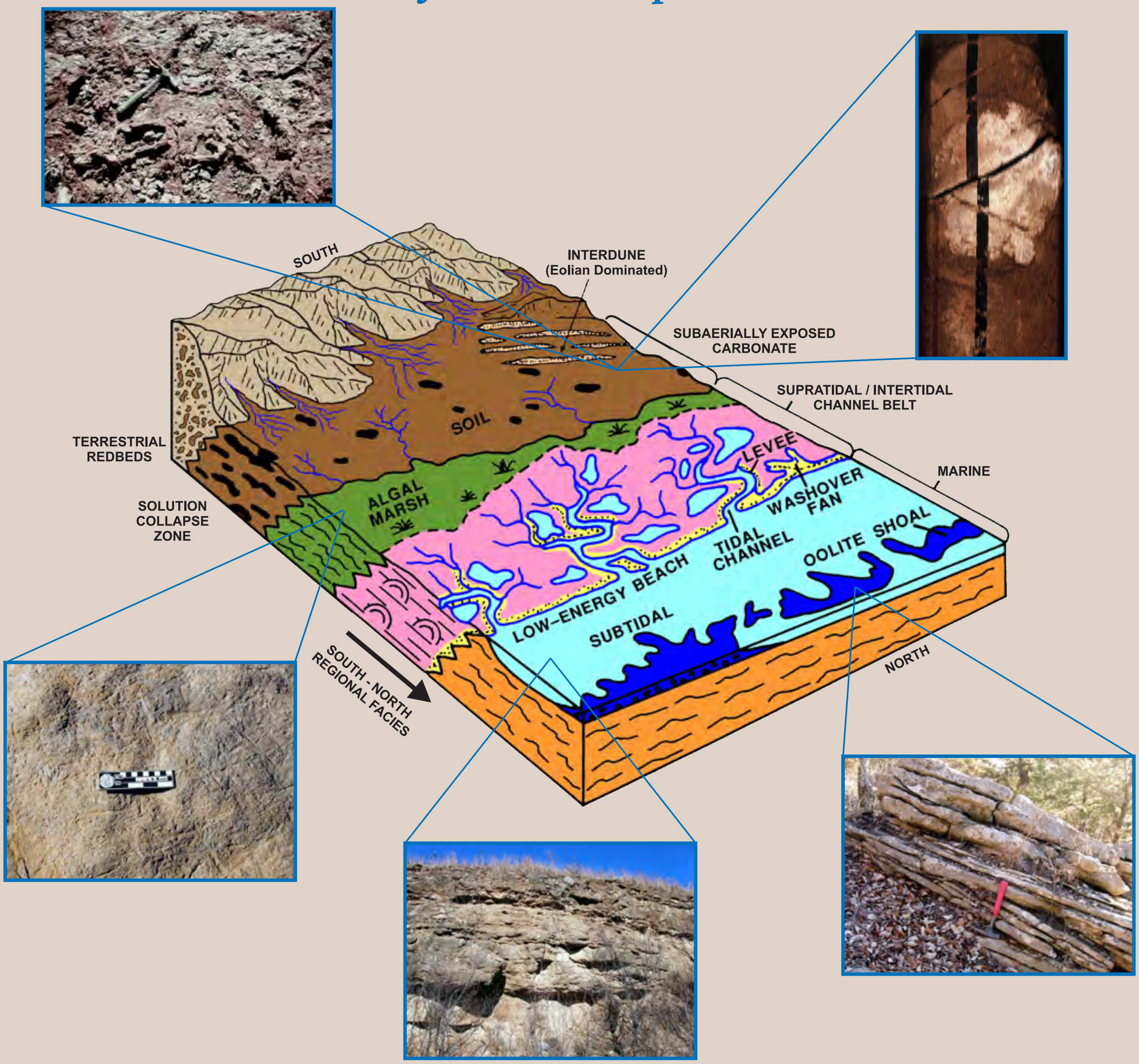
STRATIGRAPHIC ANALYSIS OF THE PERMIAN CHASE GROUP IN NORTHERN OKLAHOMA–OUTCROP ANALOGS OF RESERVOIR ROCKS IN THE HUGOTON EMBAYMENT OF NORTHWESTERN OKLAHOMA AND SOUTHWESTERN KANSAS

By
James R. Chaplin



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James R. Chaplin
Oklahoma Geological Survey
Norman, Oklahoma

This guidebook was prepared for the second day of a field trip in April 2009, to southern Kansas—northern Oklahoma, co–sponsored by the Oklahoma City Geological Society and the Kansas Geological Society. The first day of the field trip in southern Kansas was led by Dr. Sal Mazzullo, Department of Geology, Wichita State University, Wichita, Kansas.

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The University of Oklahoma
Spring, 2010

Front Cover

Proposed depositional model of a mixed carbonate–siliciclastic system
for the Permian Chase Group in northern Oklahoma

Clockwise–Top

- Desiccation features in the Matfield Shale, Pioneer Cove, Kaw City, Kay County
- Brecciated caliche nodule in the Doyle Shale, core hole KC–5, depth 130.0 ft, Kay County
- Low–angle crossbedded oolitic grainstones in the lower part of the Nolans Limestone (Herington Limestone Member) in an ooid shoal depositional setting, Kay County
- Massive beds of coated–grain packstone/grainstone facies overlain by nodular and wavy–bedded shaly–packstone facies in the Fort Riley Limestone Member, Vap's Pass, Kay County
- Outcrop surface of the Luta Limestone Member covered with horizontal, striated gastropod feeding/locomotion trails that criss–cross or overlap to form a distinctive V–shaped pattern, Newkirk Oil Field section, Kay County

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James R. Chaplin

Oklahoma Geological Survey

INTRODUCTION

This field trip will focus on the southern facies of the Chase Group as traced from southern Kansas into northern Oklahoma. The stratigraphic, lithologic, and biotic character of the Chase Group formations will be examined. To the south, the carbonate units become more clastic–rich and eventually pinch out; the clastic units thicken and become more sand–rich at the expense of the carbonates.

The general study area extends from southeastern Nebraska across central Kansas into northern Oklahoma where extensive beds of Permian rocks crop out in roughly parallel north–south belts.

The primary study area for this field trip is located in north–central Oklahoma. Specifically, it is located in Kay County, which includes all or part of Tps. 25 N., to 29 N., and Rgs. 2 W. to 5 E. (Fig. 1).

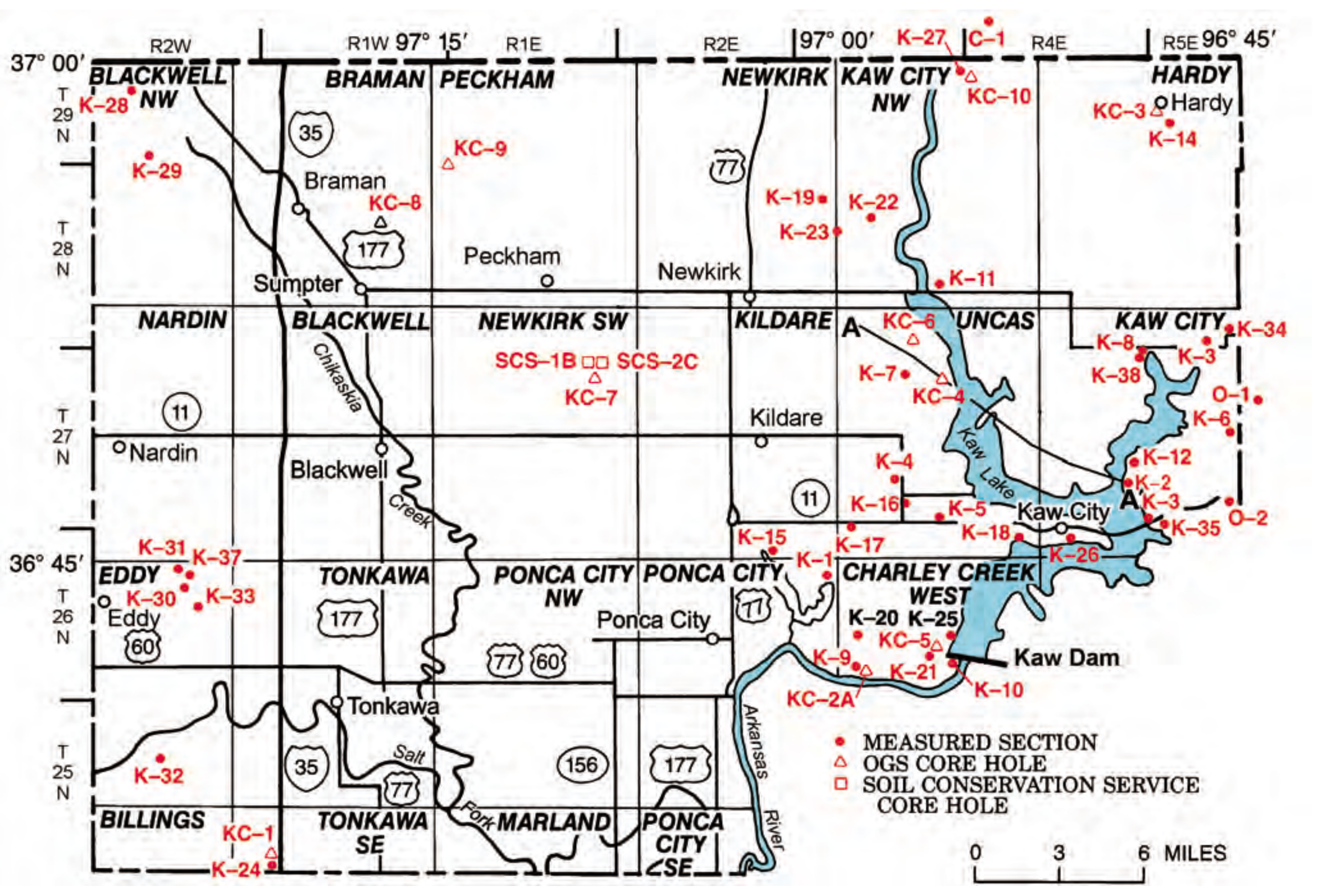


Figure 1. Index map of Kay County showing locations of measured sections and core holes with respect to 7.5' quadrangles. Location of cross–section A–A' is also shown in Figure 4. The cross section is shown in Figure 5.

The secondary study area for this field trip is located in southwestern Osage County, western Pawnee County, Noble County, and northernmost Payne County which includes all or part of Tps. 19 to 24 N., and Rgs. 1 E. to 4 E.

Siliciclastic–dominated, mixed carbonate–siliciclastic sediments of the Early Permian Chase Group were deposited in epicontinental marine, marginal–marine, and terrestrial environments in the Midcontinent region of North America. The Chase Group includes a predominantly marine, carbonate–dominated lithofacies in southeastern Nebraska and central Kansas and a dominantly marginal–marine to terrestrial siliciclastic lithofacies in northern Oklahoma. There is a pronounced north–south facies change from a dominantly marine carbonate platform, shallow–water open–marine subtidal facies in Nebraska and Kansas, to restricted marine and marginal–marine subtidal to peritidal and terrestrial facies in northern Oklahoma. In central Oklahoma, the carbonate units merge into, and disappear within, a thick wedge of dominantly fluvial and/or terrestrial redbed siliciclastics.

The Chase Group is a coherent depositional sequence of stratigraphic units consisting of cyclic couplets of mixed carbonates and clastics (Fig. 2). The carbonates and clastics of each depositional couplet correlate to major transgressive and regressive events, respectively. Regressive parts of the depositional couplets consist of thicker (33–131 ft), more clastic–rich marginal–marine and/or terrestrial facies dominantly composed of red and green mudstones and/or shales locally capped by exposure surfaces and variably developed paleosols. Transgressive parts of the couplets consist of thinner (3–66 ft), more carbonate–rich marine and marginal–marine facies dominantly composed of shallowing–upward units of coated–grain, fossiliferous wackestones, packstones, and grainstones

The persistent lateral distribution and repetitive vertical succession of the siliciclastic facies over marine carbonates suggest an extensive sabkha environment across parts of northern Oklahoma periodically during Early Permian sea–level lowstands. Progradation of the sabkha across the marine carbonates results in a time–transgressive surface. This event is culminated by a marine transgression that results in the deposition of a shallowing–upward succession of marine carbonates.

Significant ichnological events help to identify discontinuity surfaces associated with major regressions and transgressions. Within each depositional couplet, trace fossil–associations in the Chase Group are assigned to the substrate–controlled *Glossifungites* ichnofacies. The *Glossifungites* ichnofacies, at least in this particular geographic and stratigraphic setting, characterizes discontinuity surfaces that correlate to hiatuses in deposition, typically concomitant with

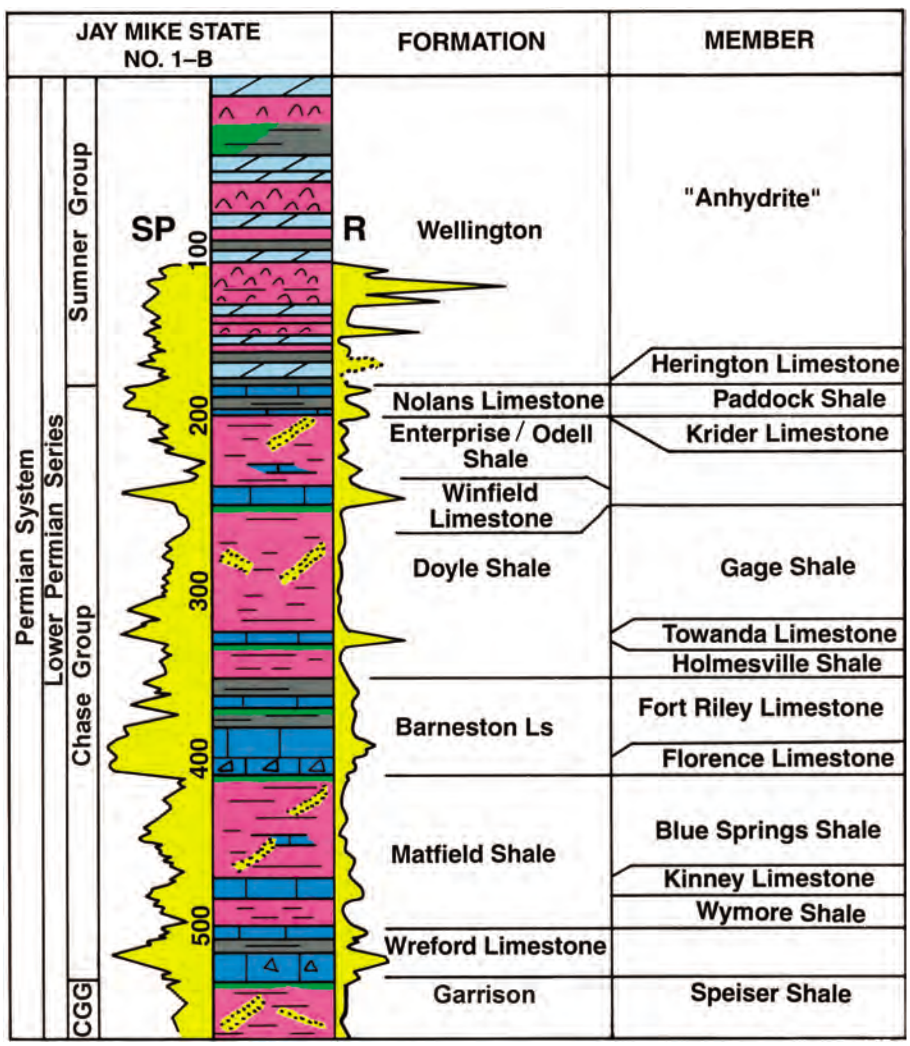


Figure 2. Schematic diagram showing electric–log response to vertical lithofacies within the Permian Chase Group. (*CGG=Council Grove Group)

shallow–water erosion associated with transgressive–regressive events.

STRUCTURAL SETTING

Figure 3 is a generalized late Paleozoic tectonic map of Oklahoma and parts of adjacent states in the northern Midcontinent. Regionally, Kay County, the primary study area for this field trip, is part of the Central Oklahoma Platform (commonly referred to as the Cherokee Platform in Kansas). The Central Oklahoma Platform extends northeast into south–central Kansas where it abuts the Bourbon Arch. The eastern boundary is the Ozark Uplift. The Central Oklahoma Platform is covered with a succession of thin repetitive Pennsylvanian and Permian shallow–water carbonates and clastics. West of the platform, dominantly clastic–rich basinal sediments predominate.

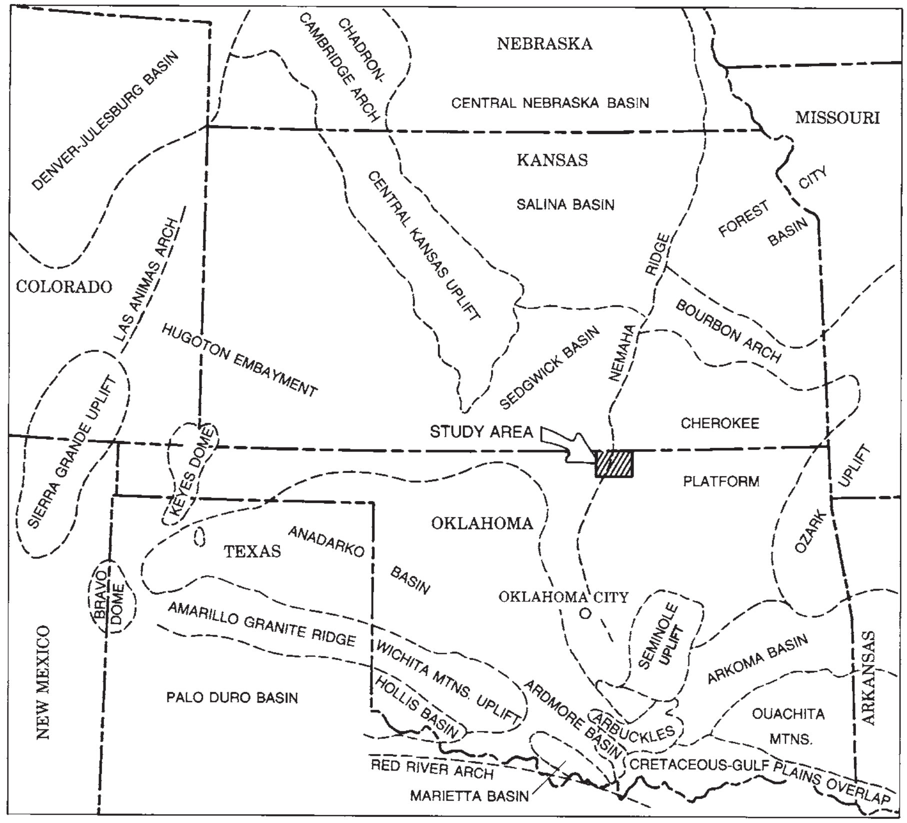


Figure 3. Location of detailed study area relative to tectonic features of the Midcontinent region.

Regional dip of strata in Kay County averages 40 ft/mi (<1°) to the west–southwest. Locally, in the vicinity of northeast–trending anticlinal folds across the eastern one–third of Kay County, dips may exceed 10°. The strata strike approximately north–south.

The major tectonic structure in north–central Oklahoma is the Nemaha Ridge (Fig. 3). The Nemaha Ridge is a series of northeast– to north–south–trending faults extending ~900 mi northward from central Oklahoma across eastern Kansas and southeastern Nebraska into Iowa, Wisconsin, and Minnesota. The Nemaha Ridge trends northeasterly across the western one–third of Kay County. This structural zone is ~30 mi wide in northern Kay County and narrows southwestward to less than 6 mi wide in central Oklahoma. In Oklahoma, the Nemaha Ridge consists of a number of small crustal blocks (horst and graben fault–block pattern) that were uplifted and eroded in Late Mississippian and Early Pennsylvanian time (Luza and Lawson, 1982, p. 26). Rotation and lateral movement of fault blocks are cited by Luza and Lawson (1982, p. 26) as evidence for wrench–fault tectonics.

Two pronounced anticlines (Ponca and Mervine), trending northeast–southwest across eastern Kay County, have topographic relief, and are confirmed by outcrop and core–hole studies (Fig. 4). Their surface expression is in the form of inliers or other deviations from a normal outcrop pattern. The axis of the Ponca Anticline extends northeast to Ponca City, makes a well–defined curve eastward and extends northeast into the Mervine Anticline area, a distance of ~18 mi (Fig. 4).

The Mervine Anticline is the northern continuation of the Ponca Anticline and lies on the main axis of folding extending south from the Dexter Anticline in Kansas (Fig. 4). Locally, the Mervine Anticline is the structure best seen at the surface. The axis of this fold trends ~N. 20° E., with the crest exposed in the center of sec. 2, T. 27 N., R. 3 E., (Uncas 7.5' Quadrangle) near OGS core hole KC–4 drilled on the east flank of the Mervine Anticline (Fig. 5). The topographic profile and general structure section (A–A') shown in Figure 5 demonstrates the pronounced asymmetry of the anticline which has a steeply dipping east limb (dips as much as 25°) and a more gently dipping west limb (dips generally less than 5°); the dip of the west limb abruptly merges into the prevailing regional dip (30–40 ft/mi).

STRATIGRAPHIC FRAMEWORK FOR THE CHASE GROUP

Chase Group

Kay County

In Kay County the Chase Group varies in thickness from 300–334 ft and includes all beds between the base of the Wreford Limestone and the top of the Nolans Limestone (Herington Limestone Member) (Fig. 6). Table 1 shows the general characteristics of the Chase Group southward from Cowley County, Kansas to Payne County, Oklahoma. Table 2 shows the thickness variations of formations within the Chase Group from Nebraska, through Kansas, into Payne County, Oklahoma.

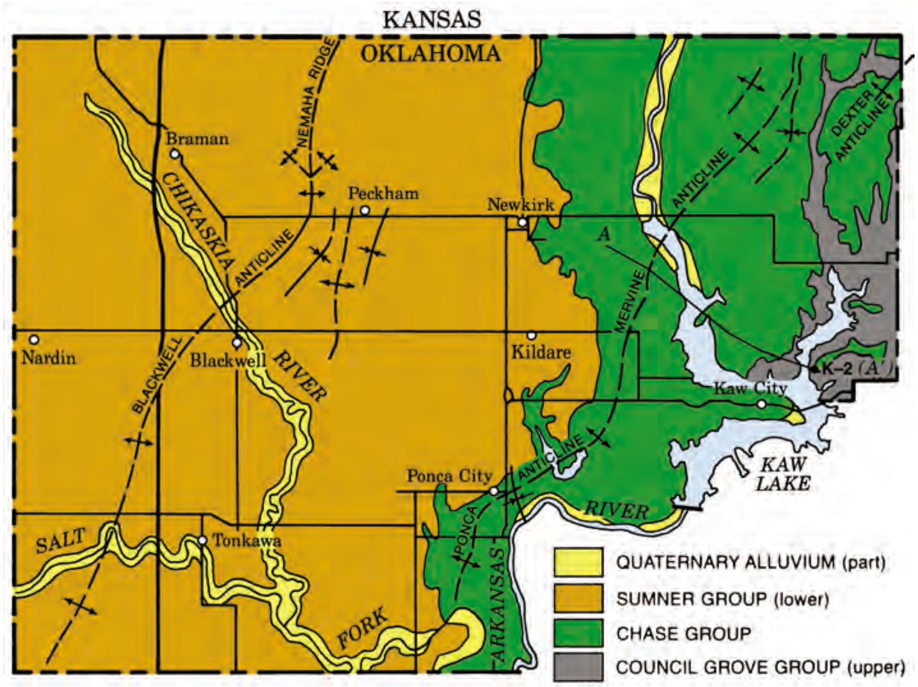


Figure 4. Generalized geologic map of the surface rocks in Kay County showing major local structures.

Because the formations characteristically exhibit a southward facies change, it is appropriate to describe the Lower Permian succession in terms of a northern and southern facies in Kay County, Oklahoma. Northern Kay County includes Tps. 28 to 29 N., Rgs. 2 W. to 5 E., and southern Kay County includes Tps. 25 to 27 N., Rgs. 2 W. to 5 E. The stratigraphic succession, general lithologies, and average thicknesses of the northern and southern facies are shown in Figures 7 and 8. Table 3 summarizes the general facies changes in these rocks from the northern to the southern boundary of Kay County.

Osage County

The Chase Group is exposed in southwestern Osage County with an average thickness of ~350 ft. Carbonates comprise 14 percent of the section. Chase lithologies consist of alternating beds of limestone and shales with a few sandstone lenses. Sandstone beds increase noticeably in thickness to the south.

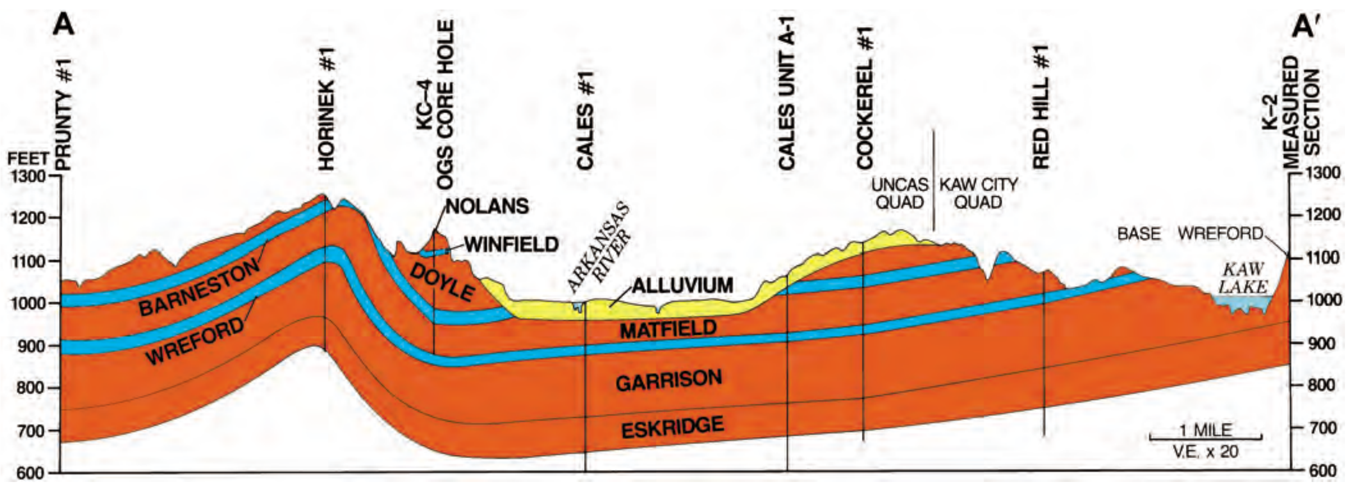


Figure 5. Generalized cross section across the Mervine Anticline (see Figure 4 above for specific location of cross section). (Modified from Noll, 1955).

Kansas–Nebraska Stratigraphic Nomenclature Group	Formation	Member	Outcropping Lithologic Units Recognized in Northernmost Kay County, OK	Outcropping Lithologic Units Recognized in Southernmost Kay County, OK	Stratigraphic Nomenclature Adopted for Field Mapping Units in Kay County, OK
Chase	Nolans Limestone	Herington Ls.	Herington Ls.	Herington Ls.	* = Nolans Ls.
		Paddock Sh.	Paddock Sh.		
		Krider Ls.	Krider Ls.		
	Odell Shale		Enterprise/Odell Sh. Luta Ls. Mbr.	Enterprise/Odell Sh. Luta Ls. Mbr.	Enterprise/Odell Sh. Luta Ls. Mbr.
	Winfield Limestone	Cresswell Ls.	Cresswell Ls.	Cresswell Ls.	*Winfield Ls.
		Grant Sh.			
		Stovall Ls.			
	Doyle Shale	Gage Sh.	Gage Sh.	Gage Sh.	*Doyle Sh.
		Towanda Ls.	Towanda Ls.	Towanda Ls.	
		Holmesville Sh.	Holmesville Sh.	Holmesville Sh.	
	Barneston Limestone	Ft. Riley Ls.	Ft. Riley Ls.	Ft. Riley Ls.	*Barneston Ls.
		Oketo Sh.	Florence Ls.		
		Florence Ls.			
	Matfield Shale	Blue Springs Sh.	Blue Springs Sh.	Matfield Sh.	*Matfield Sh.
		Kinney Ls.	Kinney Ls.		
		Wymore Sh.	Wymore Sh.		
	Wreford Limestone	Schroyer Ls.		*Wreford Ls.	*Wreford Ls.
		Havensville Sh.			
		Threemile Ls.			
Council Grove	Speiser Shale		Garrison Formation Speiser Sh. Mbr.	Garrison Formation Speiser Sh. Mbr.	*Garrison Formation (Part)

* = Undivided

Figure 6. Kansas–Nebraska stratigraphic nomenclature, outcropping lithologic units recognized in Kay County, and the stratigraphic nomenclature adopted for field–mapping–units in Kay County for the Chase Group.

Table 1. General characteristics of the Chase Group southward from Cowley County, Kansas to Payne County, Oklahoma

CHARACTERISTICS	Cowley County, Kansas	Kay County, Oklahoma	Osage County, Oklahoma	Noble County, Oklahoma	Pawnee County, Oklahoma	Payne County, Oklahoma
1. Stratigraphic interval	Wreford–Winfield	Wreford–Nolans Limestone (Herington)	Wreford–Nolans Limestone (Herington)	Wreford–Nolans Limestone (Herington)	Wreford–Winfield	Wreford–Nolans Limestone (Herington)
2. Average thickness (ft)	275	300–334	350–360	300–350	300	300–340
a. Average thickness of carbonate units	20	23	8	3	<1	<1
b. Average thickness of shale/mudstone units	14	35	43	40	15	40–50
c. Average thickness of sandstone units	<5	12	17	15	10	30
3. General lithofacies	Light–gray, coated–grain cherty skeletal packstones to grainstones interbedded with gray to maroon, calcareous, locally fossiliferous shales	Yellowish–gray, coated–grain skeletal wackestones to grainstones, with rare chert, red to greenish–gray noncalcareous dominantly unfossiliferous shales/mudstones, and reddish–brown, unfossiliferous, very fine grained, cross–bedded sandstones	Gray, algal, noncherty limestones becoming sandy to the south; maroon, unfossiliferous, shales/mudstones; reddish–gray, non–calcareous, unfossiliferous, lenticular, very fine grained sandstones increasing in thickness to the south	Sandy, skeletal grainstones, algal boundstones, and calcareous shales/ sandstones grading southward into red nodular, peloidal dolomitic mudstones	Dominantly red/green shales and sandstones with minor sandy, non–cherty limestones; only 4 of the 10 limestones in the Kansas section are present (Wreford, Ft. Riley, Winfield, and Herington)	Dominantly reddish–gray, very fine grained lenticular sandstones and red/green, unfossiliferous shale/mudstone; locally with nodular to conglomeratic, locally sparsely fossiliferous dolomitic limestone lenses
4. Percent of section composed of carbonate	46	34	14	14	10	3
5. Percent of section composed of clastics	54	66	86	86	90	97
6. Contacts	*Upper*—not well exposed *Lower*—sharp, planar, conformable	*Upper*—gradational, poorly exposed *Lower*—sharp, planar, well exposed, conformable	*Upper*—poorly exposed *Lower*—sharp, planar, conformable, locally well exposed	*Upper*—usually poorly exposed, locally sharp, erosional *Lower*—sharp, planar, conformable	*Upper*—poorly exposed *Lower*—gradational to sharp, locally erosional	*Upper*—poorly exposed, highly gradational *Lower*—poorly exposed, highly gradational

Table 2. Thickness variations for the Chase Group (Wreford–Nolans Limestone) from Nebraska, through Kansas, into Payne County, Oklahoma

		KANSAS									OKLAHOMA					
											Kay County					
Lithostratigraphy	Nebraska	Marshall County	Pottawatomie County	Riley/ Geary Counties	Morris County	Dickinson County	Marion County	Chase County	Butler County	Cowley County	Northern	Southern	SW Osage County	Noble County	Pawnee County	Payne County
Chase Group	303	288		337	304.6		340+	[a]301		349	300	333	348	343		337
Nolans Limestone	28+	19	NE	20	23.1		30	22	3	[b]40	16.5	10	15±	<1–8	NE	<1
Herington Limestone	8	6		6	7	[a]9	18	12	3	[b]27		8–19.5	15±	<1–8		<1
Paddock Shale	[a]14	11		12	15		10	7	ND	7	ND	ND	ND	ND		ND
Krider Limestone	[a]6	2		2	1.1		2	3	ND	6	ND	ND	ND	ND		ND
Enterprise/Odell Shale	[a]30	25	NE	20	20	35–45	30	25	35	38	36	28–62	48	70	NE	60
Winfield Limestone	25	22	NE	28.5	23.5		40	20	9	[a]25	16	14	15±	5±	<1–7	<1
Cresswell Limestone	6	15		17	12		28	11	ND	[a]25	10–23	8–21	ND	ND	ND	ND
Grant Shale	17	16		10	10		[a]10	6	ND	ND	ND	ND	ND	ND	ND	ND
Stovall Limestone	2	3		1.5	1.5		[a]2	3	ND	ND	ND	ND	ND	ND	ND	ND
Doyle Shale	64	80		83±	67		[a]80	62	97	87	85	136	135	150	155	170
Gage Shale	[a]35	50	NE	50	40		45	41	55	60	47–70	105	ND	ND	ND	ND
Towanda Limestone	8	10	15	2–15	11		10	9	[a]7	2	4	3	2	ND	ND	ND
Holmesville Shale	[a]21	20	30	23	16		25	12	35	25	23	9–37	28	ND	ND	ND
Barneston Limestone	[a]50	50	61	83±	68		80	80	85	65–80	52	18–39	3–6	<1–30	5–18	<1–1
Ft. Riley Limestone	27	25	18	[a]35	37		39	40	50	45–55	37–47	18–39	3–6	ND	ND	<1–1
Oketo Shale	ND	[a]1–3	13	1–17	6		2	0–3	ND	ND	ND	ND	ND	ND	ND	ND
Florence Limestone	23	22	30	33–45	25		[a]39	39	35	12–35	8–22	ND	ND	ND	ND	ND
Matfield Shale	63+	57	55	66±	66±		70	[a]54	NE	56	66	81	100–125	100	100	100
Blue Springs Shale	[a]29+	34	35	25–45	34		35	17		34	24–38	54	ND	ND	ND	ND
Kinney Limestone	[a]12	3	3	1–22	<1–4		5	18		10	3–18	5	ND	ND	ND	ND
Wymore Shale	[a]22	20	17	20	30		30	19		12	25	10–35	ND	ND	ND	ND
Wreford Limestone	43	35	33	[a]37	37		10+	38	NE	31	19–34	23–36	3–16	0–6	0–7	1–10
Schroyer Limestone	[a]20	11	8–18	18	12		10	10		6	ND	ND	ND	ND	ND	ND
Havensville Shale	15+	17	[a]6–20	10	12		NE	10		7	ND	ND	ND	ND	ND	ND
Threemile Limestone	8	7	7	[a]9	13		NE	18		18	ND	ND	ND	ND	ND	ND

[a]Denotes type locality. —— NE – Not exposed. —— ND – Not divided. —— [b]Probably includes transitional lithologies (±19 ft) of the Wellington Formation

Table 3. Comparison of the northernmost and southernmost facies of Lower Permian Rocks in Kay County, Oklahoma

		Northernmost Kay County	Southernmost Kay County
1. General Comparisons			
		Lithologies, thicknesses, and facies distribution for the Council Grove and Chase Groups compare more favorably with Kansas and Nebraska sections	Lithologies and thicknesses not as similar to those units occupying equivalent stratigraphic positions in Kansas and Nebraska
2. Description/Thickness			
	Limestones	Cherty character of units in Wreford Limestone and lowest member of the Barneston Limestone (Florence) retained	Diagnostic chert in the Wreford Limestone and lowest member of the Barneston Limestone (Florence) is absent
		No chert in the Winfield Limestone	No chert in the Winfield Limestone
		Chert is rare in the Nolans Limestone	No chert in the Nolans Limestone
		Less silt and sand	Noticeable increase in silt and sand; in general, units become more shaly
		Comparatively thicker throughout the entire section	Thinner and commonly cut out by sandstone channels making differentiation of subjacent shale units difficult
	Sandstones	Common, thin, lenticular	Increase in abundance and thickness throughout the entire section
	Shales	Relatively consistent in thickness and lithology	Overall increase in thickness at expense of limestone, but overall aggregate group thickness remains constant
3. Formations/Members			
		Most subdivisions of formations (e.g., Wreford, Barneston, and Nolans) can be locally divided	Many subdivisions of formations (especially within the Wreford, Barneston, and Nolans) cannot be divided
		Subdivisions of the Winfield Limestone not recognized	Subdivisions of the Winfield Limestone not recognized
4. Correlation			
		Units lithostratigraphically correlative with Kansas and Nebraska sections	Units partly lithostratigraphically correlative with Kansas and Nebraska sections
5. Paleontology			
		Units contain an abundant and diverse marine fauna throughout the entire stratigraphic interval	Less fossiliferous throughout the entire stratigraphic interval

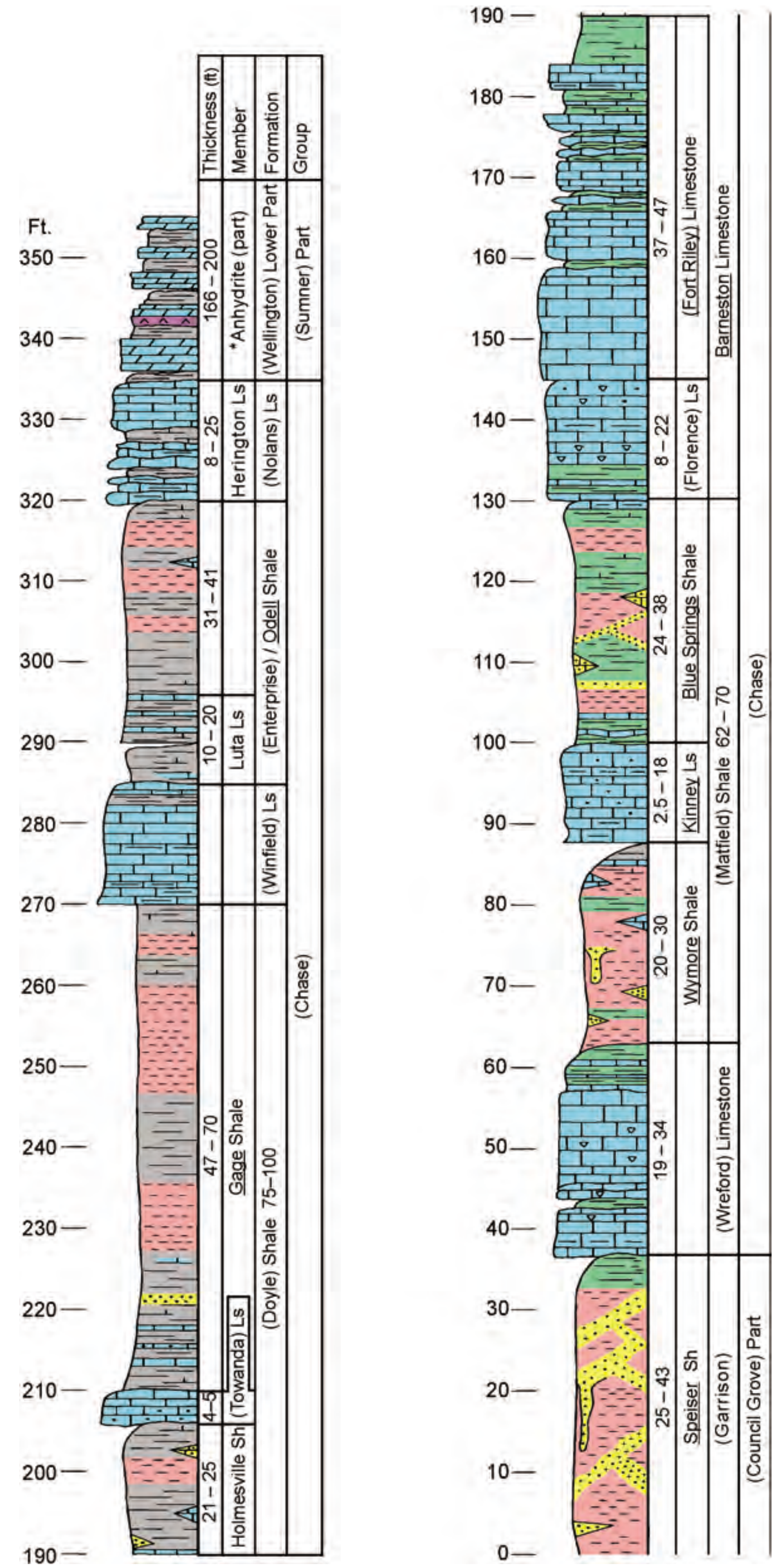


Figure 7. Composite stratigraphic section for the Chase Group in northern Kay County, Tps. 28–29 N., Rgs. 2 W.–5 E. Data from measured sections and cores (Chaplin, 1988). See Figure 8 on following page for explanation of symbols.

Pawnee County

The Chase Group is approximately 300 ft thick in Pawnee County. It is composed primarily of sandstones and shales with thin remnants of only three (Wreford, Fort Riley, Winfield) of the ten limestones comprising the Kansas section. Carbonates comprise only 10 percent of the section. No exposures of the Enterprise/Odell Shale or the Herington Limestone occur in Pawnee County. The carbonates have a high sand content but contain no chert.

Noble County

The Chase Group is ~300–350 ft thick in Noble County as determined primarily from electric logs. Approximately 14 percent of the section consists of carbonates.

Payne County

The Chase Group in Payne County ranges in thickness from 300–340 ft. Approximately 3 percent of the section is composed of carbonates.

Wreford Limestone

Kay County

The base of the Wreford Limestone defines the base of the Chase Group (Fig. 6). The Wreford Limestone is underlain by the Speiser Shale of the Garrison Formation (Figs. 6, 7, 8, and 9). To the north in OGS core hole KC–3 (Fig. 1), the Wreford Limestone can be subdivided into three formally recognized units in Kansas and Nebraska: a lower limestone unit (Threemile), a middle shale unit (Havensville), and an upper limestone unit (Schroyer) (Fig. 6). However, locally to the south and southeast in Noble, Osage, Pawnee and Payne Counties, those lithologic subdivisions are often difficult to identify; as the chert content decreases, units thin appreciably, the entire interval becomes very shaly and locally sandy (Fig. 8), and the formation is poorly exposed.

The Wreford Limestone is commonly 25–30 ft thick and composed predominantly of limestone beds. The limestones (skeletal wackestones and packstones) are bluish–gray, vuggy, shaly, algal (osagid grains), fossiliferous and locally chert bearing. The osagid grains consist of intergrowths of algae and various encrusting foraminifera. Many

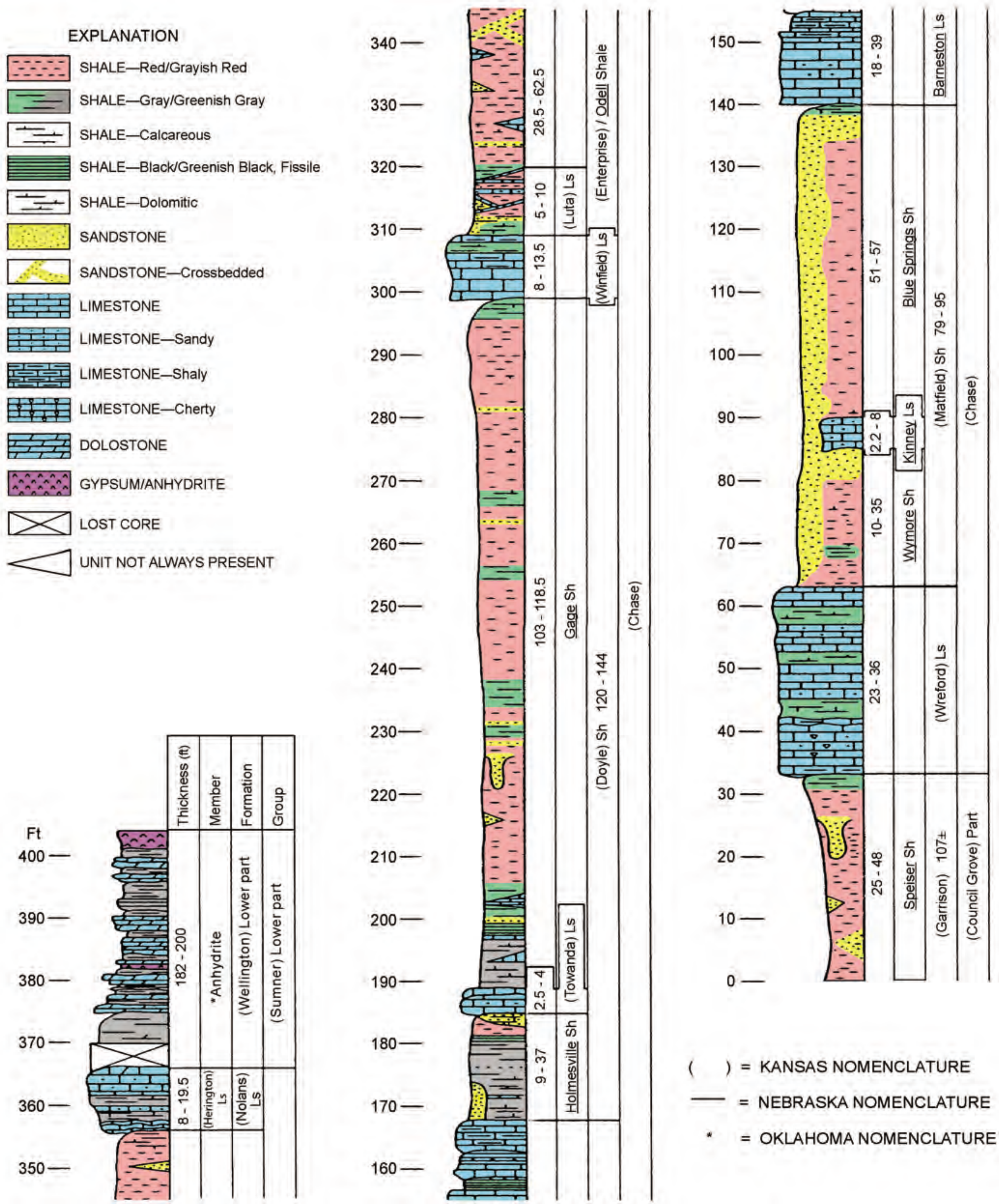


Figure 8. Composite stratigraphic section for the Chase Group in southern Kay County, Tps. 25–27 N., Rgs. 2 W.–5 E. Data from measured sections and cores (Chaplin, 1988). Lithologic symbols shown in explanation are used on later stratigraphic sections.

