Petrographic Characteristics of Kansas Building Limestones

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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.

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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

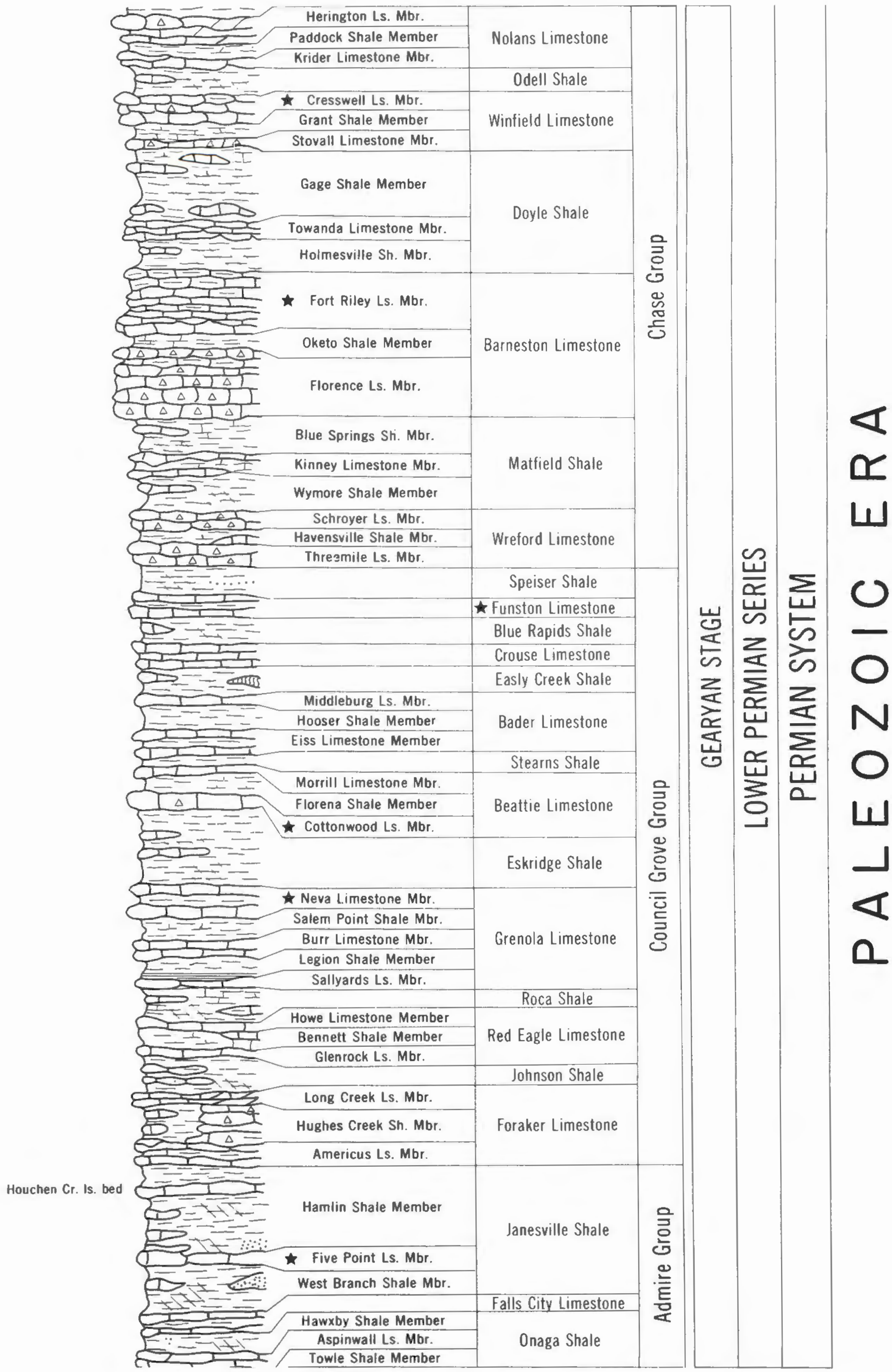

FIGURE 1. Stratigraphic succession of a portion of the Lower Permian sequence in Kansas (Zeller, 1968). Stars indicate Kansas limestones that are currently used for the construction of buildings.

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.

