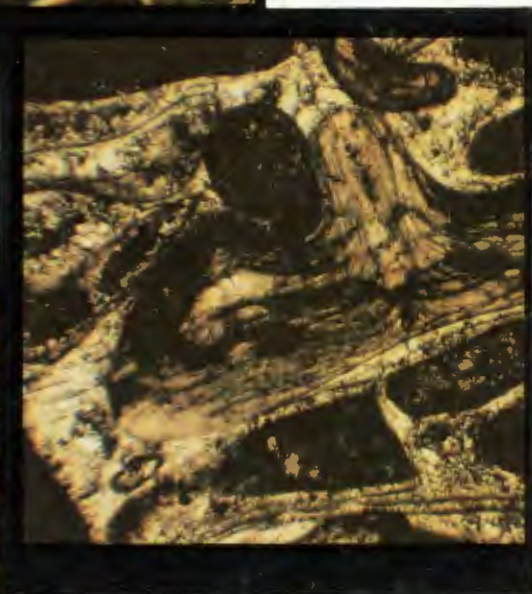
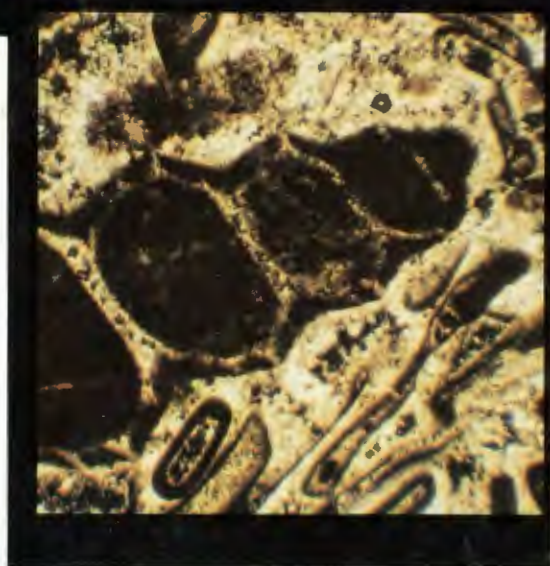


Petrographic Characteristics of Kansas Building Limestones



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Susan Ward Aber and David A. Grisafe

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By

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Susan Ward Aber¹ and David A. Grisafe²

Petrographic Characteristics of Kansas Building Limestones

ABSTRACT

Thin sections of eight different Kansas building limestones, taken from current quarry sites, were studied parallel and perpendicular to their bedding plane. A comparison of the resulting data shows that considerable variations in the petrographic characteristics occur among these limestones.

The Five Point Limestone in northeastern Pottawatomie County is a highly fossiliferous, medium- to coarse-grained packstone with color varying from brownish-yellow to pinkish-gray and possessing around seven percent porosity. In Riley County the Neva Limestone is a fine- to medium-grained, pellet-bearing wackestone with a light gray color. It is divided into hard and soft ledges, with porosities of less than one and two percent, respectively; the latter ledge contains three times as many opaques as the former. The light gray Cottonwood Limestone in Chase County is divided into upper and lower ledges. The upper bed is a fine- to medium-grained fusulinid wackestone with five percent porosity, while the lower bed is a fine-grained wackestone with less than one percent porosity. In eastern Pottawatomie County, the Funston Limestone is a fine- to medium-grained wackestone with a light buff-gray color and 12 percent porosity. The Fort Riley Limestone in southern Cowley County is a fine- to medium-grained algal wackestone packstone with a light brownish-yellow color and five percent porosity. The Cresswell Limestone in Cowley County is a very fine grained, burrowed, pellet-bearing wackestone that is nearly white in color and has less than one percent porosity.

INTRODUCTION

PURPOSE

This report is a detailed examination of the petrographic characteristics of several Kansas building limestones collected from local quarry operators. This petrographic study is a portion of a larger project, being conducted at the Kansas Geological Survey, that deals ultimately with obtaining a better understanding of the weathering of building stone. The overall project is divided into four parts. Part one (Grisafe, 1976) gives an overall view of Kansas building limestone including history, quarrying and processing, advantages, and various uses of building limestone. Part two, the initial petrographic examination of building stone in Kansas, is reported here. Part three will be a determination of chemical, mineralogical, and physical properties unique to each stone as well as the durability response to artificial weathering tests. The conclusion of the overall project, part four, will be a correlation of petrographic, chemical, mineralogical, and physical properties of building limestone to obtain a better understanding of weathering

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processes and to determine whether petrographic studies alone can be used to estimate the stone's properties and quality.

LOWER PERMIAN SERIES—GEARYAN STAGE

The limestones currently quarried in Kansas for use as building stone are the Five Point Limestone Member, the Neva Limestone Member, the Cottonwood Limestone Member, the Funston Limestone Formation, the Fort Riley Limestone Member, and the Cresswell Limestone Member (Fig. 1). These Kansas building stones are from the Gearyan Stage of the Lower Permian Series, and crop out in Kansas in a narrow band extending from Marshall, Nemaha, and Brown counties on the north to Cowley County on the south. Figure 2 illustrates the outcropping Gearyan Stage rock plus locations of current building stone quarries and fabricating plants.

In Kansas, Lower Permian rocks are subdivided into two stages: Gearyan (older) and Cimarronian (younger) (Zeller, 1968). The Gearyan Stage is approximately 240 m (790 ft) thick and consists of limestones interbedded with shales plus a small amount of gypsum. For the most part, the Lower Permian strata dip gently west or north-westerly at about 3 to 6.4 m/km (15-35 ft/mi) (Risser, 1960). These Lower Permian limestones are fine to coarse grained in texture and are a variety of light colors. Some of these limestones contain chert. Because of chert's hardness and brittleness, such limestones are difficult to cut and machine, causing the rock to be undesirable as a building material. A list of currently used stone, as well as sample locations for this study, is given in Table 1.

Admire Group

The oldest group in the Gearyan Stage is the Admire Group (Fig. 1). This group in Kansas consists primarily of clastics (mostly shale) plus thin beds of limestone and coal (Risser, 1960). The Five Point Limestone Member is located in the Janesville Formation of the Admire Group (Fig. 1). This member ranges from 0.3 to 4 m (1-13 ft) thick and is made up of one or two limestone beds separated by a gray to dark gray shale that thickens from north to south (Zeller, 1968). In northern Pottawatomie County, where it is quarried, the upper portion of this

limestone, commonly 0.5 to 1 m (1.5-3.0 ft) thick, varies from brownish-yellow to pinkish-gray in color and is a coquina. This coquina facies is referred to as the Chestnut Shell by stone producers because of its sometimes light chestnut color and high shell content. The Chestnut Shell forms a distinguishable but not prominent hillside ledge. The rock is easily quarried with a front end loader and is quite popular because of its unique and interesting texture. The quarry for the Chestnut Shell is in Pottawatomie County, Sec. 12, T.6S, R.10E.

Council Grove Group

Above the Admire Group are approximately 95 to 100 m (310-330 ft) of limestone and shale of the Council Grove Group (Fig. 1). The Neva Limestone Member of the Grenola Limestone Formation, the Cottonwood Limestone Member of the Beattie Limestone Formation, and the Funston Limestone Formation are all quarried from this group (Fig. 1).

The Neva Limestone Member is the lowermost limestone of the Council Grove Group used for building stone. The Neva Member consists of light gray limestone beds interbedded with gray to grayish-green shales with an overall thickness of 2.7 to 8.5 m (9-28 ft) (Zeller, 1968). The two groups of samples studied here are called soft Neva and hard Neva by stone producers.

The basal bed, 0.1 to 1.1 m (0.3-3.5 ft) thick, is a gray limestone that is overlain by about 1 m (3 ft) of silty, calcareous, medium to dark gray shale. Above this is the middle, massive, gray limestone bed, 0.5 to 4 m (1.5-13 ft) thick. The hard and soft Neva appear to be quarried from this middle bed. A gray to grayish-green fossiliferous shale approximately 1 m (3 ft) thick separates the middle bed from the upper bed. The upper limestone is a gray, fossiliferous bed, 0.2 to 2 m (0.7-6.5 ft) thick (Zeller, 1968). The Neva is locally very hard, highly laminated, and dense (in some cases with a "marble-like" appearance), making it expensive to cut and work in certain areas (Risser, 1960). The Neva is often used in residential building, primarily as a rubble or split face. This limestone is quarried only south of Manhattan in Riley County, Sec. 29, T.10S, R.8E. At this site there is approximately 0.3 m (9-12 in) of hard Neva overlain by the same thickness of soft Neva. Above and below this

TABLE 1. Stratigraphic information and sample locations of currently quarried Kansas building limestones. All limestones are members or formations of the Gearyan Stage, Lower Permian Series.

GEOLOGICAL GROUP	GEOLOGICAL NAME	LOCAL OR INDUSTRY NAME	COUNTY	SECTION-TOWNSHIP-RANGE		
Admire	Five Point	Chestnut Shell	Pottawatomie	12	6S	10E
Council Grove	Neva	Neva	Riley	29	10S	8E
	Cottonwood	Cottonwood	Chase	12	19S	6E
	Funston	Onaga	Pottawatomie	15	7S	12E
Chase	Fort Riley	Silverdale	Cowley	3	35S	5E
	Cresswell	Winfield	Cowley	11	33S	4E

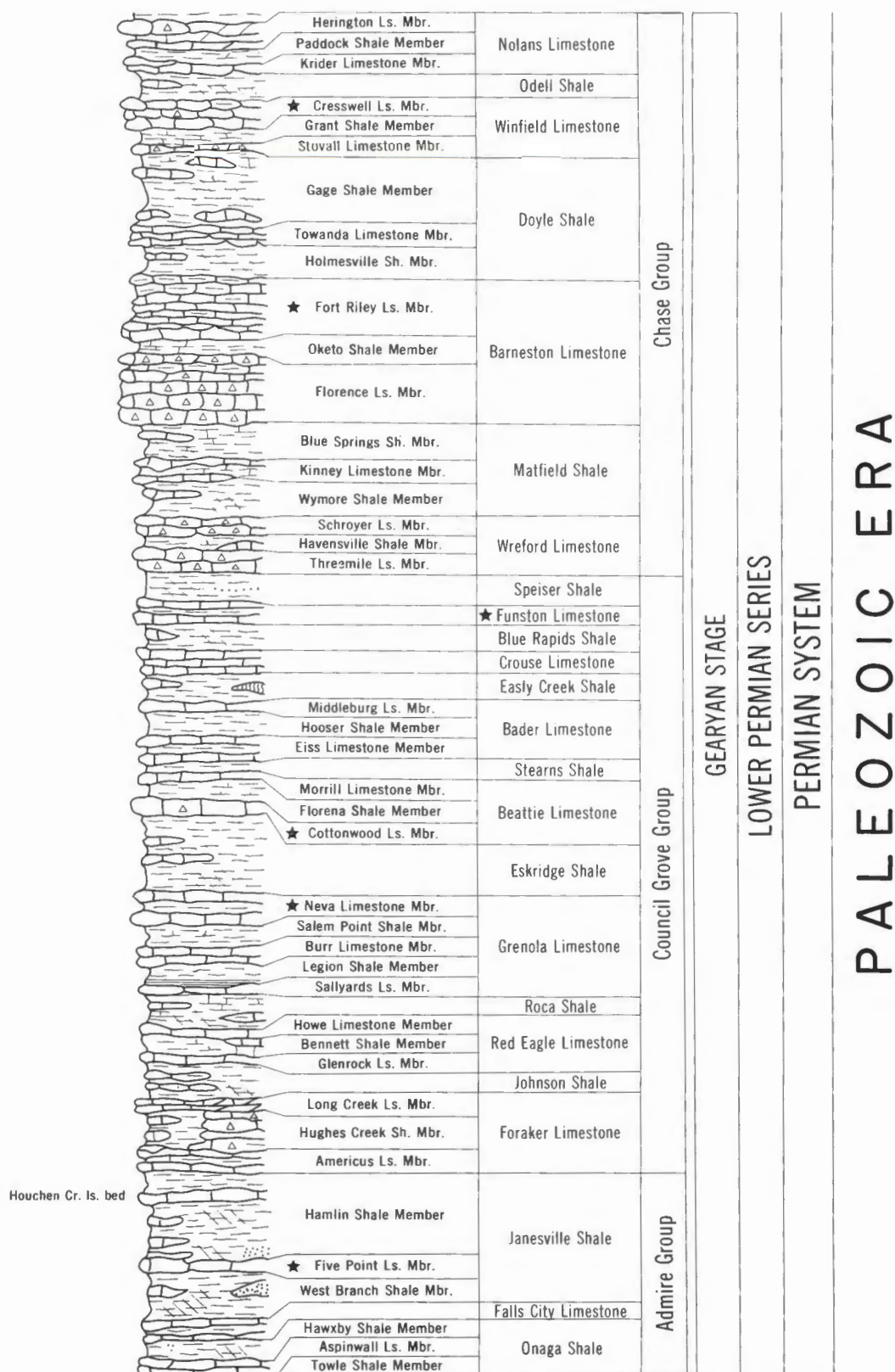


FIGURE 1. Stratigraphic succession of a portion of the Lower Permian sequence in Kansas (Zeller, 1968). Stars indicate Kansas limestones that are currently used for the construction of buildings.

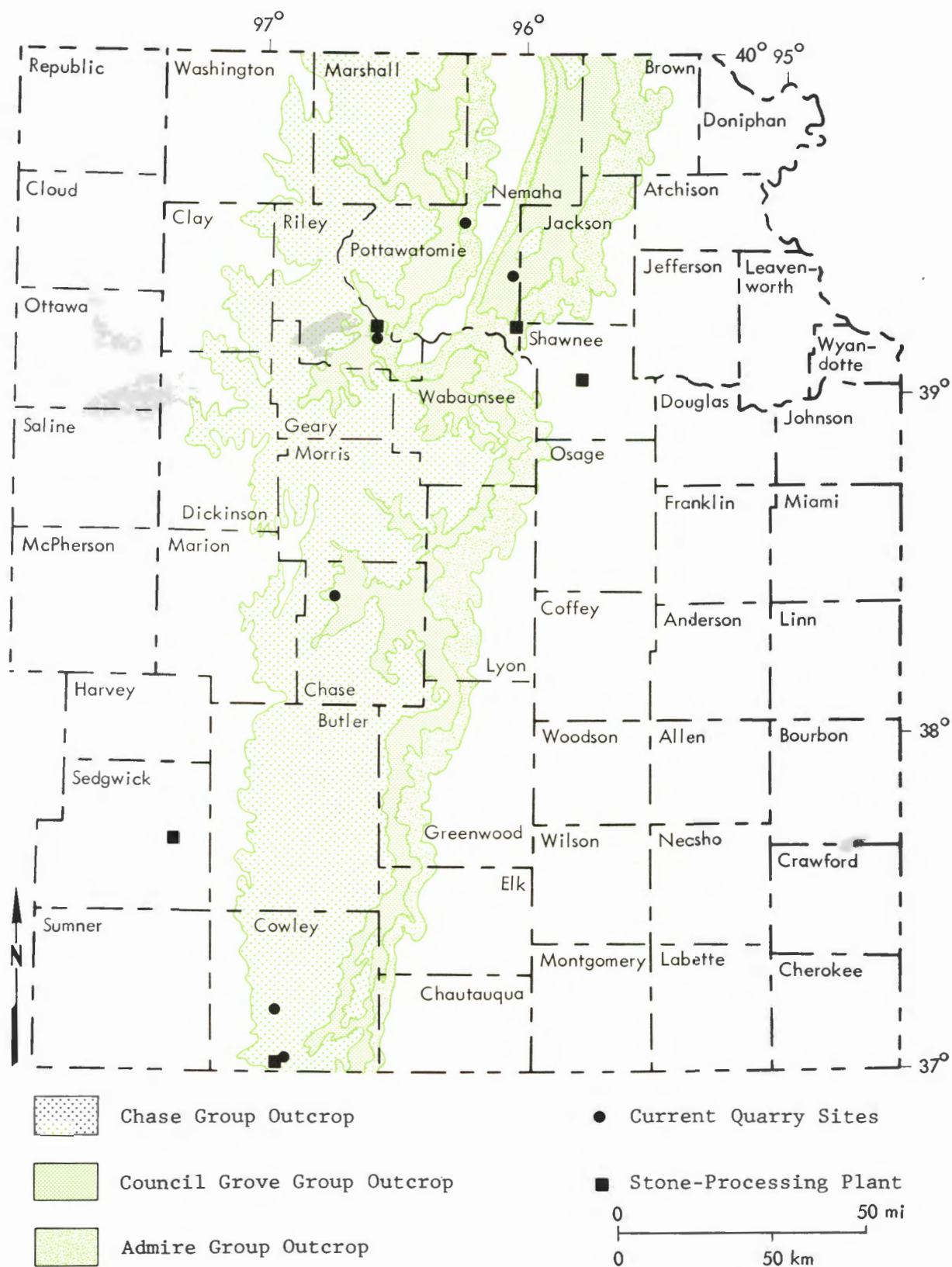


FIGURE 2. Locations of Gearyan Stage (Lower Permian) outcrops in eastern Kansas, current building limestone quarry sites, and stone-processing plants.

zone of building stone lie 1.5 m (4-5 ft) of Neva Limestone that is suitable for crushed rock applications.

