


Figure 9. Measured section 2, type locality of Stockwether Limestone, bank of Bull Creek, Robert See ranch, southern Coleman County, Texas.

Figure 10. Home Creek locality, Stockwether Limestone, eastern Coleman County, Texas, along Highway 283, seven miles south of Santa Anna, Texas.

The Stockwether Limestone varies greatly in thickness across the study area. In the southern part, near the type locality, it is up to 3.8 meters (12.5 feet) thick. At Dry Creek, four miles to the north, it is one meter (3.3 feet) thick; three miles north of Dry Creek, at the Home Creek exposures, the unit has again thickened to about 3.25 meters (10.6 feet). Five miles north of Home Creek, the limestone is only 0.45 meter (1.5 feet) thick where present and no longer forms a resistant escarpment. From Santa Anna north to Jim Ned Creek the Stockwether outcrops are quite thin, 10 cm (4 inches) (Figure 11) and very difficult to trace. From Jim Ned Creek north about 10 miles to Pecan Bayou, no Stockwether Limestone is present; instead the Coon Mountain Sandstone, a medium grained red sandstone facies, occurs in this interval. A thin, 10 cm (4 inches) sandy fossiliferous burrowed limestone, overlain by red to buff sandstone and shale (Figure 11), may be representative of the Stockwether interval because it is present at approximately the correct stratigraphic position as measured. Terriere (1960, p. 24) noted that the Stockwether was poorly exposed in this area and that it had "been removed by channel cutting." At the north end of the study area in southwestern Stephens County, the Stockwether varies in thickness from 1.3 to .75 meters (4.3 to 2.5 feet) and is intermittently present, having been locally removed by erosional sandstone channels probably of Late Tannehill age.

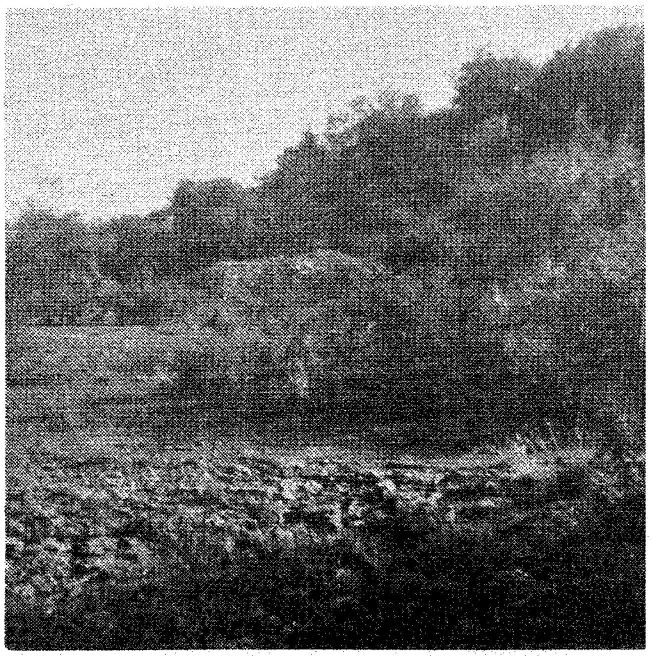


Figure 11 Stockwether Limestone, fusulinid bed capped by sandstone, measured section 6 four miles north of Santa Anna, Texas.

CAMP COLORADO LIMESTONE MEMBER

The Camp Colorado Limestone is the uppermost member of the Pueblo Formation. It was named by Drake in 1893 for outcrops at old Fort Colorado on the banks of Jim Ned Creek in northern Coleman County. Its type locality is this outcrop at Fort Colorado.

Two reference localities for the Camp Colorado Limestone, besides the type locality at old Fort Colorado are at the roadcuts along Highway 380, 8.5 miles north of Cisco in western Eastland County, and at Locality C, near a curving gravel road between Rockwood and Gouldbusk, five miles west of Rockwood. Permission must be obtained from E.W. Scott, Coleman, Texas, to visit the second reference locality.

The subsurface terminology for the Camp Colorado Limestone is the Noodle Creek Limestone.

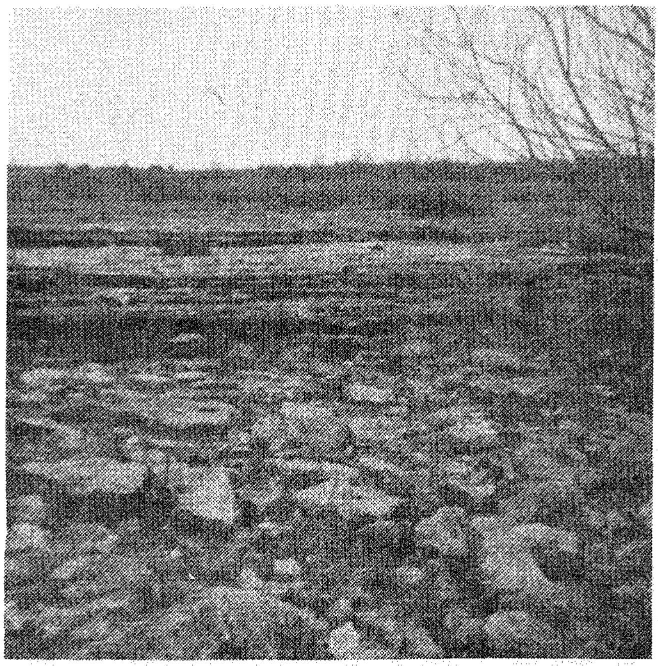


Figure 12. Measured section 1, bed of Colorado River, Camp Colorado Limestone (lower bed), nine miles west-northwest of Fife, on the border of McCulloch and Coleman counties, Texas.

Almost everywhere in the outcrop belt the member consists of two beds of limestone separated by 9 meters (29.5 feet) to 0.5 meters (1.6 feet) of shale, with minor lenses of sandstone and sandy limestone. A variable escarpment is usually present with the lower limestone bed cropping out below the bluff and the upper member capping the bluff.

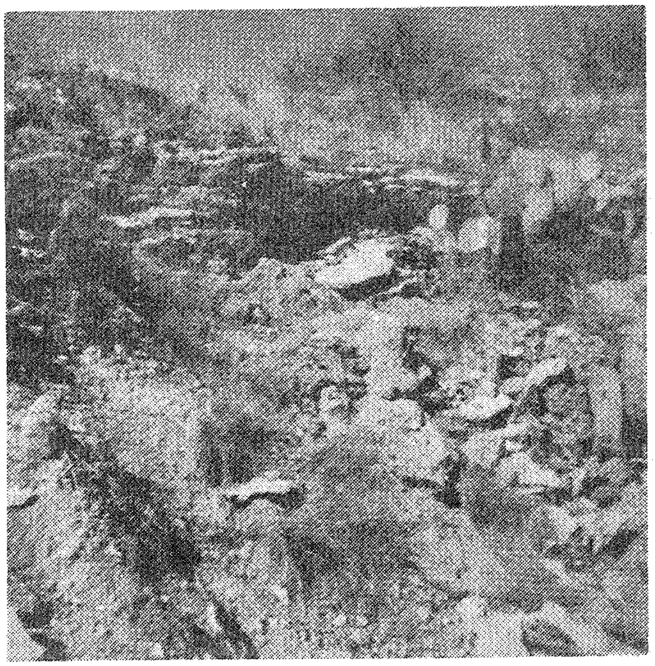


Figure 13. Locality C, Camp Colorado Limestone, lower bed, five miles northwest of Rockwood, southern Coleman County, Texas.

The Camp Colorado Limestone ranges in thickness from 10 meters (32.8 feet) in southern Coleman County to 8 meters (26.2 feet) in northern Coleman County at the type locality, to 4 meters (13 feet) in Eastland County at the northern end of the study area. The upper limestone bed of this member ranges in thickness from 1.7 to 0.1 (5.5 to .3 feet); the lower limestone is 1.9 meters (6.2 feet) thick at the southern part of the study area, 0.4 meter (1.3 feet) thick in the central part at measured section 4, thickens to 1.8 meters (5.9 feet) at the type locality and is 1.0 meter (3.3 feet) thick in Eastland County, north of Cisco, at the northern part of the study area. The Camp Colorado units are gray to buff weathering massive, block or flaggy bedded, resistant limestones.

CARBONATE LITHOFACIES IN IN THE PUEBLO FORMATION

There are seven major carbonate lithofacies in the Pueblo Formation. The rocks were described using Folk's (1962) classification. Categorization of the limestones into lithofacies types was based on the characteristic fauna present. All gradations of Dunham's (1962) textural classification could be recognized in each lithofacies.

Lithofacies 1 through 7 are present in almost every member of the Pueblo Formation. An eighth lithofacies, consisting of algal oncolites, is present at only one locality in the Salt Creek Bend Shale, is considered minor, and is not discussed in this paper. The numbering system is arbitrary, although lithofacies 1, in general, represents a low energy environment in that it often contains carbonate mud. Lithofacies 7 shows the most evidence of high energy; "**Osagia**" (blue-green algal-foraminiferal consortium) coatings occur on all sides of grains, and, of all the lithofacies, packstone to grainstone texture is most often present in lithofacies 7.

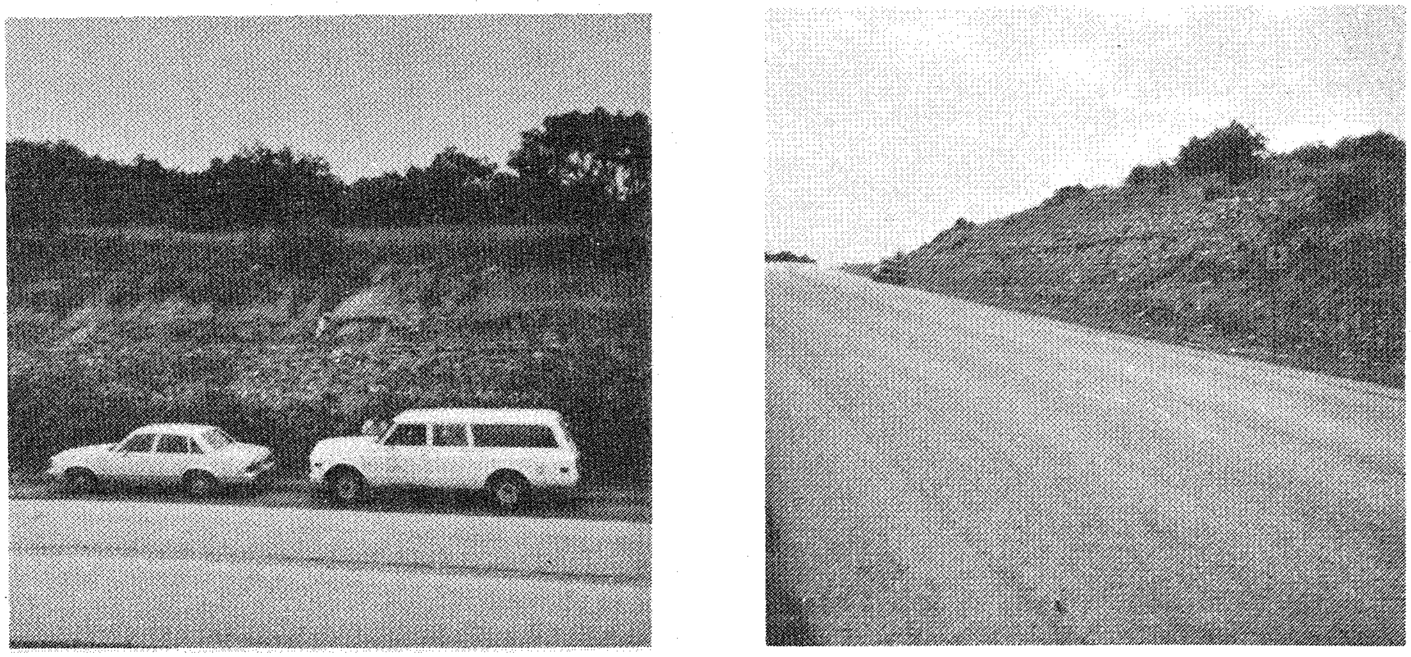


Figure 14 a, b. Measured section 9, north of Cisco along Highway 6, Eastland County, Texas.

Lithofacies 1:
Tubiphytes phylloid algal biomicrite-biomicrudite (wackestone-packstone)

Lithofacies 1 is a light gray weathering, flaggy-bedded **Tubiphytes** phylloid algal [**Eugonophyllum?**] biomicrite-biomicrudite. **Tubiphytes** encrust the phylloid algae blades, and also float freely in the pelletal matrix; subbedding of **Tubiphytes** and phylloid algae flakes is occasionally present. Other components are fenestrate bryozoans (almost always present), brachiopods [**Composita**] with preserved spiralia, ostracodes and foraminifers. Chambered foraminifers such as **Globivalvulina** and **Bradyina** are locally abundant. Most abundant are the encrusting foraminifers **Tuberitina, Apterrinella** and **Tetrataxis.** Minor components are **Epimastopora** (a green dasycladacean alga), crinoids, corals, other bryozoa, pelecypods and gastropods. Locally, quartz silt or buff-yellow clay occurs in shelter structures beneath algal blades, but mostly these shelter structures are filled with pelletal micrite or spar (Figure 15a).