Figure 9. Sharp contact between transgressive marine facies of the Wreford Limestone above and regressive marginal–marine facies of the Speiser Shale below. Core hole KC–5, depth, 346.6 ft, Kay County, Oklahoma.

Algal–molluscan limestones are the most common carbonate facies in the Wreford Limestone and are found only in the most southern Wreford Limestone exposures. The limestones are hard, dense, thin– to medium–bedded and locally contain intraclasts. Bioclasts include mollusks, crinoid hash, and ostracodes. Some thin calcareous sandstones occur locally in this facies.

A brachiopod–molluscan limestone facies is also common in the Wreford Limestone. This facies is thin–bedded to massive, dense, burrowed and contains limonitized osagid grains. Common brachiopods include *Derbyia* and *Composita* that locally may form individual shell beds or pavements encrusted with algae.

A calcareous shale facies that contains silicified fossils of crinoid columnals, brachiopod and bivalve shell fragments, and productid brachiopod and echinoid spines is recognized in the Wreford Limestone. This facies is less fossiliferous than in Kansas.

A cherty limestone facies occurs in the Wreford Limestone only in extreme northern Oklahoma (Fig. 10). This facies consists of skeletal wackestones and lime mudstones. The chert is locally calcareous or noncalcareous and concentrically banded. Dominant fossils, commonly silicified, include bryozoans, brachiopods, crinoid and echinoid fragments, and rare sponge spicules.

The southern limestone facies of the Wreford Limestone contains more coated grains (osagid), more mollusks, fewer brachiopods and bryozoans, and an increasing abundance of fine quartz sand. In addition, very fine grained, well–sorted, slightly calcareous, thin– to medium–bedded lenticular tan to red limestone beds contain wavy stringers of dark–greenish–gray shale and mudstone. Rounded clasts bearing sponge spicules are present locally. Shales and mudstones are typically dark–greenish–gray mottled dusky–red and calcareous, and they contain rounded clasts and nodules of micritic limestone.

Locally, the tops of limestone beds are brecciated suggesting subaerial exposure surfaces. The lower and upper contacts are sharp. To the south and southeast the chert content deceases, and the entire interval becomes more shaly and locally sandy.

Figure 10. Cherty facies in the Wreford Limestone, northern outcrop belt, with major shale bed below that may be, at least in part, equivalent to the Havensville Shale of Kansas. Near Hardy, Kay County, Oklahoma.

quartzose sandstones (orthoquartzites) regionally replace the algal–molluscan limestone facies of the northern outcrop belt. Limited Wreford Limestone exposures in Noble, Osage, Pawnee, and Payne Counties contain nodules/lenses of algal–molluscan limestones. These may represent remnants of originally very sandy algal–molluscan limestones in which the calcareous matrix/cement has largely been removed by leaching/dissolution.

Large burrows as much as 1 in. in diameter, probably produced by the burrowing infaunal pholad bivalve *Wilkingia* and the mytiloid bivalve *Pinna*, are common locally. Horizontal forms of the trace fossil *Rhizocorallium* are common on the top surfaces of Wreford beds, whereas horizontal branching networks of the trace fossil *Thalassinoides* are common on the soles of Wreford beds (Fig. 11).

Depositional Environment

Lithofacies in the Wreford Limestone suggest shallow, brackish to normal marine waters associated with brackish–water lagoons/bays between a redbed coastal plain and regions locally of purer quartz sand, possibly shallow nearshore bars.

The co–ocurrence of coated grains (osagid grains) and internal molds of the burrowing infaunal bivalve, *Pinna* in life position in the lower part of the Wreford Limestone marks the onset of a major marine transgressive event.

Osage County

The Wreford Limestone is ~13 ft thick, but locally less than 3 ft. It is composed of thin–bedded, unfossiliferous, osagid–grain–rich skeletal wackestones and shales.

Pawnee County

In and south of T. 20 N., the Wreford Limestone pinches out. The Wreford Limestone is best developed in the northern part of T. 22 N. and the southern part of T. 23 N., R. 4 E., where it forms a prominent escarpment north and south of Oklahoma Highway 15. The Wreford Limestone varies in thickness from 0–7 ft. It is composed of highly leached calcareous sandstone and sandy limestone interbedded with red shale. It contains a molluscan fauna of myalinid and pectenoid bivalves, and productid brachiopods (*Linoproductus*). Osagid grains are common.

Noble County

The Wreford Limestone occurs primarily as inliers in terrace deposits. The northern facies (T. 24 N., R. 3 E.) is ~6 ft thick and is composed of an upper thin grain–supported packstone with algal filaments and coarse bioclasts; the middle unit is red shale, and the lower unit consists of a thin skeletal wackestone with clay pebbles, osagid grains, and *Myalina* bivalve shells.

Payne County

The thickness of the Wreford Limestone ranges from ~1–10 ft. The Wreford Limestone is difficult to map due to the lack of topographic expression. The formation consists of nodular dolomite lenses composed of fine carbonate mud locally with septarian structures. Other nodules are composed of an intricate network of calcite or dolomite veinlets. The nodules typically are red to greenish–gray in color and range in size from less than 1 in. to nearly 1 ft in diameter.

Matfield Shale

Kay County

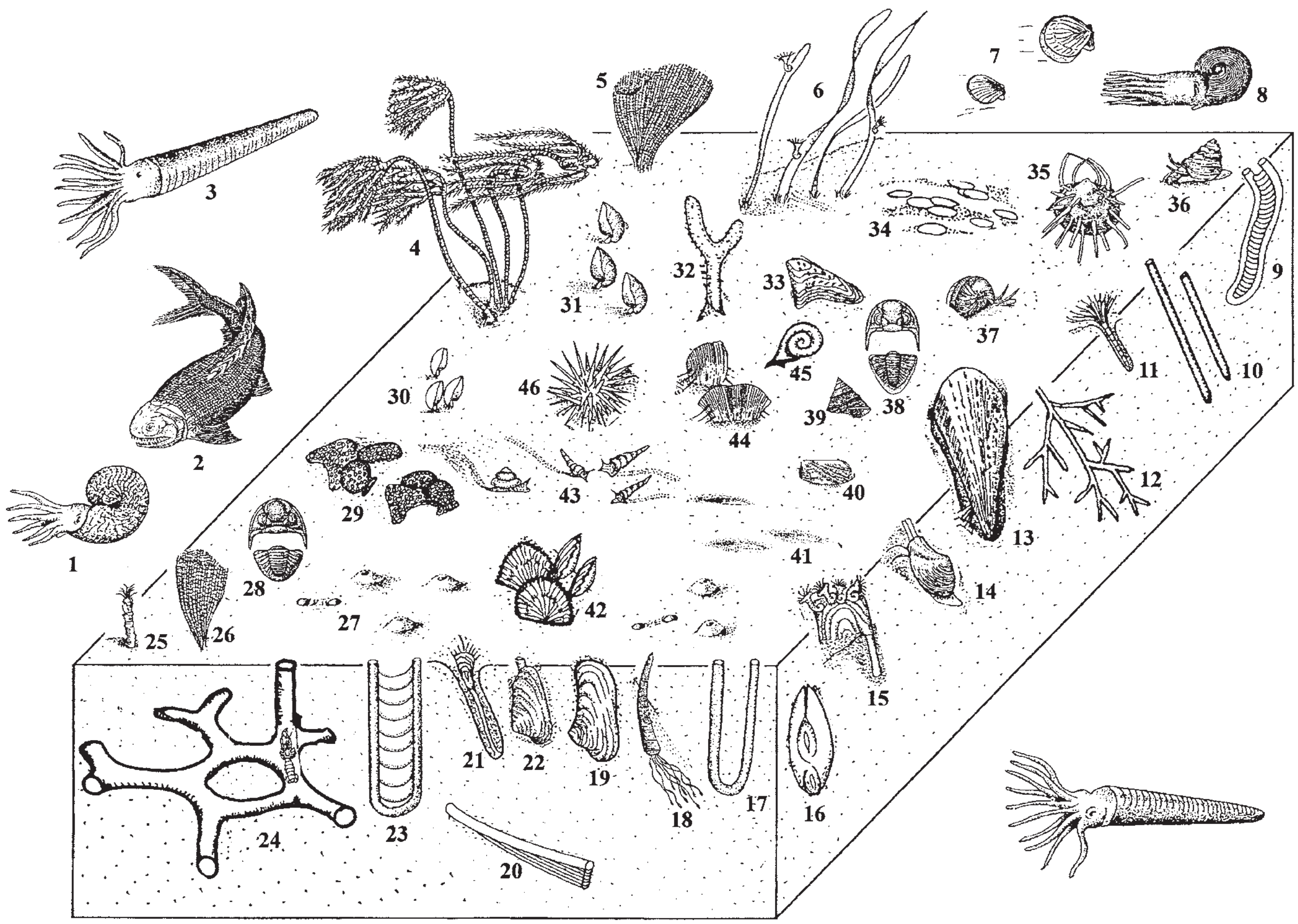
The Matfield Shale in the northern facies includes a lower 15– to 20–ft–thick shale and mudstone unit (Wymore Shale); a middle 0– to 18–ft–thick sandy limestone unit (Kinney Limestone), and an upper 20– to 30–ft–thick calcareous shale unit containing locally thin fossiliferous limestone beds and thin lenticular sandstones (Blue Springs Shale) (Fig. 2). The entire interval varies in thickness from 60–80 ft in the north to 80–90 ft in the south (Figs. 7 and 8).

The lower shale member (Wymore) locally contains thin shaly limestone beds, especially in the upper part. The interval changes facies to the south and in core hole KC–5 (Fig. 1) contains 20–25 ft of crossbedded sandstone.

The middle sandy limestone member (Kinney) is highly variable in thickness and lateral extent. To the southeast at section K–26 (Fig. 1), the Kinney Limestone is absent and the entire Matfield Shale interval primarily includes crossbedded, lenticular channel sandstones. To the south at Kaw Dam in sec. 25, T. 26 N., R. 3 E., the Kinney interval consists of a sandstone sequence that varies from 5–30 ft thick as determined from the interpretation of geological drill–hole logs provided by the U.S. Army Corps of Engineers.

The upper shale member (Blue Springs) is generally 20– to 30–ft thick, but locally attains thicknesses of 50–60 ft wherever the Kinney Limestone is thin (e.g., core holes KC–4, KC–5, KC–6) (Fig. 1). The Blue Springs Shale contains locally thin limestone beds and lenticular sandstones. The contact between the Matfield Shale below and the Barneston Limestone above is gradational (Fig. 12).

The development of sand bodies is common throughout the Matfield Shale, and in the subsurface the in-



Key to Fossils in Schematic Diagram Above

1. Ammonoid cephalopod
2. Palaeoniscoid fish
3. *Pseudorthoceras* (straight nautiloid cephalopod)
4. Attached stalked crinoid
5. Fenestrate bryozoan
6. Sea grass
7. *Aviculopecten* (pectenoid bivalve)
8. Ammonoid cephalopod
9. *Rhizocorallium* burrow system
10. *Skolithos* burrow
11. Feathered tube worms
12. *Chondrites* burrow system
13. *Pinna* (mytiloid bivalve)
14. Mollusca (bivalve)
15. *Pinna* (mytiloid bivalve) with *Spirorbis* polychaete tube worms on top
16. *Edmondia* (anomalodesmatid bivalve)
17. *Arenicolites* burrow system
18. Scaphopod mollusk
19. *Edmondia* (anomalodesmatid bivalve)
20. *Teichichnus* burrow system
21. *Lingula* (inarticulate brachiopod) in its burrow
22. *Wilkingia* (pholad bivalve)
23. *Diplocraterion* burrow system
24. *Thalassinoides* burrow system with the probable trace maker (ghost shrimp)
25. *Serpula* (annelid)
26. Fenestrate bryozoan
27. Aperture openings of the trace fossils *Thalassinoides* (24) and *Diplocraterion* (23)
28. Arthropoda (trilobite)
29. Algal biscuits
30. *Crurithyris* (spiriferid brachiopod)
31. *Composita* (spiriferid brachiopod)
32. *Tabulipora* (trepostome bryozoan)
33. Mytiloid bivalve *Myalina* with barnacle borings
34. Osagid grains (algal/foram coated–grains)
35. Productid–type brachiopod
36. Low–spired archaeogastropod
37. Archaeogastropod
38. Arthropoda (trilobite)
39. Low–spired trochoid–shaped gastropod
40. Mollusca (bivalve)
41. *Pelecypodichnus* (resting trace of a bivalve)
42. *Derbyia* (strophomenid brachiopod)
43. High–spired gastropods with trails
44. Strophomenid brachiopod
45. *Straparolus* (archaeogastropod)
46. *Archaeocidaris* (regular echinoid)

Figure 11. Interpretive diagram of a Permian marine community for the Chase Group, central northern Oklahoma. Diagram not to scale. Modified after McKerrow (1978) and Toomey and Mitchell (1986).

Figure 12. Contact between the Barneston Limestone above [Ba] and Matfield Shale below [Ma]. Uncas 7.5' Quadrangle, Kaw Lake, Kay County, Oklahoma.

terval is assigned to the "Hoy sand" zone (Figs. 13 and 14).

Depositional Environment

The mottled greenish–gray and bluish–gray mudstones and/or shales indicate deposition in a marginal–marine setting (low intertidal to very shallow subtidal), whereas the red, reddish–brown, and maroon mudstones and/or shales suggest a shift to terrestrial deposition. Periodic short–lived subaerial conditions are suggested by weakly developed paleosols locally. Marine influence is most common at the base and top of the Matfield Shale.

Thin (3–16 ft) thick, lenticular, cross–laminated, very fine grained sandstones/siltstones locally developed in the Matfield Shale suggest tidal–creek deposition.

The Kinney Limestone Member in the Matfield Shale is an intracycle carbonate (shallow subtidal to peritidal) that indicates a minor transgressive event within a siliciclastic–dominated, terrestrial redbed facies associated with a regressive event.

To the south and east in Osage, Pawnee, Noble and Payne Counties, the Matfield Shale contains multiple crossbedded, lenticular channel sandstones, some multistoried, with erosional bases that suggest a tidal flat/tidal channel depositional setting near a siliciclastic source.

Osage County

The Matfield Shale ranges in thickness from 100–125 ft. The Kinney Limestone Member of the northern outcrop belt is not recognized within the Matfield Shale in Osage County. Rare exposures of the Matfield Shale consist of red– to dusky–brown–colored unfossiliferous shales/mudstones containing lenticular, very fine grained, rarely calcareous crossbedded sandstones (some individual beds as much as 2 ft thick). Sandstones may locally channel into the underlying Wreford Limestone (Fig. 13).

Pawnee County

The Matfield cannot be distinguished from the underlying Garrison Shale south of T. 22 N. The Matfield is ~100 ft thick with unfossiliferous red shales, thick lenticular red sandstones, and a few thin nodular and conglomeratic limestones dominating the lithofacies. Carbonates within the Matfield pinch out abruptly southward along with a corresponding increase in

Figure 13. Multiple sandstone channels in the Matfield Shale (="Hoy" sand in subsurface) cutting into the Wreford Limestone below. Upper channel contains logs. Pioneer Cove, Kaw City, Kay County, Oklahoma.

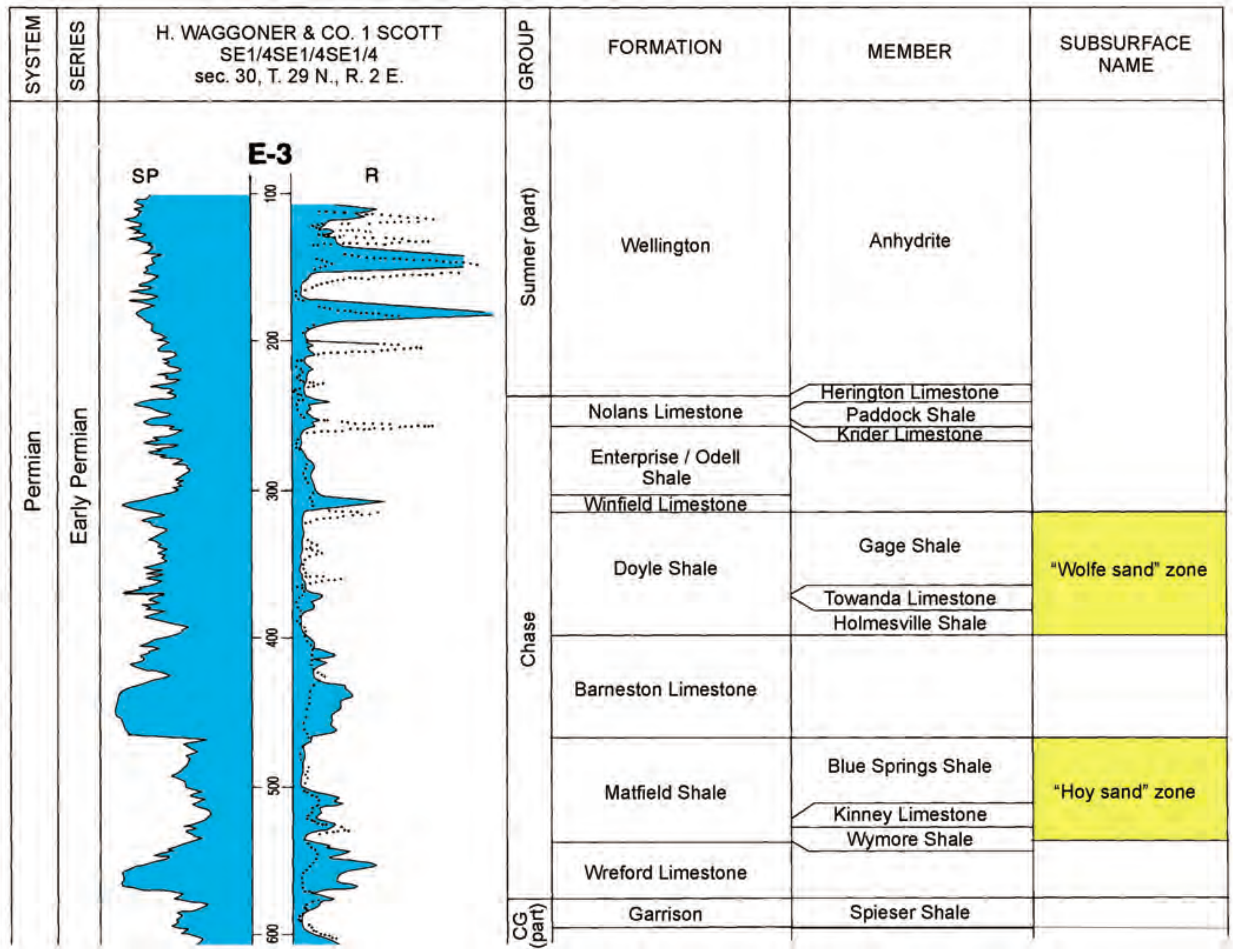


Figure 14. Reference electric log [E–3] for Lower Permian rocks cored in central northern Kay County. (*CG=Council Grove)

sandstones. Locally, individual sandstone units may be as much as 20 ft thick.

Noble County

The Matfield Shale consists of ~100 ft of red shale, mudstone, and sandstone with minor red limestone conglomerate. The sandstones are very fine grained, crossbedded, quartz–rich subarkoses with individual sandstone packages as much as 16 ft thick. The sandstones increase in total thickness southward. The primary paleocurrent direction is N. 5° W.

Payne County

The Matfield is ~100 ft thick and includes beds between the Wreford Limestone and the Barneston Limestone (Fort Riley Member). Red to reddish–brown shale, mudstone, lenticular sandstone, and thin nodular to conglomeratic limestone beds are the typicial lithologies. Sandstones comprise the greatest percentage of the section. Sandstone units vary from 10–ft–thick, upward–fining single genetic units, to 40–ft–thick multistoried complexes with erosional bases. The sandstones are fine– to very fine grained and display small– to medium–scale crossbedding. Locally, cut–out channels are filled with clay or silt and/or basal clay–pebble and dolomitic conglomerates. The average paleocurrent direction is N. 85° W.

Barneston Limestone

Kay County

The Barneston Limestone varies in thickness from 60–70 ft in the north to 40–50 ft in the central part of eastern Kay County, except in OGS core hole KC–6 where a thickness of only 25 ft is recorded. In southern Kay County the thickness varies from 40–50 ft in T. 26 N. to 20–25 ft in T. 25 N. The Barneston Limestone is usually well exposed and caps many of the east–facing cuestas in Kay County.

South of T. 27 N., the Barneston Limestone cannot be subdivided into the formations (Florence, Oketo, Fort Riley) formally recognized in Kansas and Nebraska (Fig. 6). The lower chert–bearing limestone (Florence) loses its cherty character locally in the north, and to the south chert is rare to absent. Therefore, with the absence of the shale (Oketo) that separates the two limestones (Florence and Fort Riley) in Kansas and Nebraska, and the loss of distinguishing chert in the lower limestone unit (Florence), this interval is not divided in northern Oklahoma and the term Barneston Limestone is assigned to the entire interval (Chaplin, 1988).

Throughout most of southern Kay County, the Barneston Limestone consists of only the upper thick limestone (grainstone) member, the Fort Riley, distinguished by a lower section of thick–bedded algal limestones (packstones to grainstones) overlain by a sequence of alternating thin–bedded fossiliferous, highly bioturbated shaly limestones (skeletal wackestones) and calcareous shales.

Where present in northern Kay County, the Florence Limestone Member consists of yellowish–gray to light–bluish–gray, thin– to medium–bedded cherty limestones (skeletal wackestones and lime mudstones). Macrofossils include brachiopods, solitary corals, crinoidal hash, and fusulinids. The fusulinids are concentrated particularly in chert bands in the lower 10 ft of the member. Bioclasts are commonly algal coated. The lower 10–15 ft of the Florence is locally very shaly with large algal–coated grains (osagid grains). Highly irregular, stylolitic partings occur between limestone beds. Horizontal Y–branching networks of the trace fossil *Thalassinoides* are present on the sole of the basal bed.

The upper member (Fort Riley) is composed characteristically of yellowish–gray to bluish–gray, medium– to thick–bedded, fossiliferous, algal limestones (packstones to grainstones) in the lower part. The upper part is composed of yellowish–gray shaly, algal, fossiliferous, highly bioturbated limestones (skeletal wackestones to packstones) that alternate with calcareous, highly bioturbated, and fossiliferous shales. All of the units are bioturbated, and interlacing horizontal boxworks of *Thalassinoides* systems are particularly common in the upper part. Limestones in the upper part commonly contain stylolitic partings of carbonaceous–rich grayish–black shale. Fossils include foraminifers, ostracodes, crinoid hash, brachiopods, and echinoid spines.

To the south of Kaw Dam, section K–10, just east of OGS core hole KC–5 (Fig. 1), the Barneston Limestone interval contains numerous lenticular, very fine grained sandstone bodies 5–20 ft thick, as determined from the interpretation of core logs provided by the U.S. Army Corps of Engineers.

Depositional Environment

The locally chert–bearing, fusulinid–rich skeletal wackestones and lime mudstones in the Florence Limestone Member suggest a relatively shallow, offshore marine depositional setting.

Lithologies and body fossils in the overlying Fort Riley Limestone Member indicate deposition in a shallow, moderate– to high–energy, nearshore subtidal marine depositional setting.

The Barneston Limestone in Osage, Pawnee, Noble and Payne Counties is represented by nodular, dolomitic, sandy carbonate lenses within a sand–rich sequence. The lithologies, restricted molluscan fauna, and abundant algal–coated grains suggest an intertidal to supratidal depositional setting.

Osage County

The Barneston Limestone in Osage County is 3–6 ft thick and represented by shaly skeletal wackestones to packstones containing osagid grains. Locally the Barneston Limestone is dolomitic, sandy, and fossiliferous with crinoid fragments, bryozoans, and brachiopods (*Composita*). The Barneston Limestone becomes sand–rich in a southerly direction. Locally the Barneston Limestone may be represented by limestone lenses within a dominantly sandstone sequence.

Pawnee County

The Barneston Limestone in Pawnee County is represented by very limited exposures of the Fort Riley Member. Abrupt changes in facies, thickness, and/or resistance of the Fort Riley beds effectively prevent compilation of a complete Fort Riley section (Greig, 1959).

An 18.5–foot section of Fort Riley exposed at the northeast corner of sec. 5, T. 22 N., R. 3 E., consists of ~15 ft of interbedded silty limestones separated by gray shales with a sparse molluscan fauna (myalinids). The upper 3.5 ft is composed of a skeletal wackestone with limonitic–altered osagid grains. Several sandstone beds, some locally very calcareous, have been assigned to the Fort Riley interval in Pawnee County.

In its easternmost exposure along Oklahoma Highway 15, the Fort Riley is represented by two 6–in.–thick beds of molluscan–rich skeletal wackestones separated by a thin shale bed. To the north in Kay and Noble Counties, a massive algal bed marks the basal part of the Fort Riley.

Noble County

The Barneston Limestone in the northeast is composed of ~30 ft of shale and/or siltstone beds locally containing as many as 5 limestone beds, all less than 6–ft thick. The limestones (grainstones) contain osagid grains, bioclasts replaced with limonite, and fine quartz grains. To the south (T. 21 N., R. 3 E.), the Barneston Limestone interval is represented by a single fossiliferous dolomite bed less than 1 ft thick. The Barneston Limestone pinches out directly north of the southeastern part of Noble County.

Payne County

The Barneston Limestone is represented by a 1–ft–thick limestone within a section of gray shale below a thick sandstone on the Noble/Payne County line. In sections 16 and 20, T. 19 N., R. 3 E., the Barneston Limestone occurs as a less–than–1–foot–thick unfossiliferous nodular dolomite. The nodules range from less than 1 in. to 6 in. in diameter and are composed of finely crystalline carbonate mud containing interwoven calcite or dolomite veinlets that show septarian structures.

Doyle Shale

Kay County

The Doyle Shale above the Barneston Limestone includes three identifiable facies in T. 27 N., R. 3 E.; a lower, 10–ft thick generally unfossiliferous shale and shaly limestone sequence (Holmesville Shale Member); a middle, thin, 3– to 8–ft–thick, sparsely fossiliferous sandy limestone (Towanda Limestone Member); and an upper, 100– to 120–ft–thick shale and mudstone interval (Gage Shale Member) (Fig. 8). To the south the Towanda Limestone cannot be identified locally, so the entire Doyle interval is represented by a 115–ft–thick sequence of undivided shales, mudstones, and sandstones. Rare lenses and beds with very comminuted molluscan fossil hash are present locally. The Doyle also contains abundant concretionary zones composed of grayish–white algal limestone rubble throughout. Mineralized septarian nodules with quartz veinlets occur locally.

The Holmesville is composed of variegated calcareous shales, mudstones, and shaly limestones containing lenses of very fine grained calcareous sandstones.

The Towanda Limestone is a yellowish–gray sandy limestone (skeletal wackestone) which locally is gastropod rich. The upper surface of the Towanda is covered locally by horizontally oriented spreiten–bearing forms of the trace fossil *Rhizocorallium*.

A distinct positive narrow spike is produced on the resistivity curve by this 3– to 5–ft–thick limestone (Fig. 2).

The upper shale member (Gage) is the thickest clastic unit in the Chase Group, varying in thickness from 100–120 ft. It includes grayish–red to reddish–brown, locally calcareous mudstones and shales. Calcite veinlets and pockets of brecciated micritic limestone granules/nodules are common throughout. The Gage Shale Member also locally contains some intervals of grayish–red, very fine grained, locally calcareous lenticular sandstones. Sandstone bodies between the Barneston Limestone below and the Winfield Limestone above are assigned by subsurface workers to the “Wolfe sand” zone (Fig. 14).

The top of the Gage Shale is commonly marked by a 1– to 5–ft–thick greenish–gray shale or mudstone, and the contact is sharp.

Fossils in the Doyle Shale are limited primarily to plant– (silicified wood fragments and seed fern compressions) and bone–bearing concretions.

Depositional Environment

Mottled red, reddish–brown, greenish–gray, and bluish–gray unfossiliferous massive to blocky mudstones and shales, locally with pedogenic features, terrestrial plant fossils, and shaly coal spars suggest a dominantly terrestrial depositional setting for the Doyle Shale. “Cauliflower”–shaped micritic carbonate nodules and dolomudstones such as commonly form within modern tidal flat settings along arid coastlines (i.e. sabkhas) occur locally in the Doyle Shale.

Siliciclastic deposition in the Doyle Shale was interrupted by a brief, relatively rapid, local marine deepening event as evidenced by the local occurrence of thin (~3 ft), laterally restricted, gastropodal–rich sandy skeletal, wackestones to packstones of the Towanda Limestone Member. The Towanda Limestone is interpreted as a nearshore shallow–marine peritidal deposit.

To the south and east in Osage, Pawnee, Noble, and Payne Counties, the Doyle Shale is characterized by red shales, mudstones and sandstones, locally mottled green and red with interlaminated color variation that contain spherical micritic carbonate concretions, nodular limestone beds, and dolomitic conglomerates. The lithofacies, restricted marine fauna, and pedogenic horizons suggest a semi–restricted pertidal depositional setting associated with periodic subaerial exposure events somewhat closer to a siliciclastic influx. Fossils in the Doyle Shale are limited primarily to plant– (carbonized and silicified wood fragments and seed fern compressions) and bone–bearing concretions/conglomerates indicating a strong terrestrial overprint.

Osage County

A 125– to 135–ft–thick section of Doyle Shale consists of gray to maroon shale with some siltstone in the upper part with thin gray shales and bluish–gray fossiliferous limestones in the lower and middle parts.

The lithologic three–fold subdivisions of the northern outcrop belt in Kansas and Nebraska (i.e., Holmesville Shale, Towanda Limestone, and Gage Shale) are recognized in Osage County. The basal ~28 ft consists of thin bluish–gray, sandy, slightly fossiliferous limestone interbedded with gray shales and siltstone lenses (Holmesville Member). Above the Holmesville Shale is a 2–ft–thick tan, shaly, ferruginous, coquinoid limestone (skeletal wackestone) that contains fossil fragments (echinoid debris, brachiopods, osagid grains) (Towanda Limestone). The majority of the Doyle Shale Member is represented by ~105 ft of red to variegated shale and mudstone interbedded with locally red very fine grained sandstone lenses (Gage Shale Member).

Pawnee County

The Doyle Shale ranges in thickness from 150–160 ft. Poor exposures indicate the Doyle section consists predominantly of thick red interbedded sandstones and shales with a few inches to 5 ft of green shale at the top and bottom of the formation. Locally, the Doyle contains red conglomeratic beds with rounded limestone and sandstone pebbles ~50 ft above the base. Thin, fossiliferous nodular limestone beds occur ~20–30 ft below the interval assigned to the Winfield Limestone. The limestones contain an abundant molluscan fauna (myalinids), small high–spired gastropods, and rare bellerophontid gastropods. These limestone beds in the upper part of the Doyle could possibly be, at least in part, the Pawnee County correlative of the Winfield Limestone.

Noble County

The Doyle, 120– to 170–ft–thick, is composed of red shales, mudstones and sandstones, locally mottled green and red with interlaminated color variation. The shales contain calcitic claystone pebbles. The sandstones are red, very fine grained with small–scale crossbedding and are lenticular in geometry (Fig. 15). The percentage of sandstone in the Doyle increases southward. The primary paleocurrent direction is N. 15° W.

Payne County

The Doyle Shale is ~170 ft thick and contains red shale/mudstone with lenticular sandstone and dolomite lenses. The greatest percentage of the section is comprised of very fine grained, small– and medium–scale crossbedded sandstones with erosional bases. Individual genetic sandstone units are ~10 ft thick with multistoried sandstone units 30–40 ft thick. Overall there is an upward decrease in grain size. Locally, dolomitic conglomerates, clay–pebble conglomerates and zones of calcareous and dolomite cements are present at the base of some sandstone beds. Spherical carbonate concretions and carbonized wood fragments occur locally. The primary paleocurrent direction is N. 40° W.

Winfield Limestone

Kay County

In southeastern Nebraska and northern and central Kansas, the Winfield Limestone is divided into a lower, local cherty limestone member (Stovall), a fossiliferous shale (Grant) and an upper, locally cherty limestone member (Cresswell). However, in southern Kansas and northern Oklahoma, the two lower lithologic units cannot be identified with any degree of certainty. In Kay County, the Winfield generally includes either a single massive limestone unit or two massive units of fossiliferous limestone ~8–15 ft thick.

Figure 15. Sandstone body in the Doyle Shale just east of Morrison Cemetery, Noble County, Oklahoma.

The Winfield Limestone in northern Oklahoma is lithostratigraphically correlative, at least in part, with the Cresswell Limestone Member of the northern outcrop belt (Chaplin, 1988, p. 108). Locally, in Oklahoma Geological Survey core hole KC–4 (Fig. 1), the interval is characterized by a lower limestone unit and an upper limestone unit separated by a middle shale interval. However, the correlation of these lithologic units with the three formally recognized members of the Winfield in Nebraska and Kansas has not yet been documented.

The Winfield Limestone in northernmost Oklahoma is approximately half as thick (8–15 ft) as in southern Kansas, yet still retains its typical tripartite lithologic subdivisions and similar lithofacies. The Winfield thins to ~2 ft in southern Kay County.

The Winfield Limestone rests conformably on red to reddish–brown and/or greenish–gray continental– to marginal–marine clastics composed of silty shales, siltstones, and mudstones locally with thin sandstones of the underlying Doyle Shale (Fig. 16). The Winfield is overlain by continental to marginal–marine clastics of the Enterprise/Odell Shale (Fig. 7).

The Winfield Limestone above the Doyle Shale typically consists of 8–10 ft of light–bluish–gray, silty, sandy thin– to medium–bedded and massive fossiliferous grain–supported skeletal wackestones to grainstones. The upper part is generally more shaly with alternating beds of shaly limestones and calcareous shales. No chert has been identified in the Winfield in northern Oklahoma. Abundant algal–coated grains (osagid grains) and peloids, that produce a conglomeratic–looking texture, characterize particularly the basal few feet of the Winfield Limestone, but are common throughout the unit. The osagid grains display outstanding well–preserved algal (*Girvanella*, a blue–green alga) and foraminiferal coatings. Locally, mollusc bioclasts and planispirally coiled, mud–filled fusulinids commonly serve as coated–grain nuclei, but any available bioclast or clast can be incorporated into an osagid–coated grain. Some grains are very iron–stained.

Locally, the Winfield Limestone may show faint low–angle cross–stratification, low–angle to planar bedding, unidirectional crossbedding, and wavy bedding. The upper outcrop surface may be distinctly hummocky with a characteristic solution–pitted vertical face.

Northernmost exposures in Kay County show the typical three–fold lithologic subdivisions that consist of an uppermost thin–bedded flaggy skeletal wackestone, a thicker massive packstone to grainstone middle unit, and a basal thin osagid–grain–rich grainstone.

In southern Kay County, the Winfield Limestone consists of a single massive limestone unit. The limestone is a silty, sandy skeletal coated–grain grainstone composed principally of echinodermal debris (mat–like accumulations of echinoid spines), bryozoans, and broken and abraded algal–coated grains.

In southeastern Kay County, the Winfield Limestone becomes a more clastic–rich facies. Greenish–gray to bluish–gray, locally calcareous shales occur primarily in the upper part and contain lenses/bands of crinoidal hash and echinoid spines and plates.

In southernmost Kay County, the formation loses much of its lithologic distinctiveness seen farther north and becomes a sandy, mud–supported skeletal wackestone, but still contains abundant coated grains and typical Winfield Limestone faunal elements.

The Winfield Limestone contains common silicified brachiopods, especially *Crurithyris* and *Composita* in the upper flaggy, thin–bedded part. The more massive beds contain pockets of coarse bioclasts (especially echinoid spines and plates), osagid grains, crinoidal

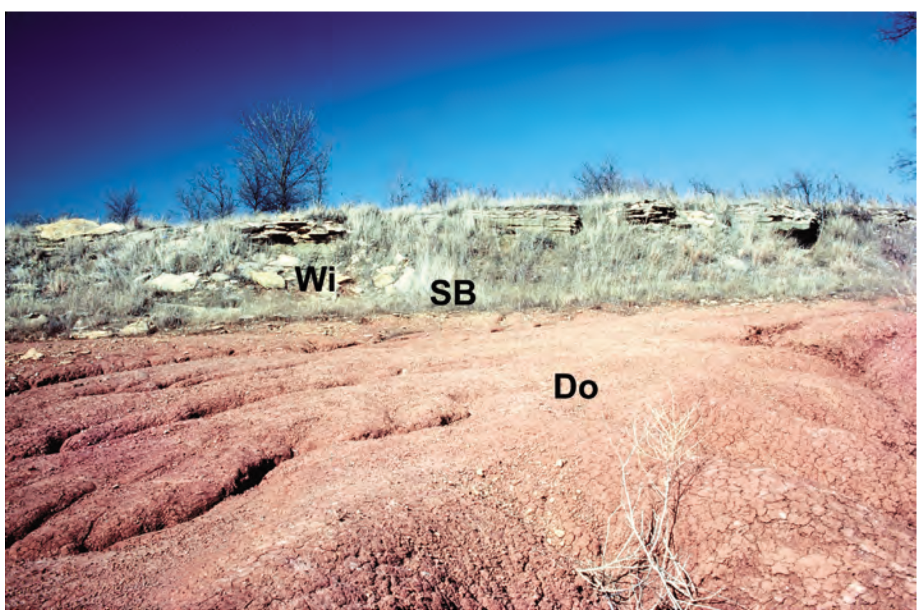


Figure 16. Sequence boundary [SB] between highstand, transgressive facies of Winfield Limestone above [Wi] and lowstand, regressive facies of the Doyle Shale below [Do]. Northern shoreline of Lake Ponca, Kildare 7.5' Quadrangle, Kay County, Oklahoma.

hash, bivalves *Myalina* and *Pinna*, and trepostome bryozoans (*Tabulipora*) within a finer skeletal grainstone matrix. Locally, coarse bioclasts are concentrated in layers, pockets and lenses.

The sole of the basal bed of the Winfield Limestone is typically covered with a maze of abundant horizontal, branched, Y–shaped networks of *Thalassinoides* burrows (Fig. 11). Locally, the Winfield contains prominent U–shaped vertical burrows (*Arenicolites*) generally filled with broken and abraded bioclasts. Some vertical burrows extend entirely through a single bed (e.g., *Skolithos*) (Fig. 11).

Depositional Environment

The depositional setting for the Winfield Limestone ranges from a dominantly relatively high–energy subtidal environment in the north to a lower–energy more restricted peritidal environment to the south, somewhat closer to a shoreline and to terrestrial redbed siliciclastics. The grain–supported packstones to grainstones suggest an overall relatively shallow subtidal depositional setting characterized by periodic agitated wave and/or current activity.

The occurrence of abundant fenestrate bryozoans, echinodermal remains, and the abundance and relative diversity of the brachiopod fauna suggests a more marine aspect for the Winfield Limestone as compared to other formations in the Chase Group.

Osage County

The Winfield Limestone in Osage County is ~15 ft thick. Lithologies include vuggy, shaly, siliceous algal limestone beds (skeletal wackestones and packstones) locally with osagid grains. Fossils include fragments of crinoids, bryozoans, and brachiopods.

Pawnee County

The Winfield Limestone is the uppermost (youngest) Permian formation exposed in Pawnee County. The southern extent of the Winfield outcrops is poorly known. The Winfield undergoes a distinct facies change from the northern facies belt, but the stratigraphic interval between the Fort Riley and Winfield is comparable to that farther north.

In western Pawnee County, the red sandstones and shales of the Doyle Shale are capped by ~7 ft of thin–bedded sandstone that contains thin lenticular beds of unfossiliferous calcareous sandstone and sandy limestone. This section, at least in part, is thought to be the Pawnee County correlative of the Winfield Limestone of northern Oklahoma and Kansas (Greig, 1959). The Winfield Limestone appears to grade southward into thick noncalcareous, massive to cross-bedded sandstones.

Noble County

In northern Noble County the Winfield Limestone is a thin–bedded, fossiliferous limestone (grainstone) ~2 ft thick. The limestone contains interbeds of bioturbated siltstone. The grainstones contain algal filaments, bioclasts, productid brachiopods and very fine grained quartz sand.

In the northeastern part of T. 22 N., R. 2 E., the Winfield Limestone is represented by a 6– to 8–ft–thick section of red sandy crossbedded limestone (grainstone to boundstone) in a predominantly red, burrow–mottled calcitic sandstone body. Macrofossils in the limestone include rare pectenoid bivalves (*Aviculopecten*), crinoid columnals, echinoid debris, and gastropods. The sandstone beds are very fine grained subarkoses with mottled or burrowed structures.

South of the middle of T. 22 N., R. 2 E., scattered exposures of red nodular micritic limestone less than 1–ft thick probably are, at least in part, equivalent to the Winfield based on stratigraphic position and on the fact that the Winfield is a shallow subsurface marker bed at that latitude (Shelton, et al., 1979).

Payne County

Projected well control and the escarpment of an underlying sandstone are used in determining the stratigraphic position of the Winfield Limestone in Payne County (Shelton, et al., 1979).

The Winfield Limestone undergoes a facies change in Noble County from ~2 ft of fossiliferous limestone (grainstone) to less than 1 ft of red unfossiliferous nodular dolomitic limestone in Payne County. The nodular limestone/dolomite can be traced southward into a dominantly red sandstone facies at approximately the Lincoln–Payne County line (Fig. 17). The formation consists of red dolomite or limestone nodules which are very similar lithologically to those observed throughout Payne County (Fig. 17). A general description of changes in the Winfield Limestone from Cowley County, Kansas, southward into Payne County, Oklahoma, is shown in Table 4.