The Neva Limestone Member and the overlying Cottonwood Limestone Member appear parallel to one another in outcrop (Risser, 1960), separated by the Eskridge Shale Member. The outcropping Cottonwood is recognized either as loose blocks or as a prominent bench with a fringe of shrubs along the outcrop. In many places, the Cottonwood contains layers of chert nodules, but chert is less prominent in Chase County where the rock is actively quarried today.

Except for becoming thin and shaly to the south, the Cottonwood is almost uniformly 1.5 to 2 m (5-6 ft) thick and contains two or more beds. Between southeastern Nebraska and northern Oklahoma, Laporte (1962) recognized five distinct facies in the Cottonwood: bioclastic, fusulinid, platy algal, shell, and silty *Osagia* facies. In the north-central part of Chase County, the Cottonwood Limestone is divided into lower and upper beds, corresponding to Laporte's bioclastic and fusulinid facies. Both beds were examined because both are used for building construction. The upper bed is characterized by its wheat-shaped fusulinids and obvious porosity while the lower bed appears as a denser fine-grained stone with a diverse fauna. The two beds are called the upper and lower Cottonwood by stone producers, all of whom quarry their stone in Chase County. The Cottonwood is light gray in color, weathering to almost white. It has been studied often and is a very popular building stone in Kansas (Laporte, 1962; Mudge and Yochelson, 1962; Risser, 1960). At the quarry site in Chase County, Sec. 12, T.19S, R.6E, both the upper and lower beds are approximately 0.7 m (2-2.5 ft) thick.

In the Council Grove Group the uppermost limestone used for building stone is the Funston Limestone Formation. The main limestone bed of the Funston is commonly called the Onaga limestone because it is quarried extensively near Onaga, Pottawatomie County, Kansas. The Onaga is a light gray to buff-gray limestone, locally cherty, separated into an upper and lower bed by a gray to yellowish-gray, fossiliferous shale. There is some vertical variation in color, texture, and hardness within the formation (Risser, 1960). The lower portion weathers darker in color, is softer, and is more porous than the upper. The Onaga occurs on the surface as loose blocks. The main bed is commonly 0.6 to 0.8 m (2-2.5 ft) thick (Risser, 1960), but the entire Funston Limestone Formation has been reported as ranging from 1.5 to 7.6 m (5-25 ft) thick (Zeller, 1968). In northeastern Pottawatomie County, where it is currently quarried, the main bed of the Funston Limestone is relatively free of chert, approximately 1.5 m (5 ft) thick, and easily cut and worked. It is used for residential structures as well as commercial buildings. As shown in Table 1, samples for testing came from the current quarry operation, Sec. 15, T.7S, R.12E.

Chase Group

The uppermost group of the Gearyan Stage is the Chase Group. This group forms prominent escarpments of limestone in the Flint Hills. It is approximately 102 m (335 ft) thick and consists of cherty limestones interbedded with brightly colored shales (Zeller, 1968). The Fort Riley Limestone Member of the Barneston Limestone Formation and the Cresswell Limestone Member of the Winfield Limestone Formation are both quarried as building stones.

Capping the western part of the Flint Hills is the Barneston Limestone Formation, with a thickness of 24 to 27 m (80-90 ft) (Zeller, 1968). This formation is composed of two thick limestone members separated by a thin shaly member (locally clay) (Zeller, 1968). The upper limestone member is a light gray, massive to thin-bedded limestone called the Fort Riley. This member ranges from 9 to 13.5 m (30-45 ft) thick (Risser, 1960). Although more than one bed within the unit appears usable, a massive 1.2 to 1.7 m (4-5.5 ft) ledge near the base of the Fort Riley appears to be most suitable for dimension stone. The Fort Riley, quarried at many sites in Cowley County, is called Silverdale limestone after the town of Silverdale, Kansas, where all current quarries and a processing plant are located. The Silverdale is fine grained and has a very uniform texture. Because this limestone is resistant to weathering and is overlain by less resistant shale, the massive limestone layer found near the tops of hills has little overburden, which is easily removed by bulldozers. Samples studied came from a quarry in Cowley County, Sec. 3, T.35S, R.5E.

The Winfield Limestone Formation, approximately 7.6 m (25 ft) thick, consists of the Cresswell (upper) and Stovall (lower) Limestones. Both limestone beds may be locally cherty, and through most of the State they are separated by gray, fossiliferous Grant Shale. When freshly fractured or smoothly surfaced, the Cresswell Limestone Member is nearly white in color. The Cresswell Member can be divided into a lower layer that is massive and sometimes fossiliferous and a middle to upper layer that is locally shale. This lower, massive layer is about 1 m (3 ft) thick until south of Butler County where it splits into two massive beds separated by a thin calcareous shale (Zeller, 1968). In southern Cowley County, the shale disappears and the lower Cresswell becomes a single bed approximately 3.5 m (12 ft) thick that can be seen outcropping near the tops of hills west of Silverdale, Kansas. A 3 m (10 ft) exposure can be seen along a road cut 4 km (2.5 mi) west of Silverdale. The Cresswell Limestone is a very popular building material in the Wichita/Winfield area. Samples were produced from a quarry in Cowley County, Sec. 11, T.33S, R.4E.

PROCEDURE

From their currently quarried limestones, quarry operators supplied cubes measuring approximately 5 to 6.5 cm (2-2.5 in) in length. To minimize variation, the cubes for a given limestone were all to be cut from a single slab parallel to the bedding plane. Eight thin sections (four parallel and four perpendicular to the natural bedding plane) were prepared from four randomly selected cubes out of a total of about 200 cubes each of Fort Riley (Silverdale) and Funston (Onaga) Limestones. From three randomly selected cubes out of about 130 samples each of Cottonwood (upper and lower beds), Cresswell, Neva (hard and soft), and Five Point (Chestnut Shell) Limestones, six thin sections were prepared (three parallel and three perpendicular to the natural bedding plane).

The following descriptions are based on the microscopic study of these samples and supplemented by information from previous investigations. Some of the major previous studies are Laporte (1962), Lane (1964), and Mudge and Yochelson (1962). Because limestone varies both laterally and vertically, these descriptions are limited to the samples discussed above and to the specific quarry from which they were taken.

The porosity classification of Choquette and Pray (1970) was used in the following descriptions. Thin sections were point-counted for porosity, grains, cement/micrite, and miscellaneous (mainly opaque minerals). At least 400 points were counted for each slide. Grain constituents were identified and the size, shape, and percentage of each grain type were estimated visually. Minimum and maximum dimensions for every pore were measured using an eyepiece micrometer. Because of irregular pore shape, the procedure followed was to first measure the minimum diameter, turn the stage 90 degrees, and measure the maximum diameter, a procedure described by Griffiths (1967) for grain shape measurements. The pore size was determined under 35 \times magnification and double-checked under 100 \times magnification when possible. Tables of pore-size distribution (see Appendix A) are based on the maximum diameter in millimeters, and tables of pore-shape distribution utilize a ratio of the maximum to minimum diameter.

The Dunham (1962) classification for limestones was used in the petrographic descriptions. Horowitz and Potter (1971) and Scholle (1978) were frequently used as an aid in identifying the petrographic constituents of the limestones.

PETROGRAPHIC DESCRIPTIONS

THE FIVE POINT LIMESTONE MEMBER

Description: The Chestnut Shell limestone is a poorly sorted, medium- to coarse-grained packstone that has a light gray (10YR 7/2) to pinkish-gray (7.5YR 7/2) background color. The overall appearance of the stone usually ranges from a pinkish-gray to brownish-yellow. A variety of grain and cement colors is present: brownish-yellow (10YR 6/6), light yellowish-brown (10YR 6/4), very pale brown (10YR 7/3), reddish-yellow (7.5YR 6/6), yellowish-red (5YR 5/6), yellow (10YR 7/6), light gray (10YR 7/1, 7.5YR 7/1), and white (10YR 8/1). Although the coquina texture often masks the natural bedding planes, they are sometimes apparent in hand specimen and under the microscope.

Each Chestnut Shell slide was point-counted for four categories: grain, cement/micrite, pore space, and miscellaneous. The point-count results averaged 23.5 percent grain, 68.6 percent cement/micrite, 6.5 percent porosity, and 1.4 percent miscellaneous (see Table 2). The petrographic constituents of the Chestnut Shell are itemized in Table 3.

Micritic envelopes are quite common throughout the Chestnut Shell (Fig. 3). Phylloid algal blades are present in abundance and can be identified because of their preservation by micritic envelopes. Thick encrusting algae are coating some of the grains, often making grain identification impossible. Some zones of encrusting algae are a dark red and contain minute opaques, indicating the presence of hematite. Such zones are pronounced under reflected light. Punctate productid brachiopod fragments are common, some with spines still attached (Fig. 4). Concentric, parallel-fibrous inner layers of brachiopod spines are preserved while the outer radial-fibrous wall is replaced by coatings or encrustations (Fig. 5). The hollow central canals of the spines are filled with micrite. Overall, the spines are spherical and medium sand-sized. Dark, spherical, silt- to sand-sized grains showing no internal structure are peloids. These are common throughout the rock. Most medium to very coarse sand-sized, nearly whole gastropods are filled with

TABLE 2. Summary of point-count averages for Kansas building limestones.

LIMESTONE	PERCENT GRAINS	PERCENT MATRIX	PERCENT PORES	PERCENT MISCELLANEOUS
Chestnut	23.5	68.6	6.5	1.4
Hard Neva	23.5	75.0	0.4	1.0
Soft Neva	26.7	67.9	2.1	3.3
Lower Cottonwood	32.2	65.7	0.4	1.7
Upper Cottonwood	39.9	55.2	4.7	0.1
Onaga	50.0	35.2	11.5	3.3
Silverdale	42.2	52.8	4.1	0.9
Cresswell	31.4	61.3	0.4	6.9

TABLE 3. Petrographic constituents of the building limestones, listed as percentages.

	Chestnut Shell	Hard Neva	Soft Neva	Lower Cottonwood	Upper Cottonwood	Onaga	Silverdale	Cresswell
GRAINS	23.5	23.5	26.7	32.2	39.9	50.0	42.2	31.4
Algal blebs encrusting algae	10	15	20	8	15	26+	35+	
Brachiopod debris and spines	25	5	5	10	5	5	5	3
Bryozoa		5	5	10	5		10	2
Echinoderm	5	8	5	10	5	10	10	2
Foraminifera	5	15	15	20	30	5*	3	2
Gastropod	15					15		
Intraclasts		5	5			5	5	
Ostracodes	5	5	5	10	10	2	3	25
Pelecypod	10	5	5			2	3	3
Pelloid Pellets	15	15	10	12	15	20	10	50
Trilobite		15	15	10	10		2	
Unknown	10	7	10	10	5	10	14	13
MATRIX	68.6	75.0	67.9	65.7	55.2	35.2	52.8	61.3
Microspar Micrite	30	50	55	70	70	50		
Microspar							25	
Micrite	25**						50	90
Blocky Calcite Spar	20	30	30	20	20	20	15	10
Dogtooth Calcite Spar	25	5	5			20		
Chalcedony		15	10	10	10	10	10	
POROSITY	6.5	0.4	2.1	0.4	4.7	11.5	4.1	0.4
	15	80	55	100	60	30sx	40sx	
	cr	sx	sx	sx	sx	mc-	mc-	
Interparticle	sms	ms	ms	ms	sms-	lms,	lms	
					smg	25cr		
						mc-		
						sms		
	25sx	20	45sx		20	30sx	35	
	ms	sx	ms		sx	mc-	sx	
Intraparticle	25cr	ms			ms	lms	mc-	
	ms				20cr		lms	
					ms			
	10sx					15	25	
	ms					cr	sx	
Moldic	10cr					mc-	ms	
	sms					sms		
	15							
Fracture	sx							
	sms							
								60
Fenestral								mc-
								sms
								40
Intercrystal								sx
								sms
MISC. OPAQUE MINERALS	1.4	1.0	3.3	1.7	0.1	3.3	0.9	6.9

LEGEND ★

Solution	s	Small megapore	smg	} ms
Cementation	c	Large mesopore	lms	
Enlarged	x	Small mesopore	sms	} ms
Reduced	r	Micropore	mc	

★ from Choquette and Pray, 1970

* excluding *Nubecularia*† *Osagia* and *Nubecularia*

‡ and sponge debris

** micrite envelopes

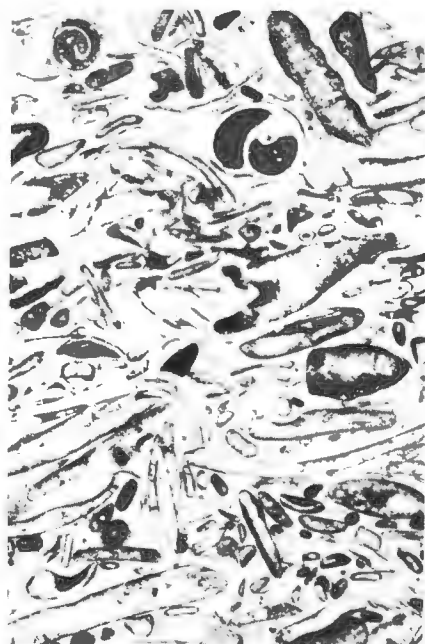


FIGURE 3. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. Photomicrograph of a sample of the Chestnut Shell Limestone that is dominated by algal blades with much lesser amounts of gastropod, pelecypod, and brachiopod fragments. Practically all grains are outlined by micrite envelopes or coated by encrusting algae. Bar scale = 3 mm. (10 \times , plane polarized light)

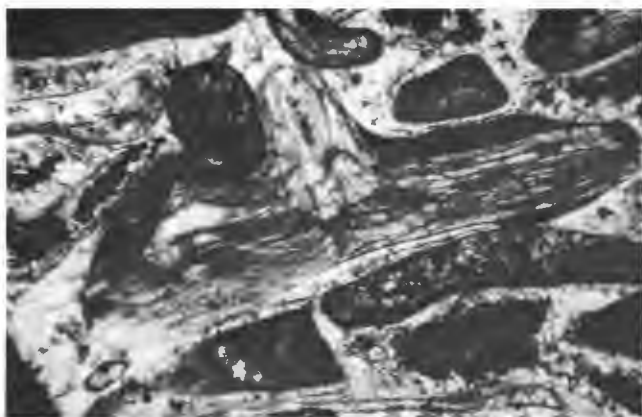


FIGURE 4. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. Productid brachiopod fragments, some with portions of spines still attached, are a relatively common occurrence. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

internal sediment. The sediment is either dark, fine-grained, uniform micrite (Fig. 6) or micrite and microspar plus other fossil fragments (Fig. 7).

Foraminifera, mainly biserial, are shown by a dark, dense, micritic infilling that has preserved their shape. Their wall structures are either microspar surrounded by

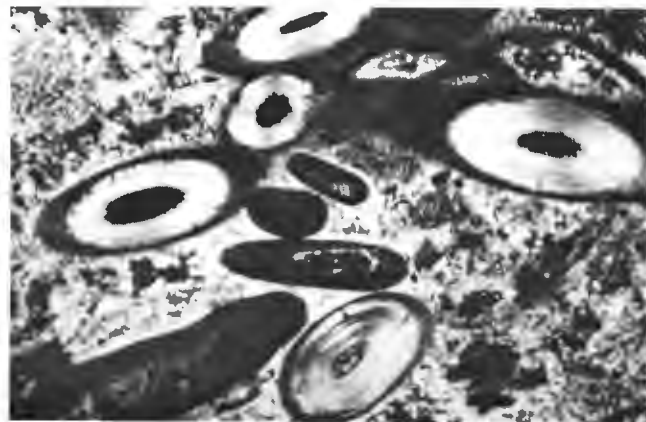


FIGURE 5. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. Cross sections of brachiopod spines. The concentric, parallel-fibrous inner layers are always preserved while the outer walls are bored or encrusted by algae. The centers of the spines are filled with micrite except for one that is filled with microspar. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

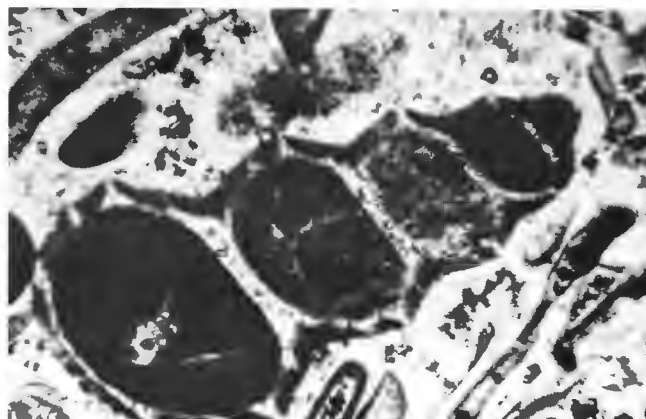


FIGURE 6. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. A high-spined gastropod with micrite infilling and a micrite envelope. Remnants of the original wall structure are marked by microspar. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

micrite or indistinguishable from the matrix. Gastropod and foraminiferal grains are often preserved by micritic envelopes and micrite fillings in their chambers. The chambers of such grains often contain areas of reddish coloration and minute red grains, suggesting the presence of hematite. Sand-sized, elongate pelecypod fragments are found; few are articulated. Many of the pelecypod fragments have dissolved wall structures and are preserved by micritic envelopes (Fig. 8). Very fine to medium sand-sized ostracodes occur with micrite and blocky-spar calcite infilling. Both articulated ostracodes and disarticulated valves are present. Medium sand-sized and finer echinoderm fragments are also found in this rock. Trilobite remains have been reported in two samples of the



FIGURE 7. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. Cross-sectional view of a gastropod surrounded by a micrite envelope and filled with micrite, microspar, and fossil fragments. Bar scale = 0.5 mm. (35 \times , crossed Nicols)



FIGURE 8. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. Portion of a pelecypod fragment whose wall structure has been partially replaced by microspar. The fragment is surrounded by a micrite envelope and a microspar matrix. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

Five Point Limestone from southern Pottawatomie and Wabaunsee counties (Mudge and Yochelson, 1962), but were not observed in the present study.