Lithofacies 2:
Sparse biomicrite (mudstone)

Lithofacies 2 is a sparse biomicrite, commonly cropping out as white to gray blocky weathering beds. It is not an abundant lithology. Scattered megafossils occurring in this lithofacies are phylloid algae, brachiopods, crinoids and foraminifers. Quartz silt is locally present. The lithofacies is always burrowed, and locally it is highly spicular (Figure 15b).

Lithofacies 3:
Crinoid biomicrite (mudstone to grainstone)

Lithofacies 3 is a crinoid biomicrite, light to dark gray, blocky weathering and medium bedded. This lithofacies ranges from a sparse crinoid biomicrite to packed biomicrudite or locally biosparite. Crinoid stems weather out on bed surfaces. Other components are phylloid algal fragments, fenestrate bryozoans, ostracodes and abundant chambered foraminifers, especially the fusulinids **Oketaella** and **Ozawainella.** The matrix is often pelletal and burrows are common (Figure 15c).

Lithofacies 4:
Fusulinid biomicrite (wackestone-packstone)

This lithofacies, where it does occur, generally is the lowest bed in a limestone member. It weathers dark gray to pale greenish gray to dark reddish purple, is generally thin bedded, and often contains traces of quartz silt. The fusulinids are commonly **Triticites, Leptotriticites** and **Schwagerina** species. Other components are locally abundant crinoids, phylloid algal fragments, fenestrate bryozoans, **Ozawainella, Oketaella,** and a few other chambered foraminifers like **Globivalvulina** (Figure 15d).

Lithofacies 5:
Crinoid-brachiopod-bryozoan biomicrite to biomicrudite (mudstone to wackestone)

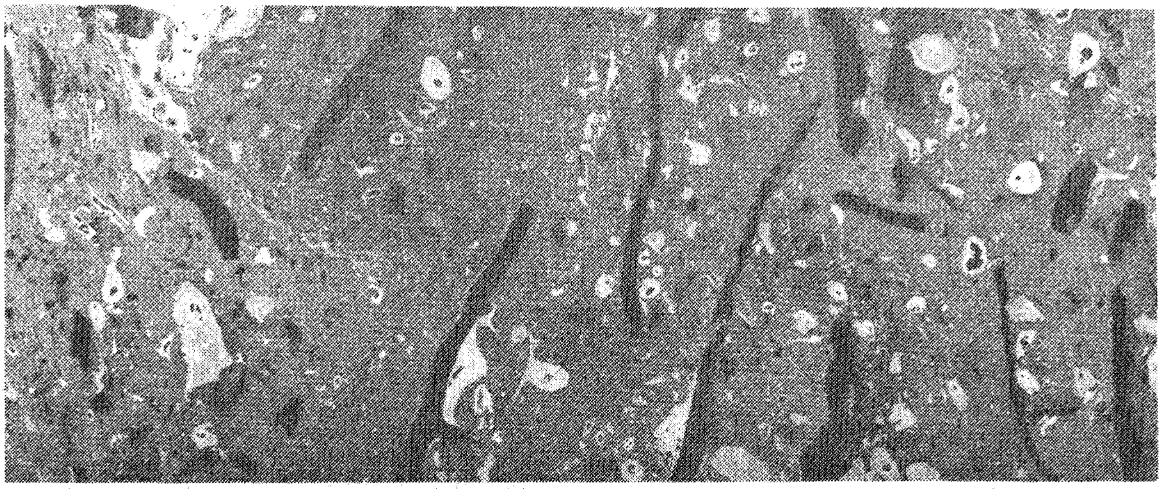
This lithofacies ranges from a biomicrite to biomicrudite fabric. Where it is a biomicrudite it is coarse-grained and consists of whole, unabraded fossil fragments, which may be in growth position (bryozoan mounds occur locally at measured section 9 in the Camp Colorado Limestone upper bed). The biomicrite lithofacies fabric can be very fine-grained and well sorted. The limestone generally weathers in flagstones with a buff to rusty color except where extensively burrowed or fine grained; then it weathers in medium beds and is resistant. It is often encased in shales. Besides the main components, lithofacies 5 contains phylloid algae, pelecypods, echinoid spines, ostracodes, trilobites, occasional **Epimastopora,** and chambered and encrusting foraminifers. Quartz silt is common throughout the unit. This lithofacies occurs mostly in the Camp Creek Shale Member, Salt Creek Bend Shale Member and in the Camp Colorado Limestone between the two main limestone beds (Figure 15f).

Lithofacies 6:
Foraminiferal algal biomicrite (wackestone-packstone)

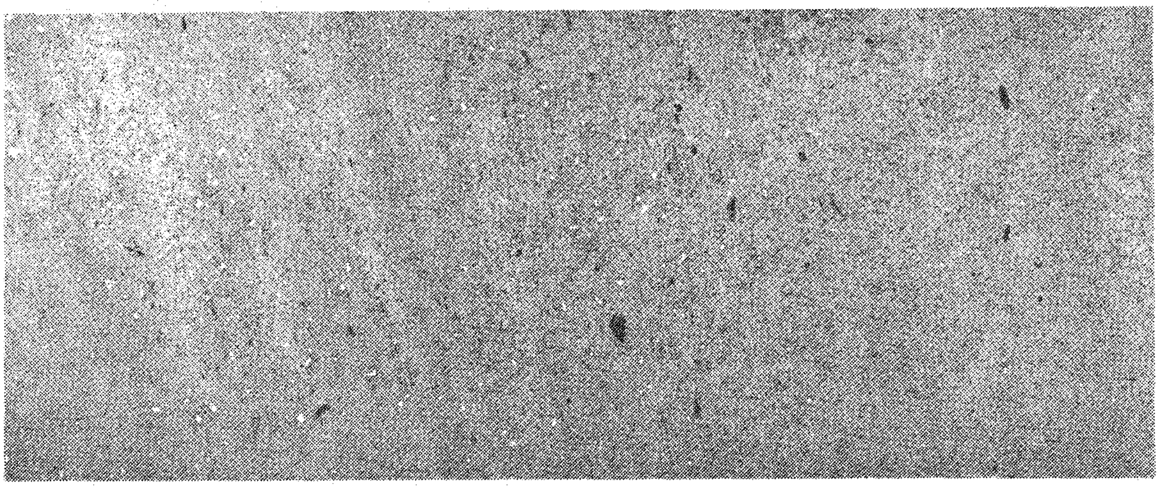
Lithofacies 6 is well-sorted, fine-grained, generally weathers light gray to buff, and forms blocky resistant beds. Besides abundant broken and abraded algal fragments it has crinoids, **Ozawainella, Oketaella, Apterrinella,** staffellids, other chambered foraminifers, brachiopods, bryozoans and ostracodes. It is often burrowed. Its fossil composition is similar to lithofacies 1, but with different foraminifers and a radially different well-sorted, fine-grained texture. It frequently occurs in close association with lithofacies 1 (Figure 15g).

Lithofacies 7:
Coated grain lithofacies

The seventh facies is characterized by coated grains (superficial oolites of Bretsky, 1966, p. 122). This coating is the commensal growth of blue green algal and encrusting foraminifers termed "**Osagia**" (Johnson, 1946, p. 1102). There are three subcategories recognized: lithofacies 7a: "**Osagia**" coated grain biomicrite-biosparite; lithofacies 7b: Sandy "**Osagia**" coated grain biomicrite-biosparite; and lithofacies 7c: Sandy fusulinid "**Osagia**" coated grain biomicrite-biosparite. This rock is commonly rusty weathering, burrowed and thin to medium bedded.



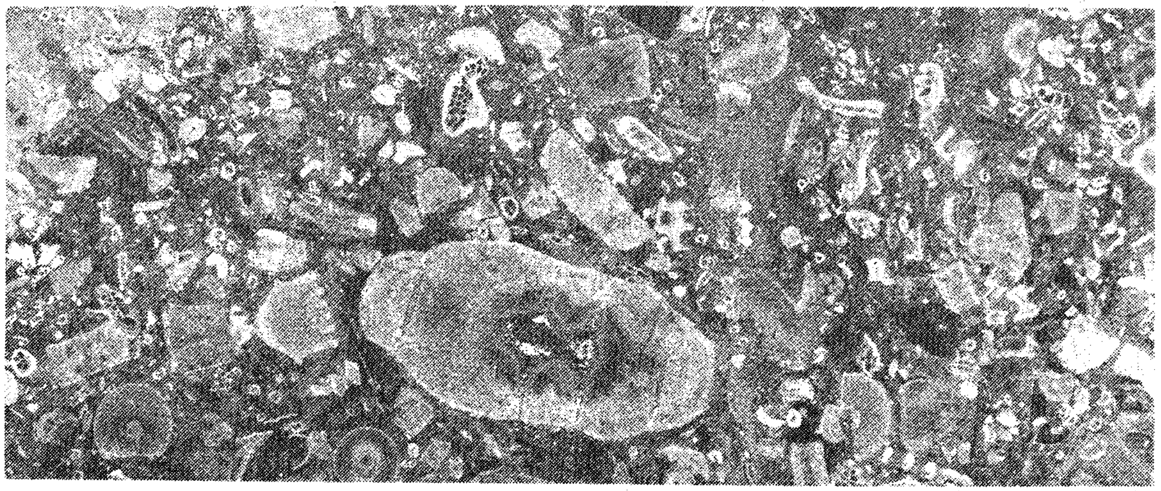
15a



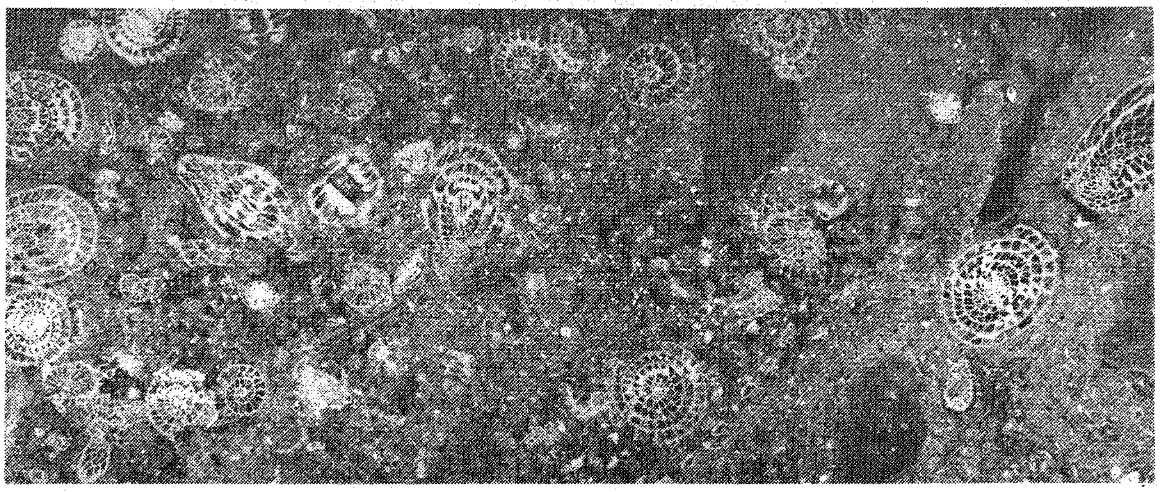
15b

Figure 15a: Sample 2-5, measured section 2, Saddle Creek Limestone, Bull Creek area, southern Coleman County, Texas. Lithofacies 1, **Tubiphytes** phylloid algal biomicrudite (wackestone). **Eugonophyllum** (?), fenestrate bryozoans. **Tubiphytes** encrust algal fragments, with algal fragments draped over the encrustations. Clean micrite matrix. Algae replaced by one or two generations of fibrous isopachous cement and coarse spar cement. Negative print, 5.2 X.

Figure 15b: Sample 1-C, measured section 1, Saddle Creek Limestone, Colorado River, McCulloch County, Texas. Lithofacies 2, sparse biomicrite (mudstone). Spicular; spicules suboriented in beds 1 mm thick. Sparse ostracodes, brachiopod fragment. Negative print, 5.2 X.