Enterprise/Odell Shale

Kay County

Above the Winfield Limestone and below the Nolans Limestone is a 30–60 ft sequence of grayish–red to reddish–brown mudstones and shales with thin, locally lenticular sandstones. This interval is tentatively assigned to the Enterprise/Odell Shale (Chaplin,

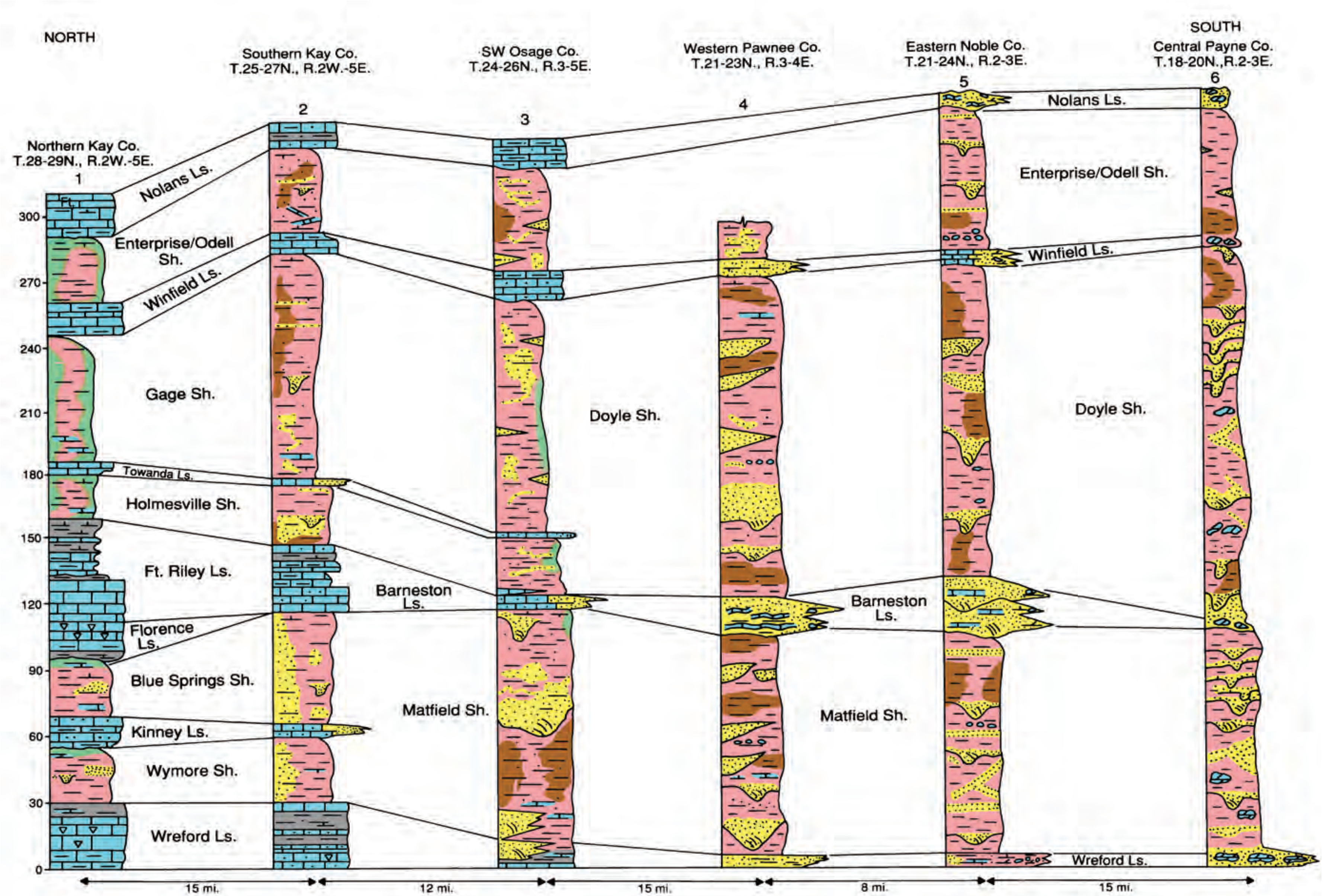


Figure 17. Strike–oriented composite stratigraphic sections for the Chase Group from Kay County, Oklahoma into Payne County, Oklahoma. Data from measured sections, core holes, and geophysical logs.

Table 4. General description of the Winfield Limestone from Cowley County, Kansas, southward into Payne County, Oklahoma

Characteristics	Southern Cowley County, Kansas	Kay County, Oklahoma		Southwestern Osage County, Oklahoma
	T. 35 S., R. 4 E.	**Northern** **Tps. 28–29 N., Rgs. 2 W. – 5 E.**	**Southern** **Tps. 25–27 N., Rgs. 2 W. – 5 E.**	**Parts Tps. 25–26 N., Rgs. 2–4 E. T. 23 N., Rgs. 3–4 E.; T. 24 N., Rgs. 3–5 E.**
1. General Location	sec. 5, T. 35 S., R. 4 E.	sec. 8 & 17, T. 28 N., R. 3 E. sec. 5, T. 28 N., R. 3 E.	sec. 33, T. 27 N., R. 3 E. sec. 35, T. 27 N., R. 3 E. sec. 8, T. 26 N., R. 3 E. sec. 28 & 33, T. 26 N., R. 3 E. sec. 12, T. 26 N., R. 3 E. sec. 25, T. 26 N., R. 3 E. sec. 21, T. 26 N., R. 3 E. sec. 26, T. 26 N., R. 3 E.	sec. 16, T. 25 N., R. 3 E. sec. 24, T. 25 N., R. 2 E. sec. 21, T. 25 N., R. 3 E.
2. Subdivisions	Cresswell Limestone Member	Cresswell Limestone Member	Cresswell Limestone Member	Undivided
3. Average thickness – ft (range in thickness)	10–11 (10–30)	16.0 (10.8–25.6)	11.6 (8–21)	15
4. Lithofacies	Massive, silty, coated–grain skeletal wackestones to packstones; generally occurring in two distinct beds; rare concretions	Massive, silty, coated–grain skeletal wackestones to packstones; upper part usually composed of flaggy skeletal wackestones/calcareous shales in beds 2– to 8–in. thick; very abundant large osagid grains in basal 1 ft	Silty to very sandy skeletal wackestones to packstones; overall a more algal–rich, shaly section; locally may occur in 1 to 2 massive beds; locally cellular, vuggy, and conglomeratic	Tripartite lithologic subdivisions: UPPER—purple to maroon, fine to medium crystalline, shaly limestone MIDDLE—light–gray, finely crystalline siliceous, slightly fossiliferous with osagid grains LOWER—3 light–bluish gray, medium crystalline, algal limestone beds with brachiopods, crinoid debris, and bryozoans
5. Biotic Components	Echinoid spines/plates crinoid debris, trepostome bryozoans, bivalves (*Pinna* and *Myalina*), brachiopods (*Crurithyris* and *Composita*)	Abundant echinoid spines/plates, crinoid columnals, trepostome and fenestrate bryozoans; brachiopods (*Linoproductus, Derbyia, Composita, Crurithyris*), bivalves *Pinna, Myalina, Wilkingia, Aviculopecten*), gastropods	Crinoid columnals, echinoid spines/plates, trepostome and fenestrate bryozoans, brachiopods *(Composita, Antiquatonia, Derbyia, Linoproductus, Crurithyris)*; bivalves *(Edmondia, Myalina, Pinna)*; gastropod *(Straparolus)*	Fossil fragments of crinoids, brachiopods, and bryozoans
6. Trace Fossils	No data	Sole with large horizontal branching burrow systems of *Thalassinoides*; unidentifiable vertical U–shaped burrows	*Thalassinoides*; vertical cylindrical cavities probably represent solution pits of former vertical traces	No data
7. Facies Change	In southern Kansas and northern Oklahoma, the two lower subdivisions (Stovall Limestone and Grant Shale), recognized in Nebraska and northern and central Kansas, cannot be identified. The Winfield Limestone of northern Oklahoma primarily consists of the Cresswell Limestone Member of the northern outcrop belt; Winfield Limestone section thins, becomes more silty, sandy, and shaly, and contains rare fossils to the south.			
8. Contacts	Gradational lower and upper contacts; rests conformably on the Doyle Shale	Lower contact usually sharp, well exposed, planar, upper contact poorly exposed, gradational, rests conformably on the Doyle Shale		Gradational lower and upper contacts
9. Inferred Depositional Environments	Dominantly relatively high–energy, shallow water, open–marine subtidal deposits	➔ Relatively agitated wave and current action; open–marine to semi–restricted subtidal deposits	Regional Facies ➔ More restricted marine/marginal–marine subtidal to peritidal deposits; relatively shallower water setting, somewhat closer to a shoreline and clastic influx	
10. E–log Character	No data	— Maintains a distinct, persistent, solid, spikey log response on the SP curve and a fairly distinct, but admittedly somewhat more variable resistivity log signature — Log signature indicates a relatively solid, dense, massive 10–ft thick carbonate section (verified from core hole data) throughout most of Kay County — Core hole data indicates interval thickens to ~20–25 ft in central and northwestern Kay County		No data

Table 4. General description of the Winfield Limestone from Cowley County, Kansas, southward into Payne County, Oklahoma—(*Continued*)

Noble County, Oklahoma			Pawnee County, Oklahoma	Payne County, Oklahoma	
Northern T. 24 N.	**Central T. 22 N.**	**Southern T. 21 N.**	**Tps. 23–22 N.; Rgs. 3–4 E.**	**Northern Tps. 21–20 N.**	**Southern T. 17 N.**
sec. 20, T. 24 N., R. 3 E.	sec. 7, T. 22 N., R. 3 E.	Middle of sec. 21, T. 21 N., R. 2 E.	sec 7, T. 22 N., R. 3 E.	sec. 16, T. 20 N., R. 3 E. sec. 31, T. 21 N., R. 3 E.	
Undivided	Undivided	Undivided	Undivided	Undivided	Undivided
2	6–8	<1	7	<1	<1
Thin–bedded, silty skeletal grainstones containing interbeds of horizontally bedded siltstones and very fine grained quartz sand	Gray, sandy, cross-bedded skeletal grainstones, red, algal mat boundstones, and red calcareous sandstones/siltstones; sandstones (fine–grained arkoses) consist of horizontal interbeds, mottled or burrowed structures, and low–angle initial dip	Discontinuous exposures of red, nodular dolomitic limestones (pelloidal lime mudstones)	Thin–bedded sandstones containing lenticular beds of unfossiliferous calcareous sandstone and sandy limestone	Scattered exposures of red, nodular, dolomitic, pelloidal limestones Note: Winfield Limestone is not identifiable south of T. 17 N., as it loses its identity within a thick wedge of dominantly fluvial/terrestrial red–bed siliciclastics	Rare red, sandy dolomite or limestone nodules associated with clastics
Algal filaments and rods; fossil fragments of productid brachiopods	Pectenoid bivalves, crinoid and echinoderm debris, and gastropods	Unfossiliferous	Unfossiliferous	Unfossiliferous	Unfossilferous
Small unidentifiable burrows	No data	No data	No data	No data	No data
Skeletal grainstones, siltstones, quartz sand	Sandy skeletal grainstones, algal mat boundstones, and calcareous sandstones/ siltstones	Scattered exposures of nodular dolomitic, pelloidal lime mudstones	Distinct facies change southward into thick, noncalcareous, massive to crossbedded sandstone; thickness of interval between Ft. Riley and Winfield Lss. is comparable to that in the northern facies belt	Red nodular, unfossiliferous, dolomitic limestone	Red, unfossiliferous, dolomite or limestone nodules associated with clastics
Lower and upper contacts are poorly defined, gradational, locally erosional; thin carbonate beds occurring in the upper part of the underlying Doyle Shale may be, at least in part, lithologic equivalents to the Winfield Limestone of the northern outcrop belt.					
➔ Regional Facies Marginal marine, semi–restricted, peritidal deposits			Restricted marginal–marine, high–intertidal to terrestrial redbed clastics; locally with periodic subaerial exposure surfaces.		
No data	No data	No data	No data	No data	No data

1988, p. 92). The lack of good continuous exposures that demonstrate clearly the boundary relationships at the type localities or in the vicinity (Odell in Nebraska, Enterprise in Kansas), and the lack of designated type sections introduce some uncertainty as to what name to retain until more detailed regional core studies of the strata relations and lithologic character of the interval in Oklahoma is completed.

The mudstones are typically variegated: grayish–red–purple, grayish–red, light–bluish–gray, and light–olive–gray with color mottling. These mudstones are generally calcareous and contain scattered micritic limestone granules/nodules, stringers of greenish–gray mudstone, and thin lenses of very fine grained sandstones.

Sandstones in the interval typically are grayish–red, very fine grained (nearly siltstone in grain size), locally calcareous, and locally display ripple–drift cross–laminations. Most of the sandstones are bioturbated with abundant *Chondrites*. Some sandstones exhibit parallel to lenticular laminae. The sandstones increase in abundance and thickness as the sequence thickens to the south (Fig. 8).

Limestones are rare in the interval, but where present they are brownish–gray, sandy, crossbedded, and sparsely fossiliferous skeletal wackestones and packstones. The interval is particularly carbonate rich in northwestern Kay County (confirmed by drill core) and characteristically lacking in sandstone beds (Fig. 7).

The upper 2–5 ft of the sequence is marked by a greenish–gray, locally fossiliferous and calcareous marginal–marine shale or mudstone underlain by clastic–rich continental redbeds (Fig. 18). Both the lower and upper contacts are sharp and distinctly recessed.

Poorly developed paleosols occur in the Enterprise/Odell Formation. Pedogenic features locally include scattered grayish–white "cauliflower"–shaped calcareous nodules (caliche), mudstones with blocky fabrics (crude bedding), gleyed (color mottled) zones, slickensided fracture surfaces/peds, brecciated micritic limestone nodules, pisoliths and pervasive veins of fracture–filling calcite cement, some appearing to follow mudcracks. Locally some thin limestones contain distinctive "boxwork" structures that suggest a desiccated mud–cracked interval associated with a subaerial exposure surface (paleocaliche).

Some paleosols may contain both marine and pedogenic carbonate, indicating a multi–stage origin. For example, some caliche nodules contain fossils such as crinoid hash, bivalves and brachiopods, indicating that the carbonate horizon originated as a marine limestone that subsequently underwent pedogenesis.

Luta Limestone Member

Approximately 5–10 ft above the top of the Winfield Limestone is a 5– to 20–ft–thick interval of thin, slabby, ripple–marked, crossbedded, bioturbated, grayish–red sandy, silty, peloidal grainstones and mud–supported skeletal wackestones and calcareous shales. The beds in the interval are probably physically correlative, at least in part, with the Luta Limestone of Kansas (Chaplin, 1988, fig. 6). Subsurface workers often include this interval in the Winfield Limestone.

Whether the Luta should be included in the underlying Winfield has been a point of contention. The author chooses to designate the Luta Limestone as the lower limestone member of the Enterprise/Odell Shale sequence because: 1) the sequence is separated from the underlying limestones of the Winfield by a ubiquitous 3– to 5–ft–thick greenish–gray to reddish–brown shale or mudstone; 2) the Luta carbonate lithologies are interbedded with typical Enterprise/Odell shales; 3) the faunal content of the Luta is decidedly different from the underlying Winfield Limestone in that it includes abundant low– and high–spired gastropods, abundant trace fossils including *Chondrites*, rare *Diplocraterion* and feeding/locomotion trails of gas-

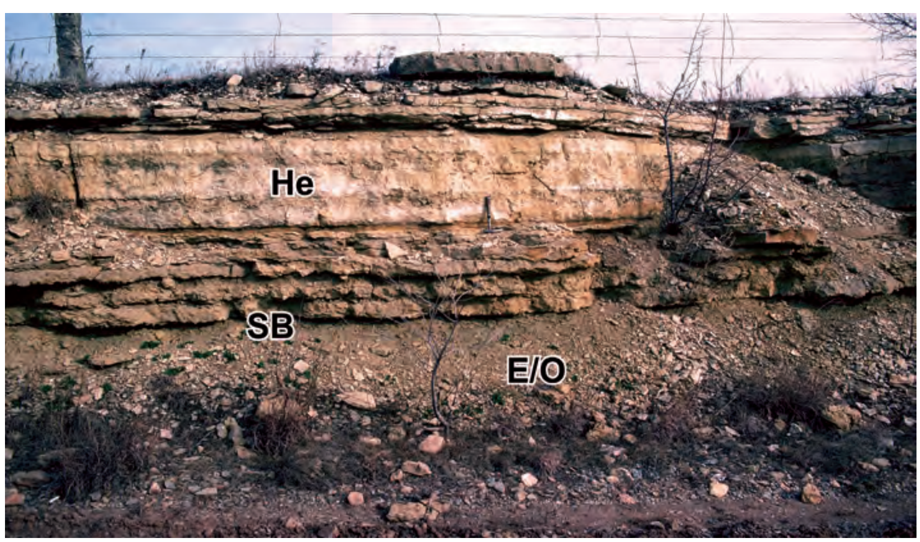


Figure 18. Sequence boundary [SB] between marine transgressive Herington Limestone Member above (He) and marginal–marine to terrestrial/regressive Enterprise/Odell Shale below [E/O]. Uncas 7.5' Quadrangle, Kay County, Oklahoma.

tropods, and locally "shell pavements" of brachiopods, especially *Derbyia*; and 4) the upper part of the Luta Limestone includes Enterprise–like shales and mudstones as it changes facies into the overlying Enterprise/Odell clastics. This transitional contact is best observed in the Newkirk oil field section, K–23, Stop 1. Therefore, the Luta Limestone is included within the Enterprise/Odell Shale in northern Oklahoma as a distinct, but highly variable, member in lithology, thickness, and lateral distribution.

The Luta Limestone Member of the Enterprise Shale is a relatively thick marginal–marine unit in southern Kansas. In northern Oklahoma, the member is thinner, discontinuous, and consists of interbeds of both a marine and nonmarine facies. In northern Oklahoma, the Luta Limestone Member varies in thickness from ~19.5 ft at Stop 1 (section K–23) to less than 2 ft ~1 mi west of Kaw City in southeastern Kay County. Luta outcrops have not been observed south of the Arkansas River.

The Luta Limestone is composed of mud–supported, bioturbated, sandy, skeletal wackestones and peloidal grainstones interbedded with thinner, grayish–green, brachiopod–rich recessive shales. All lithologies contain abundant comminuted bioclasts. Locally some beds are distinctly jointed.

Physical sedimentary structures/features in the more silty/sandy intervals include: 1) iron–stained mud clasts; 2) selected soles with small–scale load casts; 3) rare convolute bedding; 4) well–sorted siltstone laminae; 5) rare asymmetrical/symmetrical ripple marks; 6) ripple–drift cross–laminations; 7) low–angle, small–scale crossbedding; and 8) rare "cauliflower"–shaped chert nodules.

Silicified strophomenid brachiopods, especially *Derbyia*, form "shell pavements" on both the tops and soles of beds. Abundant low– and high–spired gastropods occur in the more mud–rich lithologies. Subordinate fossils include the burrowing infaunal mytiloid bivalves *Myalina* and *Pinna*, the burrowing infaunal pholad bivalve *Wilkingia*, the spiriferid brachiopod *Composita*, fenestrate bryozoans, the straight nautiloid cephalopod *Pseudoorthoceras*, the pectenoid bivalve *Aviculopecten* and crinoid columnals.

Some brachiopod valves are heavily encrusted with epizoans, especially the polychaete tube worm *Spirorbis*. Mud–filled barnacle borings are common on both brachiopod and bivalve shells. Some *Composita* brachiopod shells are compacted, distorted, and bored. Some bioclast molds are filled with sparry calcite.

Trace fossils include *Chondrites*, rare *Diplocraterion*, *Rhizocorallium*, and *Thalassinoides*. Some *Chondrites* probes penetrate through the entire thickness of single beds and locally contain distinctive fecal pellets. Rare *Diplocraterion* and *Rhizocorallium* burrows are present on the tops of beds. Large, horizontal Y–shaped burrow networks of *Thalassinoides* occur locally on the soles of some beds. Some of these burrows are infilled with bioclasts. Large "armored" burrows (~6–8 in. in length, ~1 in. in diameter) characterize selected mud–rich lithologies.

Depositional Environment

Greenish–gray to reddish–brown, poorly fossiliferous silty shales, blocky mudstones, and siltstones suggest deposition in a semi–restricted marginal–marine setting (especially in the upper part), whereas the change to more typical red to reddish–brown, unfossiliferous blocky mudstones and siltstones/sandstones, locally associated with weakly developed paleosols, suggest a facies shift to terrestrial/fluvial deposition.

Locally, thin beds of "boxwork" limestone (paleocaliche), "cauliflower"–shaped micritic limestone concretions, and pervasive veins of sparry calcite that follow a mud–cracked pattern are common throughout the Enterprise/Odell Shale, suggesting periodic subaerial exposure events.

Thin (3–10 ft) thick, lenticular, cross–laminated, very fine grained sandstone channels of probable tidal creek origin occur locally in the Enterprise/Odell Shale.

The Luta Limestone Member in the Enterprise/Odell Shale changes facies from a shallow–water marine environment in southern Kansas to a variety of more marginal–marine depositional settings in Kay County reflecting the increasing influence of terrestrial/fluvial/deltaic sediments from the south. Mud–supported skeletal wackestones, body fossils, and trace fossils suggest a diversity of marginal–marine depositional settings in Kay County ranging from a somewhat semi–restricted, relatively shallow–marine lagoon adjacent to an algal marsh to tidal flat deposits. Trace fossils in the Luta Limestone Member suggest a substrate that was actively grazed upon by organisms, probably a variety of gastropods, and one that was firm enough for organism exploitation.

Osage County

A 48–ft–thick poorly exposed section of red, blocky bedded shales/mudstones with locally thin, red to maroon siltstone lenses is assigned to the Enterprise/Odell Shale.

Pawnee County

No exposures of the Enterprise/Odell occur in Pawnee County.

Noble County

The Enterprise/Odell Shale crops out in the eastern part of Noble County where it is ~70 ft thick. It is composed of predominantly red shale/mudstone and sandstone. Locally thin beds (<5 ft thick) of red limestone conglomerate are common in the lower part. The sandstones are red, very fine grained and lenticular with small–scale crossbedding. The percentage of sandstone increases southward into Payne County. The average paleocurrent direction is N. 50° W.

The Enterprise/Odell Shale is the oldest stratigraphic unit that extends continuously southward through Noble County either at the surface or beneath thin alluvium.

Payne County

The Enterprise/Odell Shale interval of Payne County is ~60 ft thick and is distinguished from other lithologic units of the Chase Group in that it is relatively free of sandstone and nodular dolomite. Where it crops out, it consists of red clay or mudstone with locally thin, lenticular sandstone beds.

Nolans Limestone

Kay County

Herington Limestone Member

The Nolans Limestone in southeastern Nebraska and north–central Kansas consists of an upper limestone member (Herington) and a lower limestone member (Krider) separated by a shale member (Paddock) (Fig. 6). In southern Kansas and northern Oklahoma, the member boundaries are rarely distinguishable in surface exposures. The Nolans in Kay County, particularly in southern Kay County, consists primarily of only the upper member (Herington). However, the three–fold lithologic subdivision of the Nolans is recognizable on electric logs in the northern and western parts of Kay County (Fig. 2), but becomes less identifiable to the south.

The Nolans Limestone is typically 20–30 ft thick in the north and 8–15 ft thick in the south with a common thickness of ~8 ft. The Herington Limestone Member typically is composed of alternating thick massive, iron–stained limestones separated by thin–bedded flaggy limestone units and calcareous shales. The limestones (skeletal wackestones to grainstones) are light–bluish–gray to yellowish–gray, algal–rich, peloidal, silty to sandy, locally vuggy, bioturbated, highly fossiliferous (molluscan– and brachiopod–rich) units. The units weather out into 1– to 2–ft–thick beds. Many of the limestones are very shaly. Selected skeletal wackestones contain distinctive "armored burrows," relatively large mud–filled bivalves, and algal–coated grains (osagid grains). Some myalinid–*Derbyia*–rich shell beds are present near the base in association with algal–coated shells ("algal biscuits"), particularly in the more shaly mud–supported limestone facies. These algal–coated grains commonly have nuclei of fenestrate and "stick" bryozoans and crushed, though still articulated, brachiopods (*Composita*). Chert nodules only occur in the northernmost facies in Kay County.

Common macrofauna include fenestrate bryozoans, bivalves (especially *Myalina*, *Aviculopecten*, *Wilkingia*, and *Edmondia*), gastropods and scattered echinodermal debris. Many of the fossiliferous beds in the Herington may be described as "shell beds." These beds consist principally of thick accumulations of the brachiopods *Derbyia* and *Composita*, and the bivalves *Myalina* and *Aviculopecten*. These shells form "shell pavements" (hardground surfaces). Some of the shells are imbricated. Algal biscuits are associated with this shelly fauna. Some bedding–plane surfaces are covered with abundant articulated *Composita* brachiopods, many of which are encrusted with the tube worm *Spirorbis*.

Most of the Herington Limestone beds are highly bioturbated. Some of the burrows contain distinctive fecal–pellet accumulations ("armored burrows"). Crawling (locomotion and grazing) gastropod trails are abundant on some bedding–plane surfaces. On the soles of some Herington Limestone blocks, especially those that overlie shaly interbeds, large horizontal, Y–shaped, branching burrow networks of the trace fossil *Thalassinoides* cover bedding–plane surfaces. On the tops of other limestone beds horizontal, U–shaped, spreiten–filled burrows of the trace fossil *Rhizocorallium* are common.

In southern Kay County, just west of OGS core hole KC–2 (Fig. 1), and overlooking the Arkansas River (Prentice Road—section K–9), a prominent facies change occurs within the Herington Limestone. This local facies consists of ~7 ft of thick–bedded, sandy, crossbedded grainstone, the basal 2 ft of which is oolitic. Some of the ooids exhibit superficial concentric laminae. This area contains an east–west trending belt of oolite shoals.

The upper part of the Herington Limestone commonly contains a laterally continuous distinctive, resistant 1–ft–thick crinoidal grainstone bed. In Kay County the top of the Herington Limestone (Nolans

Figure 19. Contact between terrestrial reddish–brown conglomeratic sandstone of the Wellington Formation [We] and underlying grayish sand–rich marginal–marine Herington Limestone Member [He]. OG&E Reservoir, Noble County, Oklahoma.

Limestone) is placed at the top of this crinoidal limestone marker bed. The contact of the Nolans (Herington Limestone) with the Wellington Formation (Sumner Group) above is rarely exposed (Fig. 19). Thicknesses, stratal relations, and facies sequences are based on core–hole data. Core–hole data and electric–log interpretations indicate that the interval between the top of the Herington Limestone, as defined above, and the base of the characteristic anhydrite beds in the Wellington Formation (Anhydrite Member) above includes a transitional interval of ~30–35 ft of thin dolomite and dolomudstone beds alternating with greenish–gray dolomitic shales containing very thin gypsum partings/veinlets (Fig. 8). The contact between the Nolans (Herington Limestone Member) and the overlying Wellington Formation was observed in the subsurface only in OGS core hole KC–5 (Fig. 1) and is sharp. This contact, where exposed at the surface in eastern Kay County, is placed at the highest continuous sequence of fossiliferous limestones and calcareous shales, and the lowest continuous sequence of greenish–gray, grayish–red and light–olive–gray unfossiliferous, gypsum/anhydrite–bearing dolomitic mudstones and shales.

Depositional Environment

The Herington Limestone records a variety of depositional settings ranging from a shallow subtidal setting upon a relatively widespread carbonate platform (southern Cowley County, Kansas to southern Kay County) to an ooid–bank shoal (southernmost Kay County, Prentice Road, measured section K–9) to a shallow–water intertidal to supratidal setting in Noble County. Still farther south into Payne County, the Herington Limestone thins, occurring only as discontinuous, nodular, red dolomitic limestones and dolomudstones with pedogenic features within a thick siliciclastic wedge of fluvial/deltaic redbeds.

In Kay County, the Herington Limestone reflects a depositional setting characterized by alternating periods of both low– and high–energy conditions. Mud–supported burrowed skeletal wackestones separated by thin fossiliferous shales record a depositional setting characterized by periods of relatively low wave and/or current activity. However, the occurrence of ooids and low–angle inclined stratification locally suggests the periodic influence of strong current and/or wave activity. Shell beds, composed principally of the epifaunal mytiloid bivalve *Myalina*, associated with mud–filled bioclasts and rounded intraclasts suggest episodic storm events. Infaunal pholad bivalves in life position (e.g. *Wilkingia*) indicate a shallow marginal–marine environment.

Osage County

The Nolans Limestone is represented by the Herington Limestone in Osage County where it is ~15 ft thick. It is composed of an upper ~1– to 2–ft–thick coquinoid limestone (packstone) with reworked broken shell fragments, some infilled with limonite; a 3.5–ft–thick middle unit of gray blocky mudstone interbedded with thin gray shale stringers; and a lower 8– to 10–ft–thick gray fossiliferous, highly pitted, algal (osagid) skeletal wackestone with a distinct “rotten” ferruginous texture. The lower limestone unit contains crinoid fragments, bryozoans, brachiopods, gastropods, and bivalves. Whether this tripartite lithologic subdivision correlates with the Krider Limestone, Paddock Shale, and the Herington Limestone of the northern outcrop belt in Kansas and Nebraska is still not resolved.

Pawnee County

No outcrops of the Nolans Limestone occur in Pawnee County.

Noble County

The Herington Limestone Member forms cuestas and bluffs in the northern outcrop belt of the county.

In northern Noble County (T. 24 N.) the Herington consists of ~8 ft of thin–bedded silty peloidal packstones to grainstones with osagid grains. The limestones are interbedded with fine–grained sandstones. Rare fossils locally include gastropods, cephalopods, bivalves, brachiopods, bryozoans, crinoid hash, and ostracodes.

In central Noble County (T. 22 N.) the Herington thins to ~4 ft and is composed of thin beds of red, mottled, dolomitic limestones interbedded with fine–grained sandstones. The mottling of the dolomitic limestones may reflect the weathering of disrupted algal mats (Shelton et al., 1979).

In southern Noble County (T. 21 N.), the southern facies of the Herington is less than a foot thick and is characterized as a series of discontinuous exposures of thin, red dolomitic limestones interbedded with very fine grained, small–scale crossbedded sandstones and brecciated nodular micritic limestones with sand–sized grains.

Payne County

The Herington Limestone in Payne County resembles lithologically the red, nodular, dolomitic limestone of southern Noble County (Fig. 17). It occurs in lenses less than 1–ft thick with pink, finely crystalline nodules commonly associated with a thin (<5 ft thick) lenticular very fine grained sandstone.

Figure 20 shows a general electric–log correlation of the Chase Group from Sedgwick County, Kansas to Noble County, Oklahoma. The general characteristic log signatures for formations/members of the Chase Group are described.

DEPOSITIONAL CYCLICITY WITHIN THE CHASE GROUP

Introduction

Early Permian carbonates and siliciclastics within the Chase Group can be grouped into depositional couplets (cycles) of a carbonate–dominated facies and a clastic–dominated facies (Fig. 21). These two lithofacies recur repetitively throughout the Chase Group. Lithologic successions within the Chase Group are vertically asymmetric, consisting of thicker clastic–dominated facies (33–131 ft) and thinner carbonate–dominated facies (3–66 ft). Successions within the Chase Group also are lithologically asymmetric. Carbonate facies are composed dominantly of shallowing–upward stratigraphic units of coated–grain wackestones, packstones, and grainstones (Fig. 21). Conversely, the clastic facies consist of red and green mudstones and/or shales locally capped by exposure surfaces. Thin (3–16 ft), lenticular, very fine grained sandstones–siltstones compose minor parts of the clastic facies, increasing noticeably in both frequency and thickness east and south of Kay County. Some major characteristics of the carbonate– and clastic–dominated facies are listed in Tables 5 and 6, respectively.

The carbonates and clastics of the couplets are correlatable to both major transgressive and regressive events, respectively. The mudstone–carbonate interface at the base of each couplet reflects the final stage of a marine regression and the initial stage of a transgressive event, respectively.

The discontinuity at the top of each carbonate sequence represents a shallowing–upward event (initial regression), accompanying locally periodic subaerial exposure and concomitant deposition of marginal–marine and terrestrial redbed clastics. Continuous terrestrial redbeds with pedogenic features mark both the base and top of each carbonate depositional cycle.

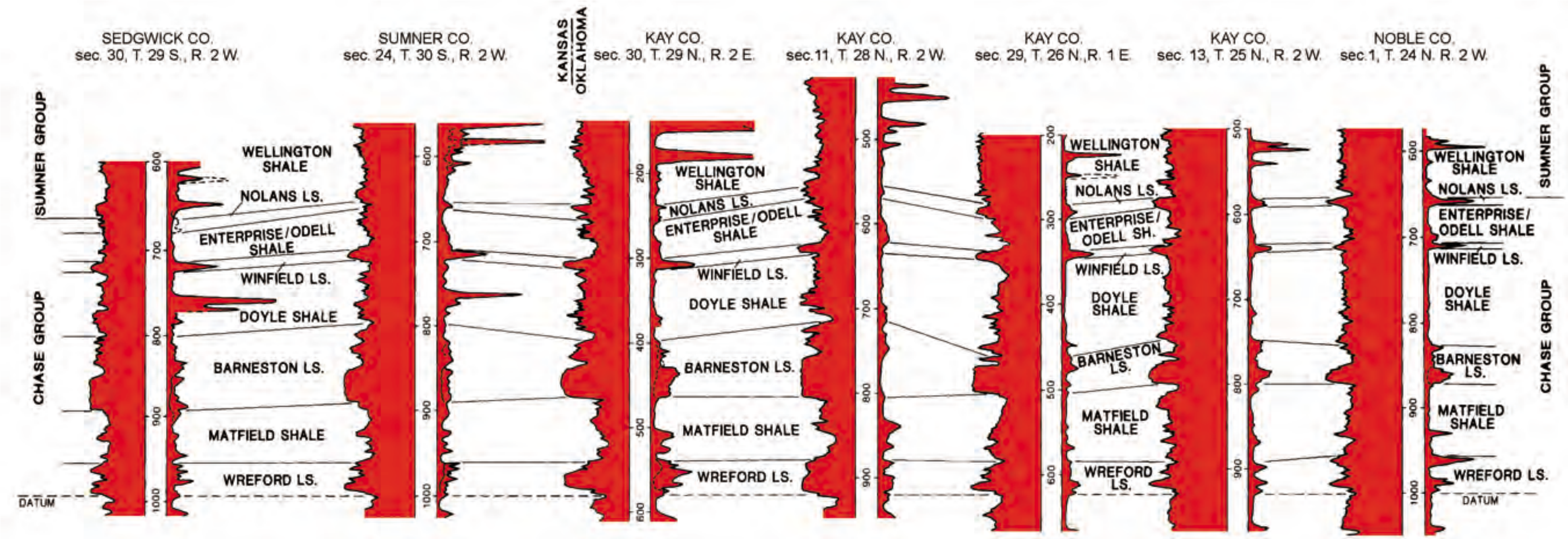
Depositional textures, sedimentary features and structures, major biota, and sequence stratigraphy for the clastic– and carbonate–dominated facies are shown in Figure 22.

Table 7 shows a general comparison between sedimentary cycles in the Chase Group in southern Kansas and northern Oklahoma.

DEPOSITIONAL ENVIRONMENTS IN THE CHASE GROUP

Reconstruction of the paleogeographic depositional setting for the Chase Group in northern Oklahoma is based on observed lithologic, biologic, stratigraphic, and sedimentary features of the sedimentary facies (and subfacies) recognized in outcrops, cores, and on wireline logs (Fig. 23).

The general regional trend of Chase environments in northern Oklahoma ranges from dominantly relatively high–energy, shallow–water, open marine to semi–restricted subtidal deposits (Tps. 28–29 N., Rgs. 2 W.–5 E., northern Kay County); to more restricted marine/marginal–marine subtidal to peritidal deposits somewhat closer to a clastic influx (Tps. 25–27 N., Rgs. 2–5 E., southern Kay County, southwestern Osage County); to marginal–marine, semi–restricted peritidal deposits closer to a paleoshoreline and clastic



Wreford Limestone — The Wreford Limestone usually produces a characteristic triparite log signature consisting of two distinct strong deflections to the left and right on the SP and resistivity curves, respectively, indicating the presence of both the lower and upper limestone units, separated by a distinct negative deflection (kick) that represents the middle shale member (Fig. 2).

Matfield Shale

Kinney Limestone Member — When present, this member of the Matfield Shale exhibits a positive deflection on both the SP and resistivity curves ~10–15 ft above the top of the Wreford Limestone within an otherwise dominantly shale section (serrated log signature) (Fig. 2).

Barneston Limestone — Produces a highly distinctive, blocky SP log signature in the lower one–half of the formation and a highly serrated (ratty) log signature on both the SP and resistivity curves in the upper one–half of the formation reflecting a gradational shaly limestone facies.

Doyle Shale — Log signatures indicate a distinct solid predominantly shale section (railroad track) for the Doyle Shale. Locally, a small, but distinct positive spike on both the SP and resistivity curves ~10–15 ft above the base probably reflects the presence of the Towanda Limestone Member of the northern outcrop belt (Fig. 2).

Winfield Limestone — The Winfield exhibits a distinct, persistent solid spikey log response on the SP curve, a fairly distinct, but admittedly somewhat more variable, resistivity log character (Fig. 2).

Enterprise/Odell Shale — The Luta Limestone Member in the Enterprise/Odell Shale produces a distinct gently sloping to rounded–shoulder log signature on the resistivity curve throughout a thickness of ~10–15 ft. Commonly this interval is logged as one unit of limestone.

Nolans Limestone — The Nolans Limestone, especially in northwestern Kay County, is represented by two subdued spikes on the SP and resistivity curves separated by a negative deflection on both curves (corresponds to Krider Limestone, Paddock Shale, and Herington Limestone as recognized in Kansas). However, throughout most of Kay County and to the south, the Nolans is represented by a single spike on the SP and resistivity curves reflecting only the Herington Limestone Member.

Note — Some of the more shale–prone successions (e.g., Matfield Shale, Doyle Shale, etc.) have elevated gamma–ray log signatures in selected stratigraphic intervals.

Figure 20. Generalized electric–log correlation of Chase Group from Sedgwick County, Kansas to Noble County, Oklahoma.

influx (Tps. 20–24 N., Rgs. 2–3 E., Noble and Pawnee Counties); to restricted marginal marine, high intertidal to terrestrial redbed clastics, locally with periodic subaerial exposure as the paleoshoreline is approached (Tps. 17–21 N., R. 3 E., Payne County). South of Payne County the Chase Group changes facies into a thick wedge of dominantly fluvial/deltaic/ alluvial fan redbed siliciclastics (Fig. 23).

Approximately 10 mi west of the Chase outcrop belt in Kay County, data from OGS core holes KC–7 and KC–9 (Fig. 1) indicate locally the alternation between deposition of evaporitic lithologies in a more restricted high–intertidal/sabkha–type setting and semi–restricted carbonate–dominated lithologies. Progressive evaporation of surface and subsurface waters on the sabkha precipitates sulfate minerals and increases the molar ratio concentrations of magnesium to calcium in the pore fluids resulting in dolomitization of lime muds (Friedman and Sanders, 1967). Anhydrite cement and gypsum fracture linings/nodules suggest that sometime after deposition and possibly dissolution, these carbonate rocks were saturated with sulfate–enriched brines from a nearby evaporite environment. Anhydrite and gypsum show a patchy distribution throughout the evaporite facies. Anhydrite is present either as displacive nodules scattered throughout the matrix, replacing skeletal material, or filling rare vertical fractures. Gypsum occurs either as parallel bands or as linings of slickensided fracture surfaces. Carbonate parts of the depositional couplets in core hole 9 (northwestern Kay County) are thicker (Herington = 25 ft; Winfield = 26 ft; Barneston = 66 ft). Clastic parts of the couplets are thinner (Enterprise/Odell = 39 ft; Doyle = 74 ft). Sedimentary structures/ features supporting a restricted evaporite environment subject to periodic subaerial exposure include the following: 1) color mottling, 2) gypsum laminae and bands, 3) gypsum–lined fracture surfaces, 4) slickensided fracture surfaces, 5) dolomitic lime mudstones, 6) abundant wavy stromatolitic laminae, 7) brecciated dolomite, 8) nodular anhydrite, 9) clotted textures/fabrics, 10) large algal–coated (osagid) grains, 11) vesicular dolomite nodules, and 12) vuggy textures.

Table 8 lists some criteria for the recognition of depositional environments in the Chase Group of northern Oklahoma.

SEQUENCE STRATIGRAPHY

Understanding the sequence stratigraphic setting is of primary importance when describing and predicting reservoirs in the Chase Group. Transgressive systems tracts normally will develop poor reservoirs because of the mud/silt texture of the carbonate rocks

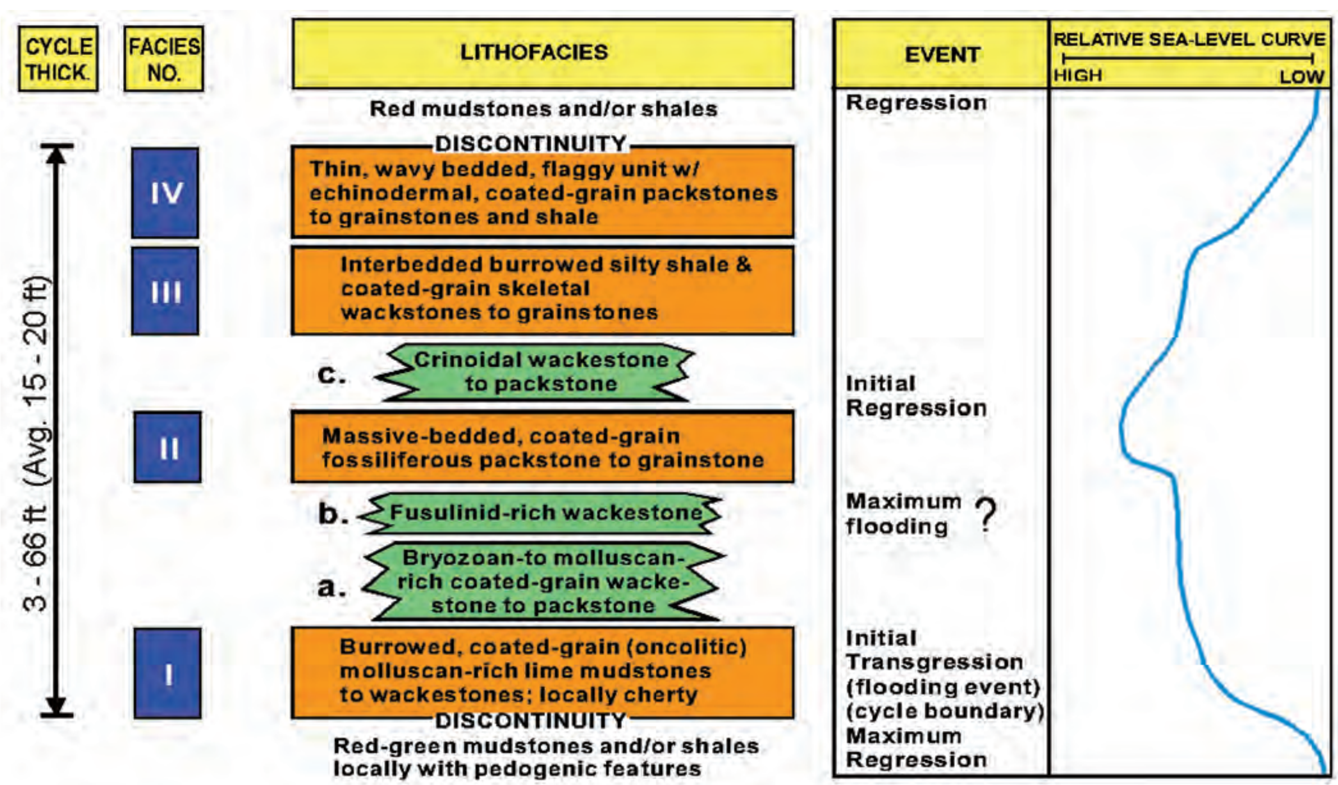


Figure 21. Idealized shallowing–upward cycle of carbonate–dominated facies, Chase Group, northern Oklahoma.

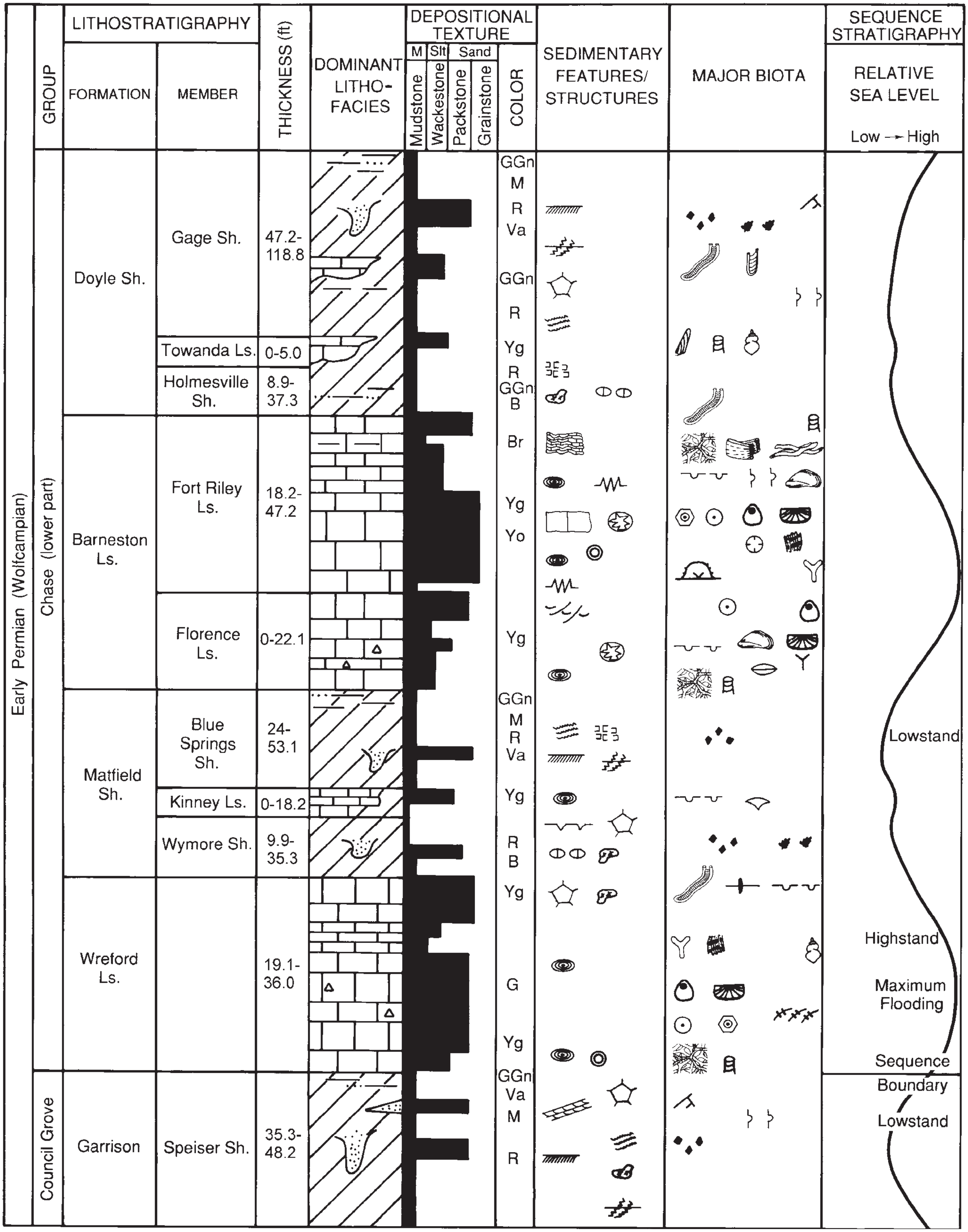


Figure 22. Generalized stratigraphic section showing the stratigraphic framework, member thicknesses, dominant lithofacies, depositional textures, sedimentary features and structures, major biota, and sequence stratigraphy of the Chase Group in northern Oklahoma.