Micrite is found as internal sediment, and micritic envelopes are quite common. Under reflected light, finely disseminated hematite is often seen in the envelopes. Microspar/micrite also occurs as an interparticle cement.

A rim of dogtooth-spar calcite cement occurs both on the inside and outside of shell walls. Blocky-spar, void-filling calcite cement is found, as well as a microspar infilling cement. Chalcedony is found in some fractures and replacing some grains.

The Chestnut Shell has a complex diagenetic history. Many grains are preserved only by a characteristic shape that is outlined by a micritic envelope. Micritic envelopes are usually the result of algal borings, followed by dissolution of the unstable aragonite skeleton. A rim cement is found both on the inside and outside of shell walls as well as on micritic envelopes. In several places, the grains are fractured. Fractures passing through a single grain are due to penecontemporaneous deformation. In cases where a fracture passes through grains and matrix, one assumes the fractures are due to stresses such as those resulting from compaction after cementation during later stages of diagenesis.

A variety of porosity types was observed in the Chestnut Shell limestone. There is an abundance of solution-enlarged and cement-reduced intraparticle and moldic porosity, mesopore in size. This type of porosity is represented by grains with dissolved interior structure and a rim cement growing on the inside of the grain wall or micritic envelope (Fig. 9). Cement-reduced mesointerparticle pores are found between grains. There are some fractures through this rock (Fig. 10), resulting in solution-enlarged small mesofracture porosity.



FIGURE 9. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. A good example of moldic porosity. The original grain shape is preserved by the micrite envelope, the latter coated with dogtooth microspar. Bar scale = 3 mm. (10 \times , plane polarized light)



FIGURE 10. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. An example of fracture porosity (running north-south). Near-horizontal alignment of grains parallels the direction of the bedding plane. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

Interpretation: The environment of deposition was possibly one of shallow water, moderate wave and current action, and some restriction of circulation. The diverse fauna and lack of micrite in places suggest the moderate wave and current action, while restriction of circulation is suggested by the internal sediment and micrite filling in grains.

THE NEVA LIMESTONE MEMBER

Description: Both the hard and soft Neva are poorly sorted, fine- to medium-grained, pellet-bearing wackestones. Representative photomicrographs of the two beds are shown in Figures 11 and 12. There is no sharp textural or grain difference between the two, but there are differences in porosity and opaque mineral content. The soft Neva has more opaques and greater porosity than the hard Neva. There is alignment of grains at times, suggesting laminations. No burrows are apparent, but some disturbed sediment can be observed. Both the hard and soft Neva have a light gray (10YR 7/1) matrix color and grain colors of white (10YR 8/1), light gray (10YR 7/1, 7.5YR 7/1), and brownish-yellow (10YR 6/6).

Each Neva thin section was point-counted for four categories: grain, cement/micrite, pore space, and miscellaneous. The point-count results for the hard Neva averaged 23.5 percent grain, 75.0 percent cement/micrite, 0.4 percent pore space, and 1.0 percent miscellaneous. Results for the soft Neva averaged 26.7 percent grain, 67.9 percent cement/micrite, 2.1 percent pore space, and 3.3 percent miscellaneous (see Table 2). The petrographic constituents of the Neva are itemized in Table 3.

Osagia, an algal-foraminiferal intergrowth, may be

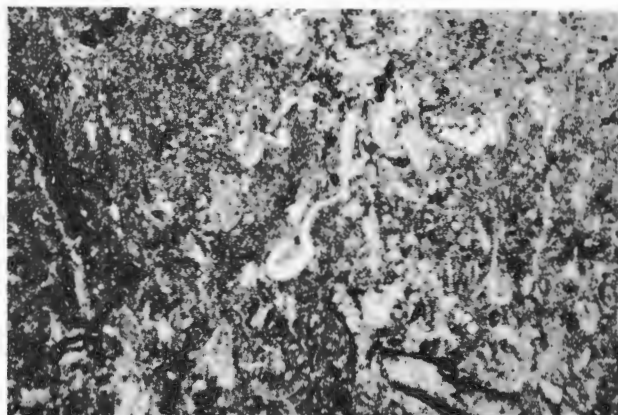


FIGURE 11. Neva Limestone Member of the Grenola Limestone—Hard Neva Bed. Representative view of the hard Neva. Biserial foraminifera, trilobite and ostracode shells, and other organic debris are common in a micritic matrix. Bar scale = 3 mm. (10 \times , plane polarized light)

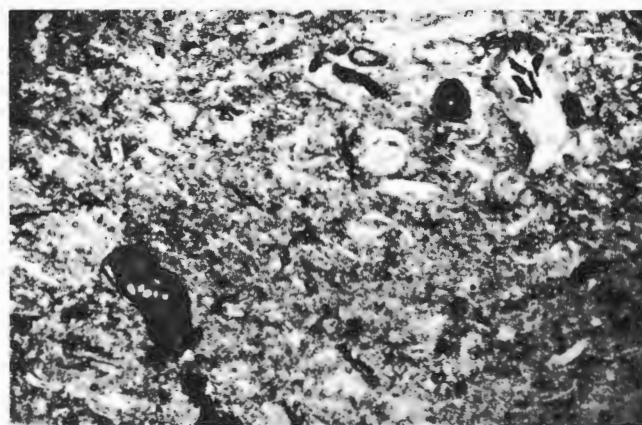


FIGURE 12. Neva Limestone Member of the Grenola Limestone—Soft Neva Bed. Photomicrograph of the soft Neva Limestone. The upper right portion shows a bryozoan partially coated by encrusting algae and a nearly circular oncolite. An irregular oncolite is present in the lower left corner. Zones of opaque material and pelloids are also shown. Bar scale = 3 mm. (10 \times , plane polarized light)

present along with other encrusting algae. Johnson (1946) reported finding *Osagia* in the Neva. The algal blebs are irregular and spherical in shape (Figs. 12 and 13) and seem to be slightly more abundant in the soft Neva. Trilobite fragments are present in many different sizes, shapes, and orientations. Lane (1964) reported finding one trilobite species of the genus *Ditomopyge*. Trilobites (Fig. 14) are a little more abundant in the hard Neva than in the soft Neva, and more than one species may be represented. Many sand-sized uniserial and biserial foraminifera (Figs. 11, 13, 15 and 16) are present. Some have micritized walls and chambers filled with a fine-

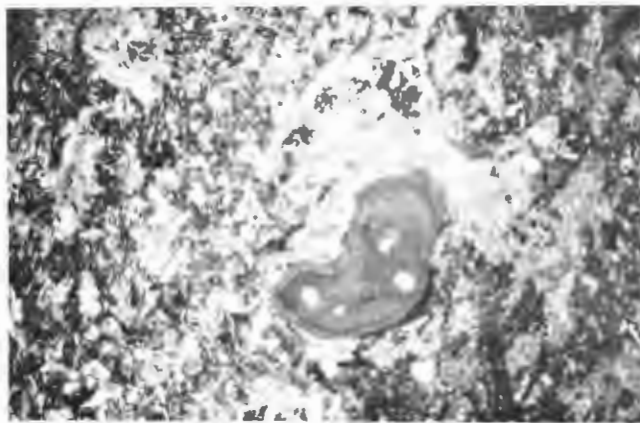


FIGURE 13. Neva Limestone Member of the Grenola Limestone—Hard Neva Bed. Oncolites, with their concentric growth patterns, and fragments of serial foraminifera are often seen in the hard Neva. Bar scale = 3 mm. (10 \times , plane polarized light)

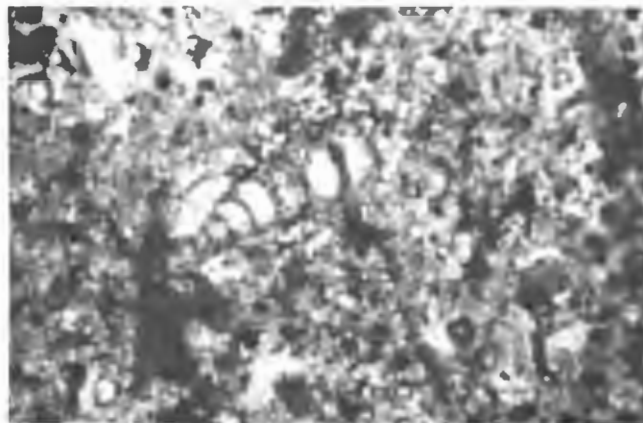


FIGURE 15. Neva Limestone Member of the Grenola Limestone—Soft Neva Bed. A uniserial(?) foraminifera surrounded by a darkened mass rich in opaque minerals and pelloids (clotted appearance). Bar scale = 0.5 mm. (35 \times , plane polarized light)

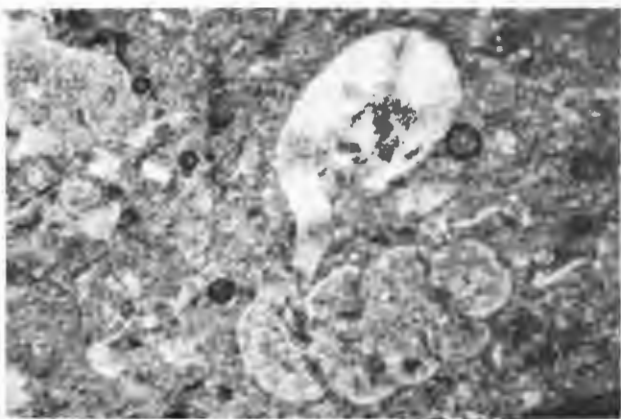


FIGURE 14. Neva Limestone Member of the Grenola Limestone—Hard Neva Bed. A trilobite fragment in the hard Neva. A highly recrystallized biserial foraminifera lies directly underneath the trilobite fragment. A few air bubbles are present (spherical shapes with heavy black outlines). Bar scale = 0.5 mm. (35 \times , crossed Nicols)

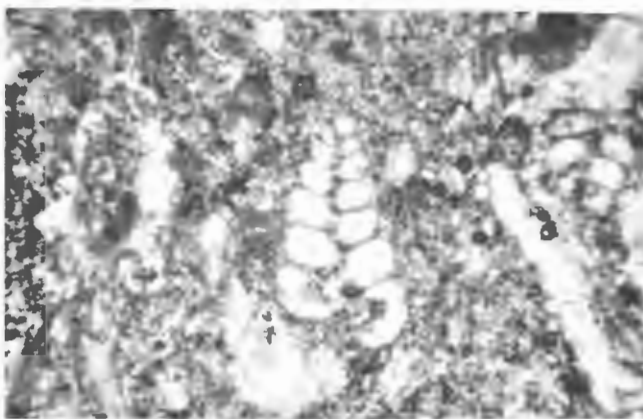


FIGURE 16. Neva Limestone Member of the Grenola Limestone—Soft Neva Bed. Typical biserial foraminifera in the soft Neva Limestone. The matrix is rich in opaque minerals and pelloids. Bar scale = 0.5 mm. (35 \times , plane polarized light)

grained micrite. Thus, the grain still retains a characteristic shape even though no distinguishable wall structure is present. Dark, silt-sized to sand-sized, spherical grains with no apparent internal structure are called pelloids. The rock shows a clotted appearance at times (Fig. 15), suggesting many more pelloids than can be readily identified, especially in the hard Neva. Rounded, sand-sized interclasts are found. Some sand-sized to granule-sized echinoderm debris is present. The echinoderm fragments are larger and slightly more abundant in the hard Neva than in the soft Neva. Sand-sized bryozoan fragments (Fig. 12) are present, with ramose and fenestrate growth forms distinguishable. Some bryozoan fragments are encrusted with algae, and have opaque iron minerals in

their chambers and wall structure. Coarse sand-sized and smaller ostracodes are common, some with a geopetal fabric inside the articulated shell (Fig. 17). Minor compaction may have occurred, as suggested by a slightly crushed articulated ostracode (Fig. 18). Medium sand-sized, articulated pelecypod shells and articulated, sand-sized brachiopods, fragments, and spines are all present. All articulated shells are filled in with microspar, micrite, dogtooth-spar calcite rim cement, or a blocky calcite spar. Some of the different brachiopods identified by Lane (1964) include *Composita*, *Linoproductus*, *Jurensia*, *Neospirifer*, and *Cruruithyrus*.

The matrix is primarily micrite. Void-filling, blocky-spar calcite cement and microspar are found. Some chal-

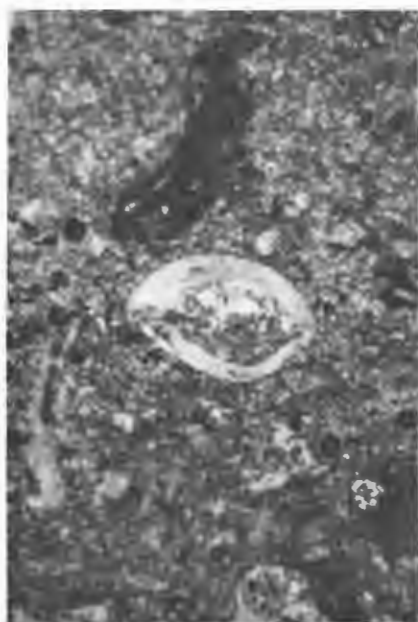


FIGURE 17. Neva Limestone Member of the Grenola Limestone—Hard Neva Bed. An ostracode showing geopetal fabric. Bar scale = 0.5 mm. (35 \times , crossed Nicols)



FIGURE 18. Neva Limestone Member of the Grenola Limestone—Soft Neva Bed. An ostracode that may have undergone deformation and filled with microspar resulting from the recrystallization of lime mud. Bar scale = 0.2 mm. (100 \times , crossed Nicols)

cedony is replacing grains, usually brachiopod and echinoderm fragments. Silt-sized quartz is interspersed throughout the matrix.

Solution-enlarged intraparticle pores are also found, mesopore in size. This porosity type occurs often within algal blebs and articulated shell debris.

It is obvious in thin section that opaque minerals are more abundant in the soft Neva. Point-count results confirm this by showing, on the average, three times more

opaques in the soft Neva than in the hard Neva. Fine sand-sized opaques occur dispersed throughout the matrix, in chambers and walls of bryozoa, and in the wall structure of various articulated shells. The only difference in the nature of the occurrence of opaques between the hard and soft Neva is in fractures or stylolites. In the soft Neva, iron minerals can occur in a narrow zig-zag and relatively horizontal pattern for several millimeters (up to about 7 mm in length). These represent fracture fillings and may originate from a pressure-solution phenomenon. Such fillings are not commonly observed in the hard Neva.

Interpretation: The above features suggest a well-illuminated, shallow-water environment. Although some current and wave activity was probably present, there was poor circulation at times. This interpretation is based on the presence of micrite, diverse fauna, intraclasts, laminations, disturbed sediment, and abundant pelloids.