15c

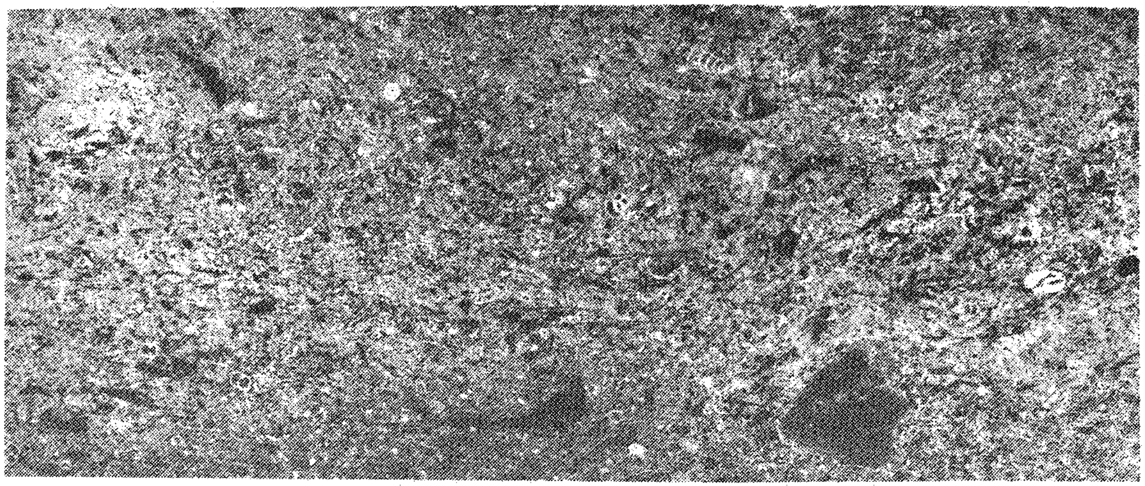


15d

Figure 15c: Sample 7-16, measured section 7, Camp Colorado Limestone, Coleman County, Texas. Lithofacies 3, crinoid biomicrite (packstone). Fenestrate and fistuliporid bryozoans, ostracode, algal fragments, **Oketaella, Climacammina.** Matrix recrystallized to microspar. Negative print, 5.2 X.

Figure 15d: Sample 1-7a, measured section 1, Stockwether Limestone, Colorado River area, McCulloch County, Texas. Lithofacies 4, fusulinid biomicrite (packstone). Trepostomate and fenestrate bryozoans, crinoids. Transition on this slide from pelletal crinoid biomicrite to fusulinid [**Leptotriticites**] biomicrite. Negative print, 5.2 X.

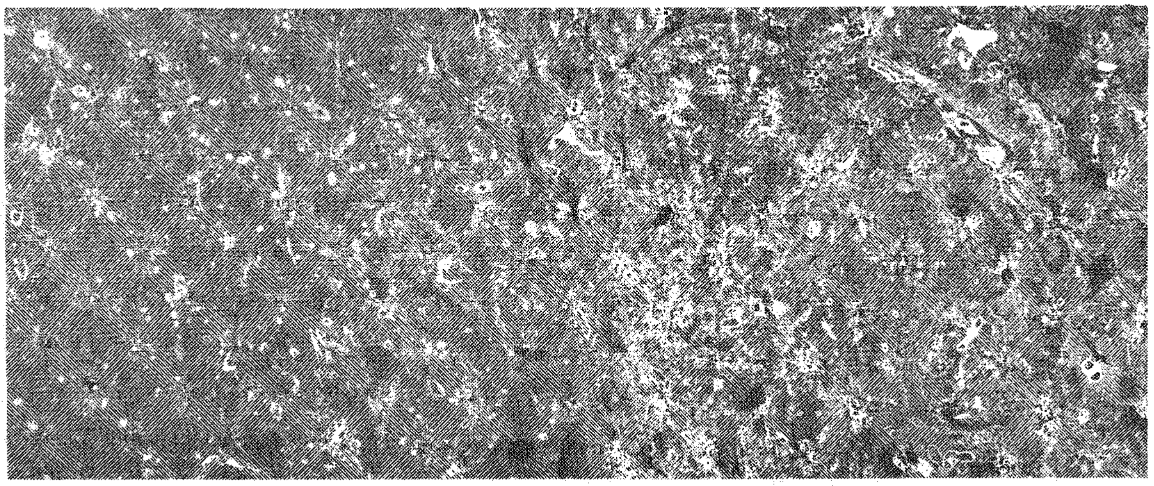
15e



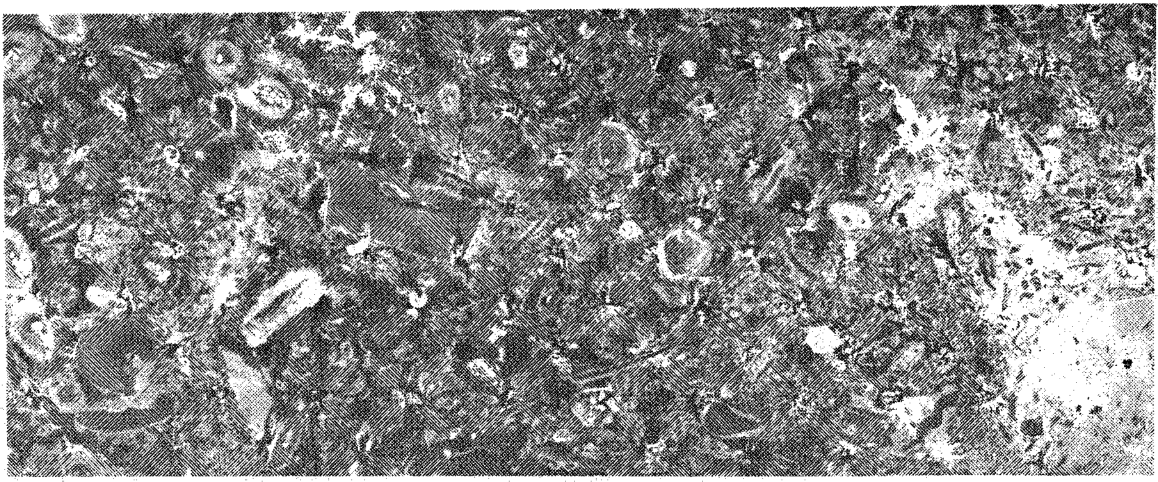
15f

Figure 15e: Sample 9-R3, measured section 9, Stockwether Limestone, north of Cisco, Stephens County, Texas. Lithofacies 5, crinoid-brachiopod-bryozoan biomicrite-biosparrudite (grainstone). Very coarse grained. Trepostomate, fenestrate and fistuliporid bryozoans, encrusting foraminifers. Negative print, 5.2 X.

Figure 15f: Sample 7-1, measured section 7, Saddle Creek Limestone, eastern Coleman County, Texas. Lithofacies 5, crinoid brachiopod bryozoan biomicrite (wackestone). 1 fine grained quartz silt. Fine grained, glauconitic. Spicules, pelecypods, ostracodes, brachiopod spine, fenestrate and fistuliporid bryozoans, **Bradyina, Climacammina, Oketaella.** Micrite matrix partly recrystallized. Negative print, 5.2 X.



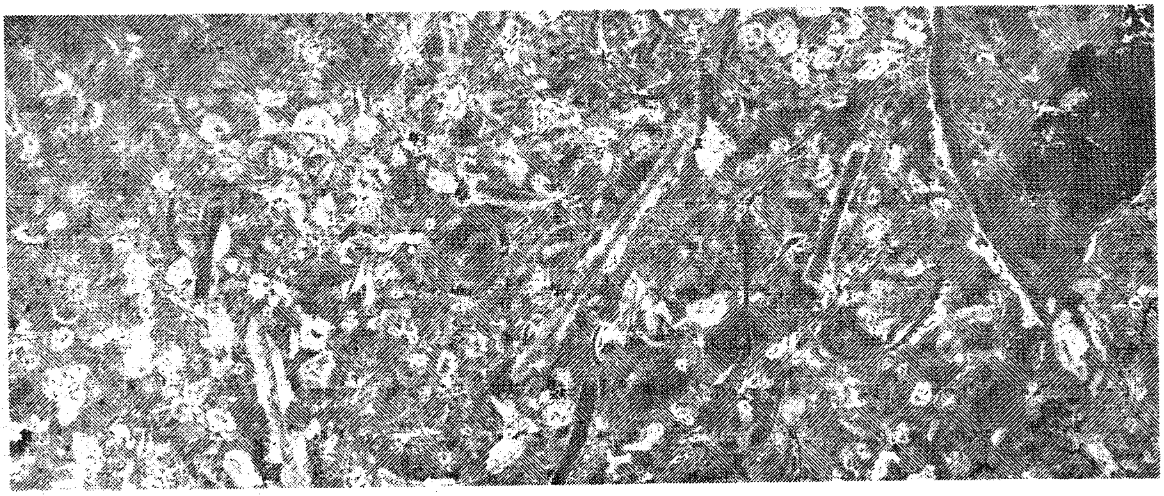
15g



15h

Figure 15g: Sample 4-11, measured section 4, Home Creek, Stockwether Limestone, Coleman County, Texas. Lithofacies 6; foraminiferal algal biomicrite (wackestone), well sorted, very fine grained. Ostracodes, **Tubiphytes**, brachiopod spines, fistuliporid and fenestrate bryozoans, heavily coated algal fragment, **Globivalvulina**, **Tuberitina**, **Nodosinella**, **Oketaella**, **Apterrinella**, **Ozawainella**, **Bradyina**, **Climacammina**. Locally partly recrystallized to spar. Negative print, 5.2 X.

Figure 15h: Sample 7-11, measured section 7, Camp Colorado Limestone, Coleman County, Texas. Lithofacies 7a: "**Osagia**" coated grain biosparite (packstone), medium to fine grained, well sorted. Crinoids, fenestrate and trepostomate bryozoans, brachiopods, ostracodes, encrusting foraminifers, gastropods, echinoid spines, algal fragments, pelecypods, **Apterrinella**, **Nodosinella**, **Oketaella**, **Globivalvulina**, **Ozawainella**. Patches of hematitic micrite cement. Burrow fillings of sparse spicular micrite. Recrystallization (?) has clumped limonitic cement. Negative print, 5.2 X.

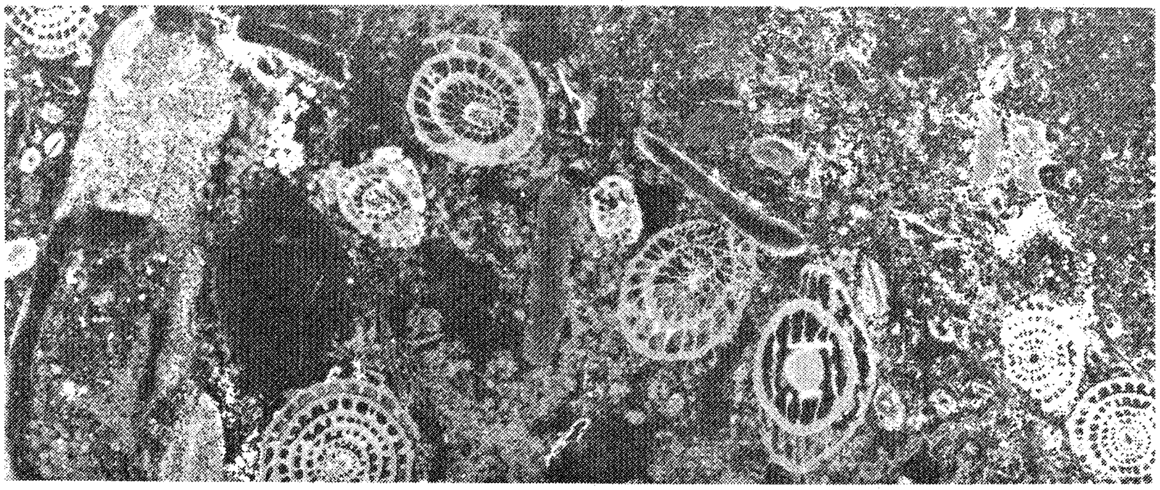


15i

15j

Figure 15i: Sample C-4, Camp Colorado Limestone, southern Coleman County, Texas. Lithofacies 7b: sandy "**Osagia**" coated grain biomicrite (packstone). Coated algal fragments, pelecypods, ostracodes, fistuliporid bryozoans, **Epimastopora** pellets, 1 fine grained quartz sand. **Climacammina, Bradyina, Apterrinella, Oketaella, Tuberitina, Nodosinella, Globivalvulina,** encrusting foraminifers. Negative print, 5.2 X; quartz sand appears black.

Figure 15j: Sample 6-6, measured section 6, Bradley's Hill, Salt Creek Bend Shale, Coleman County, Texas. Lithofacies 7b, sandy "**Osagia**" coated grain biosparite (wackestone). Phylloid algae, brachiopods, dasycladacean algae, chambered foraminifers [**Oketaella, Ozawainella, Globivalvulina, Tuberitina**], fenestrate and trepostomate bryozoans, crinoid stems, ostracodes, trilobite, 10-20 fine grained subrounded to subangular quartz sand. Poorly washed fossil fragments all micritized, abraded, coated with "**Osagia.**" Silica replacement of calcite spar. Negative print, 5.2 X, quartz sand appears black.