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
Interparticle	15 cr sms	80 sx ms	55 sx ms	100 sx ms	60 sx sms- smg	30sx mc- lms, 25cr mc- sms	40sx mc- lms	
Intraparticle	25sx ms 25cr ms	20 sx ms	45sx ms		20 sx ms 20cr ms	30sx mc- lms	35 sx mc- lms	
Moldic	10sx ms 10cr sms					15 cr mc- sms	25 sx ms	
Fracture	15 sx sms							
Fenestral								60 mc- sms
Intercrystal								40 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	
Cementation	c	Large mesopore	lms	ms (lms + sms)
Enlarged	x	Small mesopore	sms	
Reduced	r	Micropore	mc	

★ from Choquette and Pray, 1970
* excluding *Nubecularia*
† *Osagia* and *Nubecularia*
‡ and sponge debris
** micrite envelopes

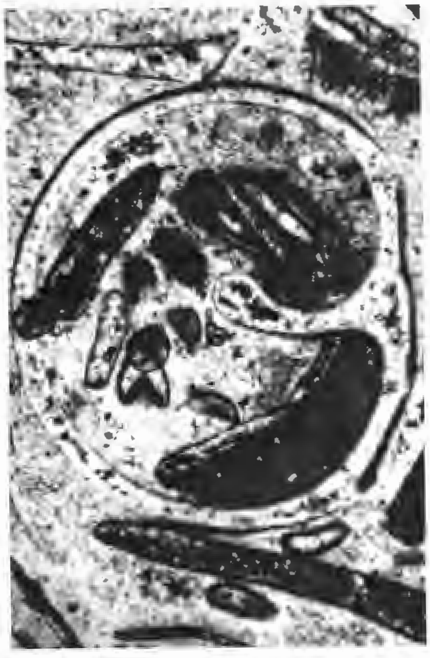

FIGURE 7. Five Point (Chestnut Shell) Limestone Member of the Janesville Limestone. Cross-sectional view of a gastropod surrounded by a micrite envelope and filled with micrite, microspar, and fossil fragments. Bar scale = 0.5 mm. (35 ×, crossed Nicols)

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 ×, 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 ×, plane polarized light)

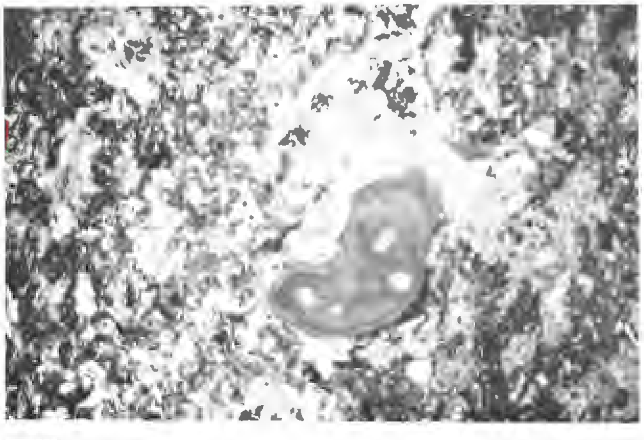

FIGURE 13. Neva Limestone Member of the Grenola Limestone—Hard Neva Bed. Oncolites, with their concentric growth patterns, and fragments of serial foraminifera are often seen in the hard Neva. Bar scale = 3 mm. (10 ×, plane polarized light)

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 ×, plane polarized light)

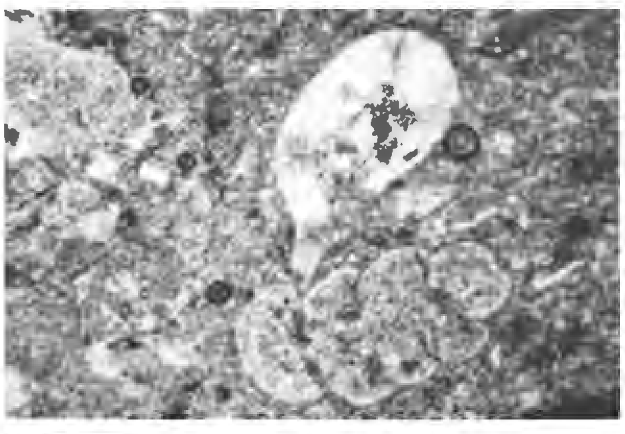

FIGURE 14. Neva Limestone Member of the Grenola Limestone—Hard Neva Bed. A trilobite fragment in the hard Neva. A highly recrystallized biserial foraminifera lies directly underneath the trilobite fragment. A few air bubbles are present (spherical shapes with heavy black outlines). Bar scale = 0.5 mm.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