THE COTTONWOOD LIMESTONE MEMBER

Description: The Cottonwood Limestone is often divided into an upper porous unit (Figs. 19 and 20) and a lower dense unit (Fig. 21). The upper Cottonwood is a poorly sorted, fine- to medium-grained fusulinid wackestone. The matrix color is light gray (10YR 7/1), and fossil colors are white (10YR 8/1) and light yellowish-brown (10YR 6/4). The upper bed has a rough, pitted wheat-grain texture and bedding planes are sometimes apparent because the long axes of fusulinids tend to be parallel to the natural bedding plane. The boundary between the upper and lower Cottonwood is evidenced by a



FIGURE 19. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. A photomicrograph of the upper Cottonwood Limestone showing typically larger grains than in the lower Cottonwood (see Fig. 21). Particularly noticeable in this photomicrograph are fragments of bryozoans and trilobites and the presence of large pores. Many grains are coated and micrite commonly fills the chambers of bryozoan fragments. Bar scale = 3 mm. (10 \times , plane polarized light)

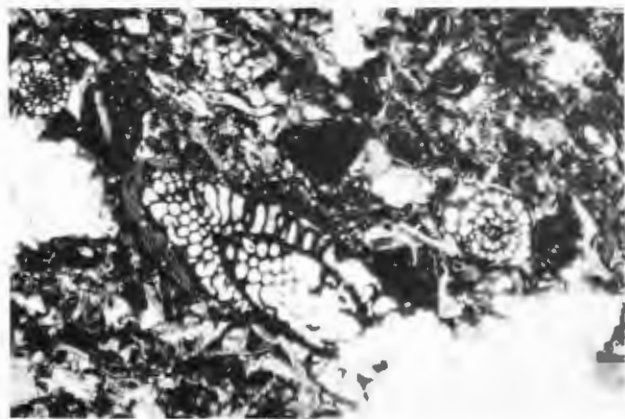


FIGURE 20. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. Another photomicrograph of the upper Cottonwood Limestone showing large grains with micrite coatings and infillings and large vugs. Note the presence of large fusulinids. These foraminifera, shaped like wheat grains, give the Cottonwood Limestone its interesting texture on buildings when the less resistant matrix has weathered away. Bar scale = 3 mm. (10 \times , plane polarized light)

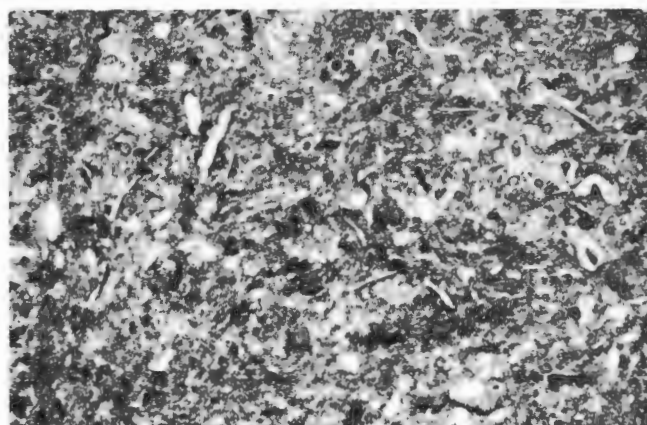


FIGURE 21. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. Representative photomicrograph of the lower Cottonwood Limestone. In general, the grain size of the lower Cottonwood is smaller and it contains fewer fusulinids and fewer large pores relative to the upper Cottonwood. Like the upper Cottonwood, this view shows a variety of fossil types. Bar scale = 3 mm. (10 \times , plane polarized light)

sharp textural contrast, porosity difference, and changes in the opaque mineral content. The lower Cottonwood has a relatively smooth, dense textural appearance with less porosity observed. It is a fine-grained, poorly sorted wackestone with a light gray (10YR 7/1) background while most fossils are brownish-yellow (10YR 6/6) or white (10YR 8/1) in color.

Each Cottonwood slide was point-counted for four categories: grain, cement/micrite, pore space, and

miscellaneous. The point-count results for the upper bed averaged 39.9 percent grain, 55.2 percent cement/micrite, 4.7 percent pore space, and 0.1 percent miscellaneous (see Table 2). The lower bed averaged 32.2 percent grain, 65.7 percent cement/micrite, 0.4 percent pore space, and 1.7 percent miscellaneous (see Table 2). The petrographic constituents of the Cottonwood are itemized in Table 3.

The Cottonwood, especially the upper Cottonwood, contains large amounts of sand-sized to granule-sized fusulinids, identified as *Schwagerina* and *Schubertella*. Some forams are nearly whole (Figs. 22 and 23) while others are broken and irregular in shape. The foraminifera wall structures are often made up of microspar/micrite (Figs. 22 and 23), but in some cases the wall structures are indistinguishable from the matrix; only the filled chambers of the foraminifera preserve their form (Fig. 23). The chambers are filled or partially filled with blocky-spar calcite cement, microspar/micrite, and opaque minerals.

Osagia, the algal-foraminiferal intergrowth, may be present along with other encrusting algae. Laporte (1962) reported finding both *Anchicodium* and *Osagia* in the Cottonwood (only *Osagia* in the upper bed). The encrusting algae are varied in shape and sand- to granule-sized. Echinoderm debris, bryozoan fragments, trilobites, fusulinids, and an occasional gastropod (Fig. 24) are the identifiable hosts of the encrusting algae, although these grains also occur without coatings. Silt- to sand-sized, irregular-shaped peloids are present. The rock has a clotted appearance at times, suggesting more peloids may be present than are identified. Many trilobite fragments (Figs. 25 and 26) are found, ranging from fine sand-sized to very coarse sand-sized. Laporte (1962) reported finding one genus of trilobite, *Ditomopyge*, in

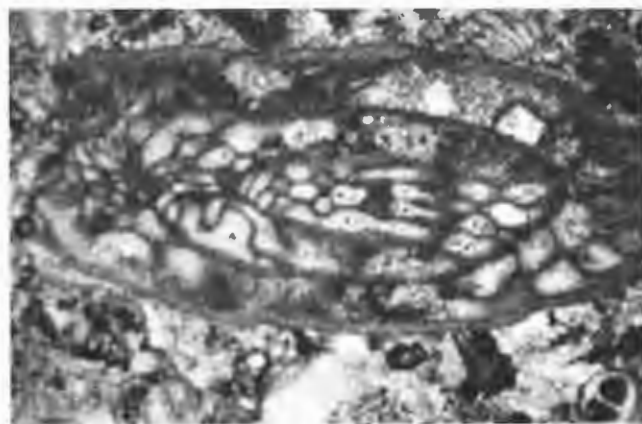


FIGURE 22. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. Tangential section of a fusulinid. Bar scale = 0.5 mm. (35 \times , crossed Nicols)



FIGURE 23. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. Many small fusulinids appear in this thin section photomicrograph of the upper Cottonwood Limestone. In the center, chalcedony has partially replaced an echinoderm fragment. Bar scale = 0.5 mm. (35 \times , crossed Nicols)



FIGURE 24. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. One of the few gastropods observed in the Cottonwood Limestone. The exterior of the last whorl appears to be coated by encrusting algae. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

the Cottonwood. Many different sizes, shapes, and orientations of trilobite fragments are found. Sand-sized echinoderm plates and spines (Figs. 27 and 28) occur, sometimes being replaced by chalcedony. Bryozoan fragments are sand-sized and have opaque minerals or blocky calcite spar filling their chambers. Sand-sized brachiopods (articulated and fragments), spines, and pelecypod



FIGURE 25. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. A trilobite fragment showing undulose extinction and coated, in part, by encrusting algae. A partially disarticulated ostracode is also present. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

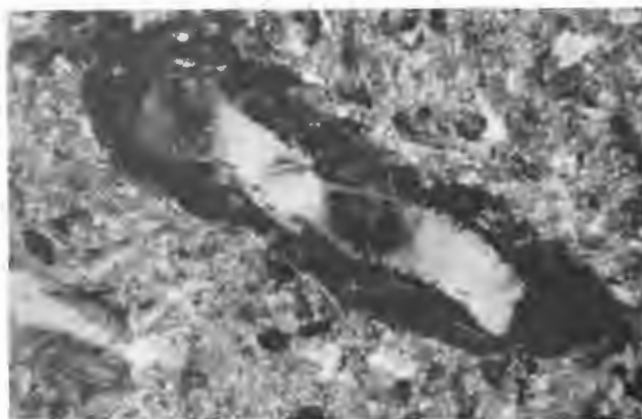


FIGURE 26. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. An algal-coated trilobite grain showing characteristic undulose extinction. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

valves are found. Silt-sized to fine sand-sized ostracodes (many articulated) are present. Articulated ostracodes are filled with blocky-spar calcite cement, single calcite crystals (Fig. 29), microspar/micrite (Fig. 29), opaque minerals, and chalcedony (partial filling illustrated in Fig. 30).

Grain constituents for the upper and lower Cottonwood are the same, but there are some differences between the beds. *Schubertella* is the dominant fusulinid in the lower bed with *Schwagerina* not as common; in the upper bed, *Schwagerina* is the dominant fusulinid (Laporte, 1962). Encrusting algae are not as abundant in the lower bed. There is an overall grain size difference with

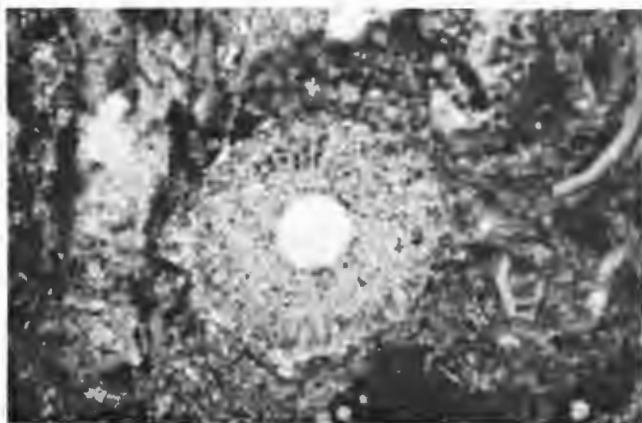


FIGURE 27. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. Cross-sectional view of an echinoid spine. The spar-filled center is in optical continuity with the spine and implies syntaxial growth. The black spots within the spine may be primary porosity. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

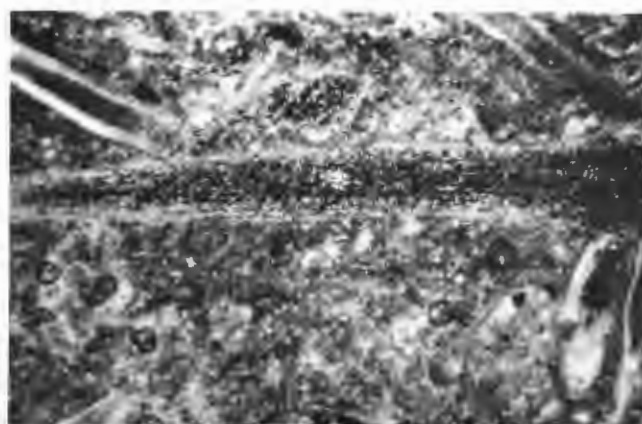


FIGURE 28. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. Longitudinal section of a highly recrystallized echinoid spine. The bulb on the right side is where the spine was originally attached to the body. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

the lower Cottonwood having a smaller grain size. The lower Cottonwood has fewer grains and much less porosity than the upper bed (Fig. 21).

Because the matrix is partially recrystallized, both microspar and micrite occur. A blocky-spar calcite cement, microspar/micrite, and opaque minerals all fill voids of articulated shells and other fossil grains and pores. Silt-sized quartz is disseminated throughout the rock. Chalcedony is found replacing echinoderm debris, microspar in the center of ostracodes, and other unidentifiable grains.

Solution-enlarged interparticle porosity is most common. In the upper bed, meso- to small megapores with a

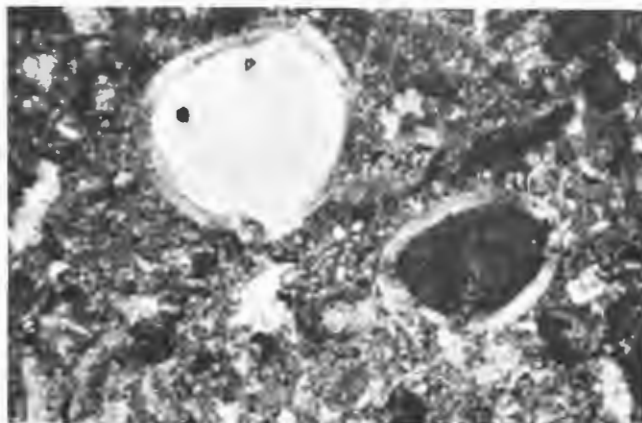


FIGURE 29. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. Two ostracodes. One is filled with a single crystal of calcite while the other is filled with micrite or lime mud. Bar scale = 0.5 mm. (35 \times , crossed Nicols)



FIGURE 30. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. View of an ostracode containing chalcedony partially replacing micrite within the articulated shells. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

maximum diameter of 8 mm are found. In the lower bed, mesopore size is found. Some solution is going on within the grains in the upper bed (usually fusulinids), resulting in solution-enlarged intraparticle porosity (Fig. 31) of mesopore size. Blocky-spar calcite cement partially fills chambers of fusulinids, leaving cement-reduced intraparticle porosity of mesopore size, again, in the upper bed.

The upper and lower Cottonwood differ in opaque mineral content. The opaque minerals are most often associated with algal blebs in the upper Cottonwood. These iron minerals (hematite in some cases) occasionally occur filling chambers of bryozoa, foraminifera, and articulated ostracodes. In the lower Cottonwood, the



FIGURE 31. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. Cross-sectional view of a fusulinid that shows appreciable intraparticle porosity. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

opaques are again associated with algae or as infillings, but are more often concentrated along fractures (narrow, irregular patterns up to about 5 mm in length).

Interpretation: A well-illuminated, shallow-water, moderately turbulent environment of deposition, with some restriction of circulation, is concluded for both the upper and lower Cottonwood beds. Some evidence to support this idea includes the following: algal growth, appearance of micrite, overall rounded grain shape, diverse fauna, and the pore size and shape. Partial recrystallization of the rock has occurred after deposition.

THE FUNSTON (ONAGA) LIMESTONE FORMATION

Description: The Onaga limestone is a poorly sorted, fine- to medium-grained grainstone that has a light gray (10YR 7/2) matrix color and a variety of grain colors: yellow (10YR 8/6, 10YR 7/6), very pale brown (10YR 8/4), and light gray (7.5YR 7/1). White (10YR 8/1) laminations are also prominent in some hand specimens. The grains are floating in a finer-grained matrix, and are both spherical and elongate in shape. Some samples display a definite bedding plane (horizontal laminations) while others are uniform in texture.

Each Onaga slide was point-counted for four categories: grain, cement/micrite, pore space, and miscellaneous. The point-count results averaged 50.0 percent grain, 35.2 percent cement/micrite, 11.5 percent pore, and 3.3 percent miscellaneous (see Table 2). The petrographic constituents of the Onaga are itemized in Table 3.

Most grains are diagenetically altered, leaving fossil "ghosts" (Figs. 32 and 33). Thus, grain identification is based in many cases on characteristic grain shapes and not wall structure. The sand-sized to granule-sized en-

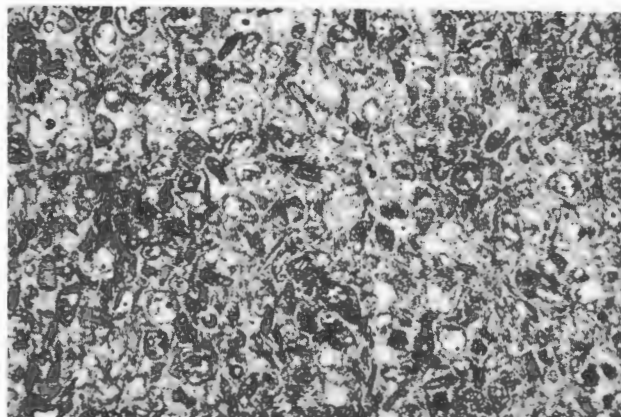


FIGURE 32. Funston (Onaga) Limestone. Photomicrograph of the Funston (Onaga) Limestone, classified as a grainstone. Note the absence of wall structures: diagenetic alteration has produced fossil "ghosts." Grain identification is often by shape rather than wall structure. The majority of the grains are coated or encrusted; encrusted grains are surrounded by sparry cement. Pelloids are also very common. Bar scale = 3 mm. (10 \times , plane polarized light)

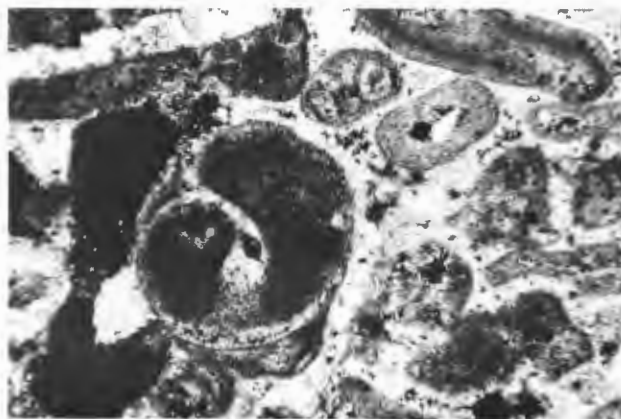


FIGURE 33. Funston (Onaga) Limestone. Closer view of the Funston Limestone showing lack of original wall structure, coated grains, equant spar rim cement, and intergranular vuggy porosity. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

crusting foraminifer *Nubecularia* is most common in this rock (Figs. 34, 35 and 36). There may also be some *Osagia* present. The *Nubecularia* and *Osagia*-like grains occur as spherical, elongate, irregular, and plumose shapes. Some of the encrusting foraminifera/algae have skeletal grains for a nucleus (Fig. 34), but their shapes are sometimes independent of the nucleus shape. The fine sand-sized foraminiferal grains (other than *Nubecularia*) are characteristically shaped ghosts with no wall structure preserved. Sand- to granule-sized pelloids are common, and occur as spherical, elongate, and irregular shapes. Some sand-sized intraclasts are present. The gastropods