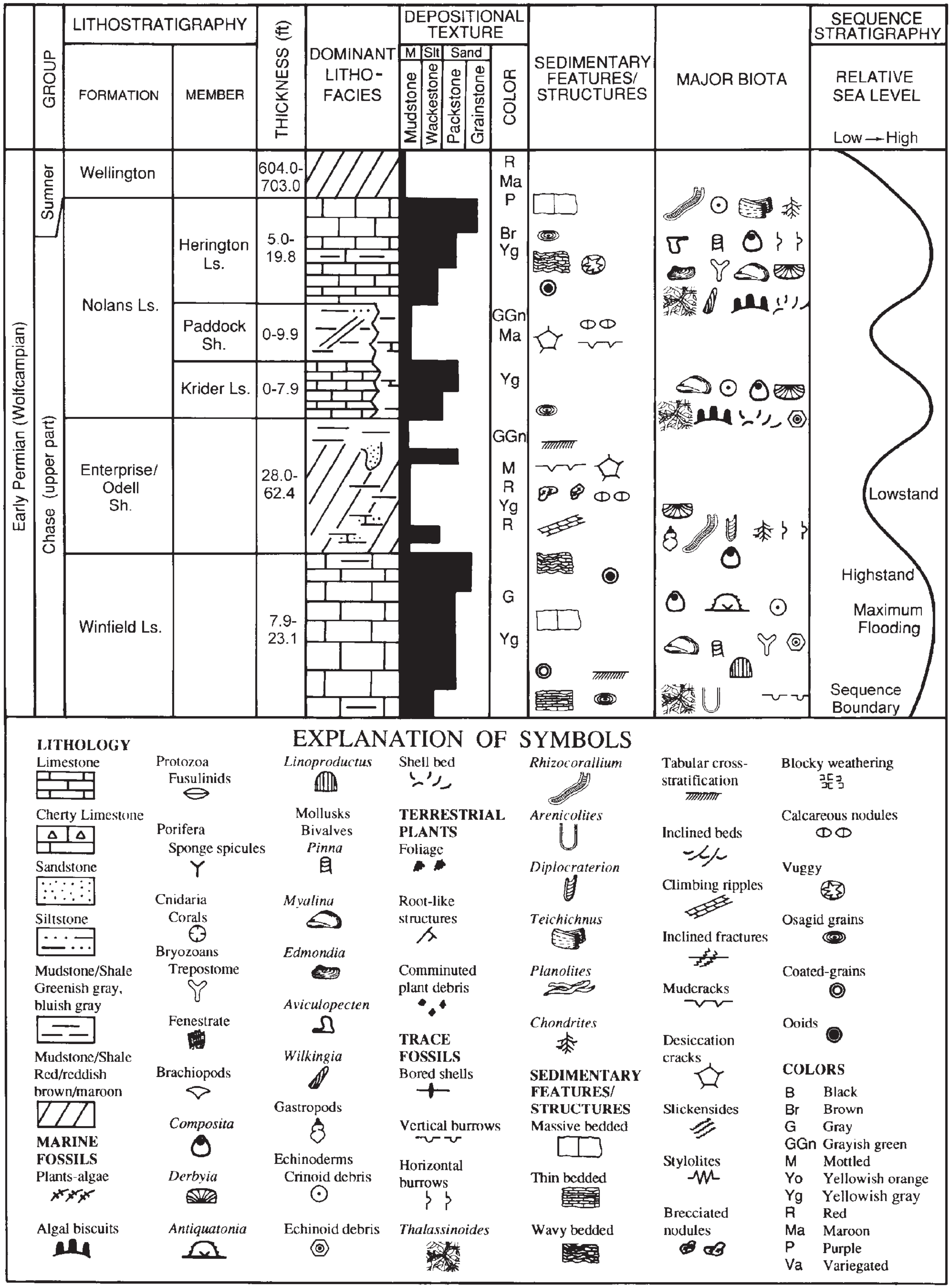


Figure 22 (*Continued*)

Table 5. Major characteristics of the carbonate–dominated facies

- Thinner (7–39 ft); less widespread geographically, but better preserved than the clastic facies
- Basal beds contain abundant infaunal burrowing phalodomyoid and mytiloid bivalves in life position that suggest the onset of marine to marginal–marine transgressive events (i.e., paleoshoreline indicators) (Fig. 22)
- Carbonate units are either thin or absent in intervals with thick clastic development
- Typically consists of stacked shallowing–upward carbonate units composed of coated–grain, fossiliferous packstones and grainstones, with subordinate marine shale and skeletal wackestone intervals
- Typical carbonate cycles consist of, in ascending order: 1) a basal coated–grain, bryozoan– to molluscan–rich wackestone to packstone, locally containing chert nodules (Fig. 22); 2) thick– to massive–bedded, coated–grain, fossiliferous packstone to grainstone; 3) interbedded marine shale and coated–grain molluscan–rich wackestone to packstone; and 4) coated–grain skeletal packstone to grainstone
- Basal contacts are sharp and burrowed and contain very abundant, large algal–foraminiferal coated grains (osagid grains), commonly with limonitic rinds
- Some infaunal mytiloid bivalve (*Pinna*) burrows extend through an entire bed thickness of 1 ft
- Overlying clastic–dominated facies indicates onset of a regression

- Base marks a transgressive surface formed during the initial marine flooding event of a relative sea–level rise (Figs. 21 and 22)
- Shell beds associated with mud–filled bioclasts and rounded intraclasts suggest periodic storm events
- Intracycle deepening events within each transgressive carbonate cycle are suggested by the presence of thin, interbedded algal– and molluscan–rich wackestones and marine shales
- Co–occurring coated grains (osagrid grains) and burrowing infaunal bivalves in life position mark the onset of an initial transgression
- Shallowing–upward coated–grain packstone to grainstone units in the upper part of each major carbonate cycle record the onset of a relative sea–level fall
- Carbonate units are directly overlain by marginal–marine and terrestrial lithologies such as typically recorded below the transgressive carbonate surfaces
- At or near the regressive–transgressive interface at the base of each major transgressive carbonate unit abundant large, horizontal, profusely branched networks of the trace fossil *Thalassinoides* occur
- On the top bedding–plane surfaces of the highest (last) carbonate unit at the transgressive–regressive interface are horizontal forms of the spreiten–bearing trace fossil *Rhizocorallium*

Table 6. Major characteristics of the clastic–dominated facies

• Average thickness of 82 ft • Thickest and most widespread, but most poorly preserved parts of the carbonate–clastic depositional couplet • Primarily composed of red to reddish–brown, greenish–gray massive to blocky mudstones and shales • Subordinate amounts of (<3 ft in thickness) of coated–grain fossiliferous wackestones to packstones and very fine grained, lenticular sandstones and/or siltstones • Locally contains terrestrial plant fossils and shaly coal spars • Interpreted as a regressive facies consisting of marginal–marine (low intertidal to very shallow subtidal) to terrestrial sedimentation	• Capped locally by subaerially exposed surfaces that may be associated with variably developed paleosols • Paleosols within clastic intervals are evidence of climatic variations below an initial transgressive surface (event) • Locally, clastic deposition was interrupted periodically by minor marine deepening events as evidenced by thin (<3 ft thick) laterally restricted carbonates and associated marine shales • Marine parts of the regressive clastic facies occur both at the base and top of the clastic–dominated facies • Bounded by major erosional discontinuities • Sharp contact with overlying transgressive carbonate unit marks a sequence boundary

Table 7. General comparison of sedimentary cycles in the Chase Group in southern Kansas and northern Oklahoma

Southern Kansas	Northern Oklahoma
1. Carbonate–dominated cycles	1. Clastic–dominated cycles
2. Clastics composed of stacked paleosols capped by flooding surfaces	2. Clastics dominated by shales and/or mudstones containing pedogenic features and locally, weakly developed paleosols
3. Clastic parts of cycles ~10– to 40–ft thick	3. Clastic parts of cycles ~20– to 120–ft thick
4. Essentially sand–poor clastic facies throughout	4. Sand–rich clastic facies become more frequent and thicker to the south
5. Most clastics associated with marine–marginal marine depositional settings	5. Most clastics represent marginal–marine to terrestrial depositional settings
6. Overall lack of regressive limestones	6. Overall lack of regressive limestones
7. Clastics may be associated with both regressive and transgressive events	7. Most clastics appear to be associated primarily with regressive event
8. Multiple–major–minor intracycle transgressions–regressions common	8. Most depositional cycles represent a single transgressive–regressive event
9. Parasequences and parasequence sets are identifiable	9. Parasequences and parasequence sets are less identifiable because minor (higher than 4th order) changes in relative sea level are not readily expressed in the marginal–marine–terrestrial facies
10. Cycle boundaries (discontinuities) are gradational within carbonate–clastic couplets	10. Cycle boundaries (discontinuities) are very sharp at carbonate–clastic interfaces (contacts)
11. Transgressive–regressive events commonly gradational	11. Sharply punctuated transgressive–regressive events
12. Overall higher marine biotic diversity	12. Overall marine biotic diversity low to absent

and because of the absence of exposure surfaces. Highstand–systems tracts (HST) offer the greatest potential for yielding highly permeable reservoirs. The regressive phase of the HST will develop economic reservoirs, but these reservoirs will degrade vertically from the base of the systems tracts.

The deposition of marine carbonate strata over the nonmarine red mudrock facies in the Chase Group suggests a marine flooding surface (sequence boundary), or alternatively an environmental shift in the depositional setting without a significant change in bathymetry (Fig. 21). The sharp contact between the red mudstone facies below and the carbonate facies above represents a flooding surface that probably marks the termination of lowstand wedge clastic deposits and the onset of transgressive marine carbonates (Fig. 21). The flooding surface is sometimes marked locally by a thin skeletal and intraclastic lag. The base of the subjacent facies overlying the flooding surface is commonly bioturbated (*Thalassinoides*) and associated with the burrowing infaunal mytiloid bivalve *Pinna* and the pholad bivalve *Wilkingia*, both occurring in life positions at or near the base of each carbonate cycle (Fig. 21). Each flooding surface (i.e., marine shale, shaly fossiliferous limestone) is a hiatus, admittedly of relatively short duration that punctuates upward–shoaling cycles, and serves to divide formations within the Chase Group into successive parasequences (Fig. 21). A complete shallow–water carbonate parasequence includes (from bottom to top): burrowed, algal, echinoderm/molluscan–rich lime mudstones to wackestones; massive–bedded coated–grain fossiliferous packstones to grainstones; interbedded burrowed silty shale and coated–grain skeletal wackestones to grainstones; and echinodermal, coated–grain packstones to crossbedded oolitic grainstones (locally restricted), and dolomitic lime mudstones and shales.

Pedogenic features throughout the Chase Group document the periodic emergence and subaerial exposure of a carbonate ramp–type depositional setting. The emergent surface of the siliciclastic nonmarine mudstone facies, interpreted to have accumulated as a paleosol, serves as a transgressive marine flooding surface. The red caliche–bearing variably developed paleosols in the Chase Group probably formed at peak marine regressions during major regressive events associated with a lowstand systems tract (LST) of the carbonate–ramp system. Laterally extensive paleosols are particularly important because they delineate temporally distinct stratigraphic sequences and are critical to reconstructing sea–level history.

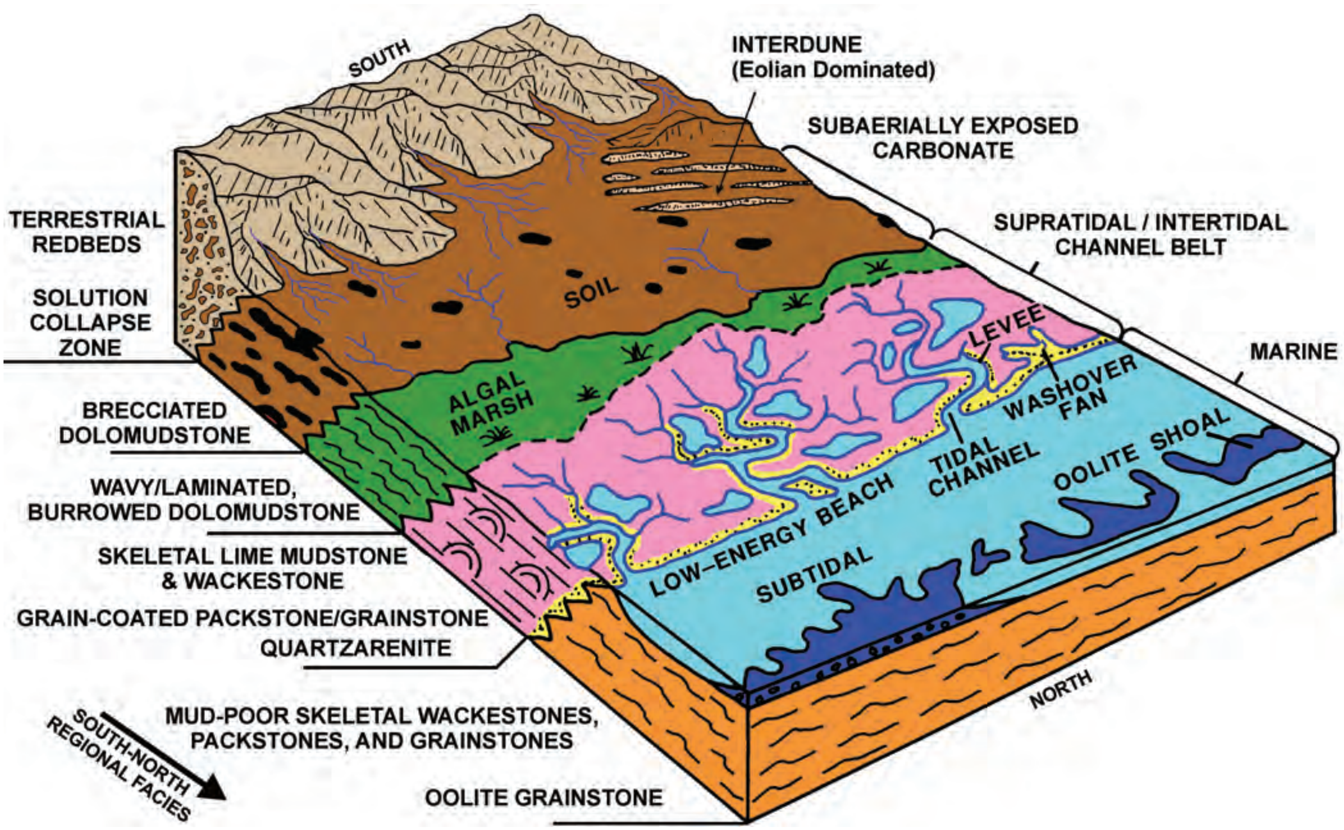


Figure 23. Schematic block diagram showing probable depositional setting of a mixed carbonate–siliciclastic system for the Permian Chase Group in northern Oklahoma (modified from Humphrey, Hendricks and White, 1994).

Table 8. General criteria for the recognition of depositional environments in the Chase Group

Sedimentary Structures/Features	Depositional Environments/Processes
1. Lack of peritidal facies (tidal mud/sand flat)	1. Abrupt fall of sea level.
2. Mixture of bioclasts and osagid grains in a silty carbonate mudstone matrix	2. Reworking of allochems into a restricted, low– to moderate–energy, slightly hypersaline, shallow subtidal or lagoonal setting with low to moderate turbidity
3. • Upward transition to skeletal packstone • Increased amounts of oncoids • Phylloid algal platelets • Bivalves, gastropods, and encrusting foraminifera	3. Increasingly wave and current–agitated, shallow, subtidal environment
4. Brachiopod–molluscan limestone facies	4. Shallow water, normal marine salinity
5. Calcareous shale facies	5. More brackish, restricted nearshore environment
6. Overall lack of obvious wet–climate paleosol features (e.g., rhizocretions, definitive root traces and horizonation)	6. Soil development was inhibited by arid conditions unsuitable for much plant growth and/or preservation
7. Mud–supported carbonate fabrics	7. Relatively low–energy setting
8. Presence of siliciclastics locally within carbonates	8. Intermittently turbid depositional setting
9. • Limited marine fauna • Presence locally of anhydrite/gypsum • Lack of ichnologic diversity • Abundant siliceous spicules in chert	9. Semi–restricted setting such as the quiet, deeper waters of a bay or lagoon prone to stressed environmental conditions
10. Osagid–grain–rich wackestone/packstones	10. • Agitated shallow depositional settings • Low–energy environment that may show evidence of stratigraphic condensation • Omission surfaces of submarine firmgrounds
11. Clastic–rich osagid–grain wackestones	11. Relatively low–energy restricted coastal embayment (bay/lagoon)
12. Osagid–grain wackestone	12. • Low to moderate energy • Slightly hypersaline restricted shallow subtidal setting
13. Relative absence of transgressive lag	13. • Minor erosional event • Indicates only a minor rise in sea level is sufficient to produce a flooding surface
14. • Dominance of well–rounded and well–sorted grain–supported fabrics • Low–angle planar cross–beds • Regularly concentric biogenically–coated grains	14. Shoal–water conditions
15. • Cyanobacterial laminations • Birdseye and fenestral fabrics • Intraclastic breccias • Desiccation features	15. Periodic conditions of alternating wetting and drying in a restricted upper intertidal to supratidal (sabkha) environment subjected to periodic subaerial exposure
16. Massive to blocky red to reddish–brown variegated mudstone	16. Pedogenic processes in the more landward part of a coastal sabkha complex
17. Discontinuous parallel– to wavy–laminated sandy shale and lenticular very fine grained sandstone	17. • Intertidal siliciclastic tidal mud/sand flat cut by meandering tidal channel • Close proximity to paleoshoreline
18. Coated, disarticulated, and abraded skeletal fragments	18. Episodic high–energy conditions (storm events)
19. Burrowing infaunal bivalves	19. Locally brackish water
20. • Diagentic fabrics associated with caliche formation • Brecciated and clotted micrite fabric • Shrinkage/desiccation cracks or solution channels • Fenestral porosity • Nodular anhydrite and gypsum bands • Caliche nodules/clasts • Mottled zones (gleying) • Slickensided fracture surfaces/peds • Calcite/gypsum–lined desiccation cracks	20. Periodic subaerial exposure (paleosol formation)
21. • Dolomudstones, dolomites, gypsum and anhydrite bands and nodules • Cryptalgal laminations	21. Semi–restricted to restricted evaporite setting
22. Oolitic grainstone with low–angle crossbedding	22. Traction transport and relatively high energy conditions in a shoal setting
23. Poorly defined nodular bedding	23. Combination of bioturbation and/or differential compaction
24. Nodular caliche	24. Seasonally dry climatic conditions
25. Pedogenic slickensides	25. Clay–rich (smectite) soils

Pedogenic alteration of subtidal deposits is direct evidence for a basinward shift of a paleoshoreline and thus is extremely useful in differentiating discontinuity–type sequence boundaries from other types of unconformities (Stapor, F.W., et al., 1992).

Intraclastic, osagid–grain wackestone to packstone facies deposited at the base of the shallowing upward succession grade upward into red silty mudstones containing carbonate lithoclasts and caliche nodules, and crusts delineating an erosional discontinuity.

During development of the regressive facies, siliciclastic deposition was interrupted periodically by minor local marine–deepening intracycle events (incursions) as evidenced by the local occurrence of thin (<3 ft thick) laterally restricted carbonates (e.g., Kinney Limestone in the Matfield Shale and the Towanda Limestone in the Doyle Shale). The occurrence of these restricted limestones may also reflect periodic waning clastic sedimentation.

Lower sequence boundaries in the Chase Group are characterized by the trace fossil *Thalassinoides* and *in situ* burrowing infaunal bivalves which separate transgressive marine carbonates above from the predominantly regressive nonmarine red beds below (Fig. 22).

Overall, depositional sequences in the Chase Group lack well–defined marine condensed sections that represent the HST.

PALEOSOLS

Introduction

The principal means of distinguishing paleosols is the recognition of diagnostic features known to occur in modern soils (Retallack, 1976). Some common pedogenic processes include rooting, burrowing, shrinking and swelling clays, and precipitation of secondary minerals that disrupt original fabric of parent material. Pedogenic changes may result from climate change and/or marine transgression.

Paleosol–bearing intervals on a less–well–drained/heavily vegetated landscape commonly display root bioturbation, green/purple reduction mottling, grayish–green mudstones/shales and a high water table. Conversely, paleosol–bearing intervals on a well–drained/sparsely vegetated landscape exhibit caliche formation and a pronounced reddening of mudstones/shales.

Some pedogenic features observed in outcrop and in thin section are listed and interpreted in Table 9. Some definitions of common features associated with paleosols are shown in Table 10. Petrographic and scanning electron microscopic (SEM) studies are required to study microscopic structures such as soil fabric, voids, and cutans present in paleosols.

Description of Chase Group Paleosols

Mudstone–shale successions, 60–150 ft thick, within the regressive (lowstand) siliciclastic facies of the Chase Group depositional couplets have been pedogenically modified into red–reddish–brown, clay–rich variably developed paleovertisols.

Macroscopic field evidence of shallow–water depth, periodic subaerial exposure (emergence), and accompanying variable development of paleosols locally include: 1) absence of marine faunas; 2) terrestrial plant fossils; 3) blocky weathering of mudstones; 4) mudstone void fills in brecciated carbonate nodules; 5) greenish gleyed (a change from reddish to greenish colors caused by pedochemical reduction of iron) mudstones overlying brecciated reddish–brown calcareous mudstones (Fig. 24A); 6) widespread brecciation (Fig. 24A); 7) brecciated unfossiliferous carbonate (micrite) nodules (Fig. 24B); 8) mud–cracked, nonlaminated mudstones; 9) root–like and blotchy color mottling (e.g., red, maroon, purple, dusky–yellow) (Fig. 24A); 10) calcretized horizons of non–biogenic alpha type, i.e., calcretes showing little or no evidence of biological activity and consisting of dense crystalline carbonate (micrite), nodules, and complex fractures in the matrix, partially or wholly filled by more coarsely crystalline calcite (Tucker and Wright, 1990); 11) polished and grooved slickensided fracture surfaces coated by manganese oxides (Fig. 24C); 12) non–laminated crudely bedded red mudstones; 13) sparry calcite– or gypsum–filled internal fractures and voids; 14) rare molds of discoidal gypsum crystals on bedding–plane surfaces; and 15) sharp truncation of the regressive facies by transgressive marine carbonates. Overlying carbonate units contain abundant infaunal burrowing pholadomyoid bivalves in life position that suggest the onset of marine to marginal–marine transgressive events (i.e., paleoshoreline indicators).

The variable development of both multiple and individual reddish–brown and greenish–gray paleosols within clastic intervals is evidence of climatic variations below an initial transgressive surface (event).

Red to reddish–brown shales well cemented by pervasive veins of sparry calcite that appear to follow a mud–cracked pattern are common in the clastic facies; some units have a boxwork appearance suggestive of paleocaliche (Fig. 24D).

Paleosol horizons containing irregularly shaped carbonate nodules (caliche), some as much as several inches in length and locally brecciated, define discon-

Table 9. Some pedogenic features observed in outcrop and thin section

I. Organic Structures

- A. Root traces
  - 1. taper and branch downward
  - 2. root molds common
  - 3. horizontal—waterlogged soils
vertical—well–drained soils
  - 4. deflection of root trace around or concentrated above a particular horizon as evidence of strong induration
- B. Calcified filaments (i.e., algae, fungi, bacteria)
- C. Needle—fiber calcite
- D. Alveolar—septal structure
- E. Phytoliths

II. Color (Munsell chart of soil scientists)

- A. Red/reddish–brown, yellow, purple
  - 1. presence of ferric oxides or hydroxides
    - a. hematite
      - 1) dehydration of an iron hydroxide precursor
      - 2) alteration product of iron–bearing minerals
      - 3) precipitation from solution
  - 2. form under oxidizing conditions
  - 3. common in subsurface soil horizons
- B. Black/dark gray
  - 1. presence of organic matter
  - 2. paucity of free oxygen
- C. Light gray/greenish/bluish
  - 1. ferrous compounds of manganese oxide
  - 2. form under reducing conditions (gley environment)
  - 3. green—glauconite/chlorite
gray—illite or smectite clays
  - 4. common in near–surface horizons
- D. Mottling
  - 1. Mottles of red/yellow in a gray or green matrix
    - a. alternating oxidizing and reducing conditions
    - b. representing a type of gleying
    - c. common in regions of fluctuating water table from seasonal precipitation

III. Paleosol Structures

- A. Peds
  - 1. granule 2. blocky 3. prismatic
  - 4. platy 5. wedge–shaped 6. columnar
- B. Desiccation cracks
  - 1. polygonal shape on bedding surfaces
  - 2. V–shaped in cross–section
  - 3. evidence of alternating wetting and drying of soils
  - 4. periodic desiccation of indurated layers such as carbonate horizons/nodules, may result in brecciation
- C. Slickensides
  - 1. force generated by expansion and contraction of expandable clays (smectite) as water is added to and lost from interlayer sites
- D. Brecciation
  - 1. periodic desiccation of indurated layers (carbonate horizons) with clasts coated by pedogenic material (cutans)
  - 2. rooting
  - 3. burrowing
- E. Glaebules and Tubules
  - 1. localized concentrations of soil material or authigenic minerals
  - 2. mineralogy is clue to local geochemistry with time of formation of structures
    - a. siderite, pyrite and manganese oxide suggest poorly oxygenated, waterlogged soils
    - b. iron oxides and calcite suggest well oxygenated soils
  - 3. glaebules
    - a. nodules—lack internal fabric
    - b. concretions—concentric internal fabric
      - 1) pisoliths = carbonate concretions
  - 4. tubules
    - a. cyclindrical concretions of soil materials or authigenic minerals
    - b. related to root traces, burrows, or desiccation cracks

Table 10. Some definitions of common features associated with paleosols (modified from Mack and James, 1992)

Calcrete—Highly indurated part of caliche profiles whether laminar or nonlaminar; formed by alteration or coating of the interior surfaces of voids and cracks in parent carbonate rock.

Cutan—A modification of the texture, structure, or fabric of a soil material (such as a soil aggregate, ped, etc.,) along a natural surface within it and caused by a concentration of a particular soil constituent; a network of irregular planes surrounding more stable aggregates of soil material (peds), surface coatings within a soil.

Concretion—Local concentrations of specific minerals with concentric internal lamination; a type of glaebule.

Gleying—Soil color mottling caused by partial oxidation and reduction of its constituent ferric iron compounds, due to conditions of intermittent water saturation.

Nodule—Local concentration of specific minerals with a homogeneous internal texture; a type of glaebule.

Paleosol—Soil that formed on a landscape of the past or under distinctly different climatic conditions of the past (fossilized soil horizon).

Ped—Natural stable aggregation of soil particles separated from others by joints, cutans, voids, or other planes of weakness.

Pedogenic—Origin related to soil-forming processes.

Pedogenic caliche—A strataform to irregular deposit, formed primarily by calcium carbonate, with earthy, concretionary, banded or massive structure that is formed in the soil or subsoil of arid and semi-arid regions.

Plasma—Pedologic constituent of a soil profile that is the relatively unstable, soluble fraction, no greater than colloidal size, that is not bound up in framework grains.

Rhizocretion—A root trace resulting from mineral encrustation around a live or decaying root.

Root cast—Sediment- or cement-filled molds or borings left after root decay.

Vertic—Process of homogenation of a soil profile by desiccation and shrinking and swelling of expandable clay minerals.

Vertisol—Paleosol containing abundant swelling clay (smectite to a presumed depth of 3 feet or to a bedrock contact, together with hummocky and swale structure (mukkara), with especially prominent slickensides or clastic dikes.

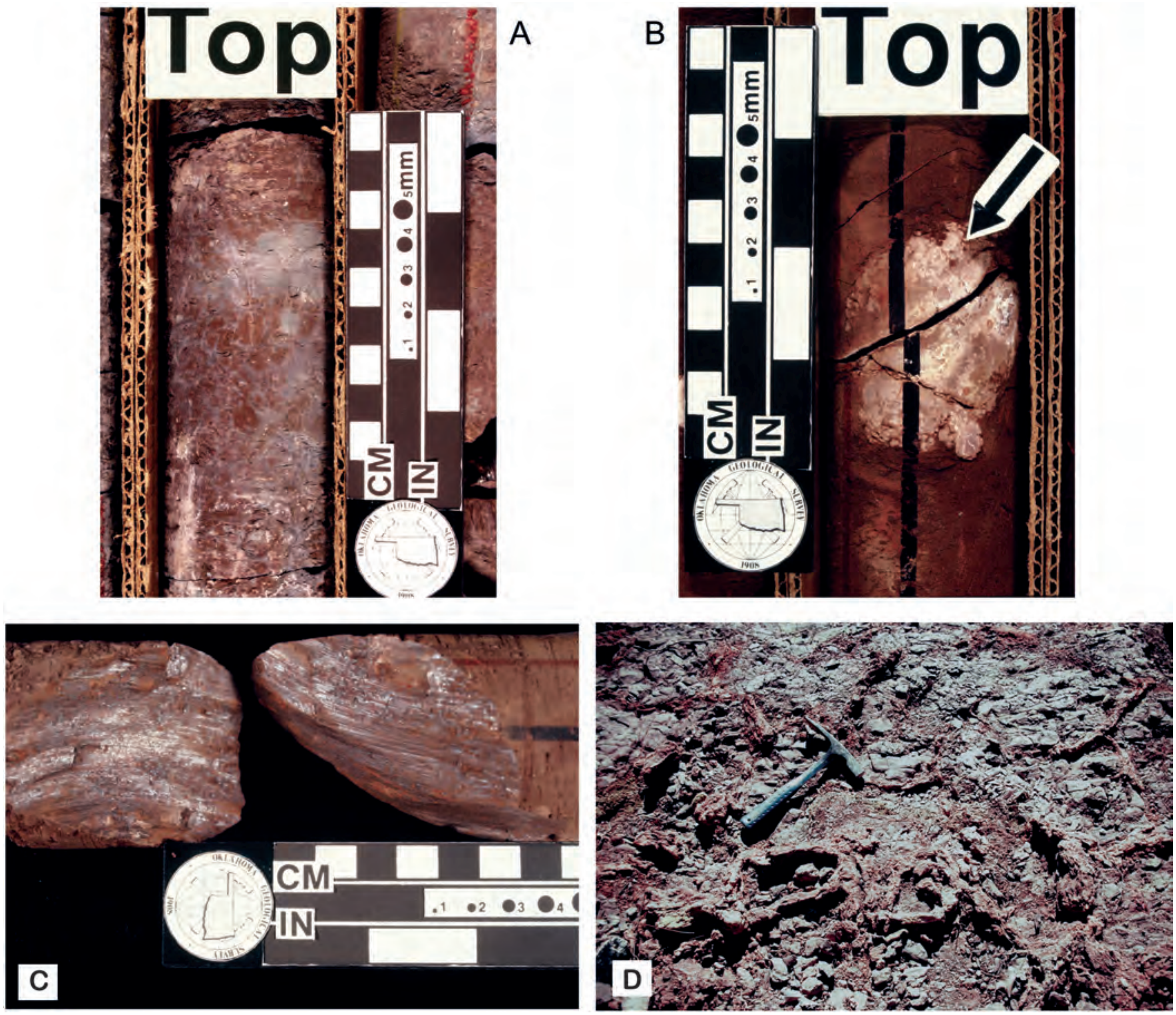


Figure 24. Pedogenic features in the Chase Group. [A] Color mottling (gleying) in the Blue Springs Shale (Matfield Shale), core hole KC–24A, depth 235.0 ft, Kay County. [B] Brecciated caliche nodule in the Doyle Shale, core hole KC–5, depth 130.0 ft, Kay County. [C] Manganese coated, grooved slickensided ped in the Doyle Shale, core hole KC–5, depth 126.2 ft, Kay County. [D] Desiccation features in the Matfield Shale, measured section K–26, Pioneer Cove, Kaw City 7.5' Quadrangle, Kay County.

tinuous calcic zones as much as 3 ft thick. Brecciation of the caliche clasts was probably caused by displacive crystallization of Rhizocretionary calcrete.

Root traces occurring as reduction halos that branch downward over a few to tens of inches are present but rarely abundant.

The red–green color banding commonly defines pedogenic alterations that transformed mudstones into singular or stacked (multigenerational) calcic paleovertisols within otherwise continuous mudstone units. Pedogenic modification is less prevalent in the mudstone units that are interbedded with sandstone–rich bodies.

The overall degree of calcification within the Chase paleosols is greatly reduced, probably because of a short time (emergence event) for formation.

Locally, the uppermost few to tens of inches of mudstone that cap most of the red to reddish–brown paleosol profiles are characteristically leached to a light–green–grayish–green color. This color reduction probably reflects reducing conditions associated with the onset of a marine inundation (i.e., transgressive event).

Interpretation

Paleosol characteristics, including red (hematite) color, blocky soil textures, clay coatings, and slickensides are interpreted as evidence for alternating wetting and drying conditions within the B zone of a well–drained soil profile.

Root traces occurring as reduction halos also suggest well–drained rather than waterlogged conditions that would favor preservation of original organic material.

In modern strongly seasonal climates, carbonate accumulations may form during dry periods and ferruginization may occur during wet seasons. These two processes also are indicative of a well–drained soil.

In semi–arid and arid regions precipitates, and hence leaching, are inadequate to remove carbonate from the system, so the local translocation and accumulation processes dominate, forming caliche. Within the Chase Group paleosols, alkaline conditions are indicated by the presence of calcite nodules that reflect seasonally dry climatic conditions. Locally, some carbonate accumulations have been brecciated by pedogenic processes.

The thickest and most mature paleosols in the mudstone–dominated parts of the mixed carbonate–siliciclastic sediments are candidates for defining times of prolonged exposure during sea–level lowstands. Repeated regressive sequences capped by caliches (associated with variably developed paleosols), suggest cyclic episodes of sea–level rise and fall.

Variably developed calcic paleovertisols in the Chase Group display well–developed, grooved, polished, manganese–oxide–stained pedogenic slickensides and blocky pedogenic fabrics (peds) that reflect times of extended soil formation on an aggradational landscape.

Applications of Paleosols in Oil and Gas Exploration/Production

The recognition of key stratigraphic surfaces lies at the heart of the sequence stratigraphic approach to understanding and predicting sedimentological phenomena. Subaerial exposure surfaces, which may represent paleosols, form at peak marine regressions during major regressive events. These regressive successions are often bounded by major erosional discontinuities. Because diagenesis and porosity development have distinct patterns related to duration of subaerial exposure, it is imperative to understand how such porosity–paleosol relationships develop. One major mechanism to produce secondary porosity in carbonate rocks is dissolution associated with subaerial exposure.

Paleosols, or weathering surfaces, are indicative of significant depositional hiatuses. Within sedimentary packages, significant paleosols often define regionally correlatable unconformities. The stratigraphic significance of paleosols in oil and gas exploration/production is noted in Table 11.

Table 11. Stratigraphic significance of paleosols in oil and gas exploration/production

- Represent time–significant surfaces
- Indicate sea–level lowstand (emergent exposure surfaces)
- Represent potential seals or partial seals for hydrocarbons
- Aid in locating the position of sand bodies within a fluvial “package”
- May correlate locally or regionally to coal/underclay horizons
- Represent erosional surfaces that may enhance karsting events (porosity/permeability)
- Define correlation surfaces that represent approximate time slices through a reservoir
- Commonly define regressive mudrock units
- Usually separate rocks of genetically distinct stratigraphic “packages” or “sequences”
- Identify the level of a marine flooding surface above
- Provide evidence of a basinward shift of paleoshoreline
- Create most of the unconformity–type sequence boundaries
- Recognize different levels of stratigraphic compartmentation in hydrocarbon–producing reservoirs

ICHNOLOGY

Introduction

Trace–fossil distributions in the Early Permian Chase Group in northern Oklahoma are significant stratigraphic tools for recognizing transgressive–regressive events in the mixed carbonate–clastic sequences of this particular stratigraphic and geographic setting. Bedding–plane surfaces, particularly the soles of beds, are relatively common at the sharp interfaces (contacts) between carbonate (more resistant) units and clastic (less resistant) units and are extremely useful in trace–fossil studies. Core data indicate that the occurrence of bed–junction traces is much more common than outcrop studies might suggest. The sharp lithological contrast at mudstone– and/or shale–carbonate contacts provides ideal conditions for preserving trace fossils.

Well–preserved trace fossils, dominated by *Thalassinoides* isp. (Fig. 25 A,C) and horizontal forms of *Rhizocorallium* isp. (Fig. 25 B,D; Fig. 26), occur on the soles and tops, respectively, of the carbonate cycles in the Chase Group. Trace–fossil abundance and distribution appear to be facies rather than stratigraphically controlled, as these two ichnogenera occur at the bases and tops of all carbonate–dominated units within the Chase Group. Overall, ichnotaxonomic diversity is low with rare to common occurrences of the ichnogenera *Chondrites, Diplocraterion, Arenicolites, Teichichnus, Planolites, Conichnus,* and *Skolithos*. High densities of *Thalassinoides* and *Rhizocorallium* occur at the bases and tops, respectively, of each of the carbonate units in each depositional couplet (Fig. 27). The trace makers exploited a peculiar environment transitional between marginal marine and terrestrial clastic–dominated and marine carbonate–dominated depositional settings.

Major characteristics of the two abundant ichnogenera *Thalassinoides* and *Rhizocorallium* are listed in Tables 12 and 13.

ICHNOFACIES

Introduction

Ichnofacies are basically sedimentary facies defined on the basis of trace fossils. An ichnofacies is an association of trace fossils that is recurrent in time and space, and that directly reflects adaptations of trace-making organisms to environmental conditions such as substrate consistency, food supply, temperature, salinity, water turbidity, sedimentation rate, oxygen availability and hydrodynamic energy, among others. Nine recurring ichnofacies have been recognized and named for a representative ichnogenus. The recognition of each of these basic ichnofacies groupings is of great utility to sedimentologists as an aid to paleoenvironmental interpretations.

Some important principles to bear in mind when conducting ichnofacies studies include:

1. The composition, diversity, and distribution of ichnogenera comprising various ichnofacies is a function of geologic time.
2. No ichnofacies occurs exclusively within one depositional setting or facies.
3. Individual ichnotaxa and broader morphological grouping may also be encountered in more than one ichnofacies.
4. Ichnofacies determining parameters may not necessarily be present in all environments.
5. Ichnofacies are mainly dependent on the preservation potential of certain diagnostic traces.
6. None of the traces shown in Figure 28 are restricted uniquely to the *Glossifungites* ichnofacies—individual occurrences may vary in diversity, but the overall association is dominated everywhere by such combinations of firm–substrate traces.
7. Ichnofacies may overlap in their geographic distribution and ichnogenera composition.

The trace–fossil assemblage in the Chase Group is characteristic of the *Glossifungites* ichnofacies (Fig. 28). Trace fossils characteristic of the *Glossifungites* ichnofacies in the Chase Group are shown in Figure 29. The Chase Group trace–fossil assemblage is dominated by extensive, branching, horizontal networks of *Thalassinoides* and horizontal forms of *Rhizocorallium* in association with *Arenicolites, Teichichnus, Chondrites, Diplocraterion,* and *Planolites*.

The *Glossifungites* ichnofacies in the Chase Group is an important stratigraphic marker for recognizing transgressive–regressive surfaces. Colonization of substrates between carbonate–dominated and clastic–dominated facies in the Chase Group by opportunistic marine organisms apparently occurred during transgressive events, so the surfaces generally correspond to lowstand (regressive) erosion and highstand (transgressive) erosion (Fig. 27). Lowstand (emergent) conditions at the culmination of a major transgressive event and onset of a major regressive event may exhume the substrate, but marine conditions allowing colonization do not occur until the following transgressive event. Consequently, substrates containing the *Glossifungites* ichnofacies ordinarily were palimpsest (deposited in one environment and subsequently altered in another) and have relief fea-

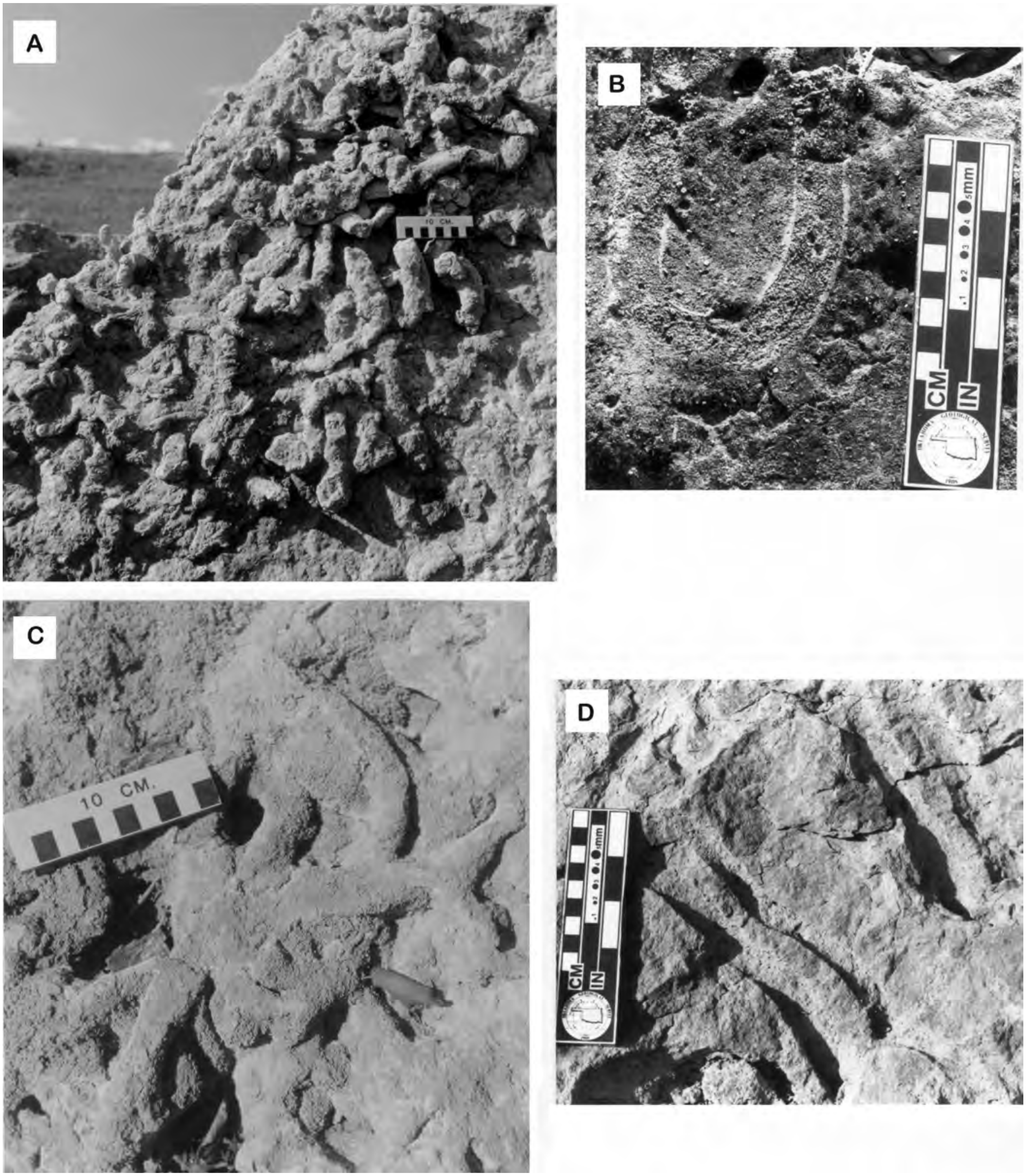


Figure 25. Trace fossils *Thalassinoides* isp. and *Rhizocorallium* isp. in the Chase Group. [A] Massive clustering of Y–shaped burrow systems of *Thalassinoides* isp. preserved as convex hyporeliefs on sole of storm bed. Winfield Limestone, Kay County. [B] U–shaped burrow of *Rhizocorallium* isp. showing two parallel tubes preserved as epirelief on bedding–plane surface. Note burrow halo around tubes. Nolans Limestone (Herington Limestone Member), Kay County. [C] Distinctive Y–shaped burrow system of *Thalassinoides* isp. preserved as positive hyporeliefs on sole of Wreford Limestone, Kay County. [D] U–shaped burrows of *Rhizocorallium* isp. preserved as negative epireliefs on bedding–plane surface. Barneston Limestone, Kay County.