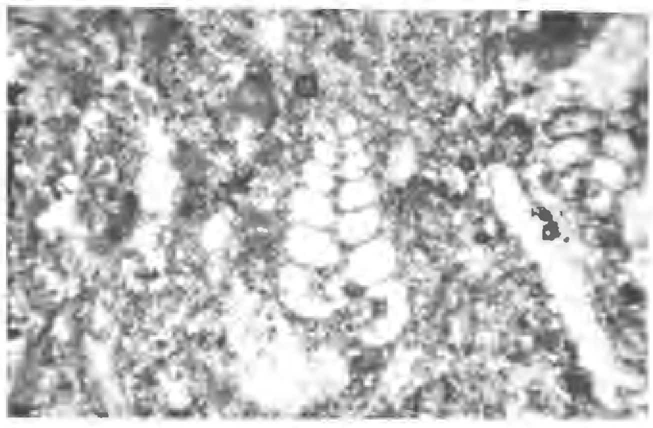

FIGURE 16. Neva Limestone Member of the Grenola Limestone—Soft Neva Bed. Typical biserial foraminifera in the soft Neva Limestone. The matrix is rich in opaque minerals and pelloids. Bar scale = 0.5 mm. (35 ×, plane polarized light)

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, Juresania, Neospirifer,* and *Cruruithyris.*

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

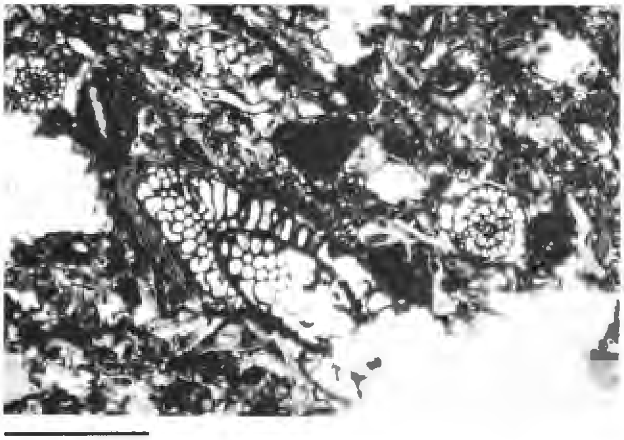

FIGURE 20. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. Another photomicrograph of the upper Cottonwood Limestone showing large grains with micrite coatings and infillings and large vugs. Note the presence of large fusulinids. These foraminifera, shaped like wheat grains,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

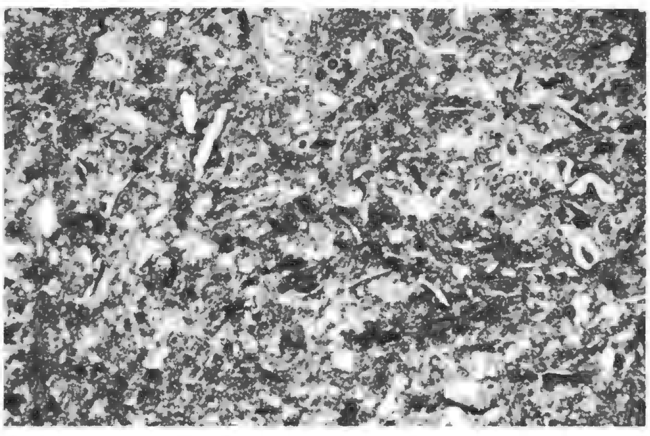

FIGURE 21. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. Representative photomicrograph of the lower Cottonwood Limestone. In general, the grain size of the lower Cottonwood is smaller and it contains fewer fusulinids and fewer large pores relative to the upper Cottonwood. Like the upper Cottonwood, this view shows a variety of fossil types. Bar scale = 3 mm. (10 ×, 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 pelloids are present. The rock has a clotted appearance at times, suggesting more pelloids 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