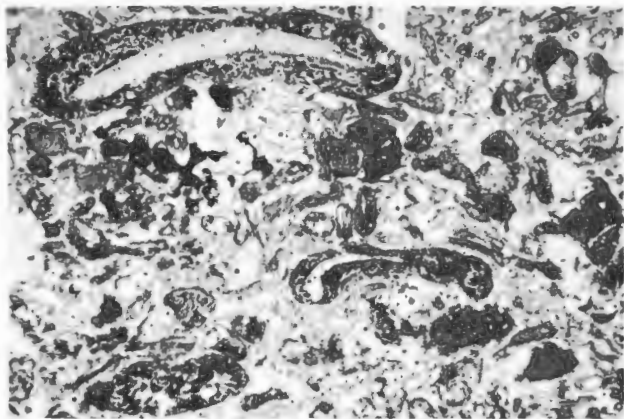


FIGURE 34. Funston (Onaga) Limestone. Encrustation of large bivalve fragments by *Nubecularia*(?), an algal-foraminiferal growth. Bar scale = 3 mm. (10 \times , plane polarized light)

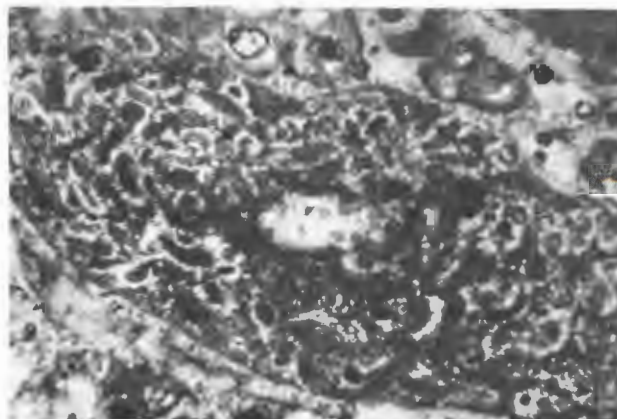


FIGURE 36. Funston (Onaga) Limestone. Closer view of algal-foraminiferal growth. Note presence of sparry rim cement. Bar scale = 0.5 mm. (35 \times , plane polarized light)

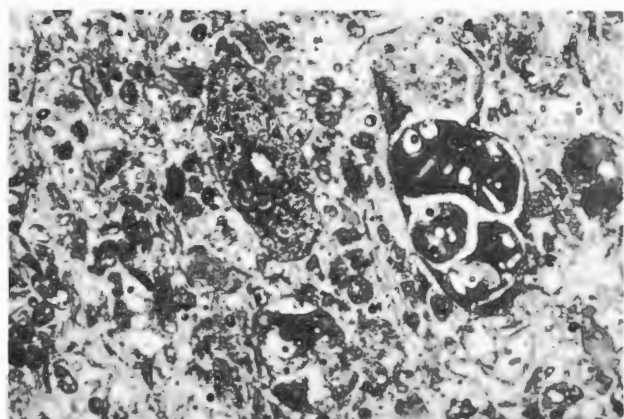


FIGURE 35. Funston (Onaga) Limestone. View showing *Nubecularia* or *Osagia* (left center) and a gastropod (sparry calcite wall structure and a micrite infilling). Note the coated grains, sparry rim cement, and abundant pelloids. Bar scale = 3 mm. (10 \times , plane polarized light)

(Figs. 33 and 35) are very interesting as they seem to display a special diagenetic history. For the most part, nearly whole gastropods are very coarse sand- to granule-sized and retain their characteristic shape. Both high- and low-spined gastropods are found and some are as small as medium sand-sized. Echinoderm debris is sand-sized and often replaced by chalcedony. The ostracodes and pelecypods tend to be fine sand-sized and the brachiopods medium to coarse sand-sized. Regardless of size, the ghosts of articulated shells are normally filled with microspar and micrite.

The matrix of this grainstone suggests a primary void-filling cement, but the diagenetic history is very complex. Microspar/micrite is most common. Blocky calcite spar and microspar/micrite occur as infilling of dissolved

grains. There are small crystals of dogtooth or equant spar outlining individual grains (Fig. 33) while the interparticle voids are filled with larger crystals. Chalcedony replaces echinoderm debris and nearly whole gastropods; it is also found finely disseminated throughout foraminiferal/algal grains. Much of the Onaga has been recrystallized.

Evidence for complex diagenesis is displayed in one of the altered, nearly whole brachiopods(?). The brachiopod(?) shape is preserved by a micritic envelope. The outline of the envelope is crushed and distorted. These features suggest solution of the shell and minor compaction of the micritic envelope. Finally, blocky calcite spar fills the interior of the entire micritic envelope (Fig. 37).

Both solution-enlarged micro- to mesointerparticle and solution-enlarged micro- to small mesointraparticle porosities are common (Fig. 38). The cement-reduced micro- to small mesointerparticle porosity usually suggests a primary feature, but is probably secondary here. Cement-reduced micro- to small mesomoldic porosity is represented in gastropod wall structures. The wall seems to be partially replaced with calcite crystals, leaving some pore space.

Interpretation: The presence of algae indicates a shallow-water environment (within the photic zone). The grainstone texture with a lack of micrite suggests that sufficient turbulence was present to remove mud-sized sediment from the environment of deposition. The diagenetic history is probably very complex, as evidenced by the gastropod described.

THE FORT RILEY (SILVERDALE) LIMESTONE MEMBER

Description: The Silverdale limestone is a poorly sorted, fine- to medium-grained algal wackestone/

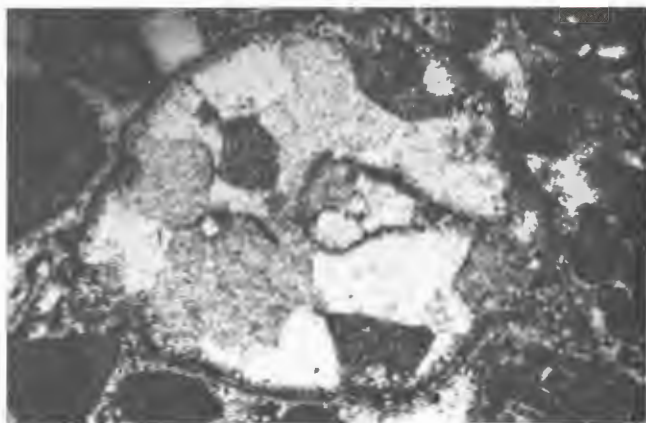


FIGURE 37. Funston (Onaga) Limestone. View of a fossil grain (probably an articulated brachiopod) that has a complex diagenetic history. Portions of the wall structure have been replaced by a micritic envelope on which dogtooth spar has been deposited (both inside and outside). The grain has also undergone some deformation and was later filled with blocky spar cement. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

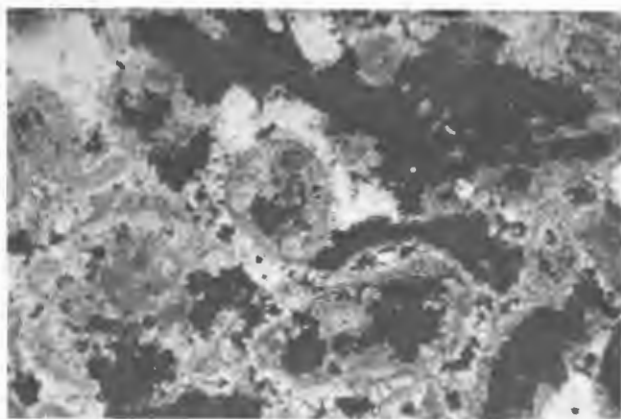


FIGURE 38. Funston (Onaga) Limestone. An example of solution-enlarged vuggy porosity. Both interparticle and intraparticle porosity are shown. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

packstone, with a light gray (10YR 7/1) matrix color. The fossils (approximately 40 percent of the rock) vary in color from white (10YR 8/1), to light gray (10YR 7/2), to brownish-yellow (10YR 6/6). Because of the high grain content, the overall color appears to be light brownish-yellow. The grains for the most part are rounded and floating within a finer-grained matrix. Because the Silverdale has a uniform texture, natural bedding planes are not obvious.

Each Silverdale slide was point-counted for four categories: grain, cement/micrite, pore space, and miscellaneous. The point-count results averaged 42.2 percent grain, 52.8 percent matrix, 4.1 percent pores, and 0.9 percent miscellaneous (see Table 2). The petrographic

constituents of the Silverdale are itemized in Table 3.

Coarse sand-sized to granule-sized coated or encrusted grains with a medium to coarse sand-sized nucleus are common in this rock (Fig. 39). The encrusting *Osagia*, an intergrowth of algal filaments with the foraminifer *Nubecularia*, is present. Many of the coated grains are filled with iron minerals that obscure the microstructure. Although *Girvanella* has not been positively identified in these samples, *Girvanella*-like tubes do occur in the *Osagia*. Johnson (1961) has reported *Osagia*, *Nubecularia*, and *Girvanella* in a specimen of Fort Riley Limestone, Cowley County, Kansas.

It has been postulated that some of the encrusting material may be sponge in origin (D. E. Nodine-Zeller, 1978, personal communication). Sponge debris commonly contains much iron and this may be the source of the iron present. The grain shape of this coating is both spherical and elongate, but relatively independent of the shape of the nucleus (Fig. 39).

A portion of a bryozoan, a crinoid plate, an echinoid spine or plate, a piece of brachiopod or mollusk shell, trilobite fragments, fusulinids, and possibly fragments of algae are all nuclei for the *Osagia* colony in the Silverdale. Dark, spherical, silt- to sand-sized grains with no internal structure are called pelloids. Rounded intraclasts (fine to coarse sand-sized) are also found. The darkness of both the pelloids and intraclasts may be due to the presence of incorporated organic matter. Sand-sized echinoderm (Fig. 40) and bryozoan (Figs. 41 and 42) grains are common, and frequently are coated (Fig. 43). Although sand-sized fragments of brachiopods are common, some coarse, sand-sized, articulated brachiopods are also present. Tiny ostracode (Fig. 44) and pelecypod shells are fre-

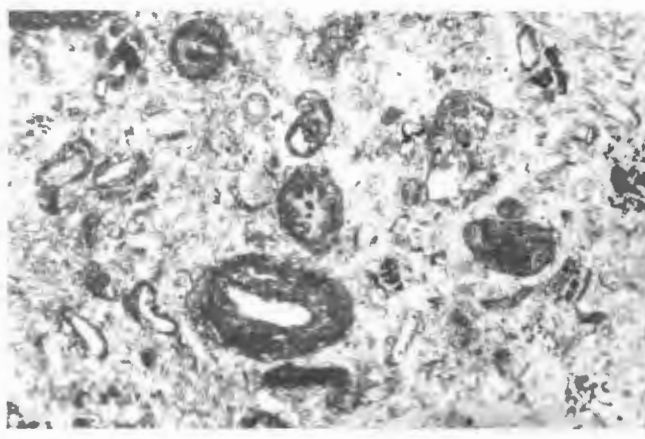


FIGURE 39. Fort Riley (Silverdale) Limestone Member of the Barnes-ton Limestone. Photomicrograph showing rounded grains that consist of fossil fragments coated with micrite or encrusting algae. Coated bryozoan, echinoderm, and mollusk fragments are common in this limestone. Bar scale = 3 mm. (10 \times , plane polarized light).

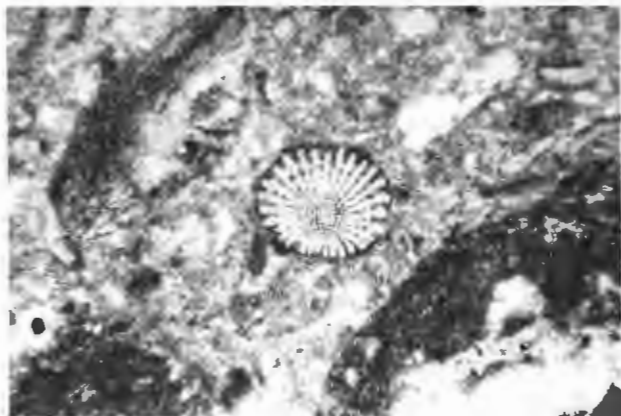


FIGURE 40. Fort Riley (Silverdale) Limestone Member of the Barnes-ton Limestone. Cross-sectional view of a lightly coated echinoid spine. The other material in this picture is poorly defined but mostly appears to be a combination of algal growth, micrite, and fossil debris. Bar scale = 0.5 mm. (35 \times , plane polarized light)

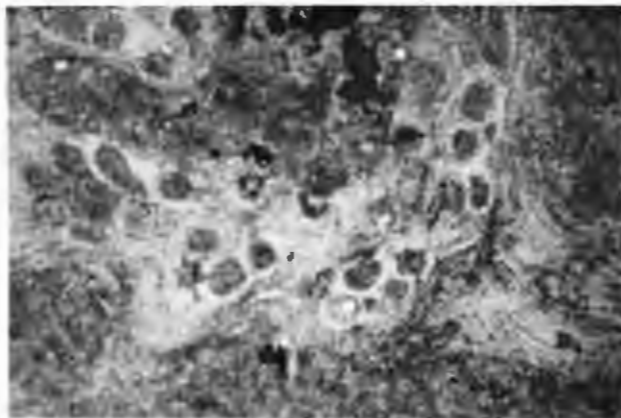


FIGURE 42. Fort Riley (Silverdale) Limestone Member of the Barnes-ton Limestone. Bryozoan fragment without a well-defined rounded envelope. Note presence of vuggy porosity. Bar scale = 0.5 mm. (35 \times , crossed Nicols)

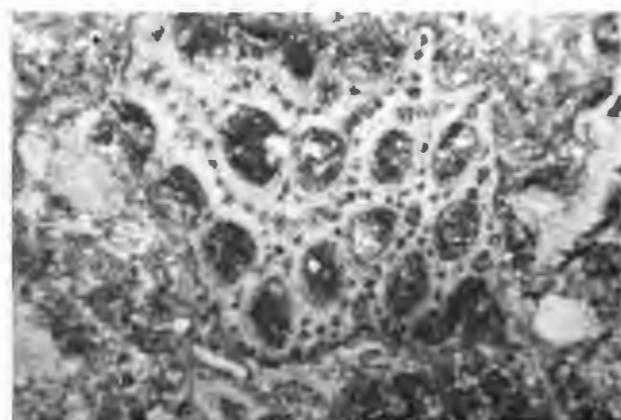


FIGURE 41. Fort Riley (Silverdale) Limestone Member of the Barnes-ton Limestone. Tangential-sectional view of a bryozoan. Note the acanthopores in the wall structure surrounding each zoecial opening. Bar scale = 0.5 mm. (35 \times , plane polarized light)



FIGURE 43. Fort Riley (Silverdale) Limestone Member of the Barnes-ton Limestone. Coated bryozoan fragment showing typical rounded grain shape with a sparry rim cement. Bar scale = 0.5 mm. (35 \times , plane polarized light)

quently still articulated. Articulated shells, regardless of size, contain void-filling calcite spar cement or micrite. Although trilobites are not commonly reported in the Fort Riley, they do occur in these specimens. Sand-sized trilobite fragments are found, some as coated grains. The Fort Riley Limestone is the youngest member in this study in which trilobites were found. Silt-sized quartz and opaque minerals are disseminated throughout the matrix. Hematite is found filling the chambers of some bryozoan grains.

The matrix is a fine-grained micrite and microspar. The rock is partially recrystallized, accounting for both the microspar and micrite. The blocky calcite spar generally occurs as a void-filling cement inside articulated

shells. Chalcedony replaces the centers of echinoderm plates and spines and other unidentifiable grains (possibly brachiopod shells). Some of these fragments have been almost completely replaced by chalcedony.

The most common pore is a solution-enlarged interparticle pore with a maximum diameter of 1.5 mm. Next in abundance is solution-enlarged intraparticle porosity of micro- to mesopore size. The latter pore-type is shown by the 0.125 mm and smaller pores found in the coatings on grains and inside such grains as articulated pelecypods, which have been filled with a void-filling calcite cement and now are going into solution. Moldic porosity, solution-enlarged, is also present, mesopore in size.

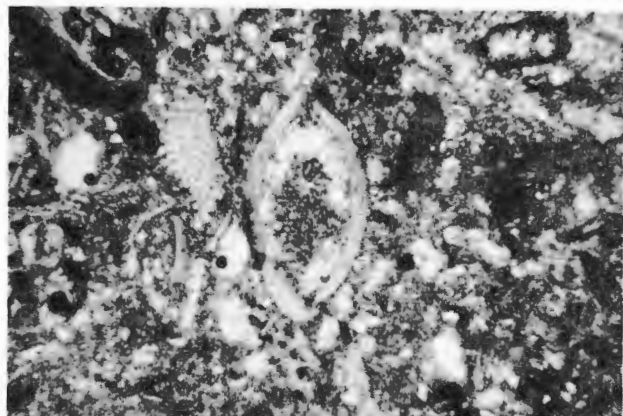


FIGURE 44. Fort Riley (Silverdale) Limestone Member of the Barnes-ton Limestone. Articulated ostracode shell filled with microspar and micrite. The rounded micrite or algal envelope is missing from the ostracode and the echinoderm fragment to the left of the ostracode. An algal coating does exist on the bryozoan fragment in the upper left portion of this photograph. Bar scale = 0.5 mm. (35 \times , plane polarized light)

Interpretation: Because algal growth requires sunlight, we can assume this limestone formed in a shallow-water environment. Some wave and current activity can be inferred, as suggested by overall rounded grain shape, heavy-shelled brachiopods, and intraclasts. This limestone has undergone partial diagenetic recrystallization, making fossil identifications difficult.