15k

Figure 15k: Sample 2-9, Camp Creek Shale, Bull Creek, southern Coleman County, Texas. Lithofacies 7c, sandy fusulinid "**Osagia**" coated grain biomicrudite (packstone). 20-30 well sorted subangular quartz silt in matrix. Crinoids, brachiopod fragment, abraded, micritized; **Leptotriticites** fusulinids; whole pelecypod, spar filled. Algae, **Tubiphytes,** pellets, fenestrate and fistuliporid bryozoans, **Globivalvulina, Staffella.** Burrow filled with silty micrite crosses slide. Negative print, 5.2 X. Quartz sand appears black.

Lithofacies 7a:
"**Osagia**" coated grain biomicrite-biosparite (wackestone-packstone)

"**Osagia**" coated fragments are predominantly phylloid algae, **Epimastopora**, crinoids, brachiopods, fenestrate bryozoans, ostracodes, pelecypods and gastropods. Foraminifers are abundant, and are rarely coated. They include **Ozawainella**, **Oketaella**, **Globivalvulina**, staffellids, **Nodosinella** and one encrusting foraminifer **Apterrinella**. The matrix is often pelletal. Lithofacies 7a is most abundant in the lower bed of the Camp Colorado Limestone in the southern part of the study area, and is often the lowest bed in a sequence or the highest bed in a sequence. It is burrowed, weathers in blocks and is resistant (Figure 15h).

Lithofacies 7b:
Sandy "**Osagia**" coated grain biomicrite-biosparite (wackestone-packstone)

Components of this rock are very similar to those in lithofacies 7a, but may have up to 30%quartz sand. Lithofacies 7b is most common at the base of a carbonate unit, and is most abundant in the base of the lower bed of the Camp Colorado Limestone in the southern part of the study area, at Locality C and at measured section 5 (Figure 15i, j).

Lithofacies 7c:
Sandy fusulinid "**Osagia**" coated grain biomicrite-biosparite (wackestone-packstone)

This rock occurs only in the southern part of the study area, in central Coleman County, at the base of the Stockwether and the base of the Saddle Creek. Components are similar to other lithofacies 7 groups with the addition of fusulinids (Figure 15k).

DEPOSITIONAL ENVIRONMENTS IN PUEBLO FORMATION CARBONATE MEMBERS

Each of the carbonate facies can be assigned to a generalized depositional environment. Based on the study of modern carbonate sediments, paleoenvironments in ancient carbonates have been inferred by many authors (e.g. Wilson, 1975; Flügel, 1982). In the basic idealized facies pattern of a carbonate platform presented by Wilson (1975, p. 24-27), these seven Pueblo Formation lithofacies could represent parts of Wilson's facies zones 6, 7 and 8; winnowed platform edge sands, open marine platform facies, and restricted marine-tidal flat facies, respectively.

Wilson further divides Pennsylvanian-Lower Permian carbonate microfacies into eleven basic types (P1-P11), based on study of sections throughout western and midcontinent United States (1975, p. 209-211). Four of these correspond closely to some of the microfacies described in this study:

Wilson (1975, p. 209-211)	This Study
P6 Platy algal mud facies	Lithofacies 1 **Tubiphytes** phylloid algal biomicrite-biomicrudite
P5 Fusulinid coquina	Lithofacies 4 Fusulinid biomicrite (packstone)
P2 Very fossiliferous shale	Facies 5 Crinoid Brachiopod-bryozoan biomicrite-biomicrudite
P8 Calcarenite shoals	Facies 7a, b, c Coated grain "**Osagia**" biomicrites-biosparite

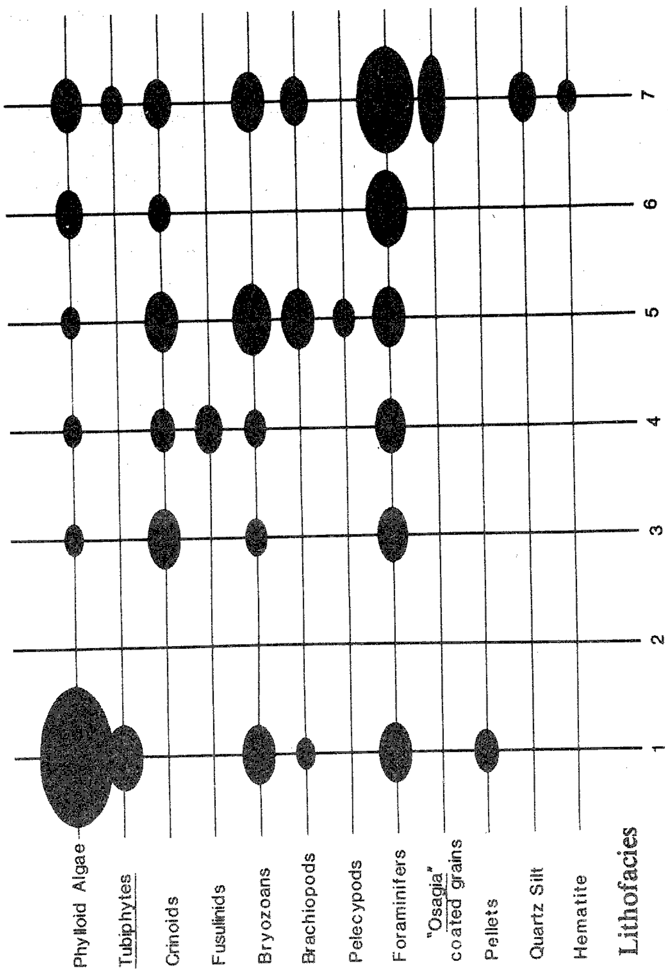


Figure 16: Relative abundance of fossil fragments in each lithofacies.

Lithofacies 1:
Tubiphytes phylloid algal biomicrite-biomicrudite

This lithofacies was deposited in a low energy environment because of the abundant presence of carbonate mud and the unbroken (some with spiralia preserved). Phylloid algae (so named by Pray et al (1963) for their leaf-like character) grow in the photic zone of marine water in subtidal and lagoonal environments, with a soft mud substrate (Wray, 1977, p. 128-129; Crowley, 1969, p. 50). The presence of locally abundant encrusting foraminifers is also an indication of photic zone growth.

Toomey (1976) indicates that since a phylloid algal faunal assemblage is fairly monotonous (an observation also made in this study) that the dense phylloid algae choked out most other growth, and formed a climax community.

The paleoenvironment which resulted in lithofacies 1 is interpreted to consist of low relief biostromes or meadows of phylloid algae with brachiopods, fenestrate bryozoans, **Tubiphytes** and encrusting foraminifers. Fenestrate bryozoans are ubiquitous here, as also noted by Wermund (1975, Fig. 13b).

Tubiphytes Maslov is a problematicum (calcareous algae according to Toomey (1965); hydrozoan according to Rigby (1958)); its biological affinity is still unknown (Flugel, 1982, p. 351). It is a very important encrusting organism in Pennsylvanian and Permian organic buildups worldwide (Toomey, 1969; Malek-Aslani, 1970; Flugel, 1981). It reportedly occurs in boundstones on exposed crests and seaward flanks of carbonate buildups (Wilson, 1975, p. 173; Malek-Aslani, 1970). In this study, no distinct relationship was noted regarding the relative abundance of **Tubiphytes** to the tops of lithofacies 1 sections. The growth habits of phylloid algae have caused them to be considered mound building organisms (Toomey, 1981; Toomey, et al, 1973, 1977; Wilson, 1975). The proposed mechanism of mound building is through baffling of fine carbonate muds, similar to mud mounds and accumulated by modern marine grasses in Florida Bay (Ginsburg and Lowenstam, 1958, p. 312-314). Ball (1977) suggested that phylloid algae do not build mounds, but are flat bedded with surrounding sediment based on the presence of thin shale partings that can be traced for miles in certain phylloid algal dominated systems.

In this study, bedding at each outcrop appeared flat overall. No obvious mounded features or mound-flank breccias (Wilson, 1975) were observed in outcrop. Evidence to support Ball's (1977) algal biostrome hypothesis is seen at measured section 4. Thin shale partings and yellow silt in between algal blades document the influx of terrigenous material, probably by mud "plumes" from a distant deltaic source (Ball, 1982). Also, most algal limestone-shale contacts are quite abrupt because the influx of the terrigenous clastic environment was very widespread and caused a regional cessation of carbonate production. However, it can be noted in Figures 18, 19 and 20 that the carbonate members are generally distinctly thicker where phylloid algal **Tubiphytes** biomicrites (lithofacies 1) are present.

The placement of the algal biostromes in preference to other carbonate facies was not studied in this paper. However, algal biostromes have been shown to grow on a foundered delta (Wermund, 1975); such may be the case with the phylloid algal sequence of beds in the Salt Creek Bend Shale at measured section 7 just above the Coon Mountain Sandstone fluvial deltaic system.

Lithofacies 2:
Sparse biomicrite

Because of the absence of fauna and its close interrelationship with lithofacies 1, lithofacies 2 is also interpreted as a low energy, adjacent to or within the algal meadows on the open marine shelf. Burrowing is very common in the sparse biomicrite lithofacies.

Lithofacies 3:
Crinoid biomicrite

This lithofacies is locally present in great abundance, for example at measured section 7 (Camp Colorado Limestone), but otherwise is present as thin beds. Crinoid biostromes are common in subtidal open marine, low energy facies and could be adjacent to the algal biostromes (Ross, 1959; Wermund, 1975, p. 25). Crinoids occur throughout the carbonate facies in a mudstone to well-washed grainstone fabric, indicating that some crinoids were transported into a high energy environment.

Lithofacies 4:
Fusulinid biomicrite

The fusulinid biomicrite most commonly occurs here as the basal bed of the Stockwether Limestone sequence, and occupies a similar position in other related types of carbonate sequences (Ross, 1969; Galloway and Brown, 1972; Wilson, 1975). Fusulinids inhabit shallow, subtidal, low energy algal meadows and crinoid biostromes in the photic zone in shallow marine environments (Ross, 1969). Toomey and Winland (1973, p. 1072) noted fusulinids present in all facies of the Nena Lucia Field study, but most common in their pelletal foraminiferal and crinoidal facies.

The fusulinid biomicrites could be the initial phase of open marine carbonate deposition or could be adjacent to an area where algal banks and carbonate mud are being deposited (Ross, 1969, p. 304). Where the fusulinids are reworked and form a packstone to grainstone, as at Home Creek locality, eight miles south of Santa Anna on State Highway 283, Coleman County, the facies could be a shoal area in a shallow marine bay

(Ross, 1969, p. 306), tidal shore zone (Ball, 1971) or shoreface (Wermund, 1975, p. 25). Ross (1969, p. 304) noted the fusulinids

> "...appear commonly in a succession of calcareous gray or purple green shale that passes upwards into an argillaceous fine grained limestone. Immediately above this horizon the matrix changes from clastic silt to micrite. This mode of fusulinid occurrence indicates a lateral shift of biotopes in which fusulinids occupied an area peripheral to a large area of carbonate mud deposition. (There is) a definite succession of biotopes that move together in lateral bands during lateral environmental shifts."

Lithofacies 5:
Crinoid-brachiopod-bryozoan biomicrite-biomicrudite

The crinoid-brachiopod-bryozoan biomicrite-biomicrudite represents a very shallow subtidal brackish deposit found in bays and shallow lagoons (Erxleben, 1975). It compares to Wilson's (1975) P2 microfacies, very fossiliferous shale. Wermund describes the same facies and interprets a paleoenvironment of bay mudstone (1975, p. 25); Ross (1969, p. 305) does the same in describing a shallow carbonate mud flat. It is a low energy deposit (Crowley, 1969, p. 50). This facies is often vertically related to a shale break, either above or below, or both. Pelecypods are common in the facies, and grew in the argillaceous environment because of the brackish water conditions present in the bay during the influx of shale deposition (Barrett, 1982). Examples of this facies are best at measured section 9 between the two beds of the Camp Colorado Limestone.

Lithofacies 6:
Foraminiferal algal biomicrite

This lithofacies has all the components of Lithofacies 1 including abundant encrusting and chambered foraminifers. Fossil fragments are very well-sorted, fine-grained, reworked and burrowed. It is interpreted to be a shoaling or flanking facies of the Tubiphytes phylloid algal paleoenvironment; a high energy reworking of Lithofacies 1 material similar to that described by Bretsky and Brooks (1964).

Lithofacies 7:

The lithofacies 7 group is characterized by "**Osagia**" coated grains. This blue green algal-encrusting foraminiferal coating is present on grains in the intertidal lagoon zone, which are tossed about by wave action and thus coated on all sides by "**Osagia**" (Wermund, 1975; Wray, 1977, p. 128-133; Crowley, 1969).