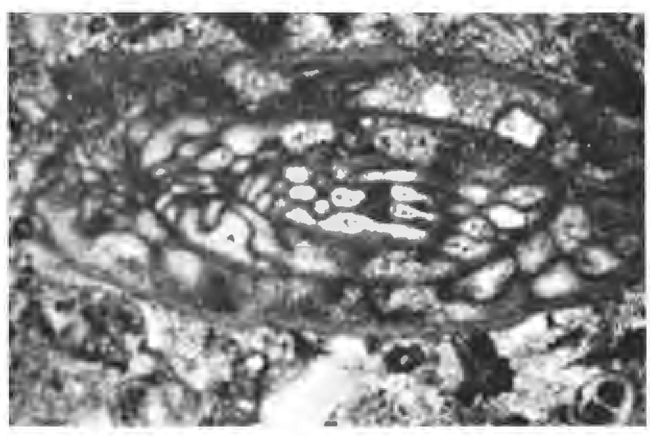

FIGURE 22. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. Tangential section of a fusulinid. Bar scale = 0.5 mm. (35 ×, crossed Nicols)

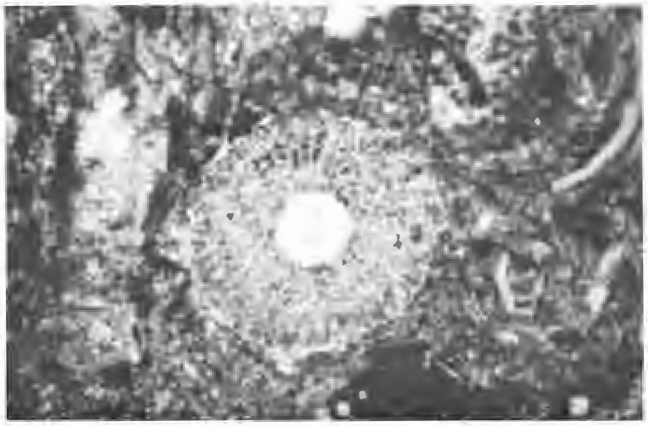

FIGURE 27. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. Cross-sectional view of an echinoid spine. The spar-filled center is in optical continuity with the spine and implies syntaxial growth. The black spots within the spine may be primary porosity. Bar scale = 0.5 mm. (35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

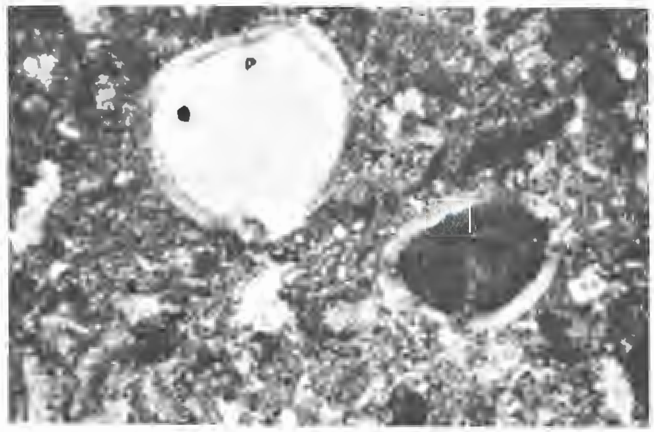

FIGURE 29. Cottonwood Limestone Member of the Beattie Limestone—Upper Cottonwood Bed. Two ostracodes. One is filled with a single crystal of calcite while the other is filled with micrite or lime mud. Bar scale = 0.5 mm. (35 ×, crossed Nicols)

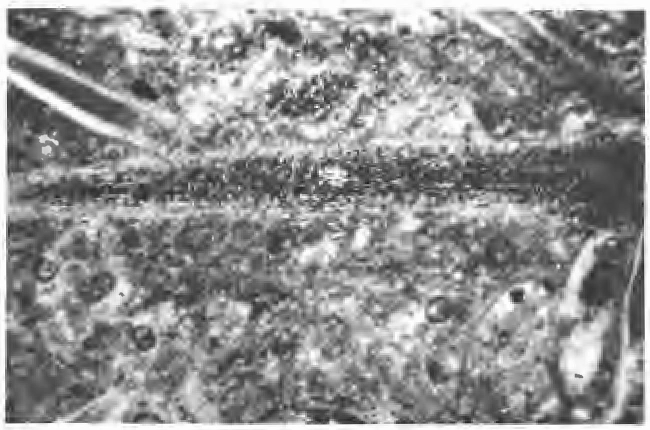

FIGURE 28. Cottonwood Limestone Member of the Beattie Limestone—Lower Cottonwood Bed. Longitudinal section of a highly recrystallized echinoid spine. The bulb on the right side is where the spine was originally attached to the body. Bar scale = 0.5 mm. (35 ×, crossed Nicols)