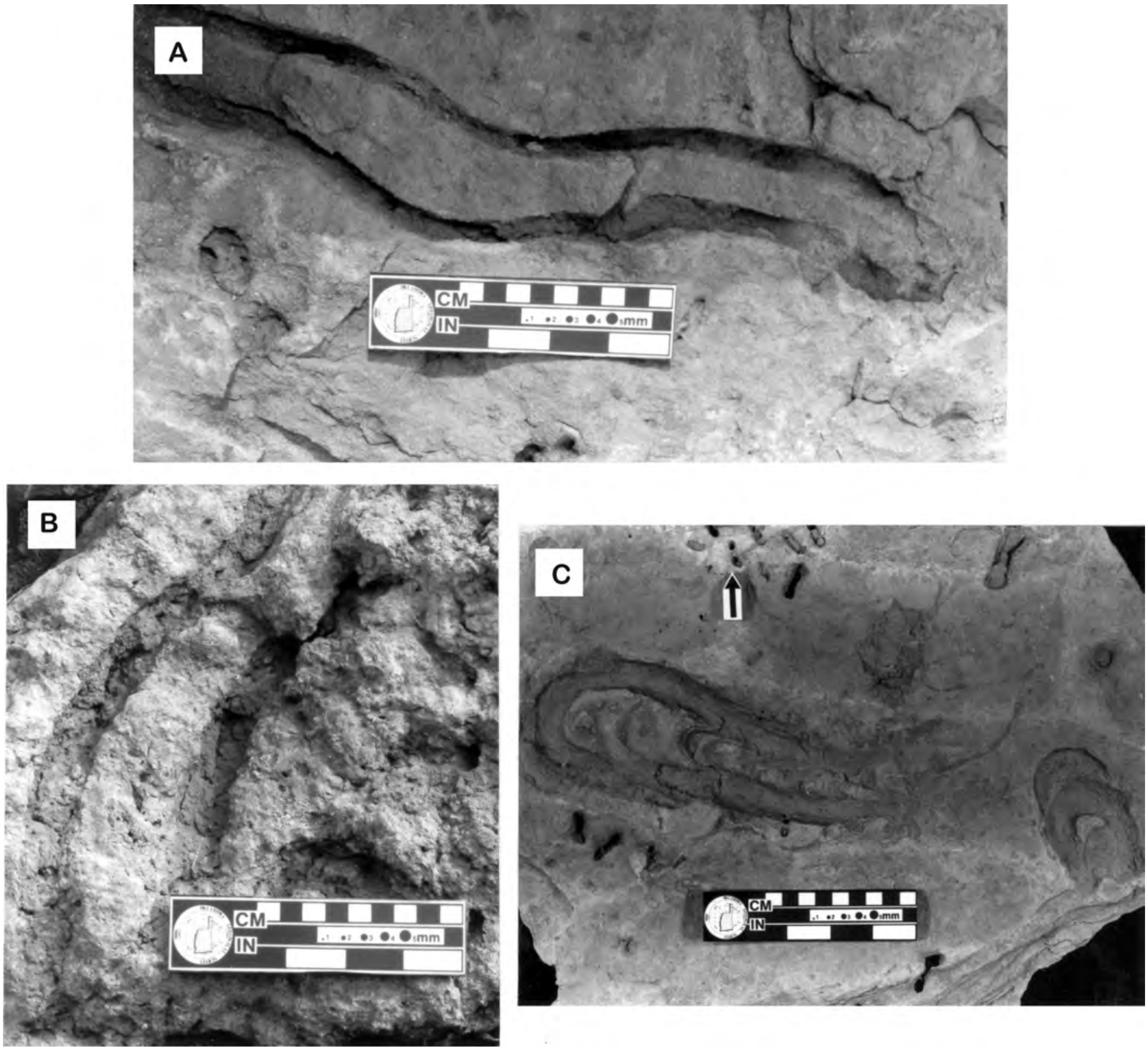


Figure 26. Trace fossil *Rhizocorallium* isp. in the Chase Group. [A] Long, horizontal form interpreted as both a dwelling structure of a suspension–feeding animal and a feeding structure of a deposit feeder. Probably produced by a crustacean. Top of bed in Towanda Limestone Member, Stop 5, Kay County. [B] *Rhizocorallium* preserved as epirelief on bedding–plane surface. Note color contrast between burrow fill and host rock. Wreford Limestone, Kay County. [C] Horizontal forms of *Rhizocorallium* isp. preserved on top surface of transgressive marine carbonate (Towanda Limestone Member). Note curved sheaths (spreiten) between U–tubes. Note paired aperture openings (above arrow) of the vertical U–tubes of the trace fossil *Diplocraterion* isp., Stop 5, Kay County.

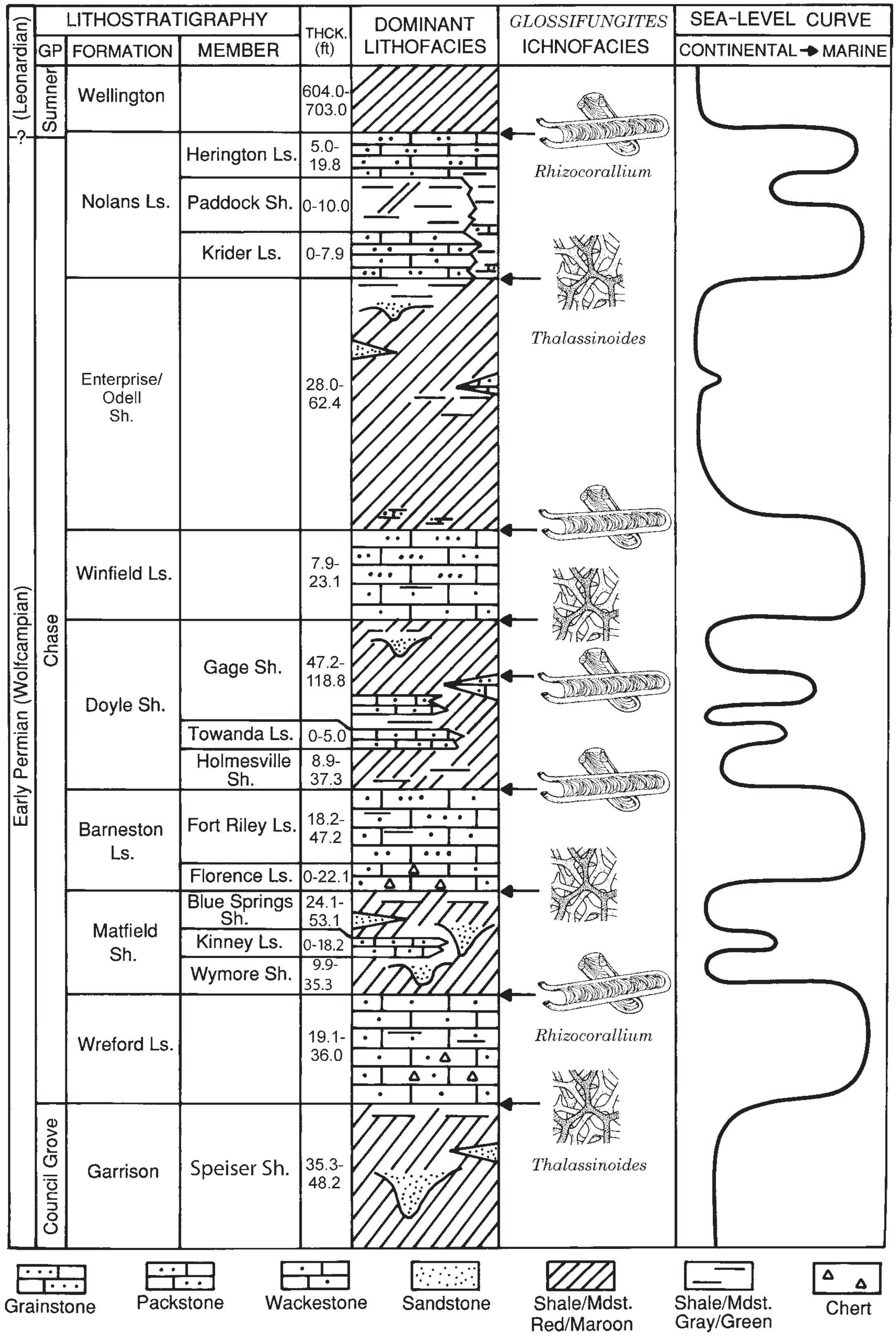


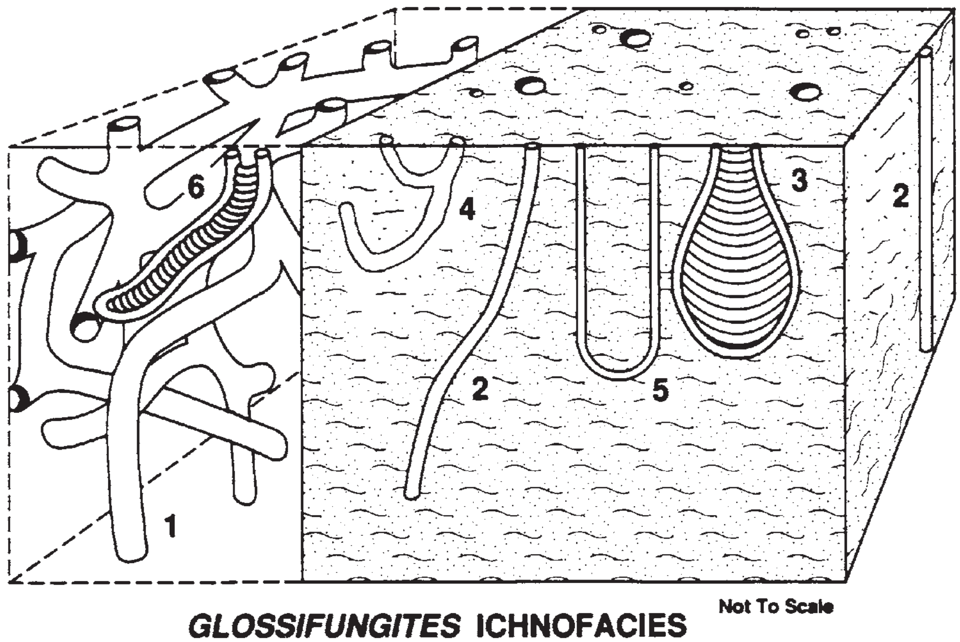
Figure 27. Stratigraphic column for the Chase Group showing thicknesses, dominant lithofacies, sea–level curve, and *Glossifungites* ichnofacies dominated by *Thalassinoides* at the base of each transgressive carbonate and *Rhizocorallium* at the top of each transgressive carbonate marking the onset of a major regressive event.

Table 12. Major characteristics of the trace fossil *Thalassinoides*

• Maze of deep, horizontal, typically Y–shaped branching burrows (Fig. 25C) • Form interfacially as excavations into marginal–marine and terrestrial mudstones below the base of casting marine carbonate • Burrow networks are intimately interwoven, but do not interconnect (Fig. 25C) • Burrow systems, when broken open, appear as distinctive, armored mud– and bioclast–filled burrows • Unlined burrow systems composed of regularly branching Y– or T–shaped bifurcations connected to the surface by vertical shafts • Recognized in core as oval to circular Y–branching burrows, usually greater than 0.4 in. in diameter • By analogy with certain modern mud shrimp, particularly *Callianassa* and *Upogebia*, *Thalassinoides* is usually interpreted as the activity of deep–burrowing, deposit–feeding decapod crustaceans • Records conditions at times of erosional exhumation associated with marine flooding that produced discontinuity surfaces that correspond to boundaries of stratigraphic significance	• Burrows commonly penetrate into underlying clastic facies (evidence of their marine origin) • Associated with regionally extensive interformational omission surfaces (i.e. discontinuity surfaces produced by halts in sedimentation) • Systems may have provided permeable pathways for the introduction of marine fluids, which became strongly reducing after burial Perhaps explains, at least in part, the ubiquitous occurrence of a greenish–gray mudstone interval immediately below each of the basal transgressive carbonate units • Occurrence is controlled primarily by substrate cohesiveness; associated with firmgrounds • Burrows originally were open domiciles, not merely feeding traces of an infaunal burrower, as suggested by burrow fill from overlying beds associated with a storm event that selectively pumped coarser skeletal grains into the burrow networks • Because it occurs in a broad bathymetric range, *Thalassinoides* is not a reliable indicator of water depth • Most common in low– to moderate–energy marine settings

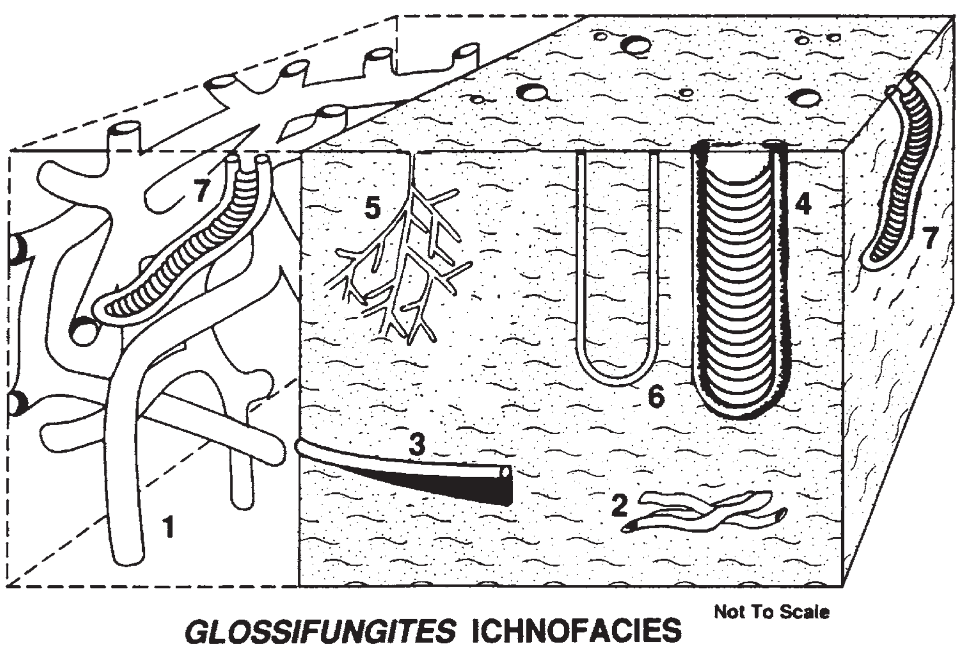
Table 13. Major characteristics of the trace fossil *Rhizocorallium*

• Horizontal forms are cast on the top surface of the highest (last) carbonate bed in each depositional couplet (Fig. 27) • Preserved on the upper surface of the marine carbonate, but it is formed interfacially below the overlying regressive, clastic–dominated facies • Burrow consists of two U–shaped parallel to subparallel tubes separated by an intervening zone of irregular, protrusive spreiten (Fig. 26C) • Relatively cohesive sediment is suggested by the lack of burrow linings and by the excellent preservation of horizontal spreiten • Commonly associated with vertical, U–shaped tubes assigned to the ichnogenus *Diplocraterion* (Fig. 26C) • Horizontal forms have been interpreted as deposit feeding or mining traces because the burrows usually are confined below bedding planes of one or two sedimentation units	• Trace makers life habit may have been similar to the behavior of some recent callianassid crustaceans that deposit feed during burrow construction and suspension feed after burrow completion • Identify brief sea–level stillstands at the terminations of transgressive events and the onsets of major regressive events (Fig. 27) • Associated with regressive, above–wave–base events during which halts in sedimentation produced discontinuity surfaces (omission surfaces) that were colonized by *Rhizocorallium* • Trace produced by a shallow–tier, burrowing deposit feeder that burrowed to depths of 0.4–1 in. • Casts of *Rhizocorallium* burrows indicate only minor erosional events



1. *Thalassinoides* 4. *Psilonichnus*
2. *Skolithos* 5. *Arenicolites*
3. *Diplocraterion* 6. *Rhizocorallium*

Figure 28. Schematic representation of trace fossils characteristic of the *Glossifungites* ichnofacies. Modified from Pemberton (1992).



1. *Thalassinoides* 5. *Chondrites*
2. *Planolites* 6. *Arenicolites*
3. *Teichichnus* 7. *Rhizocorallium*
4. *Diplocraterion*

Figure 29. Schematic representation of trace fossils characteristic of the *Glossifungites* ichnofacies in the Chase Group (Chaplin, 1996).

tures indicative of conditions prior to semiconsolidation of sediments (Pemberton, et al., 1992).

When paleosols form in coastal marine settings, marine transgression and establishment of nearshore environments not only cause erosion of upper parts of the paleosols, but may also result in the colonization and bioturbation of the paleosols by a firmground (firm substrate) marine infaunal community represented by the *Glossifungites* ichnofacies.

Some major characteristics of the *Glossifungites* ichnofacies are listed in Table 14.

Economic Aspect

Trace fossils that make up the *Glossifungites* ichnofacies can enhance the permeability and vertical transmissivity of a relatively impermeable matrix. Permeability enhancement develops when burrows into a firmground are filled with sediment from the overlying strata. If the lithology contrasts with the encapsulating firmground substrate, anisotropic porosity and permeability are developed.

RESERVOIR CHARACTERIZATION OF THE CHASE GROUP IN PART OF THE HUGOTON FIELD IN KANSAS AND OKLAHOMA

Some parts of this section are from an excellent M.S. thesis by Richard C. Stever, completed at the University of Oklahoma in 1987.

The giant Hugoton Gas Field in southwestern Kansas, northwestern Oklahoma, and north–central Texas is the largest natural gas field in North America and the second largest in the world with cumulative production over 23 trillion cubic feet (Tcf). The field was discovered in the Texas Panhandle in 1918 and subsequently extended northward. Kansas Hugoton is part of a continuous productive area that includes Guymon Hugoton in the Oklahoma Panhandle and the Panhandle field in Texas. Most hydrocarbon production within this extensive area (4,142 mi^2) is from the Lower Permian Chase Group. The average gross thickness of the Chase Group ranges from ~250–335 ft. Productive intervals lie between 2,050 and 2,920 ft drilled depth.

Table 14. Some characteristics of the *Glossifungites* ichnofacies

- Recognized as a transient phase of benthic community succession as an omission surface passes from softground through firmground to a hardground consistency
- Substrate-controlled assemblage of trace fossils
- Develops only in firm, unlithified substrate
- Characterized by sharp-walled, unlined passively filled, vertical to subvertical dwelling traces excavated into firmground substrates (MacEachern et al., 1991, 1992)
- Most traces are passively infilled with sediment, different from the surrounding matrix, that was piped down from the overlying bed
- Low in diversity but high in individual burrow density; often dominated by a single ichnogenus
- Environmentally wide ranging
- Burrow excavations predominantly occur under marine to marginal–marine conditions
- Ichnofacies identifies erosional discontinuities produced during depositional hiatuses that occurred after transgressive and/or regressive erosional events

The subsurface stratigraphic framework for the Chase Group in the Hugoton Field consists of the:

- Nolans Limestone
  - Herington Limestone Member—17 ft average thickness;
  - Paddock Shale Member—12 ft;
  - Krider Limestone Member (“upper” Krider—32 ft) and (“lower” Krider—40 ft);
- Odell Shale—13 ft
- Winfield Limestone—34 ft
- Doyle Shale
  - Gage Shale Member—25 ft;
  - Towanda Limestone Member—44 ft;
  - Holmesville Shale Member—12 ft;
- Barneston Limestone
  - Fort Riley Member—52 ft;
  - Oketo Shale Member—10 ft;
  - Florence Member—7 ft;
- Matfield Shale—20 ft;
- Wreford Limestone—22 ft.

Data from cored wells in the Oklahoma and Kansas parts of the Hugoton Field indicate that ~73 percent of the Chase Group lithofacies is composed of carbonates and ~27 percent is composed of siliciclastics, a pronounced asymmetry to the depositional cycles.

The most important gas reservoirs in the Hugoton Field are in the Nolans Limestone (“lower” Krider), Towanda Limestone (Doyle Shale), and the Winfield Limestone. Secondary gas reservoirs include the Fort Riley and Wreford Limestones and thin zones in the Nolans Limestone (Herington and “upper” Krider Limestones). The gas is stratigraphically trapped in porous shallow–marine carbonates (e.g., Krider and Towanda Limestones) sealed updip by laterally equivalent, impermeable clastic redbeds and/or by grain–size changes (e.g., Winfield Limestone).

The Chase Group consists of interbedded shallow–marine subtidal carbonates and intertidal to supratidal clastic–rich lithofacies. These lithofacies were deposited on, and adjacent to, a broad carbonate shelf in a shallow Early Permian epeiric sea. Depositional facies consist predominantly of bedded anhydrite, silty dolomudstones and siltstones, calcareous to dolomitic skeletal carbonates, and oolitic grainstones. The vertical succession of facies, as in the outcrop belt, reflects distinct upward–shallowing cycles which are cyclic in nature. These cycles may vary from the idealized Chase cycle and be incomplete due primarily to facies omission or repetition (Fig. 21).

Reservoir–prone facies occur largely within the marine carbonate facies. The siliciclastic facies are barriers/seals and do not constitute flow units.

The most prolific reservoir units are associated with: 1) dolomitized skeletal packstones to grainstones; 2) skeletal lime packstones to grainstones; 3) oolitic lime grainstones; 4) skeletal wackestones that have been intensely dolomitized and extensively dissolved; and 5) spiculitic wackestones to packstones. All of these prolific reservoirs have in common a relatively high ratio of grains to matrix (reflective of high depositional energy) that result in high depositional porosity, as well as overall coarse grain size associated with the subtidal facies. By contrast, the relatively poor reservoirs belong to those facies characterized by mud–rich matrixes, higher siliciclastic content, and finer grain size. These sediments stratigraphically delimit the reservoirs and effectively form as barriers to vertical hydrocarbon flow.

Chase Group carbonates have undergone extensive and complex diagenesis with each stage partially obscuring those preceding it. Important diagenetic events include calcite cementation, dolomitization, pervasive anhydrite emplacement, silicification, and major leaching (dissolution) related to the repetitive cycles. Both lateral and vertical facies distribution, cyclic deposits, and diagenetic alteration have collectively combined to selectively enhance or degrade reservoir qualities in Chase rocks.

Porosity/Permeability Development

Whereas production in the Hugoton Field is commonly associated with structural anomalies, porosity development appears to be strongly influenced by depositional setting and facies.

Overall porosity and permeability development within the Chase Group succession are variable but can be excellent. The much higher porosity and permeability found in most subtidal sediments, as well as the presence of abundant carbonate grains, resulted in the formation of textures not seen in the finer, more clastic–rich peritidal sediments.

Primary porosity that includes interparticle, intraparticle, and shelter pores is of minor importance in comparison to secondary porosity. Primary porosity is occasionally preserved within skeletal grains, especially fusulinids. Such pores, however, do not form a well–connected pore network.

Porosity in the Chase Group reservoirs is essentially all secondary, typically related to dolomitization and dissolution of carbonate grains, matrix cement, and bioclasts in the grain–rich facies. Locally, carbonate buildup complexes built to sea level and underwent periodic subaerial exposure and diagenesis which leached unstable carbonate mineralogies creating major amounts of secondary porosity in rocks of excellent reservoir potential. The highest porosities (>10 percent) are found in the upward–shoaling, bioclast–rich ooid skeletal grainstones where grains were dissolved to generate abundant moldic pores. Dolomitization and leaching of skeletal and matrix components produced extensive solution–modified channel, fracture and vuggy porosity with various fabric features such as breccia clasts, breccia pockets with internal vadose red silt/clay ("terra–rossa") and porosity–occluding anhydrite/gypsum cement.

The Wreford Limestone and the lower part of the Fort Riley Limestone Member are largely undolomitized. This is probably related, at least in part, to the primarily mud–rich textures of the Fort Riley and to its much greater thickness than other carbonate units in the Chase Group.

Interparticle porosity is present only in rare grainstones that occur near the tops of some cycles but are not continuous between wells. The creation of interparticle and moldic porosity occurs where skeletal as well as non–skeletal grains, are partially, completely or selectively leached.

Some zones develop abundant intercrystalline porosity, which is very fine but often well connected, from changes in crystal shape and volume associated with dolomitization.

Porosity in the skeletal wackestone and packstone facies was formed primarily by the dissolution of mollusks, bryozoans and fusulinids, and micrite and microspar matrix following dolomitization. Locally, replacement of the carbonate matrix by medium– to coarsely–crystalline dolomite was moderate to extensive resulting in rock with excellent reservoir potential.

A variety of karstic features, such as vugs and solution channels/pits, are common in the carbonates. These features are particularly well displayed in core slabs. Some of these dissolution features are filled with infiltrated red sediment and generally exhibit porosities of <10 percent.

The low porosity and permeability of the sabkha and carbonate tidal–flat facies may form both lateral updip and overlying seals above the shallow carbonate–ramp deposits in the subsurface Chase Group. However, locally mudstones may be far more volumetrically important as seals.

Local leaching of silica may create well–developed microporosity within silicified burrow systems of *Thalassinoides*.

The volume of porosity resulting from fractures is comparatively small; however, fractures serve to improve connectivity between other types of pores.

Locally, all pore types may be occluded by a combination of calcite spar, chert, and/or anhydrite/gypsum cements.

Dolomitization of coarse–grained carbonate lithologies (i.e., packstones/grainstones) served as high–per meability pathways from early in the history of the reservoirs. Those packstones/grainstones that did not undergo dolomitization served as high–permeability pathways through shallow burial until being degraded by burial–induced chemical compaction and associated calcite cementation. The natural susceptibility of carbonates to chemical compaction contributed largely to permeability loss, especially where large admixtures of siliciclastics were present.

Leaching, by either meteoric or shallow–burial marine–like fluids, helped shape the current distribution of reservoir rocks by creating abundant moldic and secondary microporosity. The most prevalent type of cement in dolomitic intervals is anhydrite. Anhydrite is pervasive in the rocks of the Chase Group where it occurs as nodular, massive, and mosaic fabrics. Anhydrite is a diagenetic product of primary gypsum. In both recent and ancient examples, anhydrite deposition is closely associated with tidal flats (intertidal and supratidal zones), playa basins, and strongly restricted marine basins.

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I am indepted to my wife, Barbara, who assisted in much of the field work to produce this guidebook. I also would like to thank Jim Anderson, OGS Manager of Cartography, for his professional technical assistance in the final preparation of illustrations for this guidebook; Ms. Betty Bellis for her word–processing skills; and Susan Houck, Designer & Editor, Owner of Crescent Moon Designs, for her professional design, layout and editing of this publication.

Finally, I very much appreciate the careful review and constructive comments of OGS geologist, Dr. Neil Suneson.

CHASE FIELD TRIP STOPS 1—11 DAY TWO

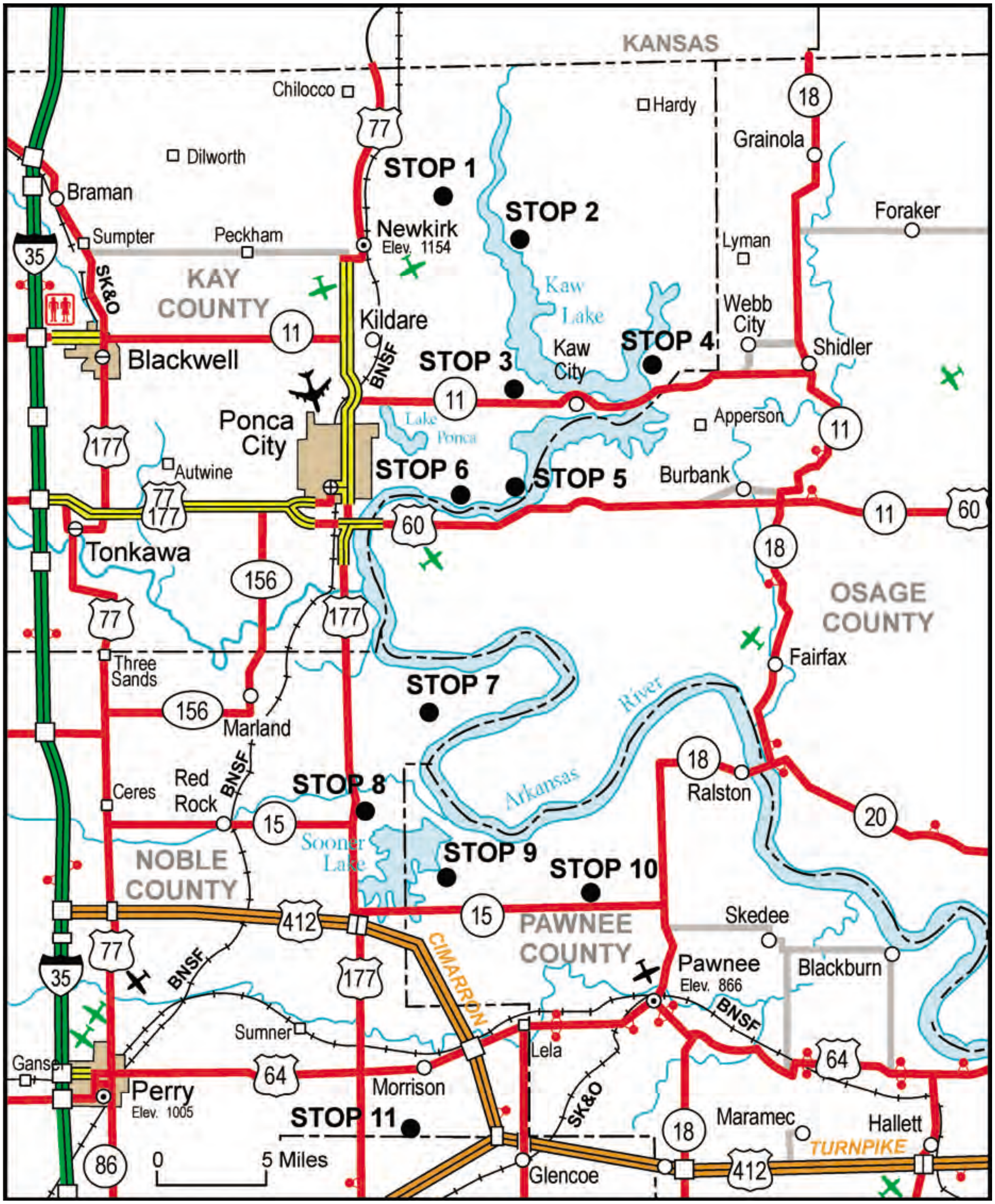

Figure 30. General index map showing locations of stops for Chase Group Field Trip—Day Two.

STOP 1

NEWKIRK OIL FIELD SECTION K–23

Location

SE¼NW¼SE¼ sec. 8, T. 28 N., R. 3 E., and NE¼NE¼ NW¼NE¼ sec. 17, T. 28 N., R. 3 E., Newkirk 7.5' Quadrangle, Kay County. Measured section begins in gullied pasture northwest of section road, and north of pump jack and oil–storage tank, and traverses south to outcrops along south side of section road. Elevation at the base of the Herington Limestone Member—1,175 ft.

Introduction

At this stop, we will walk through and examine ~50 ft of stratigraphic section comprising the Herington Limestone, Enterprise/Odell Shale (with the Luta Limestone Member), the Winfield Limestone, and the Doyle Shale (Fig. 31).

Stratigraphic Significance

- Example of the repetitive carbonate/siliciclastic depositional couplets that characterize the Chase Group (Herington Limestone–Enterprise/Odell Shale; Winfield Limestone–Doyle Shale (Fig. 31).
- Overall thickness from the Nolans Limestone to the Winfield interval is reduced about one–half, from ~100 ft in the Kansas outcrop belt to ~50 ft at this stop.
- Stratigraphic subdivisions (members) of the Nolans Limestone and Winfield Limestone are difficult to recognize.
- The Luta Limestone Member is assigned to the Enterprise/Odell Shale in northern Oklahoma.
- Discontinuity surface (sequence boundary) between a transgressive carbonate unit above (Herington Limestone) and a regressive clastic unit below (Enterprise/Odell Shale).

Nolans Limestone

<u>Herington Limestone Member</u>

- Is the Kansas Krider Limestone Member equivalent to the Oklahoma Herington Limestone Member?
- Excellent outcrop of typical Herington coated–grain (algal–foram) skeletal wackestones to grainstones.
- Interbedded shaly limestone/calcareous shales contain abundant brachiopods (*Composita, Derbyia*) and small, algal–coated stick bryozoans.
- Basal bed of the Herington is a distinctive “shell bed” composed chiefly of the bivalves *Myalina* and *Aviculopecten*; upper surface is covered with “algal biscuits.”
- Upper beds contain solution–enlarged molds of the burrowing infaunal bivalves (e.g., *Pinna*, *Wilkingia*).
- Soles of beds covered with horizontal feeding and locomotion trails.
- Base represents a transgressive surface formed during the initial marine–flooding event of a relative sea–level rise.

Enterprise/Odell Shale

- Poorly exposed interval, but composed of red to reddish–brown variegated blocky silty mudstones/shales.
- Contains some thin beds of “boxwork” limestone and pisoliths.
- Rare lenses of grayish–white, nodular algal limestones that weather chalky.
- Uppermost part consists of laminated (“varve–like”) calcareous shale.
- Typical greenish–gray Odell shales/siltstones suggest deposition in a marginal–marine setting, whereas the change to typical Enterprise red mudstones/shales suggests a facies shift to terrestrial/fluvial sedimentation.
- Represents the regressive facies of marginal–marine to terrestrial sedimentation.

<u>Luta Limestone Member</u>

- Composed of a diversity of lithofacies ranging from coated–grain, gastropodal–encrusting foram wackestones, peloidal packstones and grainstones to calcareous, greenish–gray mottled grayish–red mudstones/shales.

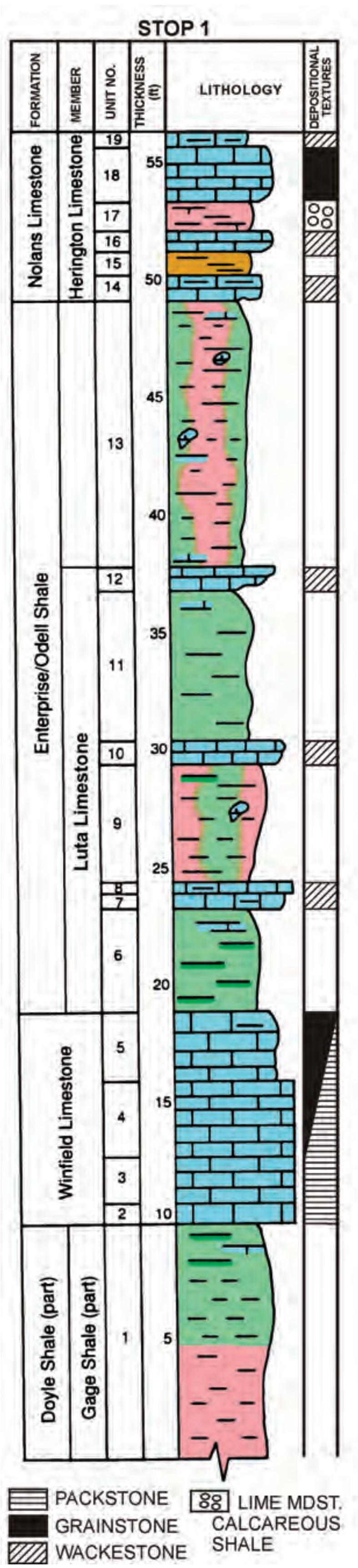

Figure 31. Stop 1. Newkirk Oil Field Section K–23

Newkirk Oil Field Section K–23

Chase Group (part)

Nolans Limestone (7.5 ft)

Herington Limestone Member (7.5 ft)	Thickness (ft)
19. Limestone (skeletal wackestone), very–pale–orange to grayish–orange, algal, shaly, vuggy, very thin–bedded; contains scattered fenestrate bryozoans and crinoid columnals; badly weathered.	0.5
18. Limestone (coated–grain skeletal grainstone), grayish–orange, algal, shaly, medium–bedded, vuggy, highly pitted; weathered surfaces chalky; some vertical cavities ~10 in. from the top, represent solution–enlarged molds of the mytiloid bivalve, *Pinna*, and the pholad bivalve, *Wilkingia*, burrows; other fossils include *Composita*, fenestrate bryozoans, and crinoids columnals; sole of bed with horizontal feeding and locomotion trails.	2.4
17. Shale, moderate–reddish–orange, very calcareous, badly weathered with very thin lenses and nodules of white, algal, nodular limestone, weathering chalky; contains iron–stained osagid grains, *Composita*, echinoid spines/plates, and fenestrate and trepostome bryozoans; algal–coated horizontal burrows and fossil fragments common; forms recess.	1.5
16. Limestone (coated–grain skeletal wackestone), yellowish–gray, algal, crinoidal; contains abundant shell debris (*Derbyia* and *Myalina*), trepostome and fenestrate bryozoans, echinoid spines/plates; rare *Pinna*; abundant *Composita* near base; very resistant bed; thickness varies laterally.	0.8–1.3
15. Shale, light–brownish–gray, calcareous, badly weathered; upper 4 in. packed with *Composita*; contains small, white "cauliflower"–shaped nodules; some shell debris of *Myalina*; forms slight recess; thickness varies laterally.	0.9–1.2
14. Limestone (coated–grain skeletal wackestone), medium–light–gray, shaly, algal; skeletal material ("shell bed") includes *Derbyia*, *Myalina*, *Aviculopecten*, *Composita*, *Edmondia*, and fenestrate bryozoans; some *Myalina* are articulated and mud–filled; upper 6 in. is flaggy–bedded and composed of very shaly limestone and calcareous shale containing very abundant weathered–out "algal biscuits" and algal–coated shells (*Myalina*, *Edmondia*, *Aviculopecten*, and *Derbyia*).	1.4

Unit	Thickness (ft)
Enterprise/Odell Shale (31.0 ft)	
13. Mudstone/shale, variegated, greenish–gray to grayish–red, blocky, locally calcareous; contains lenses of white, nodular, algal limestone that weathers chalky; dark–reddish–brown mudstone at base; uppermost part consists of laminated (varve–like) calcareous shale; interval partly covered.	11.5
Luta Limestone Member (19.5 ft)	
12. Limestone (peloidal wackestone), yellowish–gray, silty, well–sorted, laminated; top covered with Y–shaped horizontal burrows filled with skeletal debris; some soles with load casts and rare convolute bedding; trace fossil *Chondrites* common on some slabs; distinct dark–yellowish–orange iron–staining.	0.8
11. Shale, greenish–gray, calcareous in some places; includes some very thin layers of well–sorted sandstone and siltstone; poorly exposed unit.	6.5
10. Limestone (gastropodal–encrusting foram wackestone), light–gray, dense, distinctly jointed; fossils include high–spired gastropods (most abundant), *Myalina*, and rare *Pseudorthoceras*; sparry calcite–filled gastropod whorls common; trace fossils include *Rhizocorallium* and surface trails that criss–cross to form a V–shaped pattern (probably gastropod feeding/locomotion trails).	1.0
9. Shale/mudstone, greenish–gray mottled grayish–red, calcareous; contains scattered white, “cauliflower”–shaped, calcareous nodules; includes some fine, well–sorted siltstone laminae.	5.0
8. Limestone (coated–grain skeletal wackestone), light–gray, shaly, coquinite; jointed and nodular; contains silicified *Derbyia*, some *Myalina*, *Pinna*, *Wilkingia*, *Edmondia*, small low–spired gastropods, crinoid debris, bryozoans, and echinoid spines; upper part of unit is shaly with abundant compacted and distorted, weathered–out *Composita*; trace fossils dominated by horizontal, striated burrows with overlapping trails producing distinct V–shaped patterns (probably feeding and/or locomotion trails of gastropods); single resistant ledge.	0.6
7. Limestone (skeletal wackestone), medium–gray, bioturbated, shaly; skeletal fragments include abundant crinoid columnals, *Derbyia*, *Composita*, *Pinna*, and fenestrate bryozoans; some large “armored” burrows.	0.6
6. Shale, yellowish–gray to greenish–gray, calcareous; contains white, soft calcareous nodules.	5.0
Winfield Limestone (8.9 ft)	
5. Limestone (coated–grain skeletal grainstone to packstone), yellowish–gray, algal (osagid grains), flaggy bedding; shale partings separate unit into beds ~2–6 in. thick; fossils include crinoidal debris, echinoid spines/plates, coated–grains, and pockets of *Crurithyris*.	3.0
4. Limestone (skeletal grainstone to packstone), light–gray, algal, solution–pitted outcrop surface; fossils include abundant echinoid spines/plates, and less common *Crurithyris* and trepostome bryozoans, concentrated in layers and pockets (storm deposits); less–common fossils include *Linoproductus*, *Pinna*, and fronds of fenestrate bryozoans.	3.1
3. Limestone (coated–grain skeletal packstone), yellowish–gray, algal; weathered surfaces strewn with echinoid and crinoidal debris and a few *Pinna*; contains distinct vertical burrows armored and filled with skeletal grains, some burrows extend 1 ft into underlying bed.	1.9
2. Limestone (coated–grain skeletal packstone), yellowish–gray, algal (osagid grains); contains abundant large *Myalina*, some *Derbyia*, *Aviculopecten*, *Pinna*, gastropods, abundant echinoid spines/plates and crinoid columnals, fronds of fenestrate bryozoans, and rare *Pseudorthoceras*; some vertical burrows from overlying bed extend into this unit; base of unit covered with large, ramifying, horizontal, branching (Y–shaped) networks of burrows (*Thalassinoides*); sharp, planar base.	0.9
Doyle Shale (part)	
Gale Shale Member (part)	
1. Shale/mudstone, greenish–gray in upper part to dark–reddish–brown below; silty, calcareous in some places; gullies easily; base not exposed.	10.0
TOTAL	57.4

Figure 31 (*Continued*)

- Contains a distinctive, hard, strongly jointed limestone bed (Fig. 32).
- Interbedded mudstones/shales contain white soft "cauliflower"–shaped calcareous nodules.
- Contains lenses of well–sorted sand and silt.
- Limestone surfaces covered with abundant horizontal, striated burrows that criss–cross or overlap to form a distinct V–shaped pattern (gastropod feeding and/or locomotion trails) (Fig. 33).
- Highly fossiliferous beds contains low– and high–spired gastropods, bivalves (*Myalina*, *Pinna*, *Wilkingia*, *Edmondia*), brachiopods (*Derbyia*, *Composita*), echinoderm debris, and fenestrate bryozoans.
- Trace fossils include *Rhizocorallium*, *Chondrites*, and "armored" burrows.
- Upper flaggy bedded limestone facies contains silicified brachiopods (*Crurithyris*).
- Luta is more lithologically diverse, thinner and interbedded with marginal–marine shales as compared to the Kansas section.
- Rare load casts, convolute bedding, and climbing–ripple laminations.

Winfield Limestone

- Consists chiefly of the massive Cresswell Limestone Member.
- Approximately one–half as thick as in Cowley County, Kansas.
- Composed principally of relatively high–energy echinodermal skeletal packstones to grainstones with algal–coated grains (osagid grains) and peloids (Fig. 34).
- Contains distinct pockets of coarse bioclasts consisting mainly of echinoid spines and plates, and large trepostome bryozoans (storm deposits) (Fig. 34).
- Base covered with a maze of large horizontal, branching, Y–shaped networks of *Thalassinoides* burrows, some filled with coarse bioclasts.
- Base consists of abundant small, circular to ovoid–shaped algal–coated grains, commonly referred to as osagid grains.
- U–shaped burrows (*Arenicolites*) are common in the upper part of the massive lower bed.
- Some vertical, pencil–shaped burrows (*Skolithos*) penetrate almost the entire thickness of a bed (Fig. 35).
- Rests conformably on red silty shales/mudstones of the underlying Doyle Shale (regressive facies composed of marginal–marine to terrestrial deposits).