THE CRESSWELL LIMESTONE MEMBER

Description: The Cresswell Limestone is a very fine grained, burrowed, pellet-bearing wackestone that sometimes shows laminations. The Cresswell appears to be a mudstone (Fig. 45), with the exception of the disturbed and laminated areas. The burrows and light-colored laminations (Fig. 46) are composed of a fine-grained, poorly sorted hash of skeletal debris. Dark laminations (Fig. 46) are pellets for the most part. The matrix color is white (10YR 8/1), while the laminated areas are light gray (10YR 7/1) and the burrowed areas are yellow (10YR 7/8). The rock appears to have a dense, uniform texture with light gray horizontal laminations making some bedding planes obvious.

Each Cresswell slide was point-counted for the usual four categories: grain, matrix, pore space, and miscellaneous. The point-count results averaged 31.4 percent grain, 61.3 percent matrix, 0.4 percent porosity, and 6.9 percent miscellaneous (see Table 2). The petrographic constituents of the Cresswell are itemized in Table 3.

Silt-sized to fine sand-sized spherical pellets, possibly of fecal origin, are scattered throughout the rock and comprise the main component of the grains identified in the Cresswell. Certain thin sections (Fig. 47) exhibit a

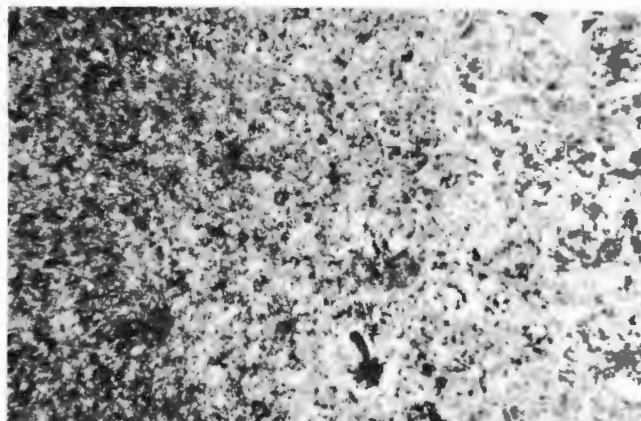


FIGURE 45. Cresswell Limestone Member of the Winfield Limestone. Typical view of the relatively uniform, microcrystalline Cresswell Limestone, the only carbonate mudstone reported in this study. Pellets and pelloids and a lesser number of ostracodes imbedded in a micrite matrix characterize this limestone. Bar scale = 0.5 mm. (35 \times , crossed Nicols)



FIGURE 46. Cresswell Limestone Member of the Winfield Limestone. Example of layering or laminations in the Cresswell Limestone that are occasionally observed in thin sections and on polished surfaces. Note the alignment of shell fragments, many of which are small ostracodes, in lighter zones. Bar scale = 3 mm. (10 \times , plane polarized light)

clotted appearance, suggesting the possibility of many more pellets than can be identified. This feature, coupled with the fine particle size and the presence of minute air bubbles, often makes it difficult to differentiate between grains and matrix and is responsible for the high miscellaneous category in Table 2. Small ostracodes, with their

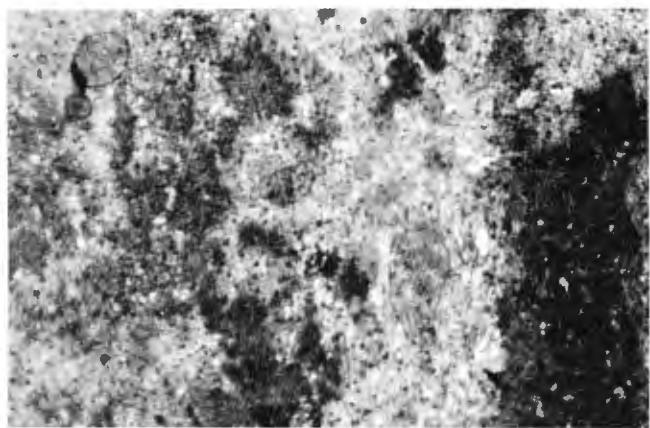


FIGURE 47. Cresswell Limestone Member of the Winfield Limestone. Bioturbation in the Cresswell Limestone caused by burrowing organisms. Note fine-sized opaque grains and pellets or pelloids that produce a clotted appearance in the photomicrograph. Bar scale=0.5 mm. (35 \times , plane polarized light)

long axes parallel to the natural bedding plane, occur among the pellets in the lighter layers of the rock and within fillings of burrows. Fine to medium sand-sized forams are found in the lighter laminations. Some of the articulated ostracodes (or tiny pelecypods?) are filled with sparry calcite cement. By contrast, some ostracodes are filled with mud. Dark, mottled layers may be compacted pellets with micrite. The burrows are filled with very fine to fine sand-sized fragments of pellets, ostracodes, pelecypods, echinoderms, brachiopods, foraminifera, and bryozoa. Opaque minerals, silt to fine sand-sized, appear disseminated throughout the rock. The iron minerals present are not usually associated with a fossil grain.

The matrix consists of micrite. Some blocky calcite spar is present, mostly as void-filling cement in some ostracodes (pelecypods?).

Some porosity is silt-sized or fine sand-sized and appears to be elongated, following the laminations. These pores occur not in the pelleted laminations but in the lighter laminations and are possibly of primary origin. The pores are a micro- to small mesofenestral type. Solution-enlarged small mesointercrystal porosity is also found. These pores are irregular in shape and located in the mudstone areas of the Cresswell.

Interpretation: A quiet, shallow-water, restricted lagoon or sheltered pool seems to be a likely environment of deposition, as suggested by the abundance of pellets, micrite, restricted fauna, horizontal laminations, and thin, delicate shells of ostracodes and pelecypods.

SUMMARY OF PETROGRAPHIC DESCRIPTIONS

The petrographic characteristics of each of the Kansas building limestones vary greatly. The characteristics are summarized below:

1. The **Chestnut Shell** is a medium- to coarse-grained packstone with an overall color of brownish-yellow and pinkish-gray. It has 23.5 percent grains, 68.6 percent matrix, 6.5 percent pore space, and 1.4 percent miscellaneous. The most common type of pore is solution-enlarged and cement-reduced mesointraparticle.

2. The **hard and soft Neva** are both medium-grained, pellet-bearing wackestones, light gray in color. The hard Neva has 23.5 percent grains, 75.0 percent matrix, 0.4 percent pore space, and 1 percent miscellaneous. The soft Neva has 26.7 percent grains, 67.9 percent matrix, 2.1 percent pore space, and 3.3 percent miscellaneous. The most common pore type for both is solution-enlarged mesointerparticle. Although petrographically the **hard and soft Neva** are similar (texture and grain), the soft Neva has more opaques and greater porosity than the hard Neva.

3. The **upper Cottonwood** is a fine- to medium-grained fusulinid wackestone and the **lower Cottonwood** is a fine-grained wackestone. Both beds are light gray in color. The upper Cottonwood has 39.9 percent grains, 55.2 percent matrix, 4.7 percent pore space, and 0.1 percent miscellaneous. The most common pore type is solution-enlarged meso- to small megainterparticle. The lower Cottonwood has 32.2 percent grains, 65.7 percent matrix, 0.4 percent pore space, and 1.7 percent miscellaneous. The most common pore type is solution-enlarged mesointerparticle. There are differences between the upper and lower Cottonwood in texture, porosity, and opaque mineral content. The upper bed has a rough, pitted, wheat-grain texture, about five percent porosity, and low opaque mineral content. The lower bed has a relatively smooth, dense textural appearance, less than one percent porosity, and a high opaque mineral content.

4. The **Onaga** is a fine- to medium-grained grainstone, light gray to light buff in color. It has 50 percent grains, 35.2 percent matrix, 11.5 percent pore space, and 3.3 percent miscellaneous. The most common pore types are solution-enlarged micro- to mesointerparticle and mesointraparticle.

5. The **Silverdale** is a medium-grained algal wackestone/packstone with an overall pale brownish-yellow color. It has 42.2 percent grains, 52.8 percent matrix, 4.1 percent pore space, and 0.9 percent miscellaneous. The most common pore type is solution-enlarged micro- to mesointerparticle.

6. The **Cresswell** is a very fine grained, burrowed, pellet-bearing wackestone, nearly white to light buff in color. It has 31.4 percent grains, 61.3 percent matrix, 0.4 percent porosity, and 6.9 percent miscellaneous. The most common pore type is micro- to small mesofenestral.

PORE-SIZE AND PORE-SHAPE DISTRIBUTIONS

For all eight building limestones, the size of each pore encountered during the point-counting was measured under $35\times$ magnification, using slides oriented both parallel and perpendicular to the bedding plane. Pore-size distributions were determined using the maximum diameters, while pore-shape distributions were determined by using the ratio of maximum (measured 90 degrees from the minimum) to minimum diameters.

Because of the large volume of data, the results for each slide as well as the average values for each limestone are listed in Appendix A. The histograms in Figure 48 conveniently illustrate the pore-size and pore-shape distributions listed in Appendix A.

Using actual pore sizes, the mean pore size and mean pore shape were calculated for each limestone oriented both parallel and perpendicular to the bedding plane. Standard deviations for the mean values were also calculated. The mean and standard deviations for each limestone are shown in Table 4, while values for each thin section are listed in Appendix B.

The Five Point (Chestnut Shell) Limestone shows the most widespread range of pore sizes and pore shapes of the eight limestones studied. Only the upper Cottonwood has more large (greater than 2.25 mm) pores than the Chestnut Shell. The mean pore size of the Chestnut Shell (see Table 4) is larger than most of the other six limestones. In addition, Appendix B and Figure 48 show that many of the pores in the Chestnut Shell have a highly elongated shape and Table 4 shows this limestone has the largest mean ratio of maximum to minimum diameter of all the limestones studied. The large ranges in pore size and pore shape are responsible for the relatively high

standard deviation values given in Table 4.

Except for the mean pore size in sections perpendicular to the bedding, the hard and soft Neva have almost identical mean values (Table 4). As mentioned in the previous section, the hard and soft Neva thin sections showed porosities of 0.4 and 2.1 percent, respectively. The low porosity associated with the hard Neva made the data for this limestone less reliable. The soft Neva has a narrow pore-size range. Figure 48 shows that over 90 percent of the pores have a maximum diameter less than 0.49 mm. Furthermore, the pore-shape data show that over 70 percent of the pores lie within the 1.00 to 1.99 ratio. Thus, most of the pores in the soft Neva are not appreciably elongated. The larger pore-shape range shown by the soft Neva is responsible for the larger standard deviation values relative to the hard Neva.

The Cottonwood Limestone is divided into a lower and upper bed and, like the preceding Neva Limestone, consists of a lower bed that has a very low porosity (0.4 percent) relative to the upper bed (4.7 percent pores). As shown in Table 4, the mean pore size is much smaller in the lower Cottonwood than in the upper Cottonwood. In both limestones, the pore size is much larger in sections cut perpendicular to the bedding than in horizontal sections. Although not included in this report, a plot of the cumulative percent versus pore size for sections oriented both parallel and perpendicular to the bedding plane shows a much greater spread between the parallel and perpendicular plots for the upper Cottonwood Limestone than for the other limestones. Because of the presence of very large pores (greater than 2.25 mm) and the scarcity of small pores, the upper Cottonwood has the largest mean pore size of all the limestones examined.

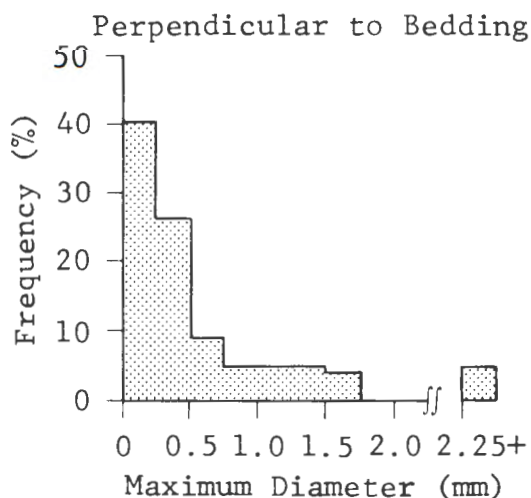
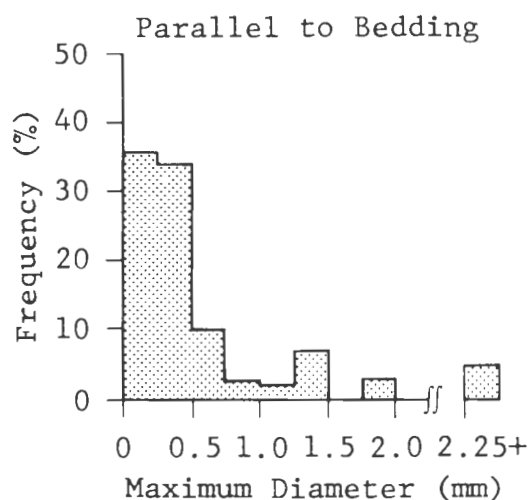
The Funston (Onaga) Limestone has the largest thin-section porosity (11.5 percent) of all the limestones studied. As shown in Table 4, it also appears to be the most consistent with regard to orientation; the mean

TABLE 4. Mean and standard deviation values derived from pore-size and pore-shape distribution of Kansas building limestones cut parallel and perpendicular to the bedding plane. \bar{X} = mean

	Pore-Size Distribution				Pore-Shape Distribution			
	Parallel to Bedding		Perpendicular to Bedding		Parallel to Bedding		Perpendicular to Bedding	
	Maximum Diameter (mm)	Standard Deviation	Maximum Diameter (mm)	Standard Deviation	Ratio of Maximum to Minimum Diameter	Standard Deviation	Ratio of Maximum to Minimum Diameter	Standard Deviation
	\bar{X}	σ	\bar{X}	σ	\bar{X}	σ	\bar{X}	σ
Five Point (Chestnut Shell)	0.734	1.284	0.533	0.618	2.966	1.895	2.738	1.845
Hard Neva	0.245	0.194	0.460	0.423	1.853	0.623	1.855	0.672
Soft Neva	0.261	0.154	0.171	0.248	1.886	1.028	1.710	0.927
Lower Cottonwood	0.342	0.461	1.018	0.918	1.457	0.369	2.347	0.733
Upper Cottonwood	1.289	0.849	2.698	1.786	1.825	0.734	1.692	0.610
Funston (Onaga)	0.411	0.429	0.382	0.407	2.027	1.424	1.993	1.059
Fort Riley (Silverdale)	0.192	0.185	0.152	0.101	2.028	1.129	2.020	0.844
Cresswell	0.176	0.140	0.124	0.035	1.670	0.536	1.806	0.838

Five Point (Chestnut Shell) Limestone

Pore-Size Distribution



Pore-Shape Distribution

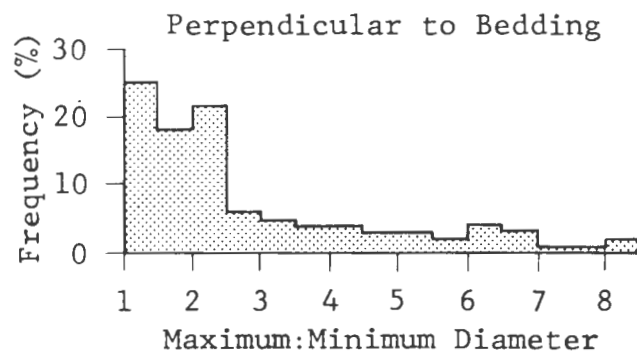
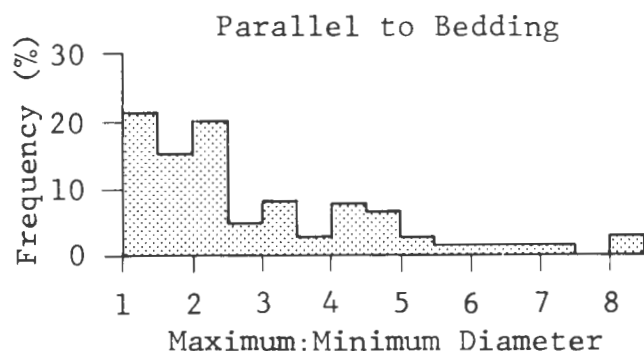


FIGURE 48. Histograms showing pore-size and pore-shape distributions of currently quarried Kansas building limestones.

values for pore size and pore shape are nearly identical for samples oriented parallel and perpendicular to the bedding. As shown in Figure 48, over 70 percent of the pores have a maximum diameter less than 0.5 mm and all pores have a maximum diameter less than 2.5 mm. Approximately 60 percent of the pores have a pore-shape ratio of 1.00 to 1.99.