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 ×, 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 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

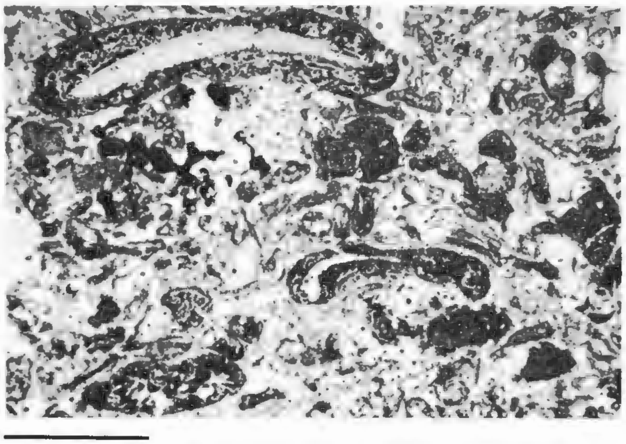

FIGURE 34. Funston (Onaga) Limestone. Encrustation of large bivalve fragments by *Nubecularia*(?), an algal-foraminiferal growth. Bar scale = 3 mm. (10×, plane polarized light)

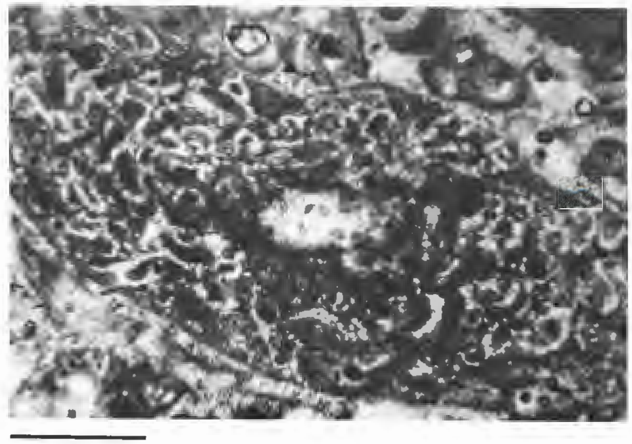

FIGURE 36. Funston (Onaga) Limestone. Closer view of algal-foraminiferal growth. Note presence of sparry rim cement. Bar scale = 0.5 mm. (35×, plane polarized light)

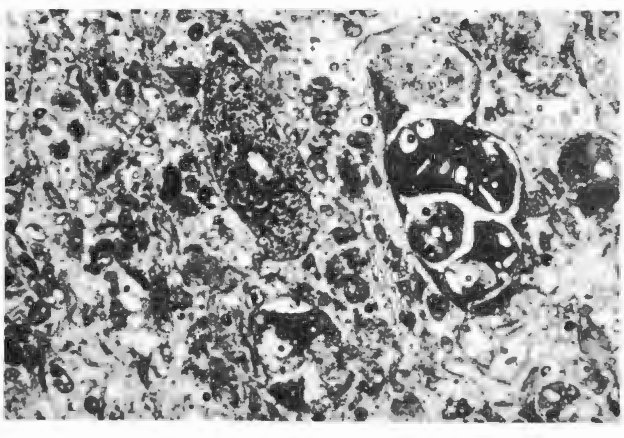

FIGURE 35. Funston (Onaga) Limestone. View showing *Nubecularia* or *Osagia* (left center) and a gastropod (sparry calcite wall structure and a micrite infilling). Note the coated grains, sparry rim cement, and abundant pelloids. Bar scale = 3 mm. (10×, plane polarized light)

(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-spired 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/