Figure 32. Distinctive, hard, strongly jointed limestone bed in the Luta Limestone Member.

Figure 33. Outcrop surface of the Luta Limestone Member covered with horizontal, striated gastropod feeding burrows and/or locomotion trails that criss–cross or overlap to form a distinctive V–shaped pattern.

Figure 34. Fossil debris of shells of the bivalve *Myalina* and echinoid spines in the Winfield Limestone.

Figure 35. Abundant, vertical, pencil–shaped burrows of *Skolithos* forming distinctive "pipe rock" texture in Winfield Limestone.

STOP 2

VAP'S PASS SECTION K–11

Location

NW¼NW¼NE¼NW¼ sec. 25, T. 28 N., R. 3 E., and SE¼SW¼SE¼SW¼ sec. 24, T. 28 N., R. 3 E., Kaw City Northwest 7.5' Quadrangle, Kay County. Measured section begins on old roadbed of abandoned quarry south of present road and traverses east on shale slope uphill along present road. Elevation at the base of the Barneston Limestone—1,128 ft.

Introduction

We will walk through ~45 ft of the Barneston Limestone: ~35 ft of the Fort Riley Limestone Member and ~10 ft of the Florence Limestone Member.

Stratigraphic Significance

Excellent roadcut and outcrop exposures of the Fort Riley and Florence Limestone Members of the Barneston Limestone. Within the Barneston Limestone, there is an overall coarsening–upward stratigraphic progression from a more mud–rich and finer grained, cherty loosely packed lime mudstone/wackestone depositional texture at the base (Florence) to a more grain–rich coarse–grained, cleanly–washed and lightly packed packstone/grainstone texture upsection (Fort Riley) (Fig. 36).

Barneston Limestone

- The thickest, most complete, and most continuous exposure in northern Oklahoma.

Fort Riley Limestone Member

- Orthogonal fracture pattern intersects roadcut (south side) at a moderate angle, forms zones 1–2 ft wide resembling cleavage (Fig. 37).
- The nodular and wavy bedding style in the Fort Riley may be the result of the combined effects of bioturbation, differential compaction, and clay content of the facies (Fig. 38).
- Locally the trace fossils *Teichichnus*, *Planolites*, *Thalassinoides*, and *Rhizocorallium* can be identified in the shaly limestone facies.
- In detrital–rich zones, bioturbation imparts a swirled or mottled texture; whereas in the more carbonate–rich zones, bioturbation is represented by zones of generalized disruption.
- Medium– to thick–bedded, coated–grain, packstone–grainstone units (shallowest part of carbonate facies) characterize the lower and middle parts of the Fort Riley (Fig. 38).
- Common fossils include echinoderm hash, productid–type brachiopods and *Composita*, bivalves (*Myalina*), and fenestrate bryozoans.
- A long period of stable deposition and progradation is suggested by the thick upward–shallowing sequence in the Fort Riley Member.

Florence Limestone Member

- Low– to moderate–relief stylolites occur at the proposed Florence–Fort Riley contact (Fig. 39).
- Pressure solution (stylolite formation) may reduce residual porosity.
- Distinctive "cannonball" chert nodules (Fig. 39).
- Within the skeletal wackestones, silica is locally present as chert that partially replaces carbonate matrix within *Thalassinoides* burrow networks and as a replacement of bioclasts, especially brachiopods, and crinoids, outside of the burrows.
- Miller and Twiss (1994) attributed the morphology of chert nodules in the Florence Member in Kansas to silicification associated with the porous and permeable pathways provided by *Thalassinoides* bioturbation.
- This is the southernmost exposure of the Florence Limestone in northern Oklahoma that is chert–bearing.
- This is the only locality in northern Oklahoma where both members of the Barneston Limestone can be recognized.
- Basal beds of the Florence Limestone contain subspherical– to elliptical–shaped grains coated on all sides with encrusting cyanobacteria and encrusting foraminifera (osagid grains). Osagid grains commonly are the dominant allochems in the skeletal wackestones typically observed at the bases of limestone beds in the transgressive parts of the depositional cycles.
- Sole of Florence Limestone is covered with a maze of horizontal, ramifying, Y–shaped burrow systems of *Thalassinoides* (Fig. 39).

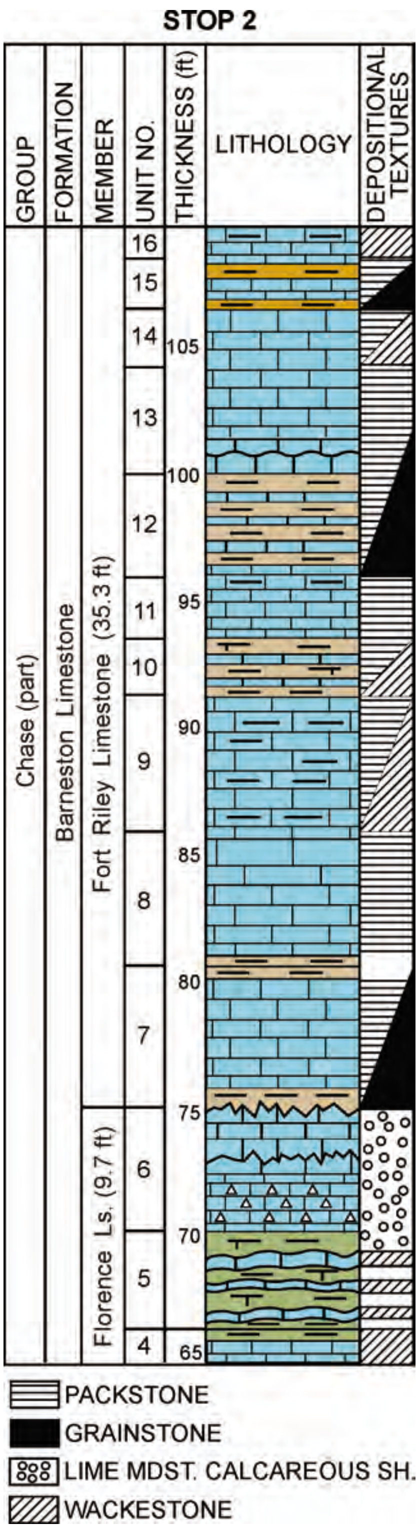

Figure 36. Stop 2. Vap's Pass Section K–11

Vap's Pass Section K–11

Chase Group (part)

Barneston Limestone (45 ft)

Fort Riley Limestone Member (35.3 ft)	Thickness (ft)
16. Limestone (skeletal wackestone), medium–light–gray, dense, crinoidal (coquinite); weathered surfaces very rough due to fossil fragments; fossiliferous, with the brachiopod, *Composita* and the bivalve, *Myalina*; sole with large horizontal burrow networks of *Thalassinoides* very resistant, forms rim–rock in roadcut.	1.2
15. Interbedded limestone and calcareous shale; limestone (packstone to grainstone), grayish–orange to light–olive–gray; shale, dark–yellowish–orange, badly weathered; fossiliferous with crinoid fragments, echinoid spines, and *Composita*; base gradational, top sharp; forms slight recess.	1.7
14. Limestone (skeletal wackestone to packstone), pale–yellowish–brown to moderate–yellowish–brown, highly crinoidal; algal; very rusty looking weathered surfaces; occurs in three 4– to 8–in. beds separated by very thin shale partings.	1.8
13. Limestone (packstone), grayish–orange to light–olive–gray, crinoidal, medium–bedded, rubbly in lower 1 ft; very fossiliferous with recrystallized bioclasts; some solution pits in upper part; horizontal curved burrow systems throughout, but especially well developed in lower 1 ft as endoreliefs; basal 1 ft consists of well–developed horizontal, curving burrow systems (some *Teichichnus*–like) and others more similar to *Thalassinoides* are covered and infilled with fossil fragments; vuggy in places; resistant bed; forms slight recess at base.	4.2
12. Interbedded limestone and calcareous shale; limestone (packstone to grainstone), yellowish–gray to grayish–orange, algal, crinoidal, silty; shale, grayish–orange, calcareous; very fossiliferous, especially at the top with fenestrate bryozoans, productid–type brachiopods, gastropods; rubbly–bedded, top and base irregular; forms slight recess.	4.0
11. Limestone (packstone), grayish–orange, algal, silty, iron stains; recrystallized crinoid fragments; weathers shaly at top; resistant.	2.6
10. Interbedded limestone and calcareous shale; limestone (skeletal wackestone to packstone), moderate–orange–pink, algal, crinoidal, thin– to rubbly–bedded, more shaly in middle; fossiliferous with abundant *Composita*; slight recess.	2.6

STOP 2 (Cont.)

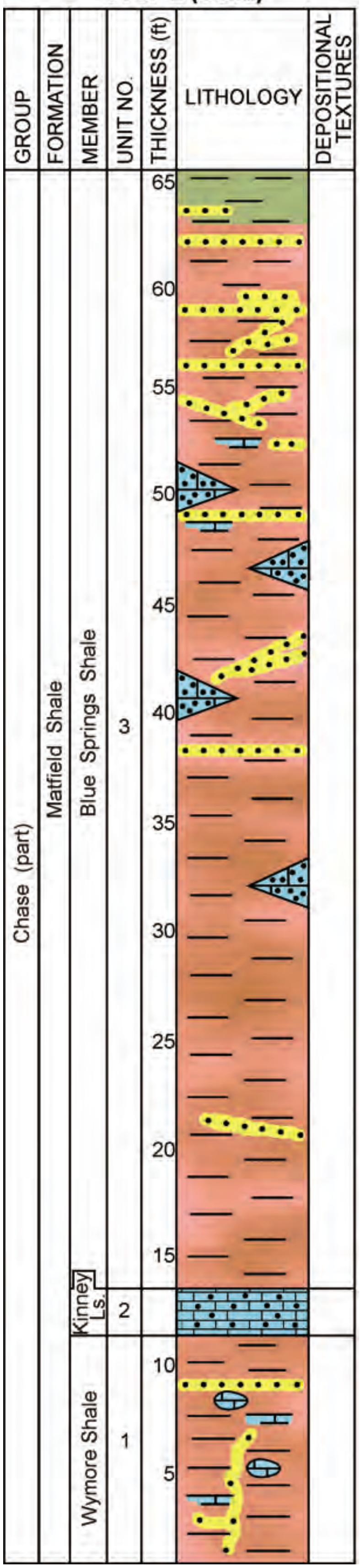

Figure 36 (*Continued*)

Thickness (ft)

9. Limestone (skeletal wackestone to packstone), yellowish–gray, algal, shaly, massive; surfaces pitted; contains medium–blue lenses of highly algal limestone (packstone to grainstone) with bituminous stringers; extensive flow deposits on outcrop surface in places; resistant. 5.7

8. Limestone (packstone), yellowish–gray to light–olive–gray, massive, limonite–weathered cavities; pitted; flow deposits on outcrop surface; very fossiliferous, especially in middle of unit with very abundant *Composita*, productid–type brachiopods, echinoid spines; very thin paleosol clay parting at base; gradational with unit 7; resistant. 5.8

7. Limestone (packstone to grainstone), light–gray to medium–light–gray, algal, medium– to thick–bedded; very fossiliferous, especially near base and in upper part; very abundant *Composita*, crinoid fragments; weathered surfaces rough due to fossil fragments; very thin bituminous shale seams at top and at base; resistant. 5.7

Florence Limestone Member (9.7 ft)

6. Limestone (lime mudstone), yellowish–gray to light–gray, shaly, iron stains, massive, stylolitic, chert–bearing, especially in lower 3 ft; distinctive "cannonball" chert nodules, commonly forming continuous layer; broken faces of nodules show concentric spherulitic growth of layers on tan to gray matrix; growth lines dark–blue, outer surfaces dark–tan to rusty–brown, chalky crust; nodules of irregular shapes (as much as 1.3 ft in greatest dimension) arranged in irregular bedded nature; stand out as brown knobs on weathered surfaces imbedded within dull–gray limestone groundmass; base and top gradational; in most places in direct contact (stylolitic) with overlying Fort Riley Limestone Member with no intervening shale interval. 4.8

5. Interbedded limestone/calcareous shale; limestone (skeletal wackestone) light–olive–gray to yellowish–gray, shaly, iron–stained, fossiliferous, especially brachiopods; thin–bedded and separated into beds by calcareous platy shale seams; very thin lenses of flowstone; shale, olive–gray to dark–greenish–gray, iron–stained, fossiliferous; unit nodular– to rubbly–bedded; base and top gradational. 3.6

4. Limestone (skeletal wackestone), yellowish–gray to light–gray, shaly, algal with elongated filaments and *Osagia*–coated fossil fragments; very fossiliferous with large *Derbyia* brachiopods; flow deposits on outcrop surface; sole with large networks of horizontal burrows covered and infilled with fossil fragments (*Thalassinoides*); very shaly at top; top gradational; resistant. 1.3

Matfield Shale (part)

	Thickness (ft)
Blue Springs Shale Member (53.5 ft)	
3. Mudstone/sandy shale/very thin bedded sandstone; mudstone/shale, moderate–reddish–brown to dark–reddish–brown, sandy, very dusky–red and dark–reddish–brown laminations; contains lenses of sandy limestone as in unit 2; upper part primarily shaly sandstone and sandstone in 1– to 4–in. beds; sandstone, moderate–reddish–brown to dark–reddish–brown, very fine grained, well–sorted, friable, cross–laminated; uppermost 2 ft consists of medium–light–gray to medium–gray mudstone with weathered, limonite–filled vugs; ostracodal; top sharp; forms distinct recess below thick carbonate section above.	39.5
Kinney Limestone Member (2.3 ft)	
2. Limestone (skeletal wackestone), grayish–red–purple to dark–reddish–brown, sandy, friable, vuggy, pitted; very thin to thin–bedded; appears to represent a subaerial exposure surface with desiccation features; underlain by a greenish–gray clay shale which is stained yellow; unit weathers to yellow–stained "cauliflower"–shaped nodular limestone zones; exposed in deeper gullies on shale slope south of road.	2.3
Wymore Shale Member (11.5 ft)	11.5
1. Shale/mudstone, pale–reddish–brown to dark–reddish–brown, slightly sandy, white calcitic stringers in upper part; thin greenish–gray shale lenses and stringers of fossiliferous limestone throughout; forms gullies on shale slope south of road; poorly exposed.	
TOTAL	98.3

Figure 36 (*Continued*)

Figure 37. Cross–sectional view of fracture Set II in the Fort Riley Limestone Member exposed in roadcut at Vap's Pass.

Figure 38. Massive beds of coated–grain packstone/grainstone facies (shallowest part of carbonate facies) overlain by nodular and wavy–bedded shaly packstone facies (intracycle deepening event) in the Fort Riley Limestone Member.

- The base of the Florence Limestone is marked by the *Glossifungites* ichnofacies—a substrate–controlled (firmground) assemblage of trace fossils; this ichnofacies identifies erosional discontinuities produced during depositional hiatuses that occurred after transgressive and/or regressive erosional events (omission surfaces).

Matfield Shale

<u>Blue Springs Shale Member</u> (*best exposed on gullied slope south of highway*)

- Contact with Florence Limestone Member above marks a discontinuity surface (sequence boundary) between clastic–dominated facies below and carbonate–dominated facies above (Fig. 40).
- Upper ~2 ft consists of greenish–gray marginal–marine mudstone; *Thalassinoides* burrows provided permeable pathways for the introduction of marine fluids which became reducing (green gleying) for the uppermost part of an otherwise red to reddish–brown mudstone succession containing variably developed paleosols locally.
- Marks regressive facies consisting of marginal–marine to terrestrial sedimentation.

Overall, primary sedimentary structures are mostly absent throughout the section possibly due to the combined effects of variable sedimentation rate, differential compaction, and bioturbation.

Figure 41 is a schematic diagram showing a cyclic sequence of carbonates within a depositional couplet of the Barneston Limestone along with lithofacies, depositional textures, diagnostic features, and a relative sea–level curve.

Fracture Pattern in the Fort Riley Limestone

(from Rizer and Queen, 1986)

An orthogonal fracture pattern is exposed in cross–section at the roadcut and in map view on the roadbed of the old quarry floor at Vap's Pass (Fig. 42). The fracture pattern consists of a systematic set (Set I) striking N. 70 E., to N. 85˚ E., and a non–systematic set (Set II) striking approximately N. 10 W., to N. 20 W. Fractures of Set II commonly terminate against those of Set 1. Both sets are essentially normal to bedding. On the quarry floor surface, both sets are clearly visible. No shear offset is observed on either facture set.

Further studies of these systematic fracture (joint) systems exposed at this stop need to address the relationship between joint density/spacing and carbonate rock properties (e.g., layer thickness, texture, porosity, facies variability, bioclast content, diagenesis, etc.) and scale.

Economic Importance

The economic importance of natural fracture systems, such as the system at Vap's Pass, is illustrated by the performance of enhanced oil–recovery operation at the North Burbank Field, located approximately 12 mi southeast of Vap's Pass (Fig. 43). The fracture system at depth in this Pennsylvanian clastic reservoir results in effective permeability five times greater in the east–west direction (subparallel to Set I) than in the north–south direction (Szpakiewicz, et al., 1986). The permeability anisotropy observed in the North Burbank Field suggests that the Set I fractures are more important permeability pathways than Set II in the subsurface.

Figure 39. Southernmost exposure of chert–bearing osagid–grain skeletal wackestone in the Florence Limestone Member. Osagid–grain–rich lithofacies are typically observed at the base of carbonate beds in the transgressive parts of Chase depositional cycles.

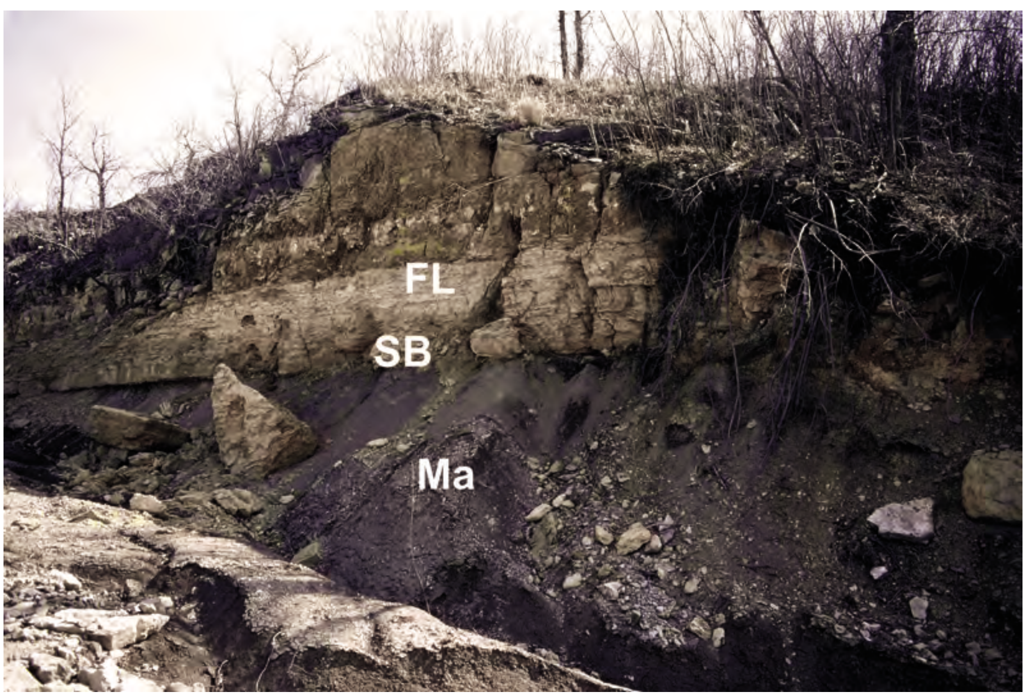

Figure 40. Sharp contact (sequence boundary [SB]) between regressive clastic facies (Matfield Shale [Ma]–Blue Springs Shale) and overlying transgressive cherty carbonate facies (Barneston Limestone–Florence Limestone Member [FL]).

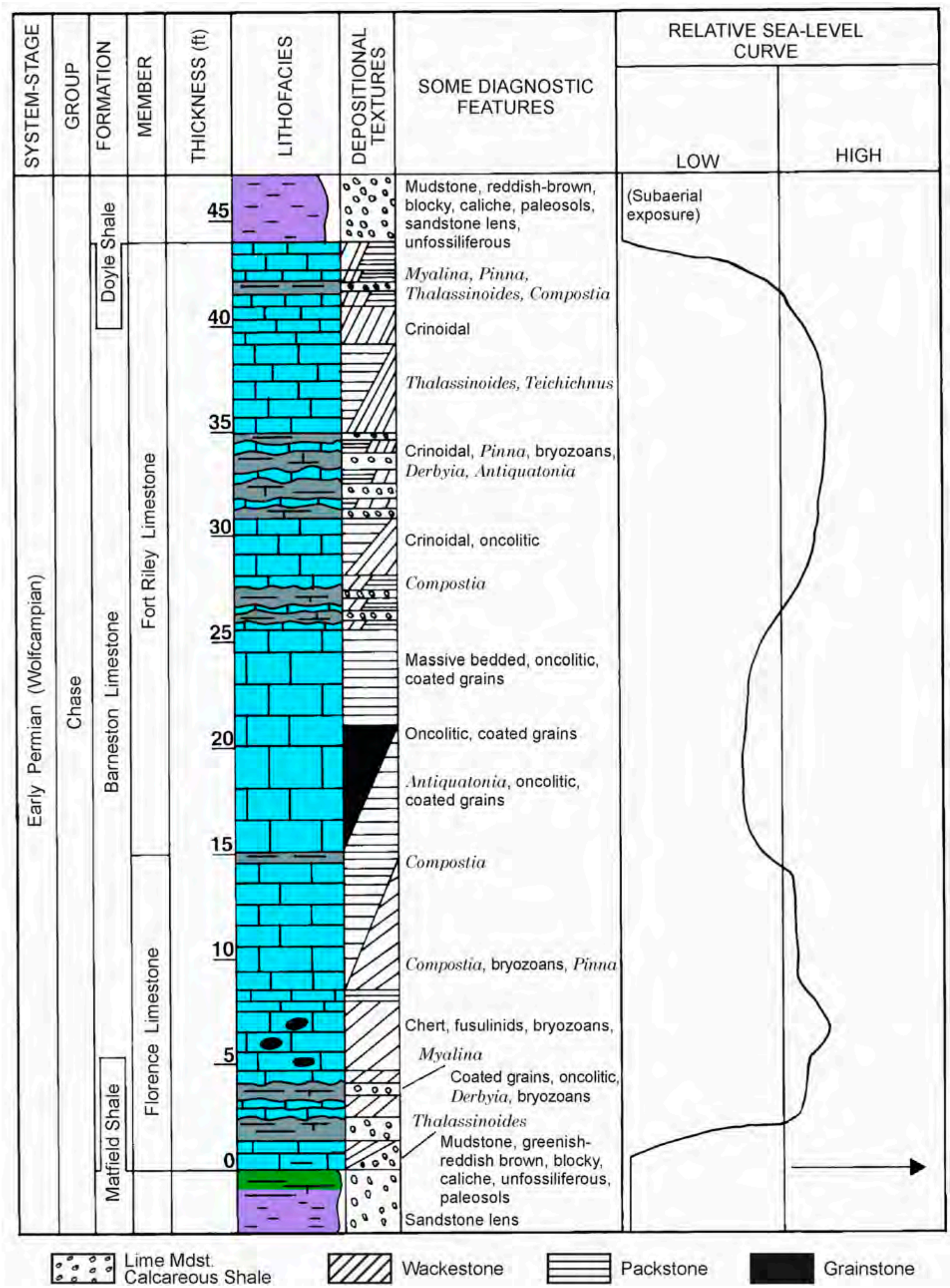

Figure 41. Schematic diagram of stratigraphic section at Vap's Pass showing a cyclic sequence of carbonates within a depositional couplet along with a relative sea–level curve.

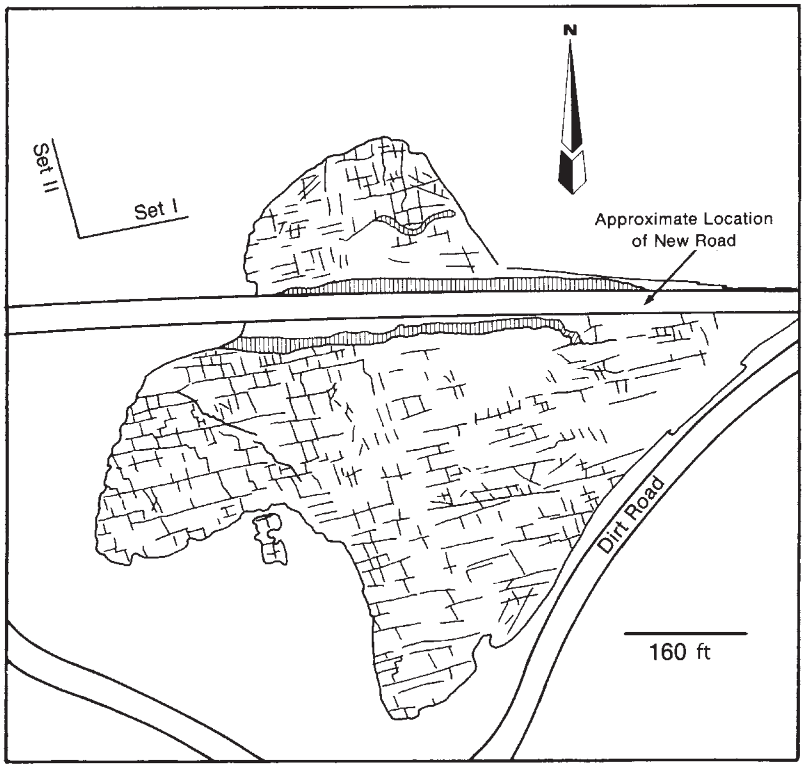

Figure 42. Map of the fracture pattern at Vap's Pass drawn from an aerial photograph taken before the present east–west road was constructed (from Rizer and Queen, 1986).

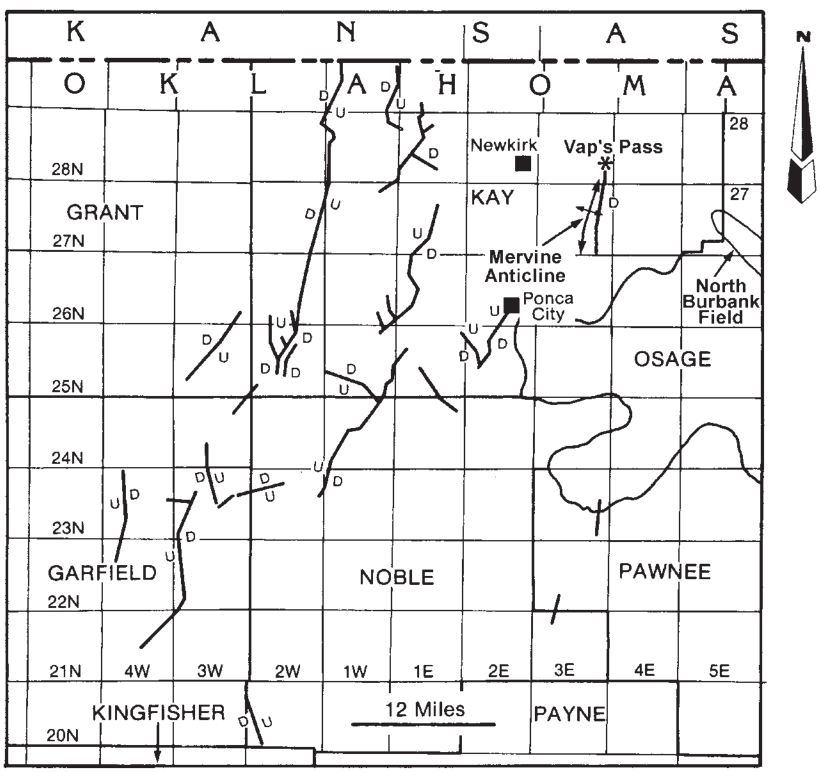

Figure 43. Map showing subsurface faults of the Nemaha Ridge (Fig. 2) which cut the basal Pennsylvanian unconformity in north–central Oklahoma (modified from Luza and Lawson, 1982).

STOP 3

OKLAHOMA HIGHWAY 11 SECTION K–5

CAUTION: THIS IS A VERY BUSY AND DANGEROUS HIGHWAY!

PLEASE STAY AS FAR AS POSSIBLE FROM THE ROADWAY ALONG THE SHOULDER.

Location

SE¼SE¼SW¼SW¼ sec. 36, T. 27 N., R. 3 E., Uncas 7.5' Quadrangle, Kay County. Measured along north side of State Highway 11, ~1.2 mi east of Enterprise Road. Elevation at the base of Herington Limestone Member—1,145 ft.

Introduction

At this stop, we will examine a roadside outcrop that is capped by ~10 ft of the Herington Limestone Member and underlain by ~14 ft of the upper part of the Enterprise/Odell Shale (Fig. 44). An excellent exposure of the sharp contact between a depositional couplet within the Chase Group consisting of an upper marine transgressive carbonate–rich facies (Herington Limestone) underlain by a more clastic–rich marginal–marine and/or terrestrial facies associated with a major regressive event (Enterprise/Odell Shale) (Fig. 45).

Red to reddish–brown mudstones, such as seen at this stop, are indicators of nonmarine deposition and represent periods of maximum regression resulting in subaerial exposure and influx of siliciclastic coastal–plain sediments over marine carbonates. The color, composition, and abundant pedogenic features suggest paleosol development locally in a coastal mud–rich sabkha environment.

Stratigraphic Significance

Nolans Limestone

Herington Limestone Member

- Exposure represents a typical Herington sequence composed of thin beds of burrowed algal packstones to grainstones with thin interbeds of calcareous shale (Fig. 45).
- Contains abundant osagid grains with limonitic rinds.
- Basal 3 ft consists of very fossiliferous beds with brachiopods, pectenoid–type bivalves, fenestrate bryozoans, and myalinid–packed limestone stringers.
- Iron–stained, deeply pitted honeycombed outcrop surface.
- A very distinct "shell bed" composed of the infaunal mytiloid bivalve *Myalina* occurs ~1.0 ft below the top of Unit 4 (storm bed).
- Myalinid beds in the Chase Group, interpreted to have accumulated in a shallow subtidal environment, help to identify the initial deepening event of a particular depositional couplet.
- Soles of some of the limestone beds are covered with distinctive networks of Y–shaped horizontal burrows of *Thalassinoides*, often "armored" with bioclasts.
- Upper 1–2 ft consists of a dense crinoidal grainstone bed which marks the top of the Herington Limestone Member in northern Oklahoma.

Enterprise/Odell Shale

- Uppermost part is composed of a greenish–gray marine shale/mudstone containing bryozoans, ostracods, crinoid columnals and foraminifera.
- Note the pronounced color change from the marine greenish–gray shales/mudstones above to the underlying unfossiliferous terrestrial red– to reddish–brown shales/mudstones and thin red siltstones (Fig. 45.).
- As trapped marine fluids became less oxygenated and more reducing (post–pedogenic "marine gleying") with burial because of microbial decay of organic matter, the resultant shift in oxidation state of the iron may have caused this observed change in coloration and consequent decrease in Fe_20_3 (Driese and Foreman, 1992).
- This transitional lithofacies immediately below the carbonate surface suggests a rapid transition from a clastic–dominated marginal–marine and terrestrial regime to a carbonate–dominated marine regime.
- Contains pedogenic features consisting of blocky mudstones, weathered calcite veinlets, and rare brecciated micritic limestone nodules and slickensided peds (Figs. 46, 47, and 48).
- The distinctive reddish–brown color of the matrix is attributed to the abundance of disseminated interstitial hematite due to the oxidation of iron.

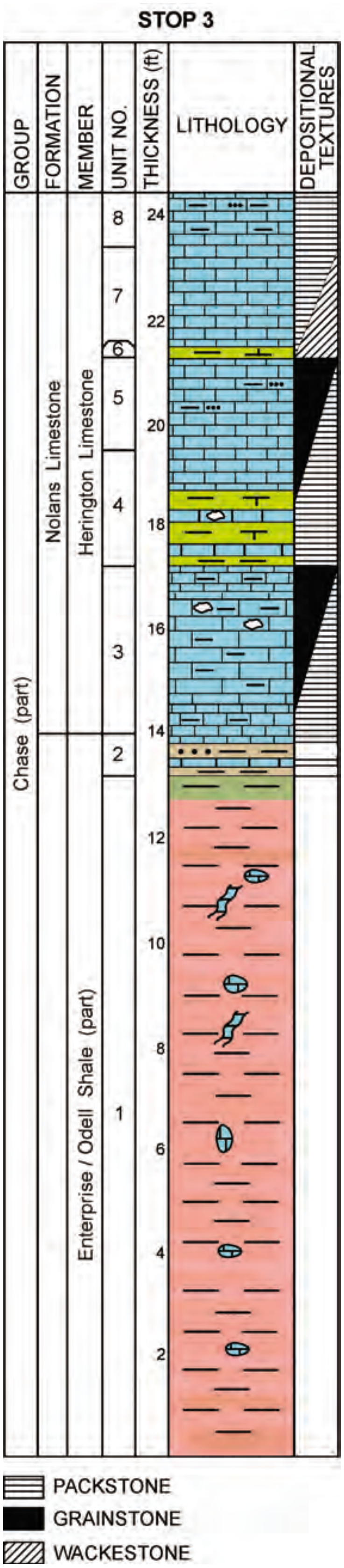

Figure 44. Stop 3. Oklahoma Highway 11 Section K–5

Oklahoma Highway 11 Measured Section K–5

Chase Group (part)

Nolans Formation (45 ft)

Herington Limestone Member (part) (10.4 ft) — Thickness (ft)

8. Limestone (packstone), yellowish–gray to pale–yellowish–orange, crinoidal, silty, thinly bedded; shale partings; iron staining; produces speckled surface when fresh. — 1.0

7. Limestone (skeletal wackestone to packstone), yellowish–gray to grayish–orange, pitted; fossiliferous with *Composita* and very abundant crinoid fragments; weathered surfaces very rough; resistant bed; sometimes splits into 2 beds with shale parting. — 1.9

6. Shale, yellowish–gray, calcareous, badly weathered; forms recess. — 0.2

5. Limestone (packstone to grainstone), dark–yellowish–orange, coquinite, silty; contains osagid grains; very fossiliferous with brachiopods, crinoid fragments, bivalves, fenestrate bryozoans; iron stains throughout; deeply pitted weathering produces a honeycombed outcrop surface; very resistant bed. — 1.9

4. Interbedded limestone (coquinite) and calcareous shale with a distinct 4– to 5–in. dark–yellowish–orange badly weathered shale at top; limestone (packstone), grayish–orange to yellowish–gray, 2– to 4–in.–thick limestone beds packed with crinoid fragments, *Composita* and *Myalina*; one distinct *Myalina* bed occurs ~1.0 ft below top of unit, geodiferous; limestone at base grades into calcareous shale above; forms recess. — 2.2

3. Limestone (packstone to grainstone), light–olive–gray weathering to dark–yellowish–orange, algal, coquinite; very iron–stained; contains thin shale partings; osagid grains with limonite rinds common; limestone more thinly bedded in lower and upper parts; very fossiliferous with brachiopods, pectenoid–type bivalves, and fenestrate bryozoans; upper 0.8 ft very fossiliferous with *Myalina*–packed limestone stringers, geodiferous; weathered outcrop surfaces very rough. — 3.2

Enterprise/Odell Shale (part) (14.0 ft)

2. Interbedded limestone and mudstone; limestone (packstone), yellowish–gray to light–olive–gray, silty, algal, fossiliferous; mudstone, 1– to 2–in.–thick beds, light–olive–gray to grayish–orange; forms recess. — 0.8

1. Mudstone, dark–reddish–brown; upper 0.8 ft is greenish–gray; stringers of weathered calcite common; some calcareous nodules throughout; forms gullied slope at east end of roadcut; slope covered with limestone talus from overlying Herington Limestone Member; base not exposed. — 13.2

TOTAL 24.4

Figure 45. Red mudstone–regressive facies below (Enterprise/Odell Shale [E/O]), and transgressive carbonate facies above (Nolans Limestone [No]). Contact identifies a discontinuity surface (sequence boundary [SB]).

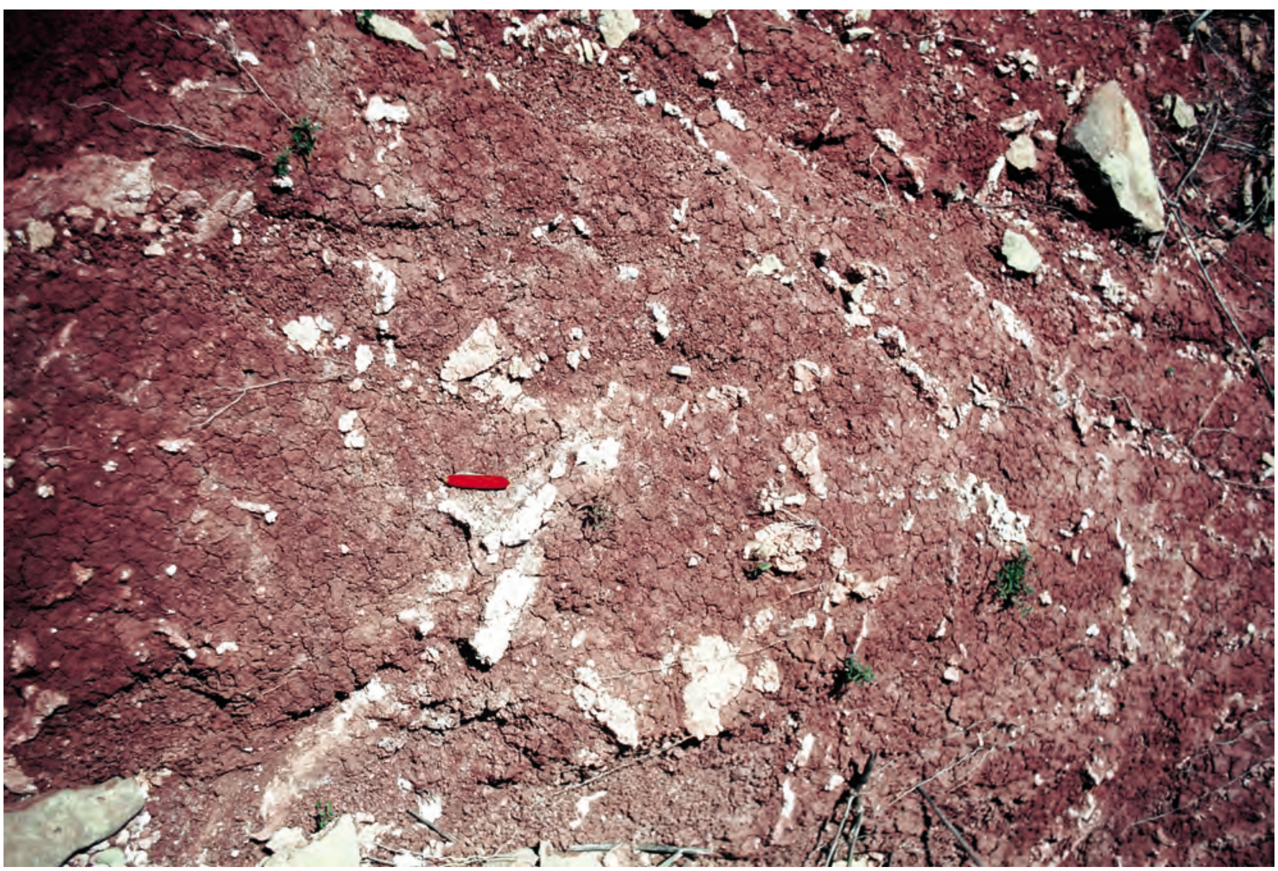

Figure 46. Calcrete nodules, calcite veinlets, and calcite sheets in red blocky crudely–bedded mudstone in the Enterprise/Odell Shale.

Figure 47. Caliche nodules in a paleosol horizon in terrestrial red mudstone facies in the Enterprise/Odell Shale.

Figure 48. Calcretized veinlets and caliche nodules from a paleosol in a red mudstone facies in the Enterprise/Odell Shale.

STOP 4

KAW LAKE–BEAVER CREEK SECTION K–12

Location

N½NE¼NE¼ sec. 25, T. 27 N., R. 4 E., Kaw City 7.5' Quadrangle, Kay County. Roadcut (north side of roadway) southeast of Beaver Creek–Kaw Lake bridge and just northwest of abandoned Standard Industries quarry.

Introduction

We will examine the Wreford Limestone and the upper part of the Speiser Shale (Garrison Formation) (Figs. 49 and 50).

Stratigraphic Significance

Chase Group (lower part)

Wreford Limestone

- Base of major Chase cycle is at the Chase/Council Grove contact.
- Mudstone-carbonate interface at the base of depositional couplet reflects the final stage of a marine regression and the initial stage of a transgressive event (Fig. 51).
- Southernmost recognized subtidal marine carbonate-rich facies of the Wreford Limestone.
- Carbonate–dominated facies correlatable to a major transgressive event.
- Basal beds contain burrowing infaunal bivalves (*Pinna*) in life position that are distinctive stratigraphic makers, traceable on outcrop for miles, that mark the onset of a transgression (i.e., paleoshoreline indicator) (Figs. 52 and 53).
- Preservation in life position of infaunal bivalves indicates that at least the lower limestone beds have not been intensely bioturbated.
- Occurrence of rare chert nodules that are characteristic of the Wreford Limestone in the Kansas section.
- Myalinid “shell beds” suggest periodic storm events.
- Brachiopods (especially *Composita*), pectenoid, mytiloid, and pholad bivalves, fenestrate bryozoans, echinoderm debris, and gastropods are common throughout each carbonate unit.
- Soles of marine carbonate beds are covered by a maze of deep, horizontal, branching *Thalassinoides* isp. boxworks which were formed interfacially above the underlying clastic interval of the marginal–marine and terrestrial regressive facies.
- These surfaces are regionally extensive interformational omission surfaces which were intensely bioturbated by the robust, firmground *Thalassinoides* producer.

Council Grove Group

Garrison Formation

Speiser Shale Member

- Clastic–rich strata deposited in response to falling sea level during a regressive event.
- Ubiquitous occurrence of a greenish-gray mottled mudstone interval ~2 ft thick immediately below a basal transgressive carbonate unit (Fig. 51).
- Color mottling may reflect localized changes in oxidation and reduction along contacts associated with permeable pathways produced by trace fossils.
- Locally, these mottled mudstone intervals alternatively may represent gleying, a change from reddish to greenish colors caused by the pedochemical reaction of iron in paleosols.
- Interval often contains lenticular fine– to very fine grained reddish–brown noncalcareous sandstones and/or siltstones locally.
- Poorly developed paleosols formed at peak marine regressions during a major regressive event occur locally.