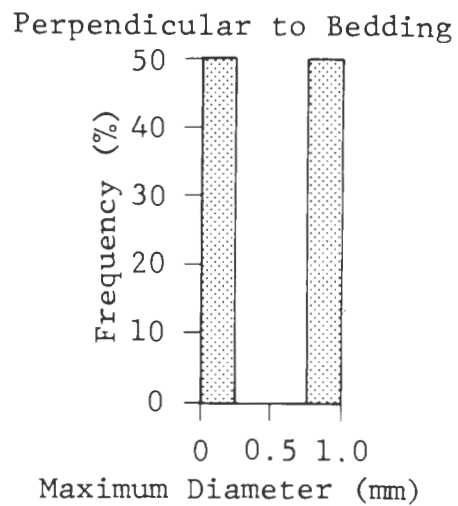
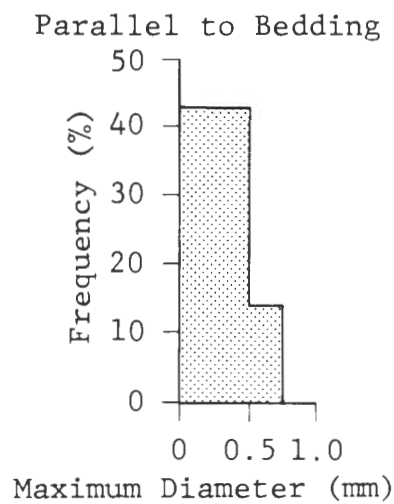
The Fort Riley (Silverdale) Limestone has a very narrow pore-size distribution, with all pores having a maximum diameter less than 1.25 mm and 95 percent of the pores less than 0.5 mm (Fig. 48). Large percentages of the pores in thin section have a maximum diameter less than 0.25 mm: 72 percent for those oriented parallel to the bedding plane and 84 percent for those oriented

perpendicular to the bedding plane. Such data are responsible for the small mean pore sizes reported in Table 4. Interestingly, the degree of pore-shape elongation is identical for thin sections cut parallel and perpendicular to the bedding plane.

The Cresswell Limestone shows only a 0.4 percent porosity, a value identical to that for the hard Neva and lower Cottonwood. Despite the limited number of pores, the data in Table 4 and Figure 48 suggest that most pores in the Cresswell are relatively small (less than 0.25 mm). Table 4 also suggests the pores in the Cresswell are not as elongated as the pores in most of the other limestones, despite the fact that fenestral-type porosity is observed in the Cresswell.

Hard Neva Limestone

Pore-Size Distribution



Pore-Shape Distribution

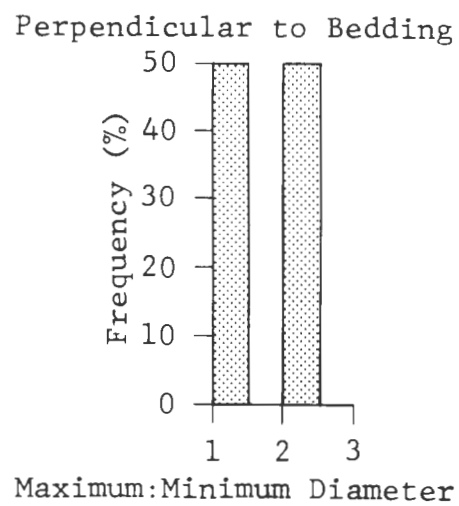
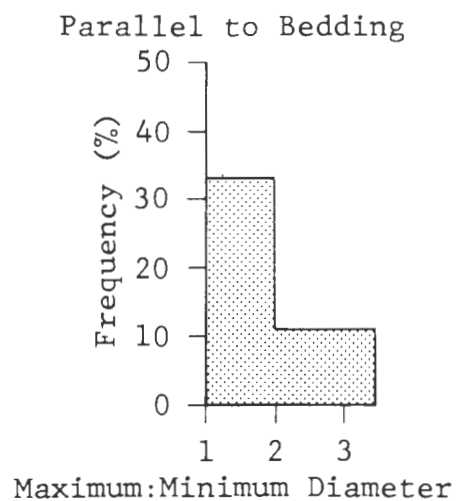
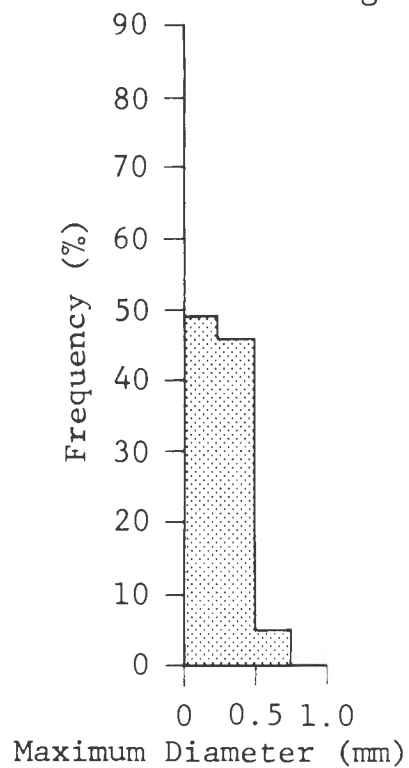


FIGURE 48. cont.

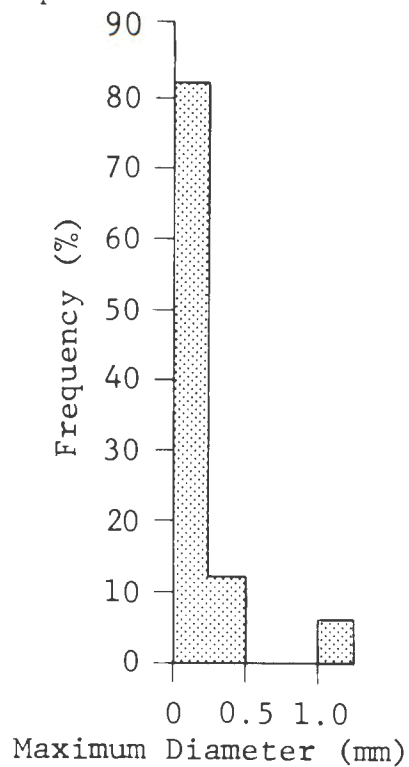
Soft Neva Limestone

Pore-Size Distribution

Parallel to Bedding

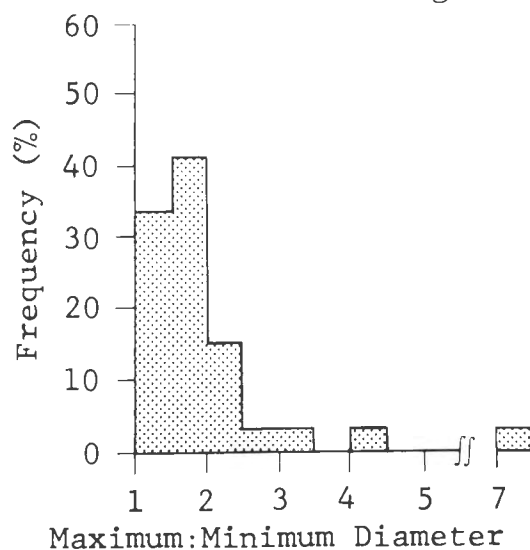


Perpendicular to Bedding



Pore-Shape Distribution

Parallel to Bedding



Perpendicular to Bedding

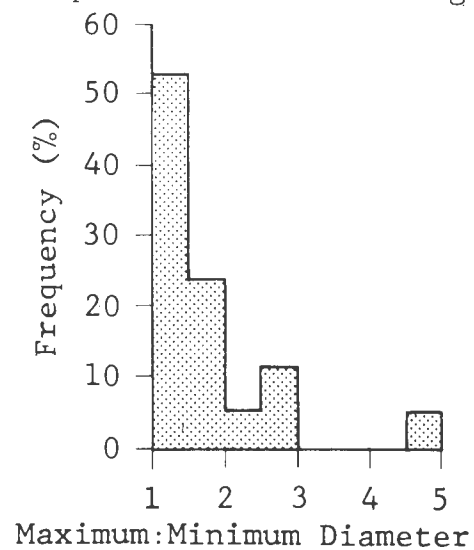
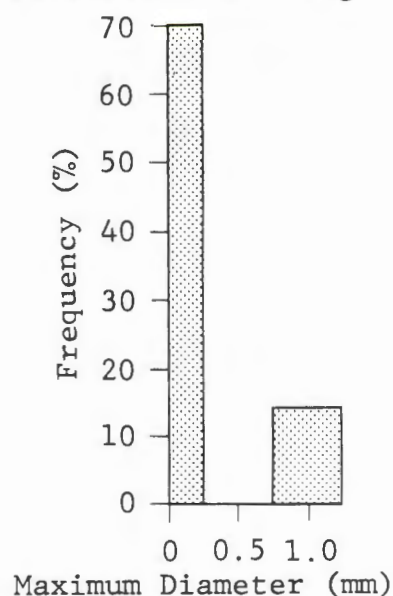


FIGURE 48. cont.

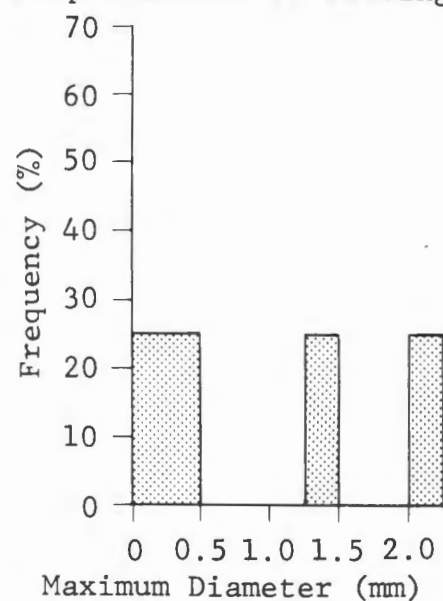
Lower Cottonwood Limestone

Pore-Size Distribution

Parallel to Bedding

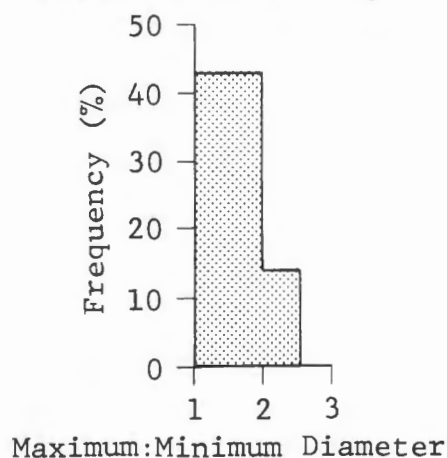


Perpendicular to Bedding



Pore-Shape Distribution

Parallel to Bedding



Perpendicular to Bedding

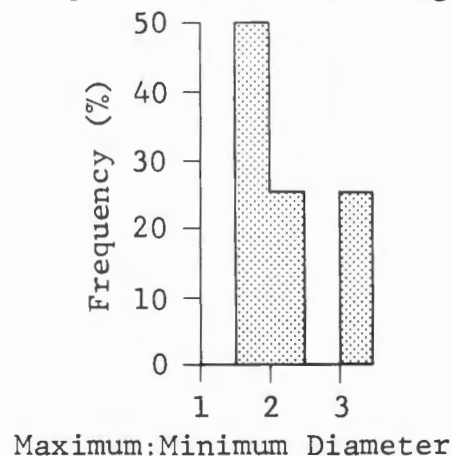
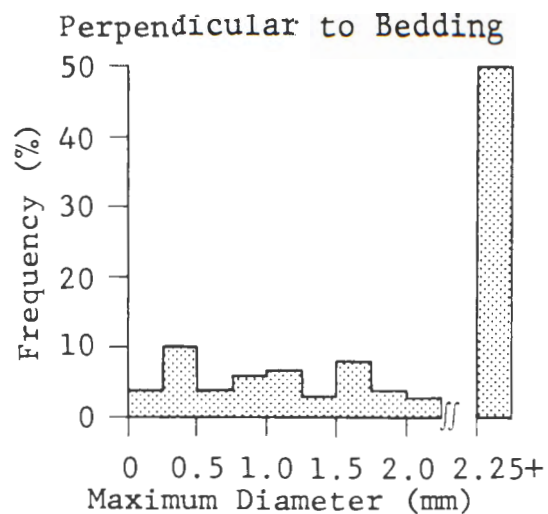
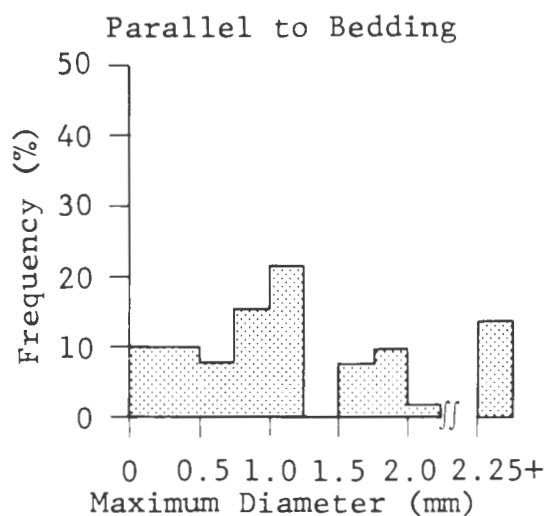


FIGURE 48, cont.

Upper Cottonwood Limestone

Pore-Size Distribution



Pore-Shape Distribution

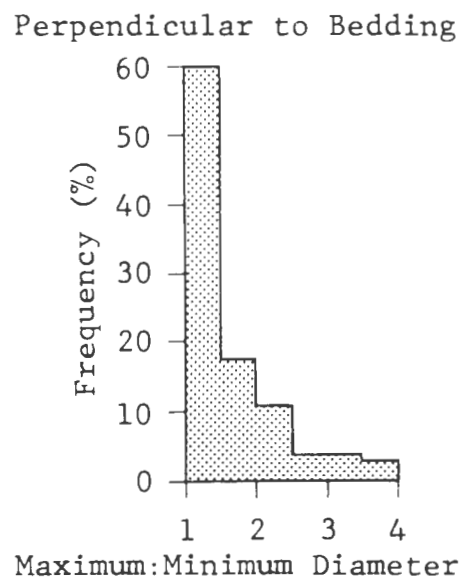
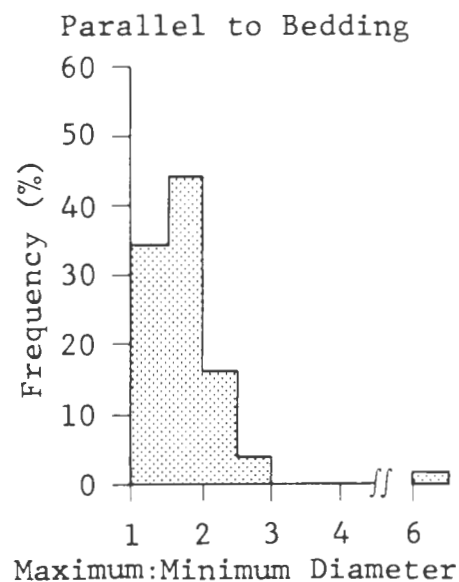
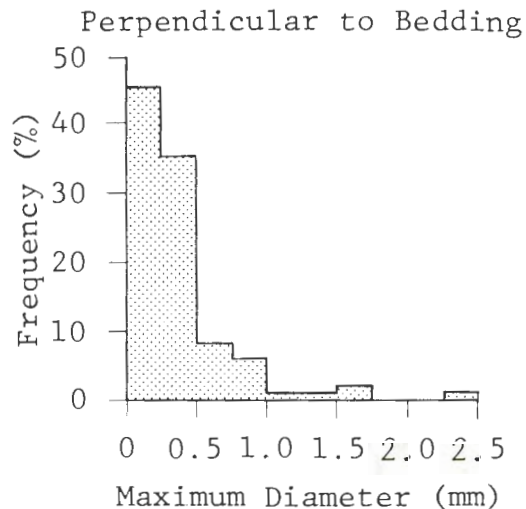
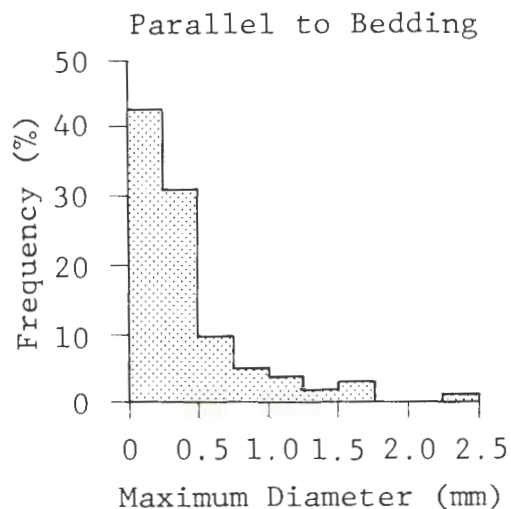


FIGURE 48, cont.