Lithofacies 7a:
Coated grain "**Osagia**" biomicrite-biosparite

Lithofacies 7a is interpreted to be deposited in a tidal washed marine facies on a bar, shoal, a shallow bank or beach. The oncolites present at Locality C are deposited in turbulent water of intertidal zone (Kotila, 1973; Crowley, 1969). Well sorted fossil fragments of almost any type are present as coated grains, foraminifers are abundant and are seldom coated.

Lithofacies 7b:
Sandy coated grain "**Osagia**" biomicrite-biosparite

Lithofacies 7b is the same as 7a, but deposited in an intertidal high energy environment with quartz sand present. Scattered sand present in carbonate rocks can be wind blown (Wilson, 1975, p. 91), part of a carbonate sand beach, or burrowed into the carbonate facies from a vertically adjacent clastic bed. Lithofacies 7b is commonly burrowed and associated vertically with a shale or clastic bed. Sand present in this lithofacies is interpreted to be from a clastic source laterally equivalent to the intertidal carbonate deposition, and being deposited at the same time. Wermund (1975, p. 24) notes quartz sand is present in the basal beds of Pennsylvanian limestone banks and is common in gradational zones toward nearshore clastic facies. Bretsky (1966) attributes the quartz sand to surges of higher energy.

Lithofacies 7c:
Sandy fusulinid coated-grain "**Osagia**" biomicrite-biosparite

Lithofacies 7c results from interaction of three depositional environments; the fusulinid biomicrite in the shallow marine bay facies, the intertidal facies where "**Osagia**" coated fragments are produced, and a nearby source of quartz sand such as a beach, bar, or deltaic facies. Wermund (1975, p. 32) noted fusulinids and "**Osagia**" limestone grading into quartz sandstone in the Possum Kingdom area (Pennsylvanian-Canyon age rocks). To get these environments combined requires high energy such as tides, or storm tides, to bring fusulinids to the intertidal ("**Osagia**" coated grain) zone, and then to bring them into a sandstone-shale sequence such as is found in measured section 5, 6S and 6 (VanDerLoop, 1983, Appendix I, Plate I). Fusulinids are known to be transported into wave built bars or terraces (Ross, 1969, p. 306), and it is postulated that fusulinid grainstones are in some cases washover fans or supratidal storm deposits (Ball, 1971; Reinick and Singh, 1973, p. 298; Wermund, 1975, p. 25; Parks, 1962). "Storm deposits are transported and deposited over various type sediments, where transitions of depositional environments are most sharp and most numerous. This is inferred in all literature cited on recent storm deposits." (Ball, 1971, p. 219).

The dasycladacean alga **Epimastopora** is present most abundantly in lithofacies 7, and next in lithofacies 1; it is indicative of a subtidal lagoon deposit, in very shallow water (Wray, 1977, p. 135). Its presence in lithofacies 7 is expected; in lithofacies 1, it is probably at a point where the water was shallow enough in the algal biostrome to encourage its growth.

SIMILAR CARBONATE LITHOFACIES IN OTHER AREAS

Some of the Pennsylvanian-Permian carbonate sequences in the midcontinent and southwest United States have carbonate lithofacies very similar to those found in this study, indicating a common paleoenvironment persisted over a large geographic area. Models of depositional environments introduced by previous authors were useful in understanding this area. A summary of similar facies is presented in Table I.

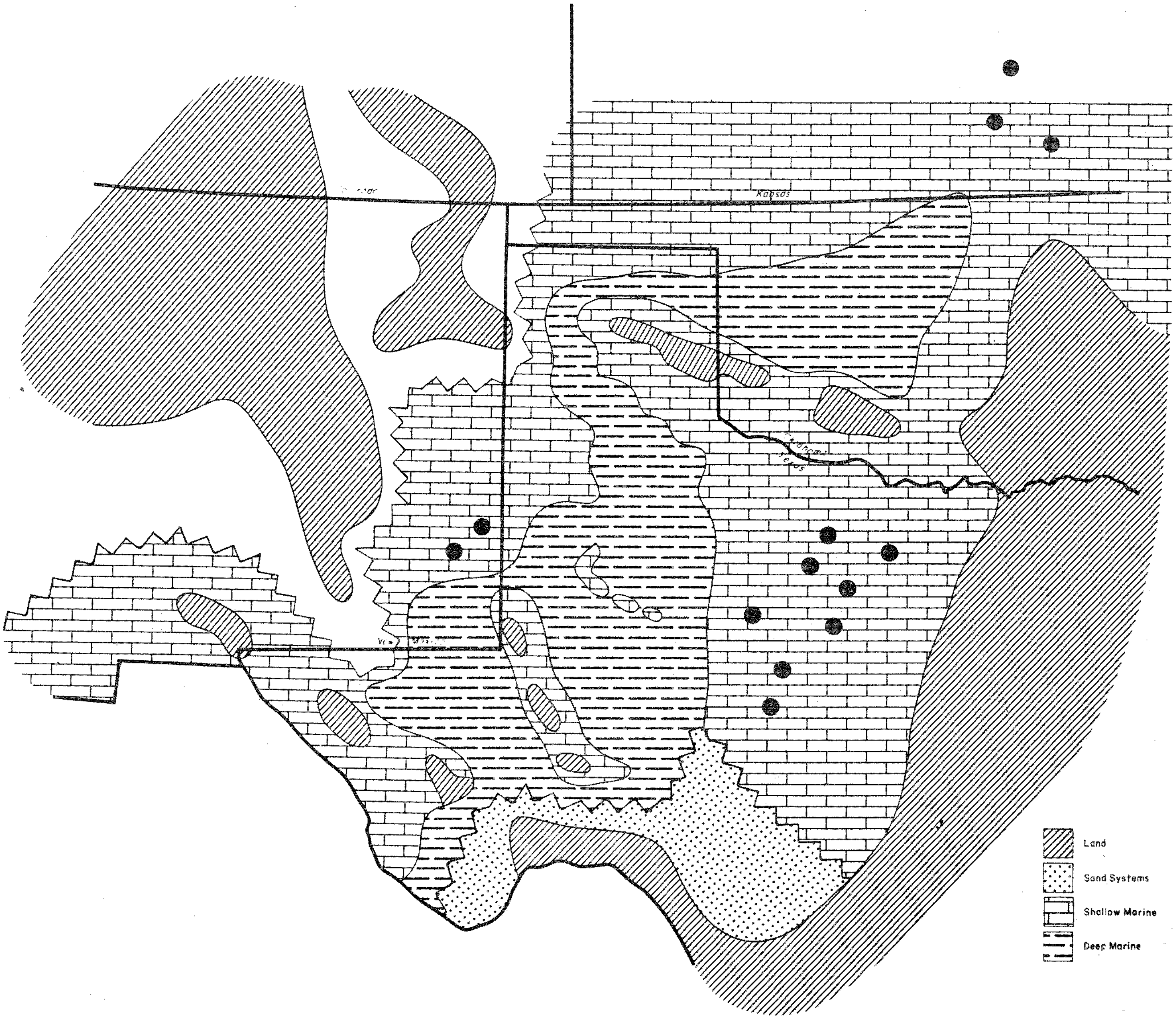


Figure 17: Lower Wolfcamp paleogeography with location of lithofacies groups similar to Pueblo Formation.

TABLE I

PUEBLO FORMATION LITHOFACIES

	Facies 1	Facies 2	Facies 3	Facies 4	Facies 5	Facies 6	Facies 7
LaPorte, 1962 Kansas, Lower Permian Beattie Limestone	X			X	X		X
Cronoble, 1962 Kansas, Pennsylvanian					X		
Terriere, 1963 Texas, Upper Pennsylvanian Graham Fm.	X			X		X	
McGowen, 1964 Texas, Lower Permian Saddle Creek Limestone	X		X	X	X	X	
Gray, 1967 Colorado, Pennsylvanian	X		X		X	X	
Crowley, 1969 Kansas, Pennsylvanian Wyandotte Limestone	X				X	X	X
Brown, 1969a Lower Cisco Limestones north central Texas	X	X		X	X		X
Malek-Aslani, 1970 New Mexico, Lower Permian	X			X	X		
Galloway and Brown, 1972 Texas, Pennsylvanian & Lower Permian	X	X		X	X		
Toomey and Winland, 1973 Texas, Pennsylvanian	X		X			X	
Wermund, 1975 Texas, Upper Pennsylvanian	X						X
Cys, 1981 New Mexico, Lower Permian Bough C	X						
VanDerLoop & Nestell, 1983	X	X	X	X	X	X	X

Table I: Comparison of Pueblo Lithofacies to other study areas.

In north-central Texas on the Eastern Shelf Galloway and Brown (1972) noted four facies types in these limestones, which they called transgressive tongues of the open shelf limestone facies, reflecting periods of reduced fluvial deltaic sedimentation over broad areas of the Eastern Shelf. These limestones display a distinct vertical faunal zonation (Galloway and Brown, 1972, p. 29); Top, Sparse biomicrite; mixed fossil biomicrite; algal biomicrite, and bottom, fusulinid biomicrite. Besides the vertical faunal zonation, lateral faunal zonation can be seen in the Saddle Creek Limestone in Stephens County as it grades to sandstone in the northeastern end of its outcrop belt. Normal open shelf Saddle Creek contains phylloid algae, brachiopods and encrusting foraminifers (lithofacies 1); transitional Saddle Creek is a sandy ferruginous biomicrite with crinoids, brachiopods and bryozoans (lithofacies 5).

Wermund (1975, p. 23) notes in a study of the Possum Kingdom area in north-central Texas that algal-mud mounds are capped by "**Osagia**" grainstones as seen in lithofacies 1 in this study area.

A schematic model of deposition was deduced from similar relationships in Lower Cisco Limestones of north-central Texas (Brown, 1969a), (Figure 18).

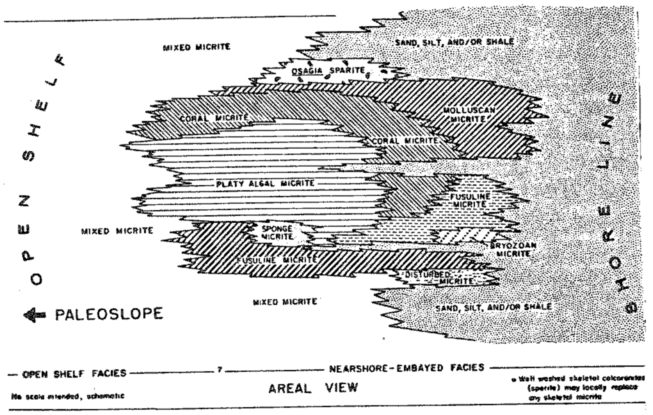


Figure 18: Schematic models of facies distribution, lower Cisco limestones, From Brown, 1969a.

CARBONATE LITHOFACIES RELATIONSHIPS IN THE PUEBLO FORMATION

The seven carbonate lithofacies in the Pueblo Formation all are interrelated and were deposited in related environments. To study the pattern of interrelationships, vertically exaggerated cross sections of the carbonate units were prepared based on the measured section descriptions (Figures 19, 20, 21).

Table II was derived from the vertical relationships seen on Figures 19, 20 and 21. Lithofacies 1, the **Tubiphytes** algal biomicrite, occurs most often with (2) sparse biomicrite, (3) crinoid biomicrite, (6) foraminiferal algal biomicrite, (7a) coated grain "**Osagia**" biomicrite, and at the base or top of a carbonate unit. Facies 2, the sparse biomicrite, occurs most often at the base of a unit and with (1) **Tubiphytes** algal biomicrite and (3) crinoid biomicrite. Lithofacies 3, crinoid biomicrite, is commonly with (1) **Tubiphytes** phylloid algal biomicrite, (2) sparse biomicrite, and at the top of a carbonate unit. Lithofacies 4, the fusulinid biomicrite, is prevalent only at the base of the unit. Lithofacies 5, the crinoid-brachiopod-bryozoan biomicrite, is common at the base of a unit, and with (6) foraminiferal algal biomicrite. Lithofacies 6, the foraminiferal algal biomicrite, is associated with (1) **Tubiphytes** phylloid algal biomicrite and the base or top of a carbonate unit.

Figure 22 was constructed using these vertical associations (Table II). If an ideal Pueblo Formation phylloid algal biostrome could be found it would in cross section resemble Figure 22. The outcrop localities at which characteristic patterns can be seen are noted at the top of Figure 22.

Figures 23 and 24 display an interpretation of a method of deposition of that vertical sequence in the Pueblo Formation by transgression of carbonate microfacies through time. Lithofacies 4 and locally lithofacies 7a, b and c are generally at the base of a carbonate sequence, and therefore at the leading edge of a marine transgression (Figure 23). Lithofacies 1 and 6 represent open marine conditions. Shoaling waters culminating the marine deposition phase and-or renewed influx of terrigneous clastics result in the deposition of lithofacies 7a and b, capping the phylloid algal biostrome.