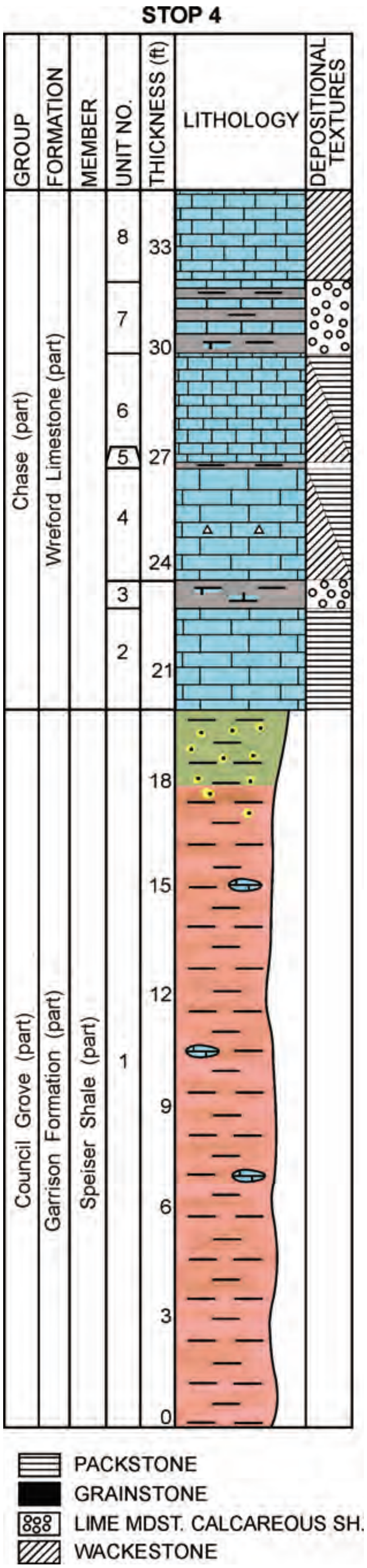

Figure 49. Stop 4. Kaw Lake–Beaver Creek Section K–12

Kaw Lake–Beaver Creek Section K–12

	Thickness (ft)
Chase Group (part)	
Wreford Limestone (13.6 ft)	
8. Limestone (skeletal wackestone), light–gray, stained grayish–orange, silty, very fossiliferous with gastropods, brachiopods, echinoid spines, crinoid fragments; fossils weather out in relief on outcrop surface with light–brown staining; sparry calcite–filled fossil molds; surface stained dark–yellowish–orange; resistant ledge.	2.3
7. Interbedded calcareous shale and shaly limestone; limestone (lime mudstone), grayish–yellow, shaly, ripple–marked, bioturbated; limestone dominant in lower 1.0 ft and upper 0.5 ft; shale weathers papery; large horizontal burrows in endorelief; limestone packed with pectenoid–type bivalves; forms recess.	2.0
6. Limestone (skeletal wackestone to packstone), yellowish–gray to light–gray, coquinite, thick–bedded; fossiliferous with very abundant large productid–type brachiopods, abundant gastropods, crinoid fragments, echinoid spines, very abundant mytiloid bivalves (*Pinna*), and very abundant *Composita*, especially at base; large horizontal burrow systems (*Thalassinoides*) on sole; resistant ledge; base undulatory.	3.0
5. Shale parting with very thin limestone stringers; may be absent locally with both thick limestone units (i.e., units 4 and 6) in direct contact.	0.1
4. Limestone (skeletal wackestone to packstone), yellowish–gray stained dark–yellowish–orange, thick–bedded; shaly in lower part, coquinite in upper part, geodiferous in certain horizons; very fossiliferous with ramose and fenestrate bryozoans, brachiopods, and the bivalve *Pinna* which is especially common in the upper 1 ft; fossils weather out in relief on outcrop surfaces; contains rare small, 2–4 in. in maximum diameter, chert nodules which weather dark–yellowish–orange; resistant ledge; top and base gradational.	2.8
3. Calcareous shale and shaly limestone; limestone (packstone), light–gray, fossiliferous with large productid–type brachiopods; shale weathers papery; rubbly bedded; *Composita* weather out on outcrop surfaces; forms recess	0.8
2. Limestone (packstone), light–gray to medium–light–gray, algal; coquinite, geodiferous, thick bedded; fossiliferous with bryozoans, crinoid fragments, bivalves (*Pinna*), and very abundant brachiopods, especially *Composita*; resistant ledge; base irregular, top gradational.	2.6
Council Grove Group (part)	
Garrison Formation (part)	
Speiser Shale Member (19.5 ft) (only upper part measured)	
1. Mudstone, dark–reddish–brown; upper 1.2 ft mudstone, greenish–gray; upper part sandy; scattered calcareous nodules; upper 1.3 ft exposed on gullied slope below limestone bench along north side of roadway; poorly exposed interval in gully is choked with limestone talus.	19.5
TOTAL	33.1

Figure 50. Outcrop showing clastic–dominated facies (Speiser Shale [Sp]) overlain by a carbonate–dominated facies (Wreford Limestone [Wr]). Discontinuity surface (sequence boundary [SB]) separates the two facies.

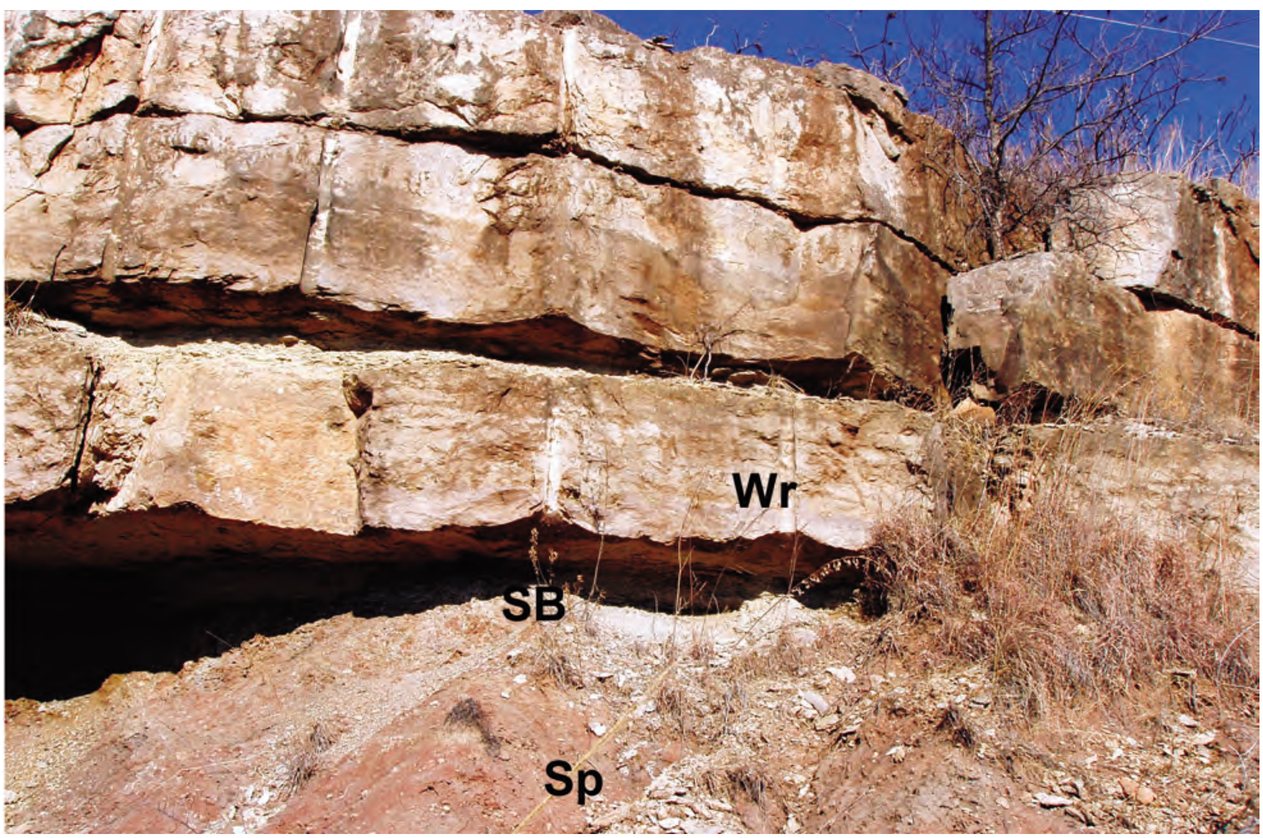

Figure 51. Closeup of Speiser Shale [Sp]/Wreford Limestone [Wr] contact. These two lithologic units are correlatable to major regressive and transgressive surfaces, respectively, that recur as distinct depositional couplets throughout the Chase Group.

Figure 52. Massive carbonate beds in the lower part of the Wreford Limestone showing internal molds of the burrowing infaunal mytiloid bivalve *Pinna* in life position.

Figure 53. Closeup view of vertical oriented (life position) internal molds of the burrowing infaunal mytiloid bivalve *Pinna*. These bivalves commonly mark the onset of a transgressive event.

STOP 5

KAW DAM–FISHERMAN'S BEND SECTION K–10

CAUTION: OUTCROP ACCESS IS LIMITED BECAUSE OF THE NARROW WALKWAY ALONG THE WEST BANK OF THE ARKANSAS RIVER

BEWARE OF FISHERMEN AND THEIR CASTING

Location

NW¼NE¼SW¼SE¼ sec. 25, T. 26 N., R. 3 E., Charlie Creek West 7.5' Quadrangle, Kay County. Measured section begins along west bank of the Arkansas River just south of Kaw Dam. Pool elevation of tailwaters at time of measurement was 930 ft. Elevation at base of Winfield Limestone—1,069 ft.

Introduction

We will examine the upper part of the Barneston Limestone, the lower part of the Doyle Shale, including the Holmesville Shale, Towanda Limestone, and basal Gage Shale Members (Figs. 54 and 55).

Stratigraphic Significance

Doyle Shale

Gage Shale Member

- Atypical marginal–marine dark–gray, fossiliferous shale, sandstone, and ripple–marked calcareous siltstone facies at the base of a normally reddish–brown terrestrial succession of blocky mudstones/shales.
- Marks deposition during a major regressive event.
- Minor erosional surfaces representing small hiatuses are probably relatively abundant within prograding terrestrial redbeds, but they are difficult to recognize due to their stratigraphic position within mudstone/shale intervals that typically are poorly exposed. Core data aid in documenting these minor erosional events.

Towanda Limestone Member

- Intracycle carbonate unit indicating a minor transgressive event within a clastic–dominated major terrestrial redbed facies associated with a major regressive event (Doyle Shale).
- Highly fossiliferous bed with crinoid debris, brachiopods, and gastropods.
- Excellent horizontal U–shaped forms of the spreiten–bearing trace fossil *Rhizocorallium* are preserved on the top bedding–plane surface of this transgressive marine carbonate (Fig. 56).
    - A relatively cohesive sediment is suggested by the lack of burrow linings and by the excellent preservation of horizontal spreiten.
- *Rhizocorallium*–dominated surfaces in the Chase Group help to identify brief sea–level stillstands at the terminations of transgressive events and the onsets of major regressive events.
- *Rhizocorallium* are associated with regressive, above wave–base events during which pauses in sedimentation produce discontinuity surfaces (omission surfaces) that are colonized by the *Rhizocorallium* trace maker.
- Cast *Rhizocorallium* burrows indicate only minor erosional events, whereas *Thalassinoides* systems indicate major erosional events.

Holmesville Shale Member

- Atypical greenish–gray fissile shale facies.
- Marks transitional marginal–marine facies.
- Marks the only cycle top where red supratidal/terrestrial sediments are not deposited.

Barneston Limestone (upper part)

- Intensely bioturbated (especially *Thalassinoides*) limestone facies.
- The outside of the *Thalassinoides* burrow systems are plastered with bioclasts and osagid grains consisting of encrustations of algae and various encrusting foraminifera ("armored" burrows) (Fig. 57).

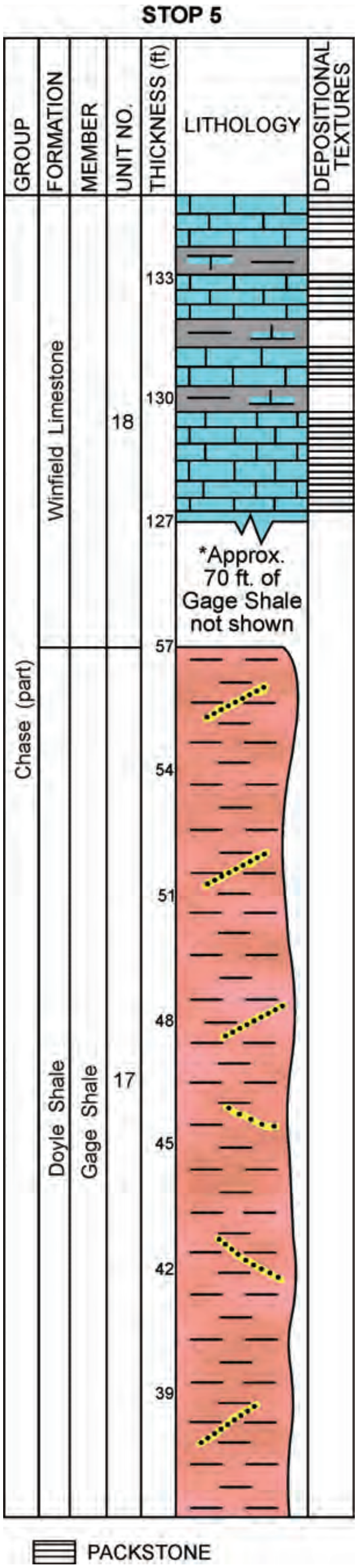

Figure 54. Stop 5. Kaw Dam–Fisherman’s Bend Section K–10

Kaw Dam–Fisherman’s Bend Section K–10

	Thickness (ft)
Chase Group (part)	
Winfield Limestone (8.0 ft)	
18. Limestone (packstone), light–brownish–gray to dark–yellowish–brown, crinoidal, algal; contains interbeds of calcareous shale; iron–stained dark–yellowish–orange; surface pitted with vertical cylindrical cavities; resistant beds; base poorly exposed due to limestone talus and grass–covered slope; caps knoll around U.S. Army Corps of Engineers’ office.	8.0
Doyle Shale (106.8 ft)	
<u>Gage Shale Member (101.3 ft)</u>	
17. Poorly exposed interval, grass–covered slopes above river and along road; interval consists primarily of shale and mudstone, grayish–red to dark–reddish–brown; sandstone, dark–reddish–brown, very fine grained, well–sorted, very thinly bedded, laminated, hematitic, exposed ~65 ft below top of unit; measured up slope from last outcrop on bank of river along road up to first limestone outcrop on knoll behind U.S. Army Corps of Engineers’ office; thickness estimated.	97.8
16. Shale, dark–gray with very thin intercalations of burrowed, fossiliferous, very fine grained sandstone; base consists of calcareous siltstone, ripple–marked and with horizontal traces on tops and bottoms; 1– to 2–in.–thick light–gray, very fine grained sandstone at top with asymmetrical ripple marks and small–scale cross–laminations; soles covered with horizontal crawling and feeding burrows; some crawling trails on surface of sandstone; unit less calcareous and more sandy in the upper part; forms recess.	3.5
<u>Towanda Limestone Member (1.5 ft)</u>	
15. Limestone (lime mudstone to packstone), medium–light–gray to medium–gray weathering dark–yellowish–orange; fossiliferous with crinoid fragments, brachiopods, and gastropods; slightly ostracodal; large round, irregular vertical protrusions on sole and conical, vertical, tapering lined burrows with flared tops (*Monocraterion*) ~5 in. in length and 2 in. in width in bed; top surface covered with molds of excellent *Rhizocorallium* with well–preserved spreiten from the filling of fossil detritus (average length of 8 in. and width of 3 in.); top sharp, base irregular; resistant bed.	1.5
<u>Holmesville Shale Member (4.0 ft)</u>	
14. Shale, olive–gray to dark–greenish–gray, fissile; forms recess.	4.0
Barneston Limestone (21.7 ft)	
13. Interbedded calcareous shale and brachiopodal, crinoidal, myalinid limestone; limestone (packstone), medium–light–gray weathering dark–yellowish–orange, highly crinoidal, rubbly bedded, in 1– to 2–in.–thick beds; coquinite limestone with *Myalina* dominates upper 1 ft; shale, olive–gray, packed with crinoid fragments and brachiopods; forms recess.	2.4

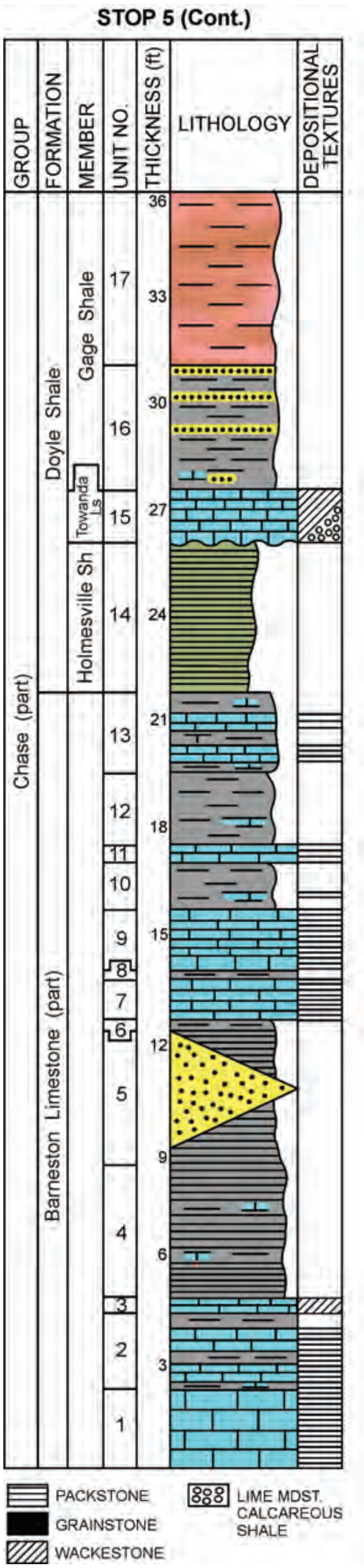

Figure 54 (*Continued*)

		Thickness (ft)
12.	Shale, olive–gray, very fossiliferous with crinoid fragments, brachiopods and *Myalina*; contains very thin ostracodal limestone lenses and stringers; forms recess.	1.9
11.	Limestone (packstone), medium–dark–gray to medium–gray; very silty, crinoidal, ostracodal, rubbly bedded; forms recess.	0.5
10.	Shale, dark–gray to medium–dark–gray, fossiliferous with crinoid fragments and brachiopods; algal; ostracodal limestone (packstone) lenses at base; forms recess.	1.5
9.	Limestone (packstone), light–olive–gray weathers dark–yellowish–orange, algal, ostracodal; very fossiliferous with crinoid fragments, echinoid spines, low– and high–spired gastropods, brachiopods, and fenestrate bryozoans; resistant bed; sole and top with horizontal burrow systems of *Thalassinoides*; base and top irregular.	1.6
8.	Shale, medium–light–gray, calcareous, weathers papery; contains horizontal calcareous burrows lined with shell fragments.	0.2
7.	Limestone (packstone), medium–dark–gray to medium–gray, silty, algal, ostracodal, dark–yellowish–orange iron staining; top shaly and packed with calcareous, intertwined horizontal burrow systems; sole of limestone bed with extensive horizontal branching burrow systems of *Thalassinoides* lined and covered with fossil detritus; some vertical bulbous protrusions associated with these horizontal burrow systems; very fossiliferous with crinoid fragments, brachiopods, and gastropods; resistant bed; top and base irregular.	1.2
6.	Shale medium–gray, papery, pyritic, weathers powdery; forms recess.	0.3
5.	Sandstone, light–gray to medium–light–gray, very fine grained, well–sorted, laminated, weathers to dark–yellowish–orange; medium– to high–angle planar cross–bedding, especially on south end of exposure; sandstone thickens to the south (wedge geometry) and to the north splits into 4 to 5 beds of dark–gray, slightly fissile organic–rich shale beds each 1– to 6–in. thick; shale with abundant horizontal burrows (endoreliefs) and sandstone soles with branching horizontal burrows and bulbous vertical protrusions (?*Bilobites*); sandstone beds contain woody material and seed ferns; base sharp; resistant beds.	3.2–3.9
4.	Shale, dark–gray to grayish–black, slightly fissile; fossiliferous with lenses of calcareous shale; forms recess.	3.8
3	Limestone (skeletal wackestone), medium–gray to medium–light–gray, very fossiliferous with fenestrate bryozoans, ostracodes, and productid–type brachiopods; extensive horizontal branching burrow systems on base and top, *Thalassinoides*.	0.5
2.	Interval consists of 1.2 ft of ostracodal mudstone with lenses of ostracodal limestone; 0.5 ft of medium–dark–gray to medium–gray, algal, ostracodal limestone (packstone); 0.3 ft of calcareous shale at base; trace fossil *Phycodes* very common in mudstone/shale intervals; forms a recess.	2.0
1.	Limestone, packstone, light–olive–gray, algal, ostracodal; single thick resistant bed; base not exposed; pool elevation of tailwaters at time of measurement was 930 ft.	2.3
	TOTAL	136.5

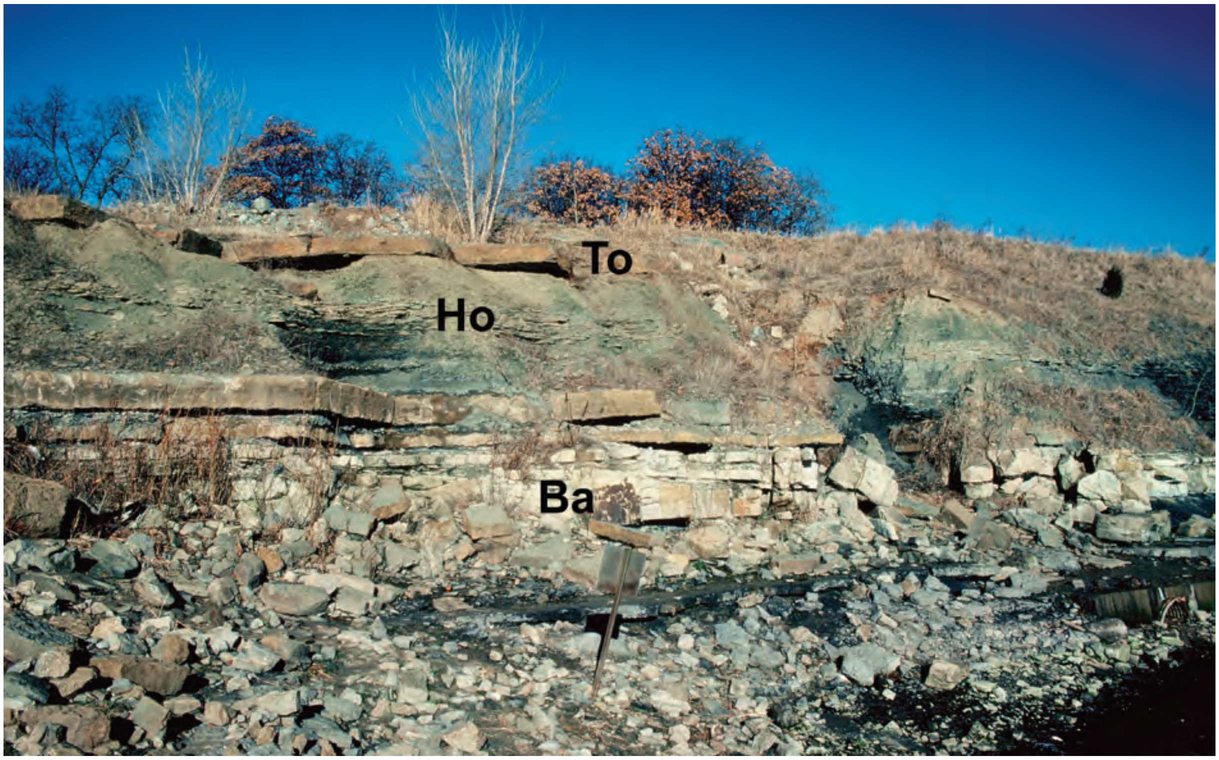

Figure 55. Outcrop photo, in ascending order, upper part of the Barneston Limestone [Ba] and Doyle Shale (Holmesville Shale [Ho], Towanda Limestone [To], and basal part of the Gage Shale).

Figure 56. Horizontal forms of *Rhizocorallium* isp. on the top surface of the intracycle Towanda Limestone Member. *Rhizocorallium*–dominated surfaces in the Chase Group help to identify brief sea–level stillstands at the termination of transgressive events and the onsets of major regressive events.

- *Thalassinoides* burrows are unlined, truncated at the top, and filled with grains of the same composition and size of the matrix suggesting that the burrows remained open after excavation by the trace maker and were constructed in cohesive sediment (firmground).
- Passive piping of sediments into the burrow systems, primarily due to burrow collapse and storm events, is suggested by textural similarity to surrounding and overlying units.
- Bioturbation has mostly disrupted primary physical sedimentary structures.
- Beds are so thoroughly bioturbated that discrete traces cannot be recognized resulting in a mixing of carbonate mud and sand due to biogenic reworking.
- Repetitive burrowing by endobenthic organisms along with storm–generated infilling can ultimately result in the complete reworking of the sediment and loss of the original facies characteristics in shallow–water marine environments.
- Abundant osagid grains suggest relatively turbulent water over calcarenite shoals.
- Encrustation of bioclastic grains by laminae of algae/foraminifers is pervasive and results in subspherical to elliptical–shaped crinkly–coated oncoid grains.
- Contains numerous coquinite *Myalina* beds that suggest periodic storm events.
- Atypical ostracodal–rich packstone facies.
- Atypical crossbedded sandstone body with wedge geometry bearing limonitic rip–up clasts, fern foliage, and woody material (Fig. 58).

Figure 59 shows cross sections of strike [A] and dip–oriented [B] stratigraphic sections demonstrating the lateral distribution and thickness variation of a sand body developed in the Matfield Shale (= "Hoy" sand zone of the subsurface) at Kaw Dam, Kay County. Data for cross sections from subsurface geological logs of bore holes completed by the U.S. Army Corps of Engineers.

Figure 57. Intensely bioturbated surface of Barneston Limestone showing deep, horizontal branching *Thalassinoides* isp. boxworks covered with bioclasts and osagid grains ("armored" burrows). These surfaces mark regionally extensive interformational omission surfaces.

Figure 58. Atypical crossbedded wedge–shaped sandstone body in the upper part of the Barneston Limestone that contains rip–up clasts, fern foliage, and woody material.

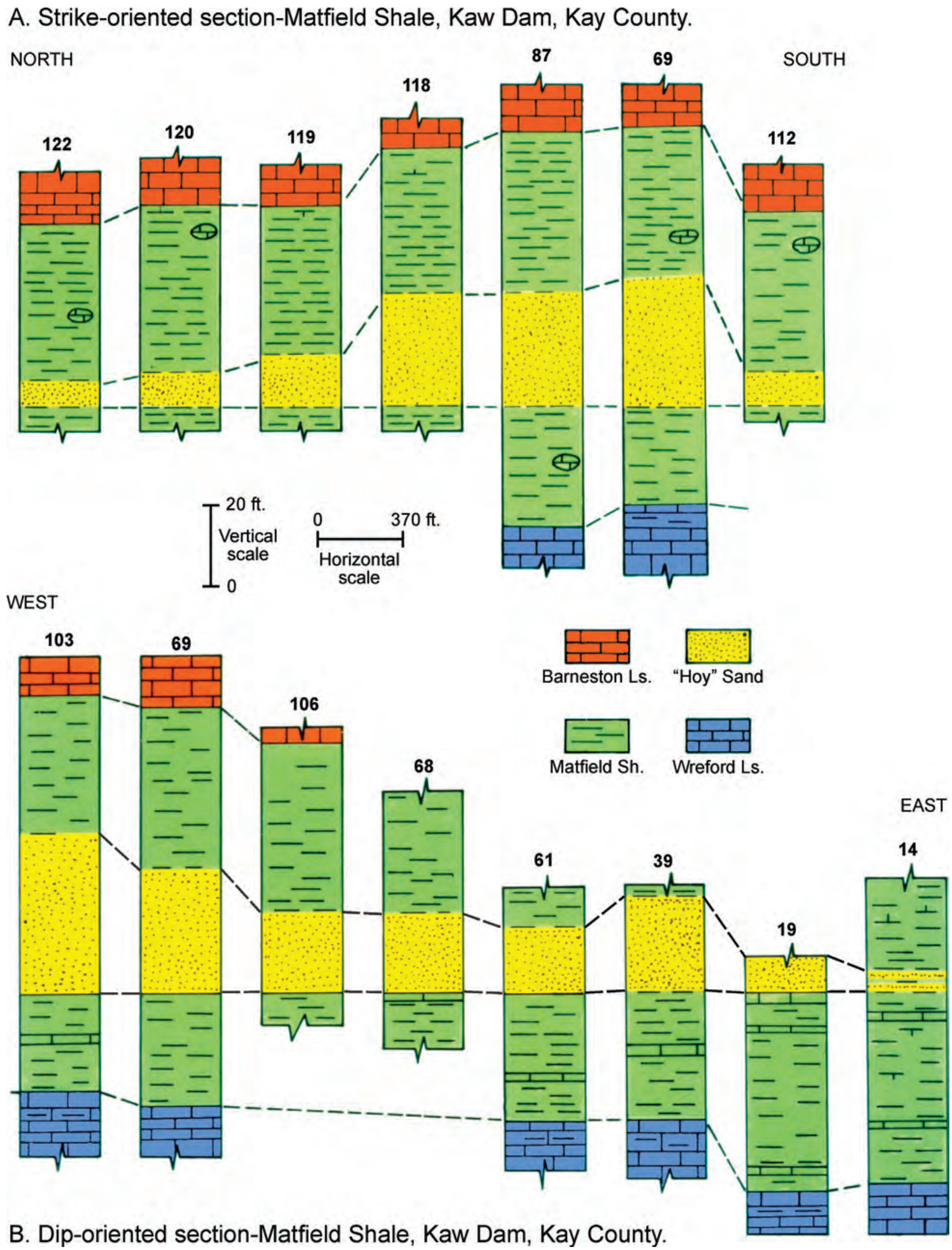

Figure 59. Strike [A] and dip–oriented [B] stratigraphic sections showing the lateral distribution and thickness variation of a sand body developed in the Matfield Shale (= "Hoy" sand zone of the subsurface) at Kaw Dam, Kay County. Data from subsurface geological logs of bore holes by the U.S. Army Corps of Engineers. See Figure 1 for location of Kaw Dam and section K–10.

STOP 6
PRENTICE ROAD SECTION K–9

LOCATION

SW¼SE¼SE¼SW¼ sec. 28, T. 26 N., R. 3 E., and NE¼NE¼NE¼ NW¼ sec. 33, T. 26 N., R. 3 E., Charlie Creek West 7.5' Quadrangle, Kay County. Measured section begins along west bank of roadway just northeast of bridge, and traverses uphill to private road that turns south toward the Arkansas River; section continues along east side of private road up to top of the ridge. Elevation at base of Winfield Limestone—986 ft.

INTRODUCTION

We will examine ~10 ft of the Winfield Limestone, ~55 ft of poorly exposed Enterprise/Odell Shale, and ~7.0 ft of the Herington Limestone Member (Nolans Limestone) (Fig. 60). Approximately 10 ft of the Luta Limestone Member (Enterprise/Odell Shale) is poorly exposed in the drainage ditch along the north side of the roadway.

STRATIGRAPHIC SIGNIFICANCE

Nolans Limestone

<u>Herington Limestone Member</u>

- The lower 3 ft is composed of cross–bedded oolitic grainstones, suggesting this area contains an east–west trending belt of oolite shoals (Fig. 61).
- Oolitic shoals are narrow, lie subparallel to the paleoshoreline, and occur in mobile belts.
- First reported occurrence of a Herington Limestone ooid bank with some geographic continuity.
- Oolitic facies in the Chase are found at the top of upward–shoaling sequences.
- Oolitic grainstone with low–angle crossbedding reflects traction transport and increased energy in an ooid–shoal setting.
- Ooliths showing internal radiating fibrous structure may enhance matrix porosity.
- Intergranular porosity (pore space between grains) prevail in the grainstone facies, whereas matrix porosity (pore space between micritic crystals) is dominant in other facies.
- Abrupt facies juxtaposing of a transgressive marine limestone on a nonmarine regressive clastic mudstone (Fig. 62).

Enterprise/Odell Shale

- Represents a non–stratified, variably calcareous clastic mudstone facies.
- Interval has increased in thickness from ~31 ft at Stop 1 to ~56 ft at this stop.
- This facies may contain lenticular bodies of very fine grained, reddish–brown sandstones locally.
- Interval commonly contains variably developed paleosols.
- Most significant aspect of this facies is its positioning and repetitious vertical stacking between carbonate packages (Herington Limestone above and Winfield Limestone below) of the Chase Group.

<u>Luta Limestone Member</u>

- Poorly exposed Luta–like lithologies become sandy.
- Exhibit asymmetrical ripple marks and ripple–drift cross–laminations.
- Contains the trace fossils *Chondrites* and *Diplocraterion*.
- Luta Limestone Member is not recognized south of the Arkansas River.

Winfield Limestone

- Facies represents the initiation of transgressive conditions.
- Overall a more alga–rich, shaly Winfield section than to the north.
- Winfield begins to lose much of its lithologic distinctiveness seen farther north, becoming a more sandy/silty skeletal wackestone to packstone facies, but still containing abundant coated grains and typical Winfield faunal elements.
- Consists dominantly of a single massive carbonate bed, probably the lithologic equivalent of the Cresswell Limestone Member of the northern outcrop belt (Fig. 60).

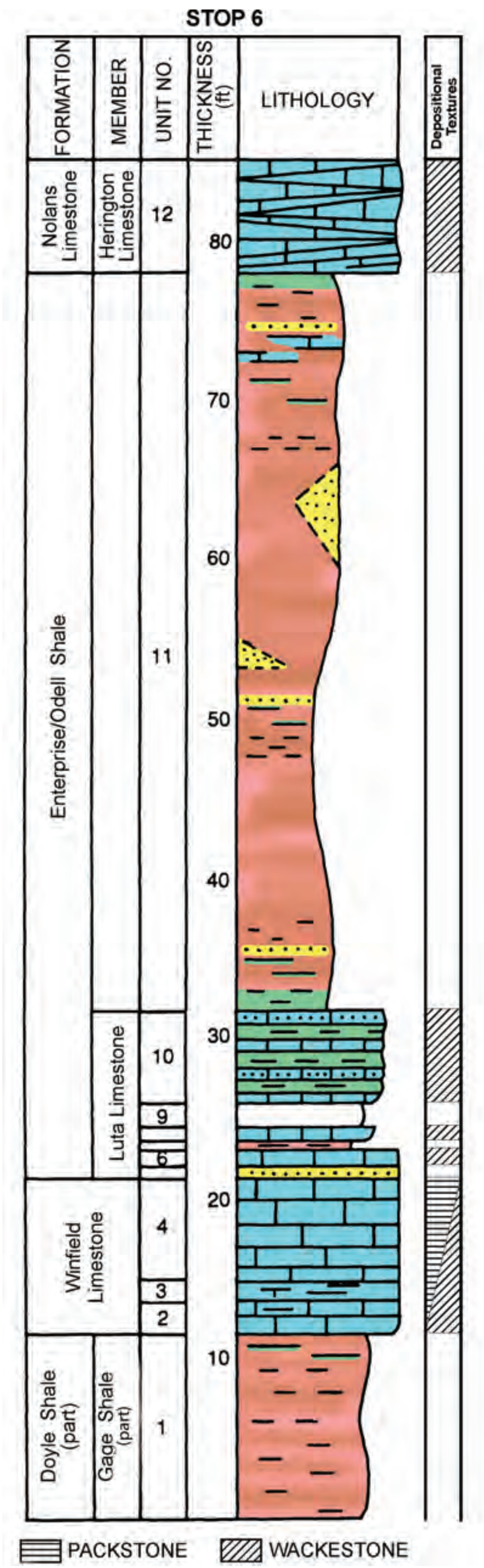

Figure 60. Stop 6. Prentice Road Section K–9

Prentice Road Section K–9

Chase Group (part)

Nolans Limestone (7.0 ft)

<u>Herington Limestone Member (7.0 ft)</u> — Thickness (ft)

12. Limestone (silty skeletal wackestone), yellowish–gray, vuggy, iron–stained, massive; lower 3 ft composed of oolitic skeletal grainstones with low–angle planar crossbedding; sandy and oolitic with a conglomeratic–like texture at base; fossiliferous with productid–type brachiopods, crinoid columnals, and gastropods; pitted outcrop surfaces and vertical cylindrical cavities; resistant ridge–former; talus blocks litter shale slope below. — 7.0

Enterprise/Odell Shale (55.7 ft)

11. Mostly covered interval with scattered limestone outcrops in drainage ditch along main road; upper part of interval best exposed along new road going south to the Arkansas River; primarily mudstone, dark–reddish–brown with some beds of greenish–gray shale in lower and upper part; overall unit is silty and sandy; upper part contains sandstone, dark–reddish–brown, very fine grained, well–sorted, silty, hematitic, lenticular; limestone (skeletal wackestone), light–olive–gray, vuggy, very fossiliferous containing limonite–filled fossil molds and iron–stained osagid grains near top of interval. — 46.0

<u>Luta Limestone Member (9.7 ft)</u>

10. Limestone (skeletal wackestone and lime mudstone), light–gray to pale–red, sandy, dense, lithographic texture; wavy– to parallel–bedded; distinct sandy intervals interlaminated with greenish–gray, calcareous shales; contains some sandy limestone beds 4 to 6 in. thick with excellent sedimentary structures, including asymmetrical ripple marks and low–angle, small–scale crossbedding with ripple–drift cross–laminations; some limestone beds are lenticular shaped; trace fossils include *Chondrites* and *Diplocraterion*. — 5.8

9. Covered interval. — 1.3

8. Limestone (skeletal wackestone), yellowish–gray, with iron stains. — 0.6

	Thickness (ft)
7. Shale/mudstone, dark–reddish–brown; poorly exposed.	0.4
6. Limestone (sandy, skeletal wackestone), greenish–gray, vuggy with brachiopod molds filled with coarse sparry calcite; fossiliferous with productid–type brachiopods, crinoid columnals, and algal filaments; bioturbated, base sharp.	0.8
5. Sandstone, grayish–orange, very fine grained, calcareous; contains greenish–gray shale wisps and stringers; very thin shale partings common; top 1 in. composed of dark–reddish–brown mudstone; fossiliferous with *Composita*; bioturbated; poorly exposed in drainage ditch going up the hill.	0.8
Winfield Limestone (9.6 ft)	
4. Limestone (coated–grain skeletal wackestone to packstone), yellowish–gray, limonitic, vuggy; contains light–olive shale clasts and stringers throughout; fossiliferous with very abundant *Composita* and crinoid columnals; upper 4 ft of interval consists of yellowish–gray, algal limestone; base with large horizontal burrow systems of *Thalassinoides*; calcareous flow deposits cover outcrop surface; massive resistant unit; base undulatory, top sharp.	6.5
3. Interbedded crinoidal limestone (coated–grain skeletal wackestone to packstone), olive–gray, very silty, algal; fossiliferous with *Composita* and very abundant crinoid columnals; shale, light–olive–gray, fissile, calcareous; top consists of very shaly crinoidal limestone with horizontal burrows; base and top undulatory; forms recess.	1.0
2. Limestone (coated–grain skeletal wackestone), grayish–orange, dense, algal, very resistant; fossiliferous with abundant crinoid columnals, gastropods, and brachiopods; ostracodal, especially at top; osagid grains with limonitic rinds; becomes very silty to sandy at the top; *Thalassinoides* burrows on sole of unit; top undulatory, base sharp.	2.1
Doyle Shale (part)	
Gale Shale Member (part)	
1. Mudstone, dark–reddish–brown to grayish–red; upper 0.5 ft light–bluish–gray to greenish–gray; contains weathered calcite stringers; base not exposed; section begins northeast of bridge opposite driveway entrance and traverses uphill to a private road going south to Arkansas River from Prentice Road.	11.5
TOTAL	83.8

Figure 60 (*Continued*)

Figure 61. Low–angle crossbedded oolitic grainstones in the lower part of the Nolans Limestone (Herington Limestone Member) in an ooid–shoal depositional setting.

Figure 62. Red mudstone regressive terrestrial facies of the Enterprise/Odell Shale. This interval commonly contains variably developed paleosols and lenticular sandstone bodies.

Some Regional Trends in the Chase Group South of This Stop

- Increase in both abundance and thickness of sandstones/siltstones in both the clastic– and carbonate–dominated facies of each depositional couplet.
- Clastic units thicken southward at the expense of carbonate units.
- Initiation of significant clastic influx (sand and silt) throughout the stratigraphic interval as the clastic source and/or paleoshoreline is approached.
- Carbonate lithologies are represented by calcareous sandstones, highly leached sandy carbonates, and discontinuous lenses of sandy nodular dolomite.

STOP 7

EAST BRESSIE SECTION N–1

LOCATION

SW¼SW¼SW¼ sec. 17, T. 24 N., R. 3 E., Ponca City Southeast 7.5' Quadrangle, Noble County. Located along north side of section–line road ~3.4 mi east of Highway 177.

INTRODUCTION

At this stop we will examine ~18 ft of section composed of the uppermost part of the Doyle Shale, Winfield Limestone, and the lower part of the Enterprise/Odell Shale (Fig. 63).

STRATIGRAPHIC SIGNIFICANCE

Enterprise/Odell Shale

- Regressive mudstone facies with very calcareous, very fine grained sandstones.
- Limited marine component suggested by rare trace fossils and rare molds of body fossils.
- Absence of Luta–like lithologies.

Winfield Limestone

- The trace of the Winfield Limestone south of the Kay–Noble County line is based dominantly on topographic expression (Shelton et al., 1979).
- Greatest thickness recorded for the Winfield in Noble County is at the midpoint of its linear outcrop belt (T. 22 N.).
- A noticeable lateral, along strike, north–south facies change within the Winfield Limestone interval.
- Winfield Limestone thickness reduced to 2 ft.
- Outcrop represents the southernmost occurrence of abundant body fossils in the Winfield.
- Interdigitation of fossiliferous calcareous shale with sandy carbonates indicates some marine clastics were deposited in the Winfield in northern Noble County (Fig. 64).
- Luta–like lithologic interval above the Winfield now represented by calcareous sandstones.
- Marginal–marine, semi–restricted peritidal depositional setting.

Doyle Shale

Gage Shale Member (upper part)

- Variegated mudstone regressive facies.
- Intracycle carbonate unit (Unit 1) suggests a minor transgressive event.
- Ubiquitous greenish–gray calcareous mudstone in upper 2.5 ft (Fig. 65).
- Occurrence of woody material and fern foliage associated with productid–type brachiopods suggests a marginal–marine semi–restricted peritidal/terrestrial depositional setting.