Funston (Onaga) Limestone

Pore-Size Distribution



Pore-Shape Distribution

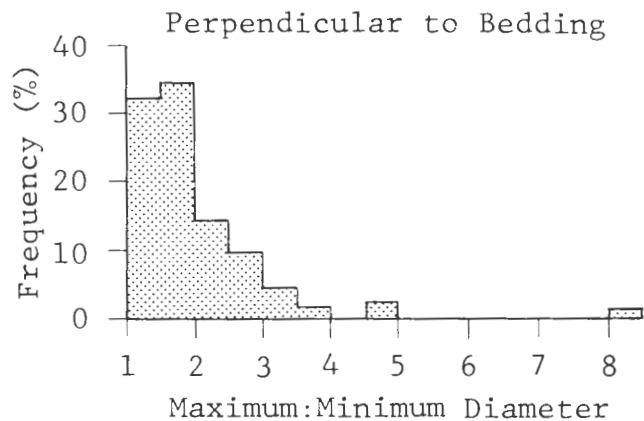
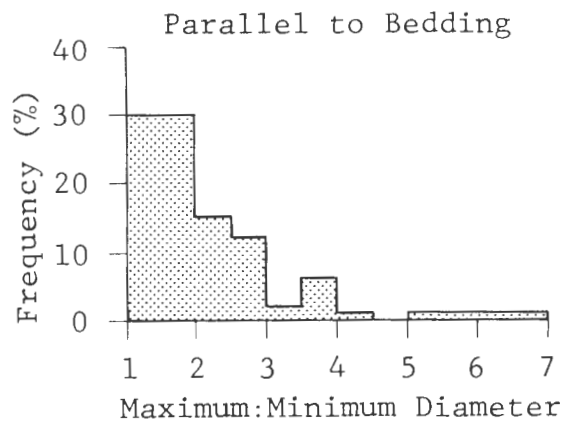
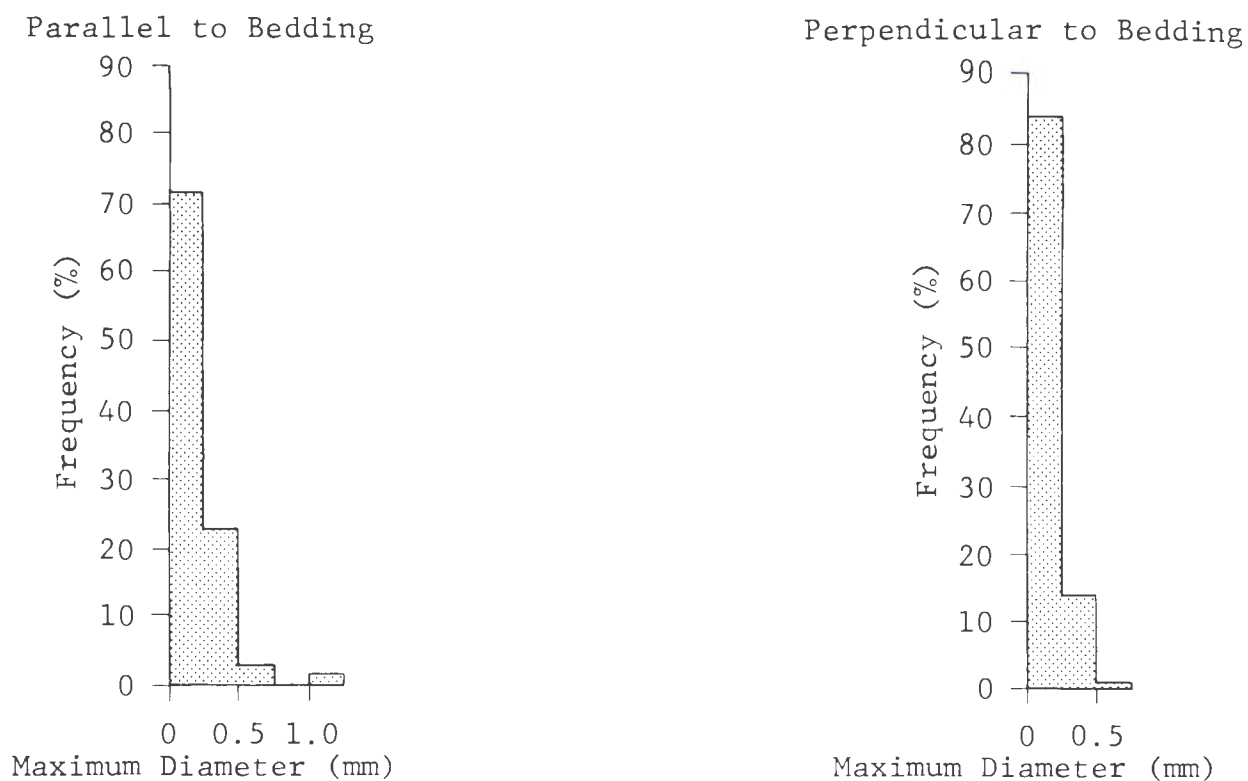


FIGURE 48, cont.

Fort Riley (Silverdale) Limestone

Pore-Size Distribution



Pore-Shape Distribution

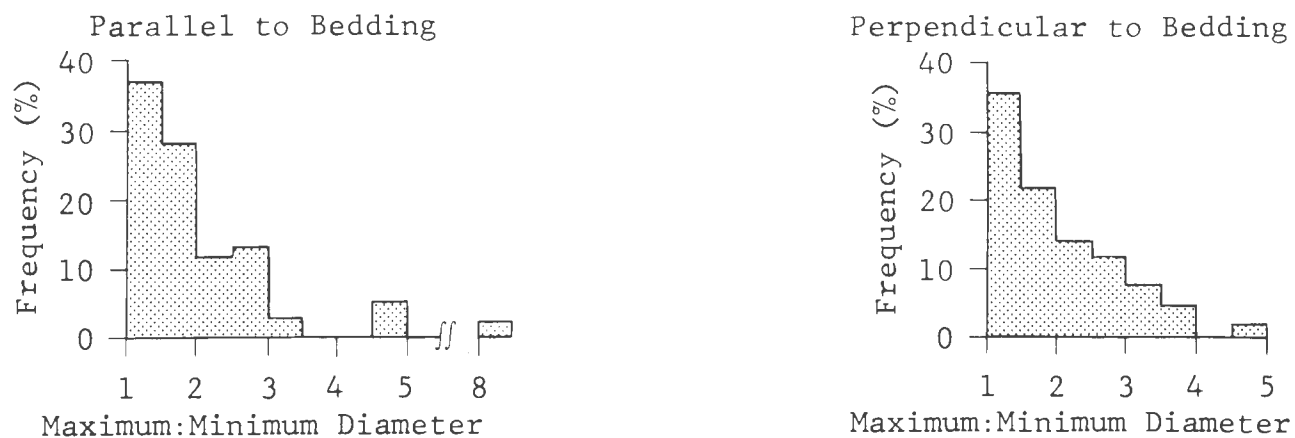
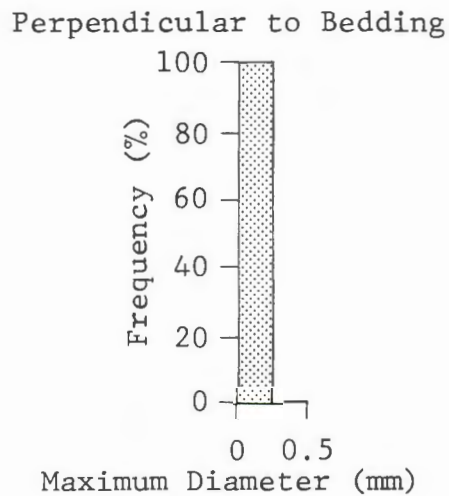
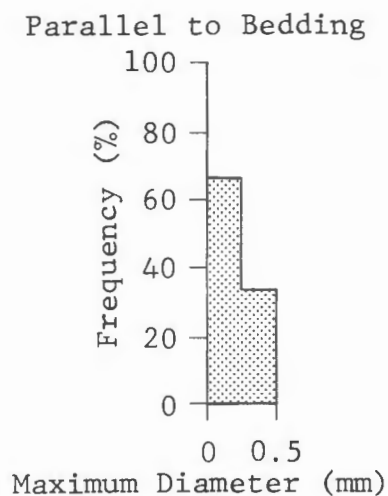


FIGURE 48, cont.

Cresswell Limestone

Pore-Size Distribution



Pore-Shape Distribution

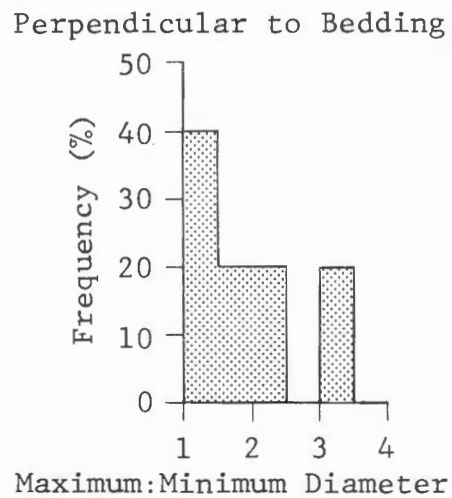
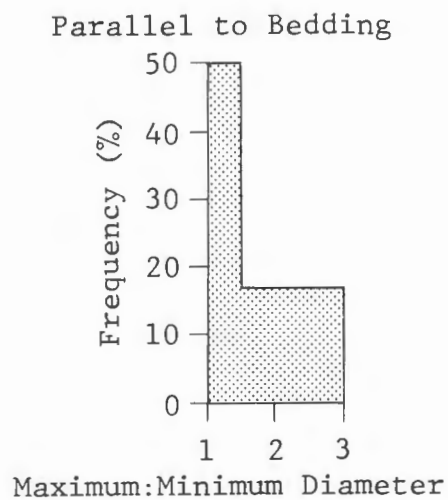


FIGURE 48, cont.

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PORE-SHAPE DISTRIBUTION OF LOWER COTTONWOOD LIMESTONE

Ratio of Maximum to Minimum Diameter	Freq. %		Freq. %		Freq. %		Sum. Freq.	Avg. %
PARALLEL TO BEDDING								
	LC-1		LC-2		LC-3			
1.00-1.49	1	50			2	67	3	43
1.50-1.99			2	100	1	33	3	43
2.00-2.49	1	50					1	14
2.50-2.99								
3.00-3.49								
							<hr/> 7	<hr/> 100
PERPENDICULAR TO BEDDING								
1.00-1.49								
1.50-1.99			2	100			2	50
2.00-2.49	1	50					1	25
2.50-2.99								
3.00-3.49	1	50					<hr/> 1	<hr/> 25
							4	100

PORE-SHAPE DISTRIBUTION OF UPPER COTTONWOOD LIMESTONE

Ratio of Maximum to Minimum Diameter	Freq. %		Freq. %		Freq. %		Sum. Freq.	Avg. %
PARALLEL TO BEDDING								
	UC-1		UC-2		UC-3			
1.00-1.49	1	8	1	11	15	52	17	34
1.50-1.99	8	67	5	56	9	31	22	44
2.00-2.49	2	17	3	33	3	10	8	16
2.50-2.99	1	8			1	3	2	4
3.00-3.49								
3.50-3.99								
≈								
6.00-6.49					1	3	<u>1</u> 50	<u>2</u> 100
PERPENDICULAR TO BEDDING								
1.00-1.49	36	72	4	33	3	30	43	60
1.50-1.99	9	18	3	25	1	10	13	18
2.00-2.49	5	10	1	8	2	20	8	11
2.50-2.99			1	8	2	20	3	4
3.00-3.49			1	8	2	20	3	4
3.50-3.99			2	17			<u>2</u> 72	<u>3</u> 100

PORE-SHAPE DISTRIBUTION OF
FUNSTON (ONAGA) LIMESTONE

Ratio of Maximum to Minimum Diameter	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Sum. Freq.	Avg. %
PARALLEL TO BEDDING										
	O-207		O-191		O-202		O-192			
1.00-1.49	10	22	17	27	12	41	14	36	53	30
1.50-1.99	12	27	20	32	7	24	14	36	53	30
2.00-2.49	7	16	10	16	5	17	5	13	27	15
2.50-2.99	6	13	9	15	4	14	2	5	21	12
3.00-3.49			1	2			3	8	4	2
3.50-3.99	7	16	4	6					11	6
4.00-4.49	2	4							2	1
4.50-4.99										
5.00-5.49	1	2							1	1
5.50-5.99					1	3			1	1
6.00-6.49			1	2					1	1
6.50-6.99							1	3	1	1
									175	100
PERPENDICULAR TO BEDDING										
1.00-1.49	14	25	15	28	15	37	23	40	67	32
1.50-1.99	19	33	18	33	13	32	22	39	72	34
2.00-2.49	8	14	9	17	4	10	8	14	29	14
2.50-2.99	8	14	7	13	3	7	1	2	19	9
3.00-3.49	4	17			3	7	1	2	8	4
3.50-3.99			2	4	1	2			3	1
4.00-4.49	1	2							1	
4.50-4.99	1	2	2	4	1	2	1	2	5	2
5.00-5.49							1	2	1	
5.50-5.99										
6.00-6.49	1	2							1	
6.50-6.99										
7.00-7.49			1	2					1	
7.50-7.99										
8.00-8.49	1	2			1	2			2	1
									209	97

APPENDIX B

MEAN AND STANDARD DEVIATION VALUES OF PORE SIZE AND PORE SHAPE
FOR EACH THIN SECTION OF KANSAS BUILDING LIMESTONE

Limestone	Sample Number	PORE-SIZE DISTRIBUTION			PORE-SHAPE DISTRIBUTION	
			Mean of Maximum Diameter (mm)	Standard Deviation (σ)	Mean of Ratio of Maximum to Minimum Diameter	Standard Deviation (σ)
Five Point (Chestnut Shell)	P-1	⊥	0.396	0.340	2.71	1.577
	P-1	∥	0.510	0.543	2.37	1.409
	P-2	⊥	0.567	0.683	2.69	2.072
	P-2	∥	0.276	0.110	2.97	1.602
	P-3	⊥	0.603	0.707	2.81	1.877
	P-3	∥	1.09	1.78	3.43	2.229
Hard Neva	HN-1	⊥	0.161		2.33	
	HN-1	∥	0.115		2.50	
	HN-2	⊥	—		1.38	
	HN-2	∥	0.334	0.177	1.70	0.316
	HN-3	⊥	—			
	HN-3	∥	0.046	0.033	2.00	1.414
Soft Neva	SN-1	⊥	0.196	0.114	1.59	0.120
	SN-1	∥	0.414	0.153	1.45	0.302
	SN-2	⊥	0.209	0.307	1.82	1.134
	SN-2	∥	0.196	0.164	2.69	2.188
	SN-3	⊥	0.087	0.055	1.53	0.682
	SN-3	∥	0.247	0.139	1.79	0.633
Lower Cottonwood	LC-1	⊥	1.30	1.28	2.85	0.785
	LC-1	∥	0.035	0.016	1.50	0.707
	LC-2	⊥	0.736	0.748	1.85	0.071
	LC-2	∥	0.115	0.065	1.63	0.177
	LC-3	⊥	—	—	—	—
	LC-3	∥	0.698	0.546	1.20	0.276
Upper Cottonwood	UC-1	⊥	3.32	1.76	1.48	0.294
	UC-1	∥	1.99	1.19	1.94	0.390
	UC-2	⊥	1.29	0.823	2.13	0.955
	UC-2	∥	0.486	0.325	1.87	0.393
	UC-3	⊥	1.27	0.681	2.25	0.696
	UC-3	∥	1.21	0.529	1.77	0.911
Funston (Onaga)	O-191	⊥	0.321	0.311	2.07	1.039
	O-191	∥	0.339	0.306	1.99	0.897
	O-192	⊥	0.540	0.580	1.70	0.726
	O-192	∥	0.752	0.580	1.92	1.010
	O-202	⊥	0.312	0.312	2.04	1.234
	O-202	∥	0.320	0.303	1.85	0.882
	O-207	⊥	0.332	0.286	2.18	1.184
	O-207	∥	0.282	0.337	2.28	0.988
Fort Riley (Silverdale)	S-182	⊥	0.162	0.104	2.01	0.763
	S-182	∥	0.219	0.138	1.75	0.533
	S-196	⊥	0.146	0.085	2.03	0.941
	S-196	∥	0.202	0.236	2.17	1.487
	S-200	⊥	0.126	0.086	1.89	0.764
	S-200	∥	0.247	0.171	2.20	0.952
	S-224	⊥	0.166	0.136	2.18	1.014
	S-224	∥	0.144	0.131	1.87	0.888
Cresswell	C-50	⊥	0.161	—	2.33	—
	C-50	∥	0.129	0.087	1.49	0.339
	C-51	⊥	0.115	0.032	1.68	0.907
	C-51	∥	0.414	—	2.57	—
	C-52	⊥	—	—	—	—
	C-52	∥	—	—	—	—

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