Related laterally to the phylloid algal biostrome is lithofacies 3, the crinoid biomicrite. Lithofacies 5 is limited to a restricted shallow water environment lateral to, and unrelated to, phylloid algae deposition (Figure 24).

CONCLUSIONS

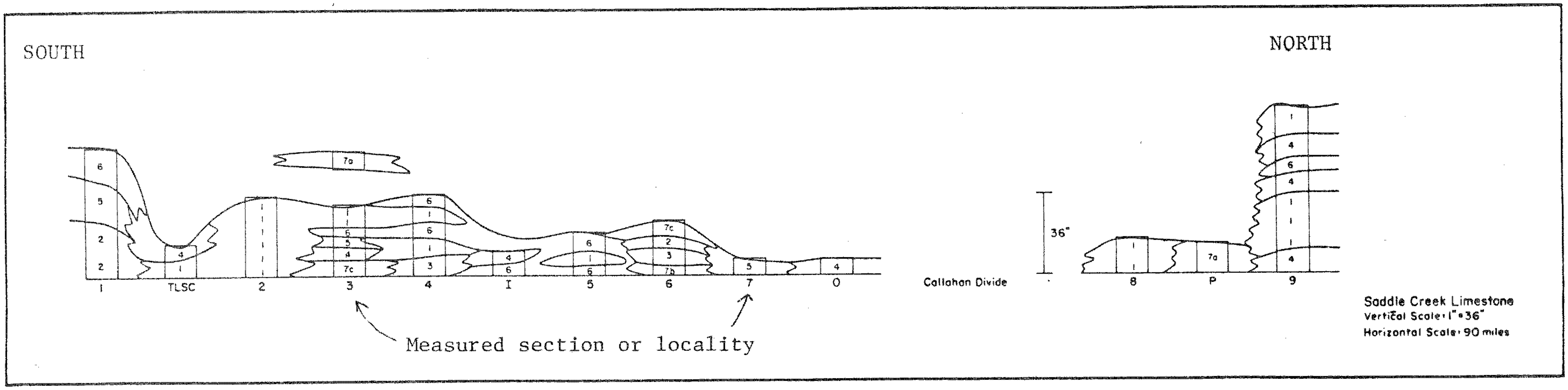
Any paleoenvironmental interpretation of the Pueblo carbonate members must take into account their significant vertical relationships to each other (Table II). "The systematic vertical changes in lithology represent principally the migration of a succession of adjoining environments past the locality of the ob-

Vertically adjacent upper facies

Vertically adjacent lower facies	Base of Carbonate Unit	Facies One	Facies Two	Facies Three	Facies Four	Facies Five	Facies Six	Facies Seven	Top of Carbonate Unit
Facies One	xxxxx xxxx xxxxx		xxx	x	xx	xx	xxxx	xxxxx	xxxxx xxxxx xxxxx
Facies Two	xxxxx xx	xxxxx xx		xxxxx x		x	x	xx	x
Facies Three	xxxx	xxxxx xx	xx			x	xx	x	xxxxx x
Facies Four	xxxxx xxx	xx	xxx	x		x	xxx		xx
Facies Five	xxxxx xx	x	x	xx			xxxx	x	xxxx
Facies Six	xxx	xxxxx xx	x	x	xx			x	xxxxx x
Facies Seven	xxxxx xxxxx xxxxx	xxx		x	x				xxxxx xxxxx x

Table II Significant vertical facies relationships, Pueblo Formation, implying significant lateral facies relationships. Method adapted from Harms (1975), Visher (1965).

Significant vertical relationships:
6-1, 7-1, 1-2, 3-2, 1-3, 1-6, 6-5
1-Base, 2-Base, 4-Base, 5-Base, 7-Base
Top-1, Top-3, Top-6, Top-7



Lithofacies 1 *Tubiphytes* phylloid algal biomicrite

Lithofacies 2 Sparse biomicrite

Lithofacies 3 Crinoid biomicrite

Lithofacies 4 Fusulinid biomicrite

Lithofacies 5 Crinoid brachiopod bryozoan biomicrite

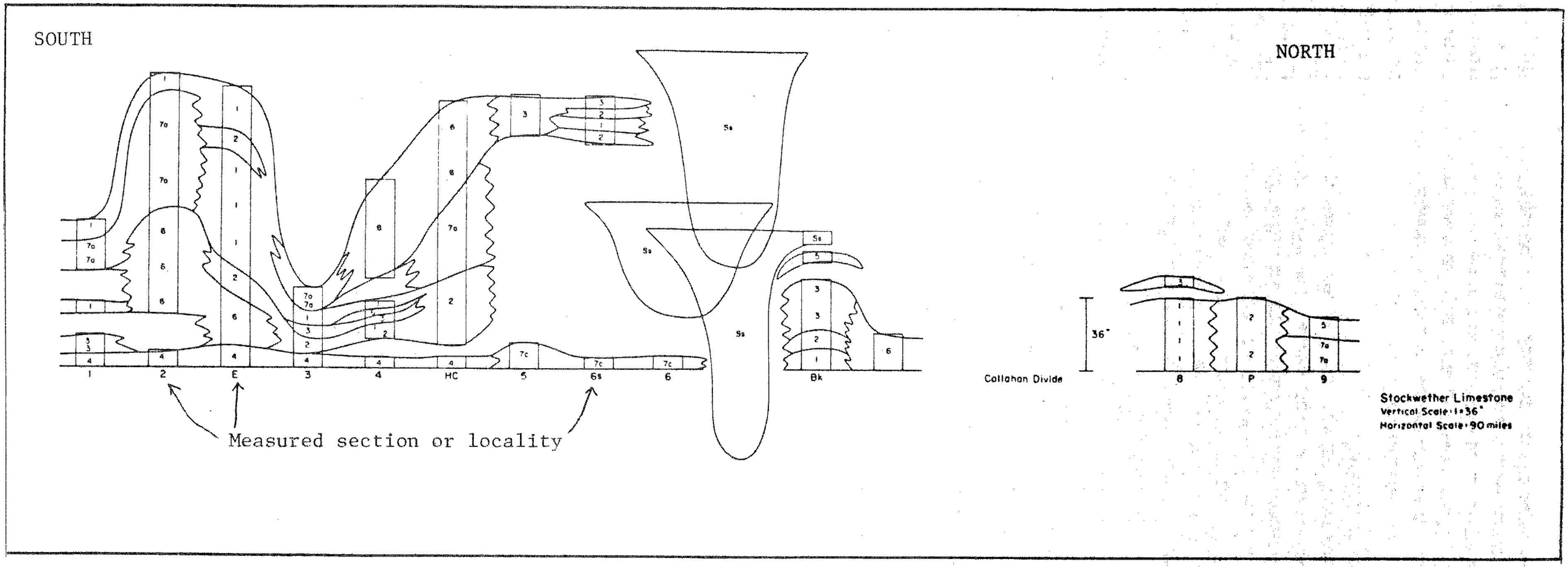
Lithofacies 6 Foraminiferal algal biomicrite

Lithofacies 7a "*Osagia*" coated grain biomicrite

Lithofacies 7b Sandy "*Osagia*" coated grain biomicrite

Lithofacies 7c Sandy fusulinid "*Osagia*" coated grain biomicrite

Figure 19: Saddle Creek Limestone lithofacies cross section south to north across outcrop area.



Lithofacies 1 Tubiphytes phylloid algal biomicrite

Lithofacies 2 Sparse biomicrite

Lithofacies 3 Crinoid biomicrite

Lithofacies 4 Fusulinid biomicrite

Lithofacies 5 Crinoid brachiopod bryozoan biomicrite

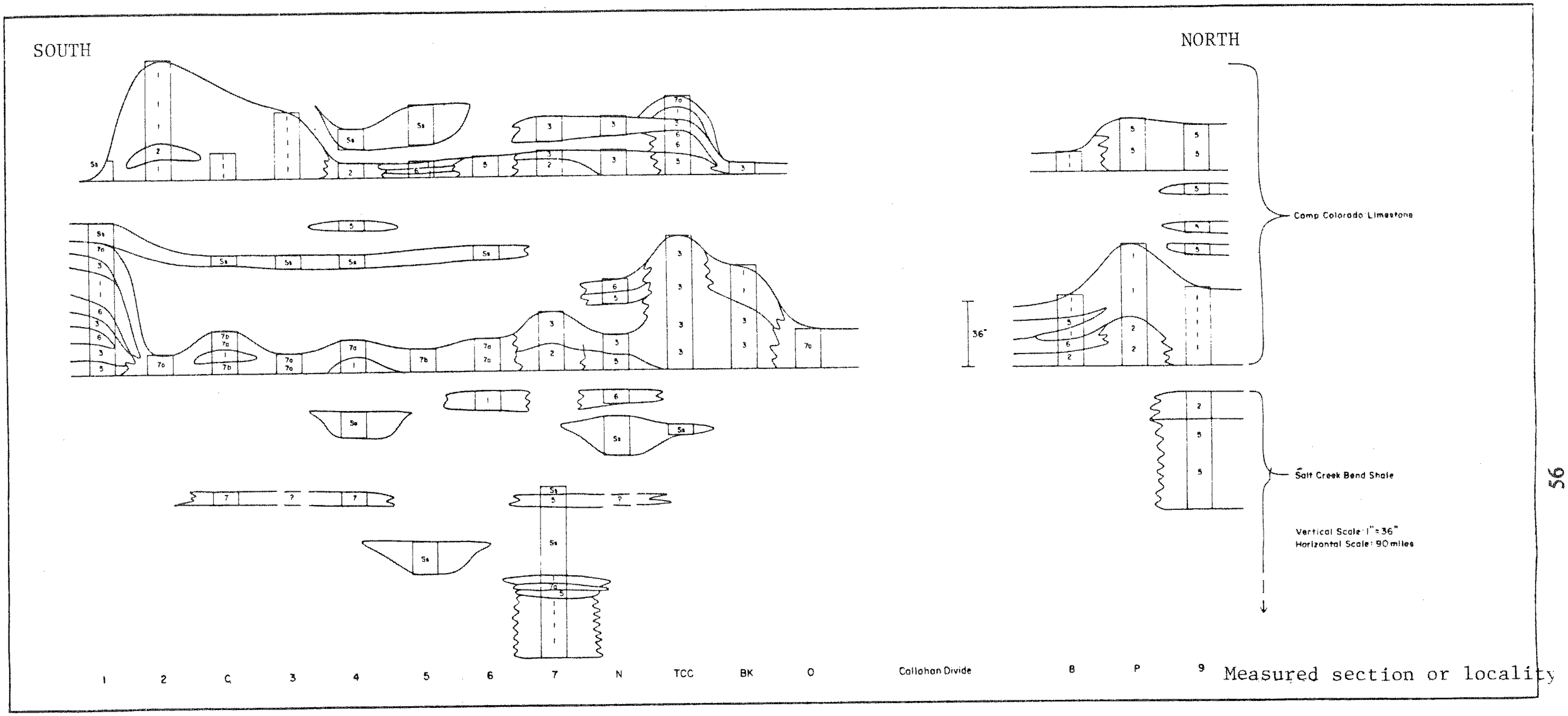
Lithofacies 6 Foraminiferal algal biomicrite

Lithofacies 7a "Osagia" coated grain biomicrite

Lithofacies 7b Sandy "Osagia" coated grain biomicrite

Lithofacies 7c Sandy fusulinid "Osagia" coated grain biomicrite

Figure 20: Stockwether Limestone lithofacies cross section south to north across outcrop area.



Lithofacies 1 *Tubiphytes* phylloid algal biomicrite

Lithofacies 2 Sparse biomicrite

Lithofacies 3 Crinoid biomicrite

Lithofacies 4 Fusulinid biomicrite

Lithofacies 5 Crinoid brachiopod bryozoan biomicrite

Lithofacies 6 Foraminiferal algal biomicrite

Lithofacies 7a "*Osagia*" coated grain biomicrite

Lithofacies 7b Sandy "*Osagia*" coated grain biomicrite

Lithofacies 7c Sandy fusulinid "*Osagia*" coated grain biomicrite

Figure 21: Camp Colorado (Noodle Creek) Limestone lithofacies cross section south to north across outcrop area.