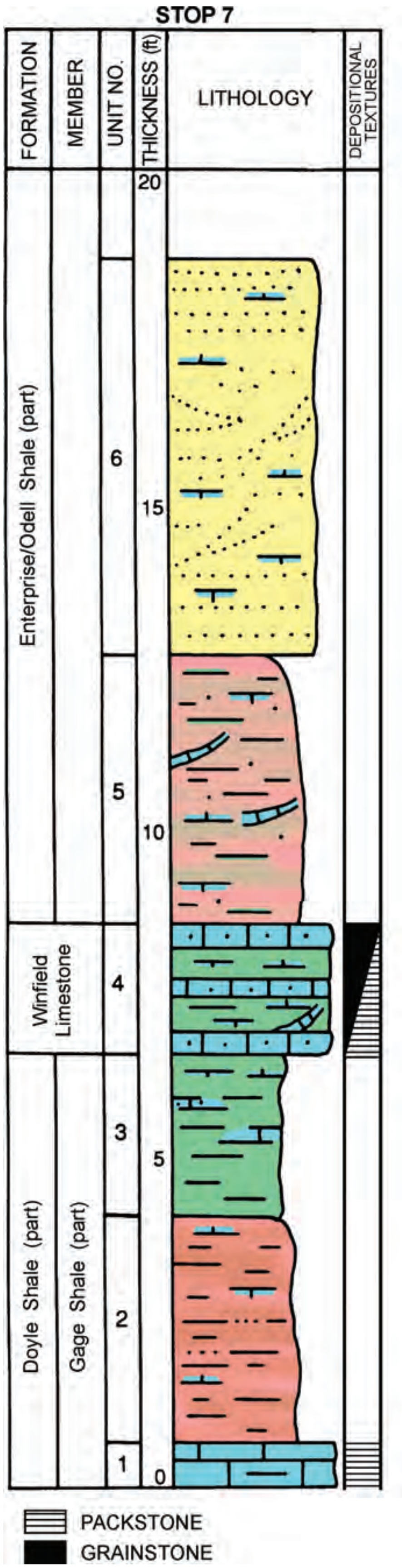

Figure 63. Stop 7. East Bressie Section N–1

East Bressie Measured Section N–1

Chase Group (part)

	Thickness (ft)
Enterprise/Odell Shale (part) (10.0 ft)	
6. Sandstone, reddish–gray, very calcareous, very fine grained, micaceous, dense, hard; includes low–angle cross–laminations; very vuggy in some places with very coarse sparry calcite fillings; bioturbated with small vertical U–shaped burrows (*Diplocraterion*) ~4 in. in length; rare fossil molds filled with highly weathered white shell material; resistant ledges ~6–8 in. thick; base gradational.	6.0
5. Shale/mudstone, variegated greenish–gray to reddish–brown, calcareous; contains fossiliferous sandy limestone/calcareous sandstone streaks throughout; forms recess.	4.0
Winfield Limestone (2.0 ft)	
4. Limestone (coquinite packstone to grainstone), light–brownish–gray to medium–light–gray, algal, sandy; interstratified with yellowish–gray, fossiliferous, calcareous shale; rubbly to flaggy bedded; low–angle cross–stratification in some places; limestone beds commonly 2 –to 4–in.–thick with 1– to 2–in.–thick shale partings; lower 6–in.–thick resistant bed; basal part very shaly and fossiliferous with compacted brachiopod shells (i.e., *Linoproductus* and *Derbyia*), and pectenoid bivalves; phylloid algal filaments and osagid grains very abundant; shell molds filled with blocky calcite (moldic porosity); a trepostome bryozoan–encrusted irregular surface ~1–2 in. thick occurs ~8 in. above the base of unit; some bedding–plane surfaces consist of shell pavements; bioturbated with horizontal trails on soles and within beds; sharp, planar basal contact.	2.0
Doyle Shale (part) (6.8 ft)	
Gage Shale Member (part) (6.8 ft)	
3. Mudstone greenish–gray, silty, calcareous; includes very thin sandy limestone streaks throughout; upper 4 in. yellowish–gray, very calcareous containing dark–gray carbonaceous films of compacted, delicately preserved productid–type brachiopods, woody material and fern foliage; rare bioturbation; gradational basal contact.	2.5
2. Mudstone, variegated greenish–gray and reddish–brown, mottled, silty, calcareous; rare bioturbation; gradational basal contact.	3.5
1. Limestone (algal packstone), grayish–yellow, dense, hard, algal; contains fragmented shell debris; some greenish–gray shale inclusions; includes some small blocky calcite–filled vugs; poorly exposed.	0.8
TOTAL	18.8

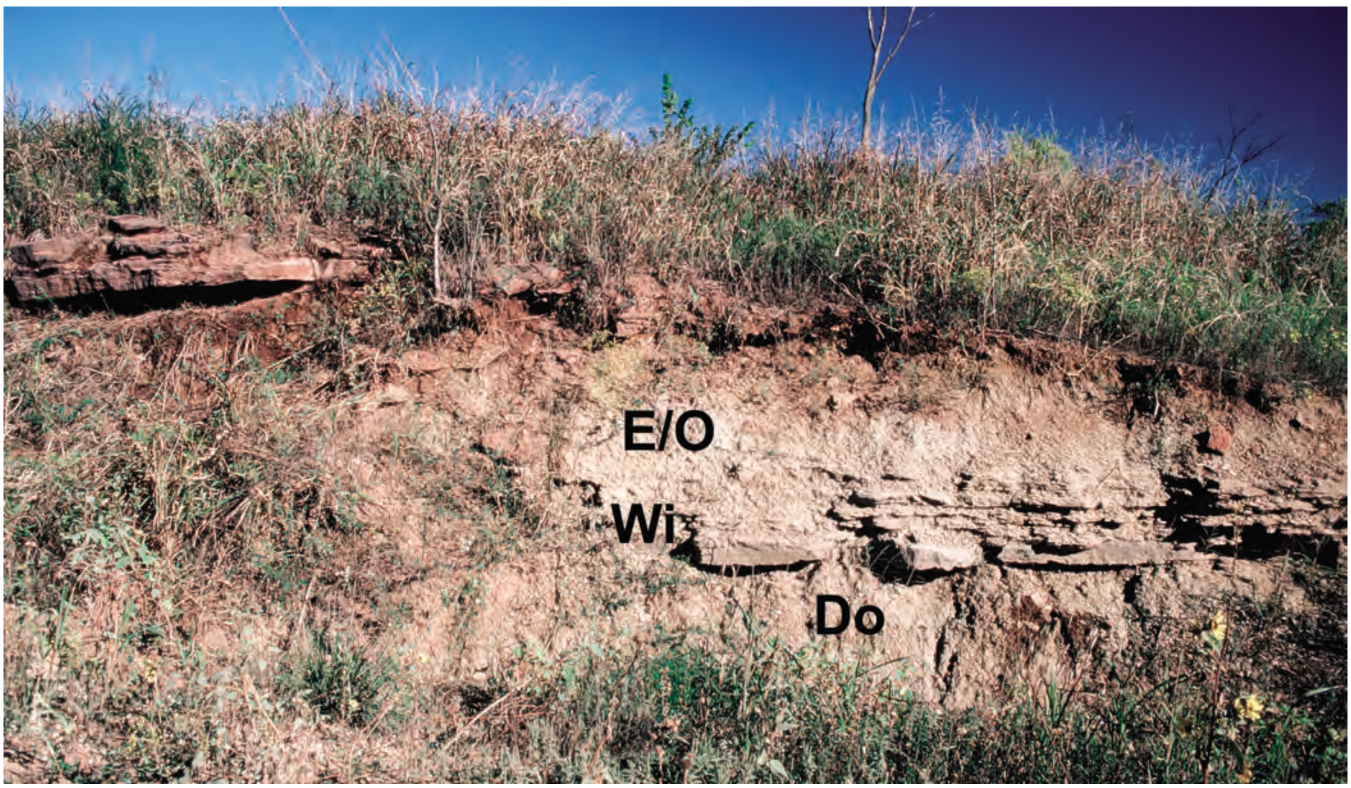

Figure 64. Abrupt facies juxtaposing of a transgressive marine sandy carbonate (Winfield Limestone [Wi]) between two non-marine regressive terrestrial mudstones (Enterprise/Odell Shale [E/O] above and Doyle Shale [Do] below).

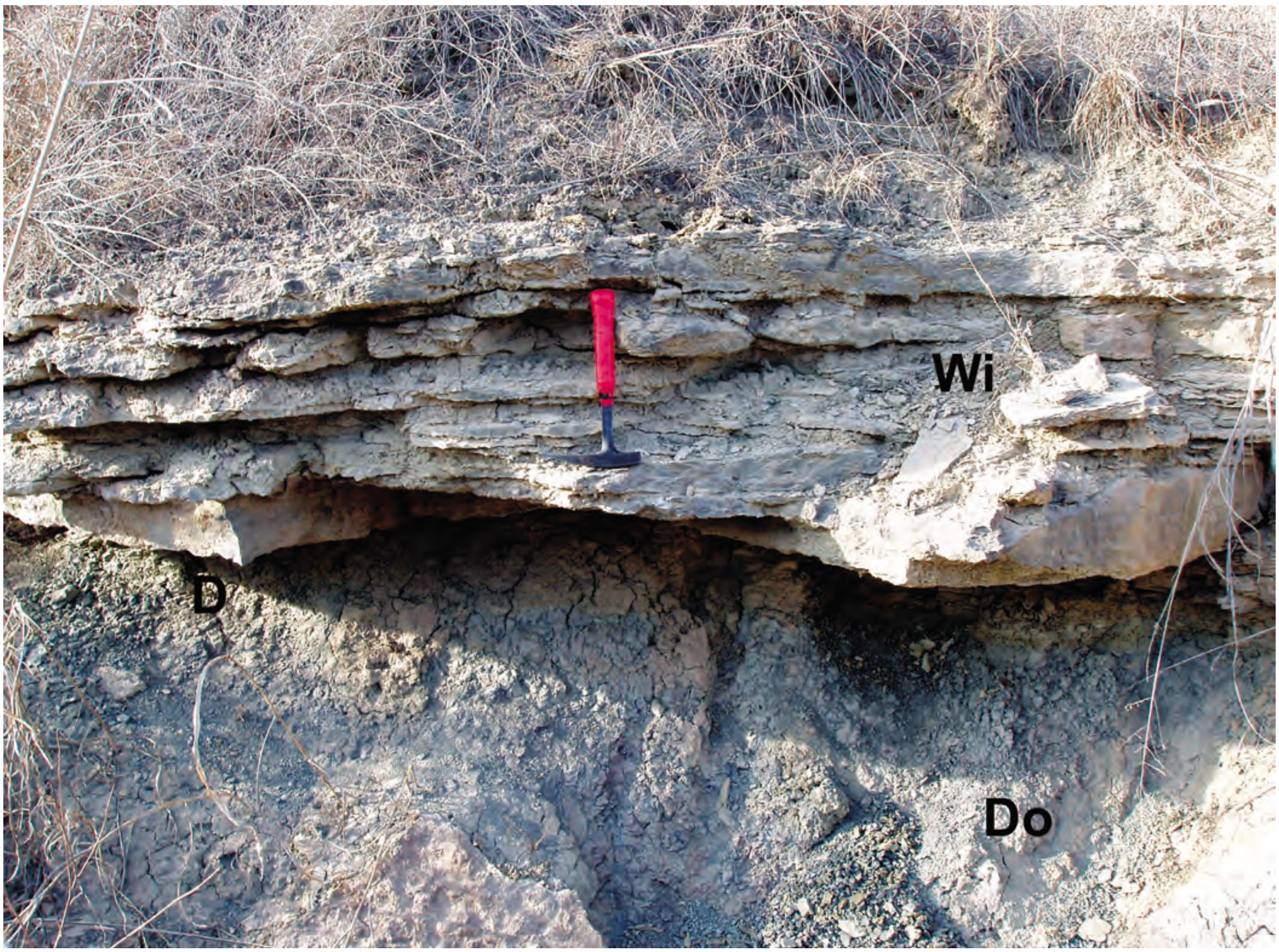

Figure 65. Closeup of contact (discontinuity surface [D]) between transgressive marginal–marine carbonate (Winfield Limestone [Wi]) and terrestrial (Doyle Shale [Do]) facies below that contains fern foliage and woody material.

STOP 8

HIGHWAY 177—COON CREEK SECTION N–2

Location

NW¼SW¼ sec. 14, T. 23 N., R. 2 E., Morrison Northeast 7.5' Quadrangle, Noble County. Along east side of Highway 177 just south of Coon Creek ~.5 mi north of Highway 15 intersection to Red Rock.

Introduction

We will examine ~4 ft of the Nolans Limestone (Herington Limestone Member) and ~12.0 ft of the upper part of the Enterprise/Odell Shale (Fig. 66).

Stratigraphic Significance

Nolans Limestone

<u>Herington Limestone Member</u>

- One of the few exposures of the Herington in the southern outcrop belt (Noble, Pawnee, and Payne Counties).
- Clastic components of carbonate facies significantly increase in frequency and thickness to the south and east.
- Base marks a transgressive surface formed during an initial marine flooding event of a relative sea–level rise.
- Sandy limestone/calcareous sandstone facies of the Herington and sandstone streaks in the Enterprise/Odell Shale suggest the beginning of a major southward facies shift to a more terrestrial influence.

Enterprise/Odell Shale

- Clastic–dominated facies indicates onset of a regression.
- Contains rare pedogenic caliche nodules that probably represent an originally brecciated dolomitic limestone facies.
- The lack of a transitional lithofacies of greenish–gray calcareous mudstone at the top of the Enterprise/Odell Shale suggests a rapid transition to a terrestrial–influenced regime.

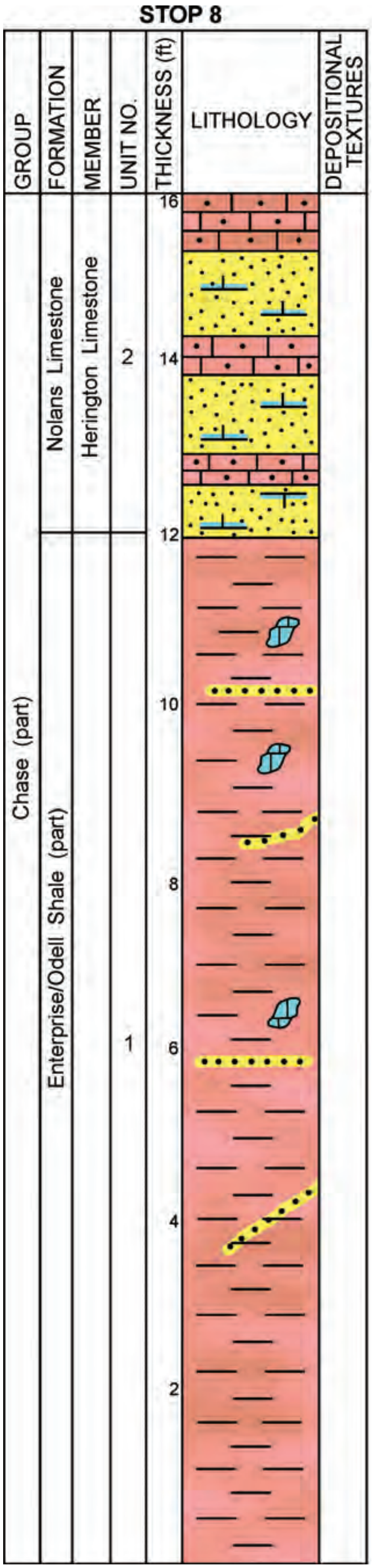

Figure 66. Stop 8. Highway 177—Coon Creek Section N–2

Coon Creek Section N–2

Chase Group (part)

Nolans Limestone (4.0 ft)

Herington Limestone Member (4.0 ft)	Thickness (ft)
2. Limestone; reddish brown, very sandy to calcareous sandstone; interbedded with thin calcareous shale and sandy limestone streaks/lenses; rare algal grains and bioclasts; hematite–stained; calcite veinlets and vugs.	4.0

Enterprise/Odell Shale (part) (12.0 ft)

1. Mudstone/shale, reddish–brown, with sandstone streaks; weathered caliche nodules probably represent an originally brecciated dolomitic limestone; poorly exposed.	12.0
TOTAL	16.0

STOP 9

WATCHORN SECTION PAW–1

Location

SE¼SW¼ sec. 32, T. 23 N., R. 3 E., Watchorn 7.5' Quadrangle, Pawnee County. Roadcut along the north side of section–line road intersection, 4 mi east of Highway 177 and 1 mi north of Highway 15.

Introduction

Approximately 21 ft of the Barneston Limestone and ~5 ft of the upper part of the Matfield Shale is exposed along the north side of the section–line road (Fig. 67).

Stratigraphic Significance

Barneston Limestone

<u>Fort Riley Limestone Member</u>

- Clastic–rich carbonate facies (Fig. 68)
- Soles of beds bioturbated
- Osagid–grains altered to limonite
- Comminuted recrystallized bioclasts (Fig. 69)
- Thickest section of Fort Riley south of Kay County
- Southernmost exposed carbonate facies of the Fort Riley Limestone Member

Matfield Shale

<u>Blue Springs Shale Member</u>

- Poorly exposed clastic–dominated regressive succession of grayish–red to greenish–gray slightly calcareous mudstones/shales.
- Contains thin beds of calcareous siltstones.

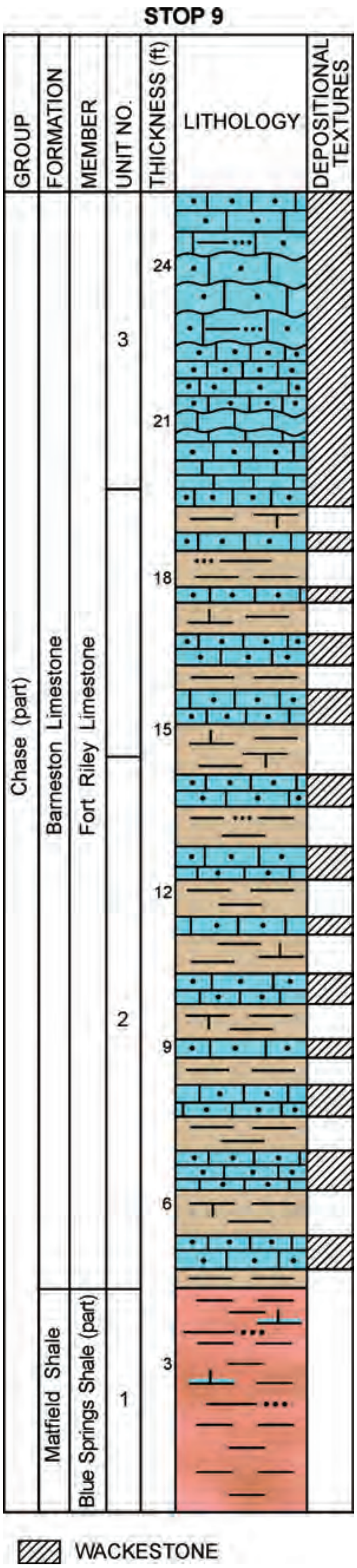

Figure 67. Stop 9. Watchorn Section Paw–1

Watchorn Section Paw–1

Chase Group (part)

Barneston Limestone

Fort Riley Limestone Member (21.0 ft)	Thickness (ft)
3. Limestone (algal skeletal wackestone), brown to grayish–brown, weathers reddish–brown; thin– to rubbly–bedded; silty to sandy; contains comminuted recrystallized bioclasts (chiefly brachiopods, gastropods, and bivalves); weathers to a "rotten" appearance; soles bioturbated; limonitic nodular crust forms on weathered surfaces; algal pellets altered to limonite are common.	6.0
2. Limestone (skeletal wackestone), grayish–brown to grayish–blue; silty to sandy; interbedded with thin shale and limestone beds 4 to 6 in. thick; bioclasts are chiefly molluscan and recrystallized; base poorly exposed.	15.0
Matfield Shale (part) (4.4 ft)	
1. Poorly exposed in drainage ditch; interval consists of grayish–red to greenish–gray shale/mudstone; locally calcareous with thin beds of calcareous siltstones.	4.4
TOTAL	25.4

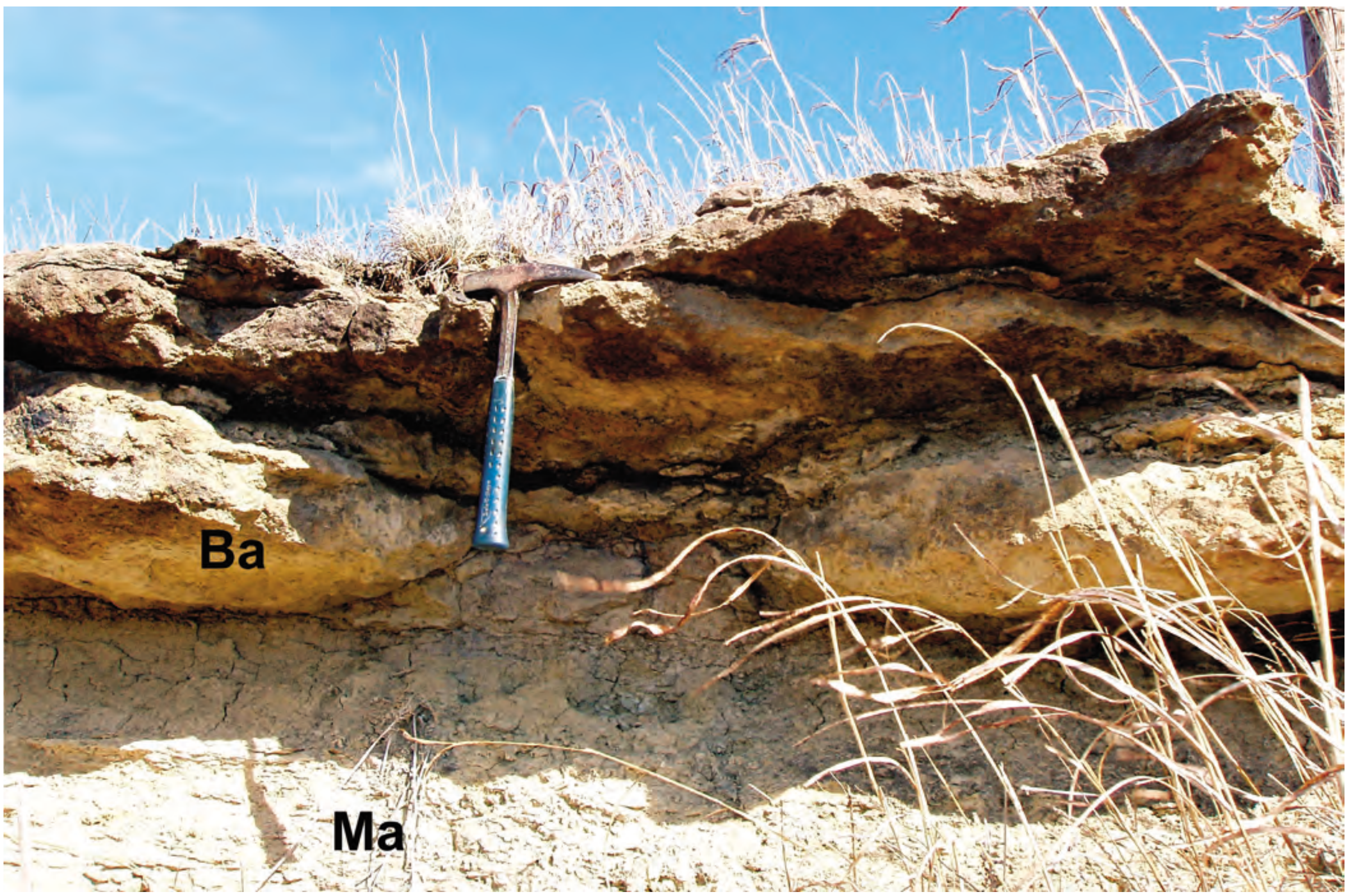

Figure 68. Southernmost exposed clastic–rich carbonate facies of the Barneston Limestone [Ba] underlain by a poorly exposed clastic–dominated regressive succession of slightly calcareous mudstones/shales of the Blue Springs Shale (Matfield Shale [Ma]).

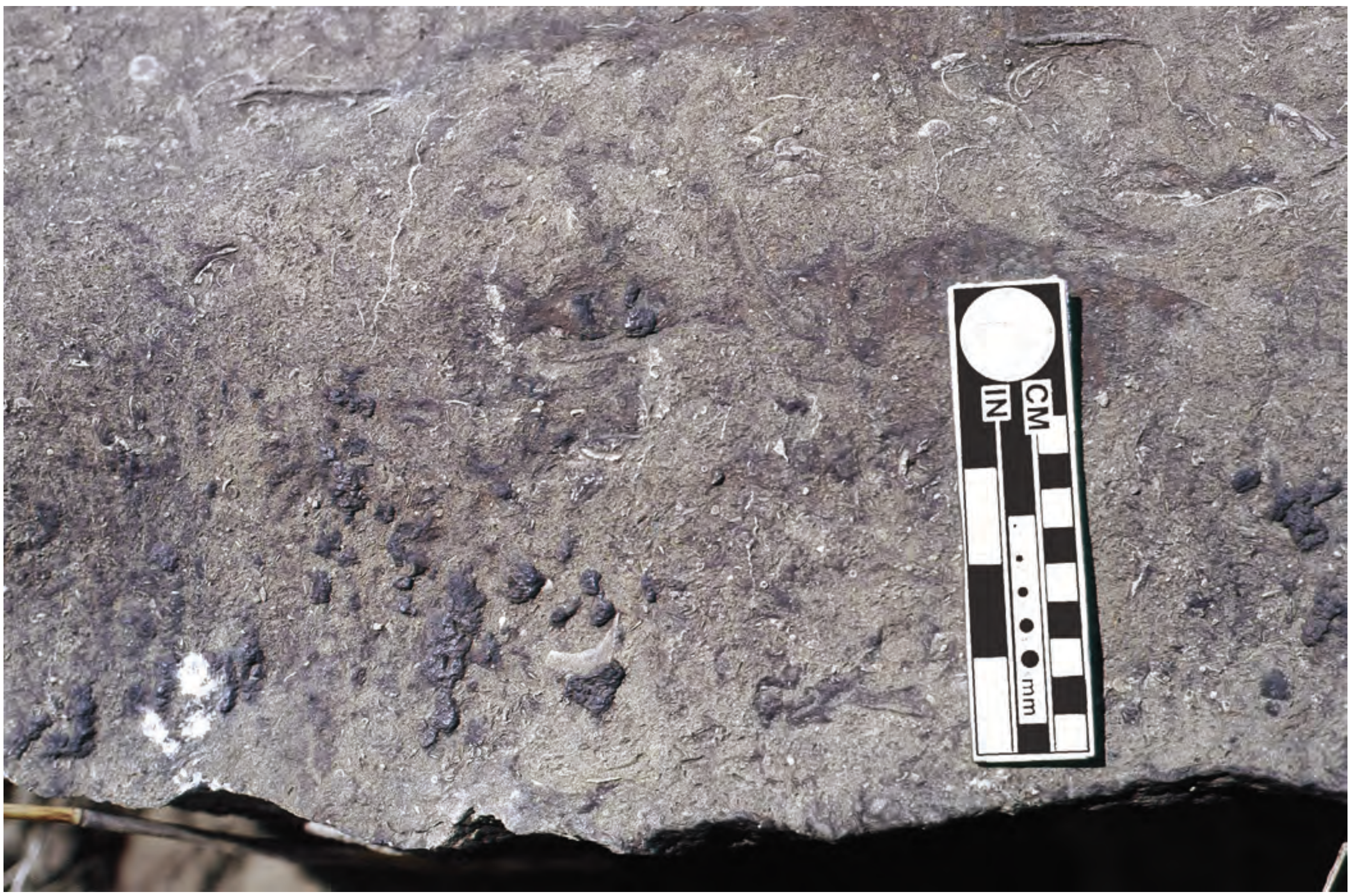

Figure 69. Closeup of sandy carbonate bed in the upper part of the Barneston Limestone that contains marine/marginal–marine fossil hash.

STOP 10
HIGHWAY 15 SECTION PAW–2

Location

NW¼NE¼ sec. 9, T. 22 N., R. 4 E., Masham 7.5' Quadrangle, Pawnee County. Outcrops along north side of Highway 15 ~4.2 mi west of Highway 18 intersection.

Introduction

Approximately 6.5 ft of the Wreford Limestone is exposed, underlain by ~12 ft of the Speiser Shale (Fig. 70). Compare this section with the section (K–12) at Stop 4.

Stratigraphic Significance

Chase Group (lower part)

Wreford Limestone

- Clastic–rich southern facies of the Wreford Limestone (Fig. 71).
- Pedogenically altered shaly limestone (caliche) at base (Fig. 71).
- Contains bivalve (*Myalina*) and brachiopod molds.
- Highly solution pitted, honeycombed outcrop surface suggests the dissolution of a former carbonate–rich lithology (calcareous sandstone) (Fig. 72).
- Approximately .2 mi east of this stop, the Wreford Limestone interval consists of very fine grained, calcareous crossbedded channel sandstones.
- In and south of T. 20 N., the Wreford Limestone pinches out and there is no lithologic criteria on which the Garrison Formation and Matfield Formations, or the Council Grove and Chase Groups, may be separated.
- The upper 4–5 ft of the Wreford Limestone in the southeastern part of the outcrop belt typically consists principally of highly leached calcareous sandstone and sandy limestone.
- Southernmost exposure of the Wreford Limestone in Pawnee County is in the SW¼ sec. 18, T. 22 N., R. 4 E., Watchorn 7.5' Quadrangle, ~1.5 mi south of Highway 15 where it consists of a few inches of nodular red limestone encased in red shale.
- Outcrop in sec. 1, T. 21 N., R. 3 E., Lela 7.5' Quadrangle, Noble County, believed to be correlative with the Wreford Limestone, is the southernmost exposure of the Wreford Limestone.

Council Grove Group

Garrison Formation (upper part)

<u>Speiser Shale Member (upper part)</u>

- Extremely clastic–rich facies.
- Rare weathered sandy caliche nodules suggests pedogenic alteration of original micritic limestone (Fig. 71).
- Rare recrystallized bioclasts and gastropods attest to restricted marine influence.

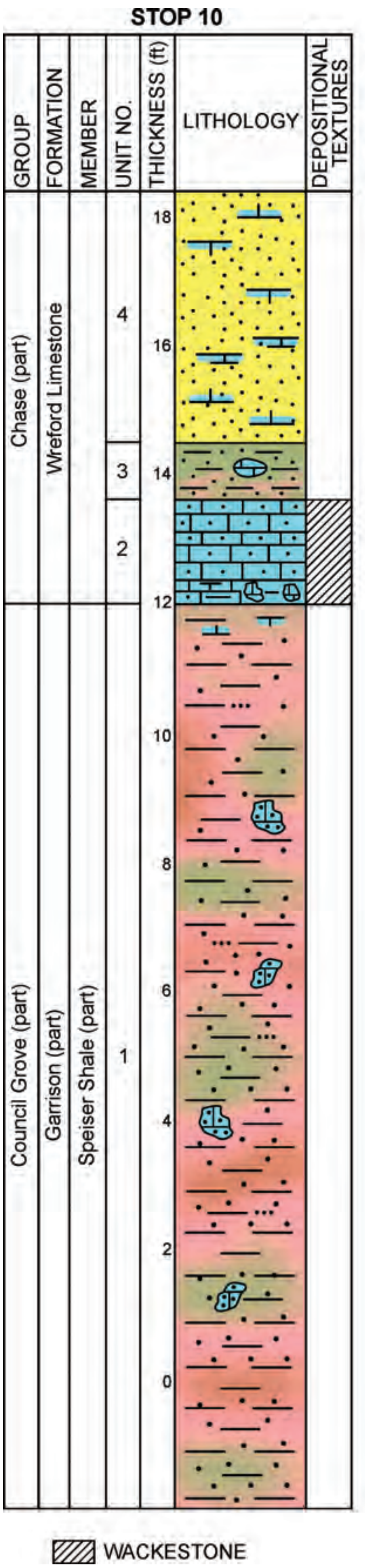

Figure 70. Stop 10. Highway 15 Section Paw–2

Highway 15 Section Paw–2

Chase Group (part)

	Thickness (ft)
Wreford Limestone (6.5 ft)	
4. Sandstone, calcareous to sandy limestone; yellowish–gray, fine–grained with rare very thin limestone lenses/streaks; highly solution pitted weathering to a honeycombed appearance; limonitic– and hematitic–stained surface; slightly fossiliferous with myalinids and brachiopod molds; resistant bed.	4.0
3. Shale, greenish–gray mottled red, sandy; contains small nodules of limestone; horizontal burrows are common.	0.9
2. Limestone (skeletal wackestone), gray to greenish–gray mottled grayish–red, very sandy; rare fossils; leopard–spotted fresh surface; outcrop highly leached with numerous solution pits and channels; calcite–lined vugs/fractures; pedogenically altered calcareous shale/shaly limestone at base (caliche); resistant bed.	1.6
Garrison Formation (12.0 ft)	
Speiser Shale Member (part) (12.0 ft)	
1. Shale, reddish–brown to greenish–gray mottled; silty to very sandy; contains calcareous sandstone/ sandy limestone caliche nodules, some highly weathered and crumbly; fossiliferous with rare gastropods; calcite veinlets; grayish–pink recrystallized bioclasts; contains some limonitic stringers/vugs.	12.0
TOTAL	18.5

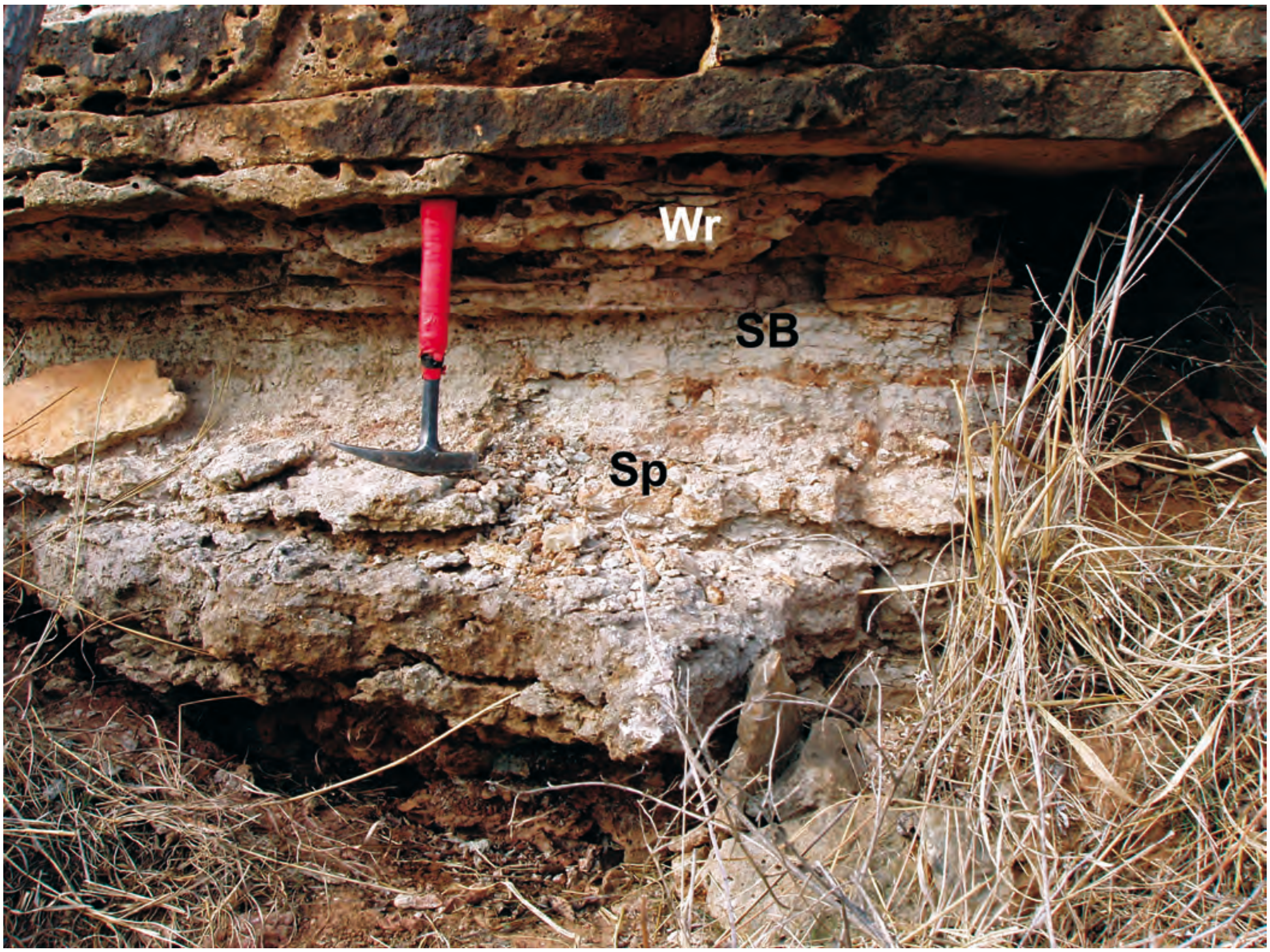

Figure 71. Clastic–rich facies of the Speiser Shale [Sp] with pedogenic features overlain by clastic–rich southern facies of the Wreford Limestone [Wr]. Note pedogenically altered shaly limestone (caliche) at base of the Wreford Limestone. SB = sequence boundary.

Figure 72. Honeycombed outcrop surface in the Wreford Limestone produced by intense solution pitting suggests dissolution of a former carbonate–rich lithofacies.

STOP 11
LONG BRANCH SECTION N–3

Location

SW¼SW¼SW¼ sec. 31, T. 21 N., R. 3 E., Stillwater North 7.5' Quadrangle, Noble County. Section is located along the north side of an east–west section–line road ~2 mi east of Highway 177 on the Noble/Payne County line.

Introduction

We will examine ~18 ft of section comprised of the uppermost part of the Doyle Shale (Gage Shale Member) and the lithologic equivalent of the Winfield Limestone (Fig. 73). The main occurrences of carbonates comprising the Chase Group in southernmost Noble County and Payne County consist of discontinuous lenses of sandy nodular dolomite, and dolomite–impregnated mudstone nodules (Fig. 17). The unfossiliferous nodular micritic limestone facies of the Winfield Limestone can be traced southward from southern Noble County into central Payne County where the formation is less than 1 ft thick and consists of red, sandy dolomite or micritic limestone nodules (Fig. 17).

Dolocretes (calcitic pedogenic carbonate nodules in the southern facies (i.e., Noble, Pawnee, and Payne Counties) were precipitated in an emergent, vertic soil formed in a marginal–marine setting. Minor, local transgressions resulted in the precipitation of thin dolomite horizons in a supratidal, evaporite environment. Downward percolation of Mg–rich solutions through the soil profile accompanied dolomite formation, and caused *in situ* dissolution and reprecipitation of the original pedogenic carbonate as dolomite.

Billings (1956) reported 6 in. of dolomite ~7 ft below the lowest sandstone in the Enterprise/Odell Shale of southern Noble County, and he correlated this dolomite to the Winfield. Shelton et al. (1985) used the escarpment of an underlying sandstone and inferences from well control to determine the stratigraphic position of the Winfield Limestone in Payne County.

The Winfield Limestone facies pinches out south of Black Bear Creek in sec. 1, T. 21 N., R. 2 E., in southern Noble County. In the absence of the carbonate facies (Winfield), the siliciclastics above (Enterprise/Odell Shale) and below (Doyle Shale) are mapped together as one undivided lithologic unit.

Stratigraphic Significance

Winfield Limestone

- Southernmost exposure of the Winfield Limestone in northern Oklahoma.
- Carbonate–rich Winfield facies of the northern outcrop belt is now much thinner and much more siliciclastic–rich (Fig. 74).
- Channel–like geometry of the Winfield sandstone facies.
- Parallel– to cross–laminated beds.
- Conglomeratic texture of lens–shaped bodies of very algal–rich sandy limestone (Fig. 75).
- Some rare nodules show “boxwork” structures.
- Overall dominance of red color and siliciclastic influx.
- Restricted marine to dominantly terrestrial red–bed clastics undergoing periodic subaerial exposure.

Doyle Shale

<u>Gage Shale Member (upper part)</u>

- Pedogenic features in the weakly developed paleosols include:
    1) Brecciated nodules that are highly dissimilar in shape and size;
        - Nodules are probably due to the presence of carbonate–impregnated mudstone aggregates that resulted from the *in place* displacive and disruptive effects of pedogenic calcite/dolomite precipitation—perhaps in the initial stages of soil nodule formation on a terrestrial paleosurface.
    2) Coarse, blocky spar–filled vugs/voids in micritic carbonate nodules;
    3) Mudstone–filled fractures;
    4) Desiccation features (i.e., “boxwork” structures);
    5) Horizons of intergrown carbonate nodules with small amounts of interstitial calcareous, silty clay (paleosol host) filling large irregular voids: the carbonate phase is micritic and yel-

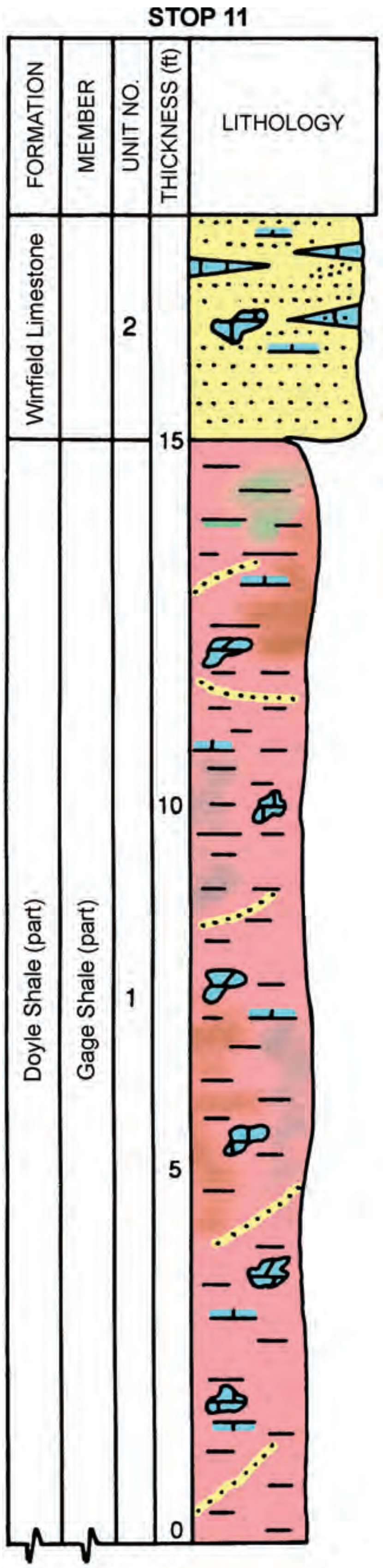

Figure 73. Stop 11. Long Branch Section N–3

Long Branch Measured Section N–3

Chase Group (part)

	Thickness (ft)
Winfield Limestone (3.0 ft)	
2. Sandstone, reddish–brown to grayish–red, micaceous, very fine grained, very friable, hematitic; calcareous in some places; parallel– to cross–laminated; very thin bedded in lower part (<1 in. thick) to thick–bedded (1–4 in. thick) in upper part; includes isolated dark–gray shale clasts; upper part with nodules and lens–shaped bodies of very algal, sandy limestone (osagite) with conglomeratic–like texture; some nodules show desiccation cracks ("boxwork" structures); some shaly sandstone intervals; bioturbated; channel–like geometry; thickness varies laterally; base irregular, erosional.	3.0
Doyle Shale (part) (15.0 ft)	
Gage Shale Member (part) (15.0 ft)	
1. Mudstone/shale, grayish–red reddish–brown with intercalations of greenish–gray, especially in upper part; calcareous, sandy intervals; includes very abundant, pinkish–gray, grossly "vase"–, "cauliflower"–, "cabbage"–shaped carbonate nodules containing crinkly phylloid algae and osagid grains; some nodules are dolomitic with faint birdseye fabric and show desiccation features ("boxwork" structures); many nodules laced with sandstone–filled veinlets; some nodules contain spar–filled vugs; scattered streaks of very fine grained sandstone throughout interval; rare bioturbation; no fossils observed; base poorly exposed.	15.0
TOTAL	18.0

Figure 74. Thinner and much more siliciclastic–rich than in the northern outcrop belt, channel–like calcareous sandstone facies of the Winfield Limestone [Wi] is underlain by the Gage Shale Member of the Doyle Shale [Do]. Facies contains stringers and lenses of marginal–marine bioclasts.

Figure 75. Lens of conglomeratic limestone in calcareous sandstone facies of the Winfield Limestone.

lowish–gray, the silty clay is greenish–gray with some reddish–gray mottling.

- Dominant pedogenic characteristics of the paleosols (most importantly the accumulation of carbonate in the form of nodules) suggest an overall dry climate (e.g., semiarid or dry subhumid).
- The terminal event in the formation of the weakly developed paleosol was the gleying of the uppermost part of the mudstone package presumably by the onset of a marine transgression.

Questions?

Do the discontinuous lenses of limestone/dolomite nodules represent the erosion and/or weathering of original tidal–flat carbonates (i.e., poorly developed transgressive limestone) and their redeposition in tidal–creek/channel settings?

OR

Do they represent pedogenic processes (i.e., displacive and disruptive effects of pedogenic dolomite precipitation) associated with the initial stages of paleosol development on a terrestrial paleosurface?

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OGS Celebrates 100 Years of Service 1908 — 2008

The Oklahoma Geological Survey has the distinction of being the only geological survey provided for in a state constitution. The legislative mandate is to:

> *Investigate the state's land, water, mineral and energy resources and disseminate the results of those investigations to promote the wise use consistent with sound environmental practices.*

Governor Charles N. Haskell signed the Enabling Act: The OGS began work on May 29, 1908

The basic mission then as now is research, field work, and mapping to produce reports and maps that add to the body of knowledge about Oklahoma's geology and resources. In cooperation with academia and industry, this information is printed, disseminated in workshops, provided over the internet, and made public through contact with individuals, schools, scout and civic groups.

Charles Newton Gould, Father of Oklahoma Geology Director, 1908–1911 and 1924–1931

When he came to OU in 1900, drive, determination and relentless energy made Dr. Charles Newton Gould the perfect person to found OU's geology program and, in 1907, to foster in the State Constitution which would become the Oklahoma Geological Survey.

Gould saw the need to blend academics, industry concerns, and public needs in a single research and public service agency that would bring together these areas to better serve Oklahoma. His actions and vision provided the foundation for Survey programs for the next 100 years.

Gould went into the oil industry in 1911, becoming one of the pioneering geologists to work in Oklahoma. He returned to the Survey, however, when needed in 1924.

Daniel W. Ohern, Director, 1911–1914
Charles W. Shannon, Director, 1914–1923

Because basic reconnaissance work still was needed, investigations of oil and gas, coal, glass sand, building stone, gypsum, lead and zinc, water, and building materials resulted in a number of publications and maps. The first full–color map of Oklahoma was issued in 1926.

Shannon noted that "The need of conservation is apparent to members of the Survey," and pointed to wastes of coal, oil, natural gas, forests and animal life. The Geological Survey still is mindful of the legislative mandate to conserve Oklahoma's natural resources and promote their wise use.


Charles Gould, right, and Survey Field Party.

Robert H. Dott, Director, 1935–1952

Dott's Survey focused on non–fuel mineral resources suitable for manufacturing and worked to develop new uses for some of the most mundane resources, Dott's "humble materials." Manufacturing added monetary value to the resource, such as making pottery, tile and brick from clay.

He saw the OGS through the depression era and World War II and, in 1935, conducted a state mineral survey that hired people to verify information for base maps, collect data on building materials, and examine industrial mineral deposits. The information and the jobs were much needed.

William E. Ham, Interim Director, 1952–1954
Carl C. Branson, Director, 1954–1967

Branson made significant contributions to the University of Oklahoma Geology Library. This effort continues today through a cooperative exchange program between the OGS and other agencies worldwide. The publications given to the OGS are donated to the Youngblood Geology Library.

Charles J. Mankin, Director, 1967–2007

During Mankin's years, the OGS became more involved in cooperative studies with many state and federal agencies, and concentrated on oil and gas activities that would help the small producers in Oklahoma. In 1978, a geophysical observatory southeast of Tulsa was added to the Survey. The Oklahoma Petroleum Information Center in Norman opened in 2002 and, in 2006, the OGS officially became affiliated with The University of Oklahoma's Mewbourne College of Earth and Energy.

G. Randy Keller, Director, 2007–present

Keller, a professor of geophysics at OU, came to the Survey to assist in operations after Mankin's retirement. His interest and enthusiasm for the OGS mission is evident. As ever, the Survey's goals remain *wise use and conservation.*