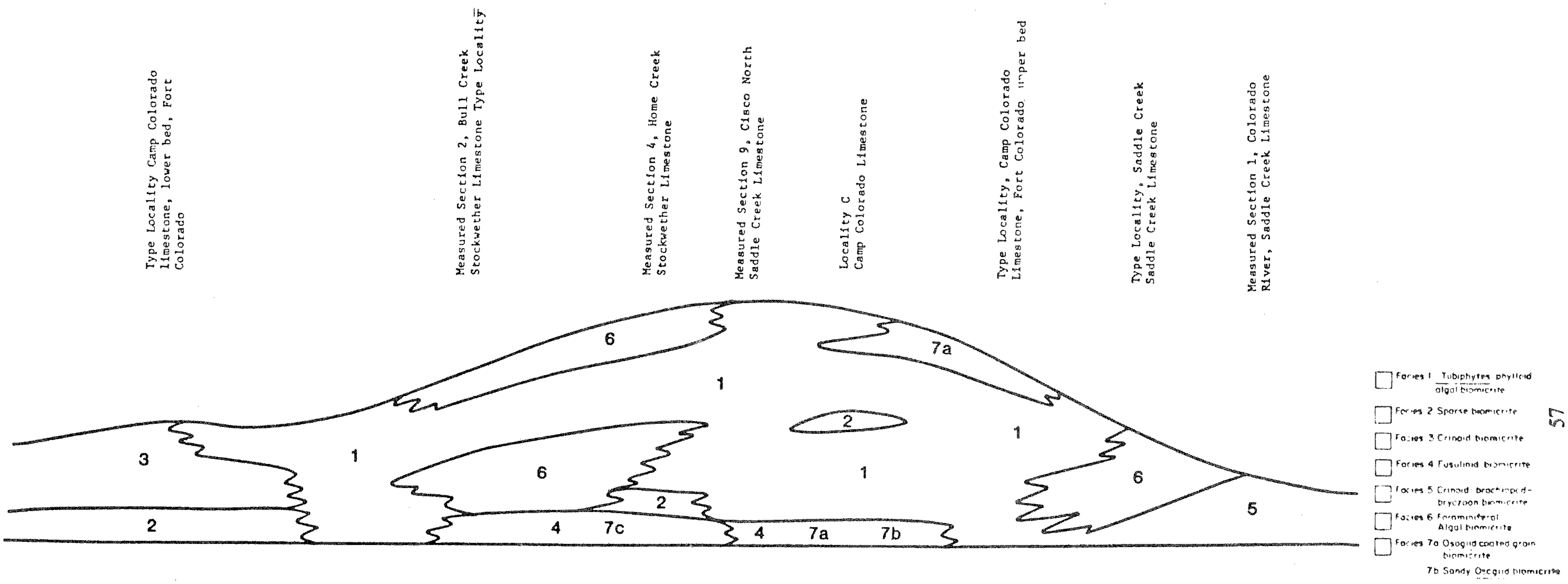
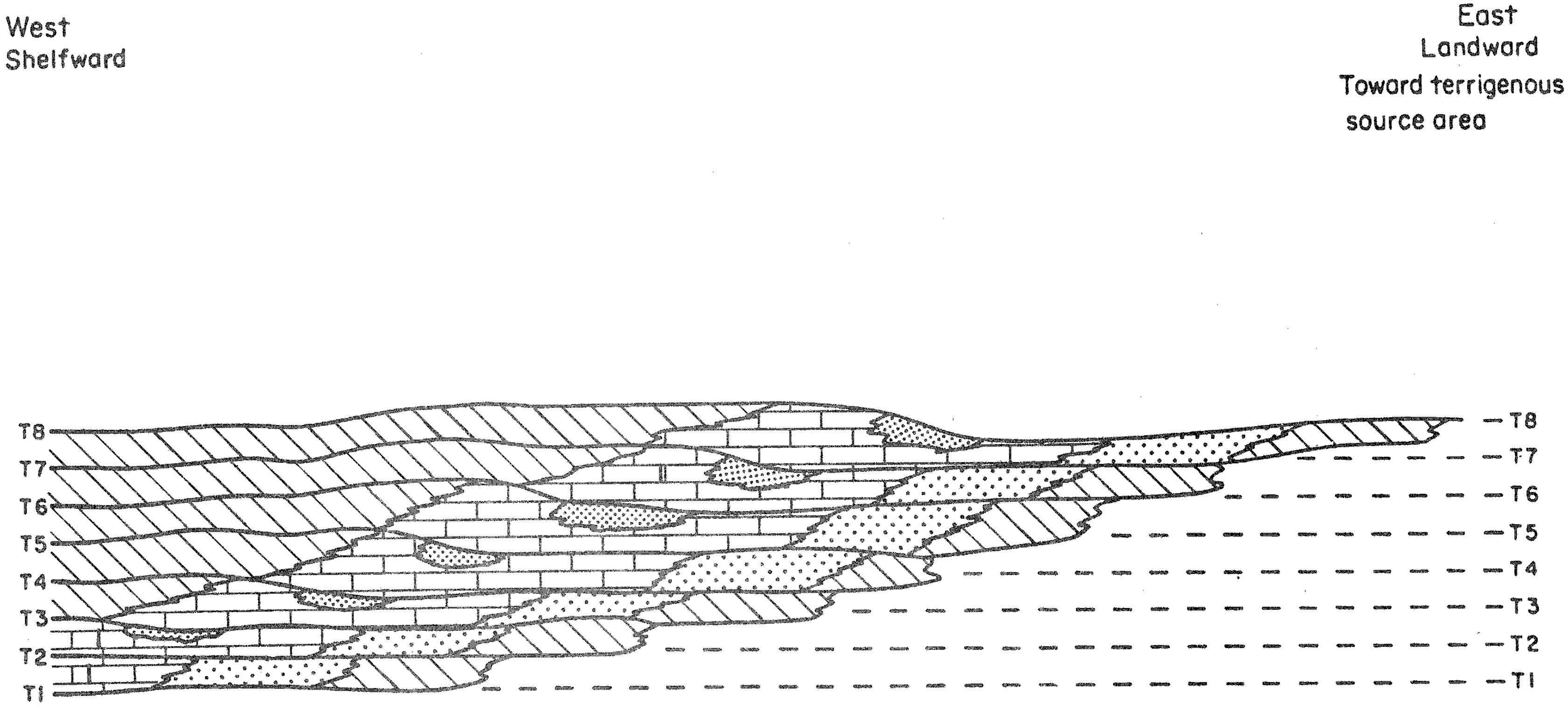


Figure 22: Idealized cross sectional view of carbonate lithofacies distribution in limestone members of the Pueblo Formation.



▨ "osagia" coated grain biomicrite

░ fusulinid biomicrite

▦ *Tubiphytes* phylloid algal biomicrite

▒ foraminiferal algal biomicrite

Figure 23: Cross sectional view of transgression of Pueblo Formation carbonate facies in depositing a phylloid algal biostromal sequence through time (T1-T8). This transgression results in the typical vertical sequence observed. No scale intended.

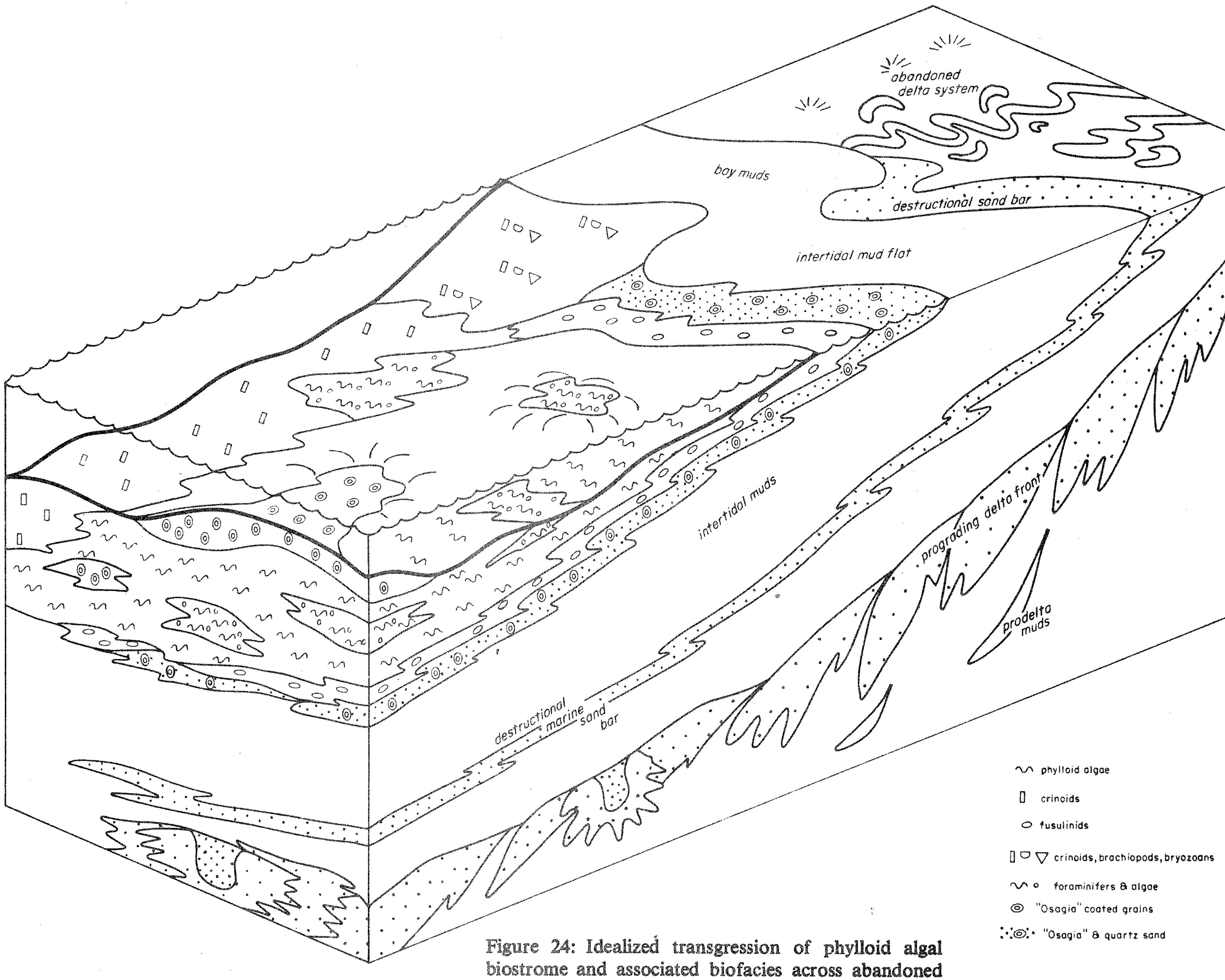


Figure 24: Idealized transgression of phylloid algal biostrome and associated biofacies across abandoned deltaic system.

server" (Van Siclen, 1966, p. 536). "Each vertical profile contains all the environments that were present in that spatial and temporal framework" (Visher, 1965, p. 46).

This study attempts to reconstruct the lateral facies patterns that deposited the Pueblo Formation carbonate members by dissecting their vertical lithofacies relationships.

Each of the lithofacies represents a distinct marine biologic community, which developed as a result of water depth, wave energy, salinity and many other factors. These communities migrated east (landward) during periods of transgression, and west (shelfward) during regressive times, leaving the vertical and lateral mosaic of lithofacies found in the rock record. The transgressions took place during periods of lack of clastic input, or rising sea level, or some balance of both those elements; the facies regressions took place when sea level dropped, clastic input decreased, or a balance of both of those factors.

The intervening clastic members between these carbonate units are parts of a fluvial deltaic system. As sea level rises over the existing sands and shales, the available sands are reworked and sand bodies are flattened by wave energy into a smooth transgressive sheet sand of a destructional marine bar (Erxleben, 1975; Brown, 1979; VanDerLoop, 1983). Intertidal muds were then deposited over the destructional sand sheet. Depending on the water depth and energy level, lithofacies 5, 7b or c, or lithofacies 4 was deposited. Lithofacies 5 preferred quiet water, while the fusulinids in Lithofacies 4 were tolerant of higher energy, and the "Osagia" coated grains in lithofacies 7 deposits resulted from shallow water high energy environment. Quartz sand could be windblown or reworked into the "Osagia" environment from the laterally equivalent, though distant, destructional marine sand bar.

Lithofacies 4, the fusulinid biomicrite, is the precursor of the phylloid algal biostromes; lithofacies 5, crinoid brachiopod bryozoan biomicrite, is not generally overlain by the phylloid algal bodies. What controls the presence of facies 4 fusulinids rather than facies 5 at the leading edge of a transgression?

Since facies 4 and 7 are more characteristic of high energy, depth of water and location on an open shore rather than quiet water in an estuarine setting could govern which facies is the leading edge of carbonate deposition (Figure 24). During compaction of the underlying clastics, sandstone bodies would stand in greater relief than surrounding compacted muds; this would cause a shoaling effect in the overlying carbonate depositional environment, inviting the deposition of "**Osagia**" coated fragments and fusulinid grainstones. The shallower water then would invite preferential growth of phylloid algal biostromes, which in turn might create enough relief over a broad area to bring the area to wave base for the development of more "**Osagia**" coated grainstones as fragments are reworked in the higher energy environment (Figure 23, 24).

Most of the production from the Noodle Creek (Camp Colorado) Limestone is from porous phylloid algal mounds. Predicting the presence of phylloid algal mounds might be possible by the use of these relationships in studying cores, cuttings, and making lithofacies maps.

ACKNOWLEDGMENTS

The authors would like to acknowledge the following individuals and institutions for their help in preparing this paper: Permian Basin Graduate Center, Midland, Texas; Monsanto Oil Company, Midland, Texas; Dave Kotila, Originala Exploration, Fort Worth, Texas; C.I. Smith, Chairman Department of Geology, University of Texas at Arlington, Arlington, Texas; M&M Enterprises, Midland, Texas; Standard Petrographic, Lubbock, Texas; Don Toomey, Conoco, Ponca City, Oklahoma; Brian Shaw, Monsanto Oil Co., Midland, Texas; George Grover, Gulf Oil Co., Midland, Texas; Roger Lindsey, Monsanto Oil Co., Midland, Texas; and Kay Crites, Monsanto Oil Co., Midland, Texas.

BIBLIOGRAPHY

Adams, J.E., et al, 1939, Standard Permian Section of North America: Bull. Amer. Assoc. Petrol. Geol., v. 23, no. 11, p. 1673-1681.

Ball, S.M., 1971, The Westphalia Limestone of the Northern Mid-continent, a possible ancient storm deposit: Jour. Sed. Pet., v. 41, p. 217-232.

—————————, 1977, Importance of phylloid algae in development of depositional topography; reality or myth: Amer. Assoc. Petrol. Geol. Studies in Geology No. 4, p. 239-259.

Barrett, M.E., 1982, Petrographic relationships in the Winchell (Upper Paleozoic) carbonate buildup, north-central Texas: **in** Middle and Upper Pennsylvanian System of North-Central and West Texas, Outcrop to Subsurface, PBS-SEPM 1982 Symposium and Field Conference Guidebook, WTGS Pub. 82-21, D. Cromwell, ed., p. 179-200.

Bretsky, P., Jr., and Brooks, J.E., 1964, Limestone petrology in the Pennsylvanian Canyon group in north-central Texas--a study in environmental changes through time (abst.): Geol. Soc. Amer. Spec. Paper 76, p. 20.

—————————, 1966, Stratigraphy and carbonate petrology of the Pennsylvanian upper Canyon group in Stephens and Palo Pinto counties, Texas: **in** Papers on Pennsylvanian Stratigraphic problems in north-central Texas: Graduate Research Center Journal, v. 35, No. 2, p. 105-137.

Brown, L.F., Jr., 1959, Problems of stratigraphic nomenclature, Upper Pennsylvanian, north-central Texas: Bull. Amer. Assoc. Petro. Geol., v. 43, no. 12, p. 2866-2871.

Brown, L.F., Jr., 1969a, Late Pennsylvanian paralic sediments: in A Guidebook to the late Pennsylvanian shelf sediments, north-central Texas: Amer. Assoc. Petrol. Geol.-Soc. Econ. Paleontol. Min., Ann. Mtg., 1969, Dallas, Texas; Dallas Geol. Soc., p. 21-33.

——————————, 1969b, Geometry of fluvial and deltaic sandstones (Pennsylvanian and Permian), north-central Texas, Univ. Texas, Bur. Econ. Geol., Circ. 69-4.

——————————, Cleaves, A.W. II, and Erxleben, A.W., 1973, Pennsylvanian depositional systems in north-central Texas; a guide for interpreting terrigenous clastic facies in a cratonic basin: Univ. Texas at Austin, Bur. Econ. Geol., Guidebook 14, 132 p.

Cheney, M.G., 1940, Geology of North Central Texas: Amer. Assoc. Petrol. Geol. Bull., v. 24, No. 1, p. 65-118.

—————————— and Goss, L.G., 1952, Tectonics of Central Texas: Amer. Assoc. Petrol Geol. Bull., v. 36, p. 2237-2265.

Cronoble, W.R., 1962, Facies relationships in and adjacent to limestone buildups of the Coffeyville and Hogshooter Formations (Missourian), Washington and Nowata Counties, Oklahoma, Kansas Geoeconomics Symposium.

Crowley, D.J., 1969, Algal bank complex in Wyandotte Limestone (Late Pennsylvanian) in Eastern Kansas: Univ. Kansas Pubs. Bull. 198, 52 p.

Cummins, W.F., 1891, Report on the geology of northwestern Texas: in Second Annual Report of the Texas Geol. Surv., 1890, p. 359-552.

Drake, N.F., 1893, Report on the Colorado Coal Field of Texas: Fourth Ann. Rept. Texas Geol. Surv., 1892, p. 357-481, reprinted in Univ. Texas Bull. No. 1755, Oct. 1, 1917, 75 p.

Dunham, R.H., 1962, Classification of carbonate rocks according to depositional texture: AAPG Memoir I, p. 108-121.

Eargle, D.H., 1960, Stratigraphy of Pennsylvanian and Lower Permian rocks in Brown and Coleman Counties, Texas: U.S. Geol. Survey Prof. Paper 315-3, p. 55-77, pls. 28-30.

Erxleben, A.W., 1975, Depositional systems in Canyon Group (Pennsylvanian System), north-central Texas: Bur. Econ. Geol., Univ. Texas at Austin, Rept. Surv. 82, 75 p.

Flugel, E., 1981, Lower Permian **Tubiphytes Archeolithoporella** buildups in southern Alps, Austria and Italy: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 30, p. 143-160.

Folk, R.L., 1962, Spectral subdivision of limestone types: Amer. Assoc. Petrol. Geol. Memoir 1, p. 52-84, Tulsa, Oklahoma.

Galloway, W.E., and Brown, L.F. Jr., 1972, Depositional systems and shelf slope relationships in Upper Pennsylvanian rocks, north-central Texas: Univ. Texas, Bur. Econ. Geol. Rept. Inv. 75, 54 p.

Ginsburg, R.N. and Lowenstam, H.A., 1958, The influence of marine bottom communities on the depositional environment of sediments: Jour. Geol., v. 55, no. 3, p. 310-318.

Gray, R.S., 1967, Cache Field; a Pennsylvanian algal reservoir in southwestern Colorado: Bull. Amer. Assoc. Petrol. Geol., v. 51, no. 10, p. 1959-1978.

Gupta, S., 1973, Palynological interpretation of the base of Permian on Eastern Shelf region of north-central Texas, U.S.A.: Boussens, France, Proc. Comm. Internac. de Microflore du Paleozoique Symposium.

Johnson, J.H., 1946, Lime-secreting algae from the Pennsylvanian and Permian of Kansas: Geol. Soc. America Bull., v. 57, no. 12, p. 1087-1120.

Kier, R.S., Brown, L.F. Jr., and McBride, E.F., 1980, Mississippian and Pennsylvanian Systems in the U.S., Texas: U.S. Geol. Surv. Prof. Paper 1110-S, reprinted by Bur. Econ. Geol., Univ. Texas, Austin, Texas.

Kotila, D., 1973, Algae and paleoecology of algal and related facies, Morrow Formation, northeastern Oklahoma, Doctoral diss., Univ. of Oklahoma, 231 p.

Lane, N.G., 1964, Paleoecology of the Council Grove Group (Lower Permian) in Kansas, based on microfossil assemblages: Kansas Geol. Surv. Bull. 170, pt. 5, 23 p.

LaPorte, L.G., 1962, Paleoecology of the Cottonwood Limestone Permian northern Mid-continent: Geol. Soc. America Bull., v. 73, p. 521-544.

Lee, W., Nickell, C.O. Williams, J.S., and Henbest, L.G., 1938, Stratigraphic and paleontologic studies of the Pennsylvanian and Permian Rocks in north-central Texas: Austin, Bur. Econ. Geol. Univ. Texas Bull. 3801, 252 p.

Malek-Aslani, Morad, 1970, Lower Wolfcampian reef in Kemnitz Field, Lea County, New Mexico: Bull. Amer. Assoc. Petrol. Geol., v. 54, no. 12, p. 17-2317- 2335.

McGowen, J.H., 1964, The stratigraphy of the Harpersville and Pueblo Formations, Southwestern Stephens County, Texas: Baylor Univ. Master's Thesis, 440 p.

Moore, R.C., 1949, Field Trip Guidebook, Abilene Geological Society Spring Field Trip.

Parks, J.M., 1962, Reef-building biota from Late Pennsylvanian reefs, Sacramento Mountains, New Mexico: Amer. Assoc. Petrol. Geol. - Soc. Econ. Paleontologists and Mineralogists (abst.) San Francisco, Calif., March 26-29, 1962, p. 49.

Plummer, F.B., and Moore, R.C., 1921, Stratigraphy of the Pennsylvanian Formations of north-central

Texas; Univ. Texas Bull. 2132, 237 p.

Pray, L.C., and Wray, J.L., 1963, Porous algal facies (Pennsylvanian) Honaker Trail, San Juan Canyon, Utah: in Shelf carbonates of the Paradox Basin, a symposium; Four Corners Geol. Soc., 4th Field Conference, p. 204-234.

Reineck, H.E., and Singh, I.B., 1973, Depositional sedimentary environments: Springer-Verlag, New

Rigby, J.K., 1959, Two new upper Paleozoic hydrozoans: Jour. Paleo., v. 32, no. 3, p. 583-586.

Ross, C.A., 1969, Paleoecology of Triticites and Dunbarinella in Upper Pennsylvanian strata of Texas: Jour. Paleo., v. 43, no. 2, p. 298-311.

Roth, R., 1931, New information on the base of the Permian in west central Texas: Jour. Paleo., v. 5, p. 295.

Rothrock, H.E., 1961a, Brown, Coleman and Runnels Counties; Second Day Road Log: in A Study of Pennsylvanian and Permian sedimentation in the Colorado River valley of west central Texas, Abilene Geol. Soc. Guidebook, 1961; Abilene, Texas, Abilene Geol. Soc., p. 8, p. 21-27.

Terriere, R.T., 1960, Geology of the Grosvenor Quadrangle, Brown and Coleman Counties, Texas; Pennsylvanian and Lower Permian stratigraphy, between the Brazos and Colorado Rivers, north-central Texas: U.S. Geol. Survey Bull., 1096-A, 35 p.

——————, 1963, Petrography and environmental analysis of some Pennsylvanian limestones from central Texas: U.S. Geol. Survey Prof. Paper 315E, p. 79-126.

Toomey, D.F., 1965, The biota of the Pennsylvanian (Virgilian) Leavenworth Limestone, Midcontinent Region, Part I, Stratigraphy, paleogeography and sediment facies relationships: Jour. Paleo., v. 43, no. 4, p. 1001-1018.

——————, 1976, Paleosynecology of a Permian plant dominated marine community: N. Jb. Geol. Paleont. Abh., 152, p. 1-18, Stuttgart, 1976.

——————. 1981, Organic buildup constructions capability of Lower Ordovician and Late Paleozoic mounds: in Communities of the Past, Jane Gray et al, ed., Hutchinson Ross Pub. Co., Strondsburg, Pa.

——————, Wilson, J.L., Rezak, R., 1977, Evolution of Yucca Mound complex, Late Pennsylvanian phylloid algal buildup, Sacramento Mtns., New Mexico: Bull. Amer. Assoc. Petrol. Geol., v. 61, no. 12, p. 2115-2133.

——————, and Winland, H.D., 1973, Rock and biotic facies associated with Middle Pennsylvanian (Desmoinesian) algal buildup, Nena Lucia Field, Nolan County, Texas: Bull. Amer. Assoc. Petrol. Geol., v. 57, no. 6, p. 1053-1074.

VanDerLoop, M.L., 1983, Stratigraphy and depositional environments in the Pueblo Formation (Lower Permian) Eastern Shelf, Texas, M.S. thesis, Univ. of Texas at Arlington, 254 p.

Van Siclen, D.C., 1966a, Depositional topography -- examples and theory: Bull. Amer. Assoc. Petrol. Geol., v. 42, no. 8, p. 1897-1913.

Visher, G.S., 1965, Use of vertical profile in environmental reconstruction: Bull. Amer. Assoc. Petrol. Geol., v. 49, p. 41-61.

Wermund, E.G., 1975, Upper Pennsylvanian Limestone Banks, North Central Texas: Austin, Bur. Econ. Geol. Circ. 75-3, 34 p.

Wilson, J.L., 1975, Carbonate facies in geologic history: Berlin, Heidelberg, Springer-Verlag, 471 p.

Winslow, M.L., 1983, The paleoecology and stratigraphy of the Harpersville Formation, southwestern Stephens County, Texas, M.S. thesis, Univ. of Texas at Arlington, 1983.

Wray, J.L., 1977, Calcareous algae: Elsevier Pub., Developments in paleontology and stratigraphy 4, 185 p.