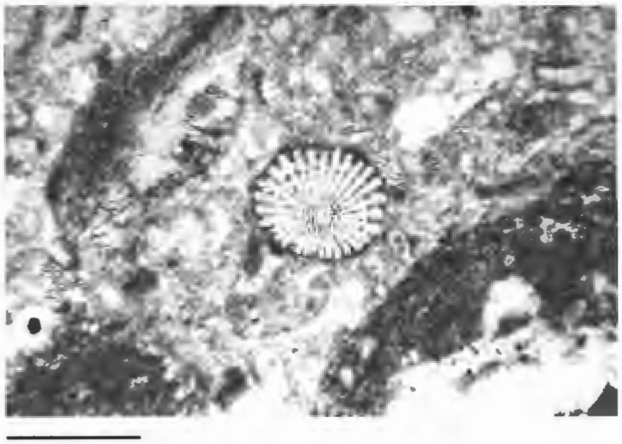

FIGURE 40. Fort Riley (Silverdale) Limestone Member of the Barneston Limestone. Cross-sectional view of a lightly coated echinoid spine. The other material in this picture is poorly defined but mostly appears to be a combination of algal growth, micrite, and fossil debris. Bar scale = 0.5 mm. (35 ×,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

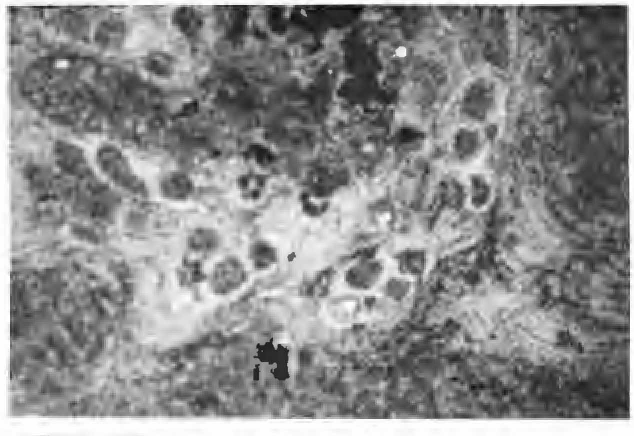

FIGURE 42. Fort Riley (Silverdale) Limestone Member of the Barneston Limestone. Bryozoan fragment without a well-defined rounded envelope. Note presence of vuggy porosity. Bar scale = 0.5 mm. (35 ×, crossed Nicols)

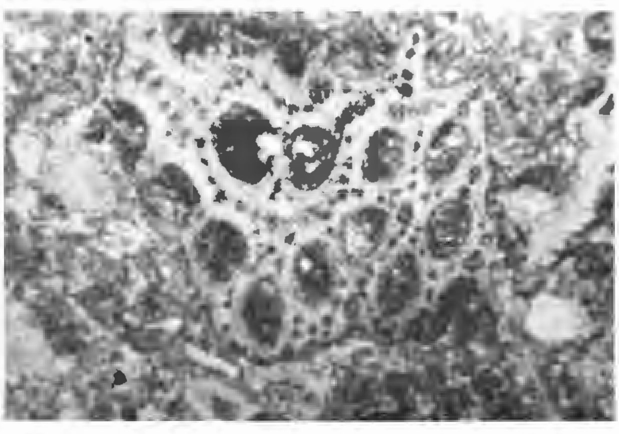

FIGURE 41. Fort Riley (Silverdale) Limestone Member of the Barneston Limestone. Tangential-sectional view of a bryozoan. Note the acanthapores in the wall structure surrounding each zooecial opening. Bar scale = 0.5 mm. (35 ×, plane polarized light)

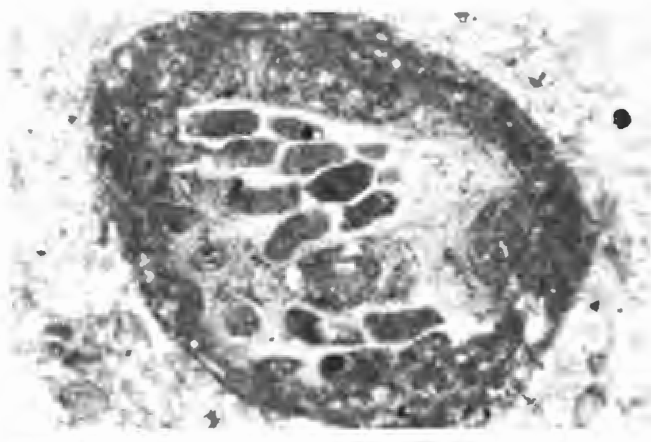

FIGURE 43. Fort Riley (Silverdale) Limestone Member of the Barneston Limestone. Coated bryozoan fragment showing typical rounded grain shape with a sparry rim cement. Bar scale = 0.5 mm. (35 ×, plane polarized light)

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.

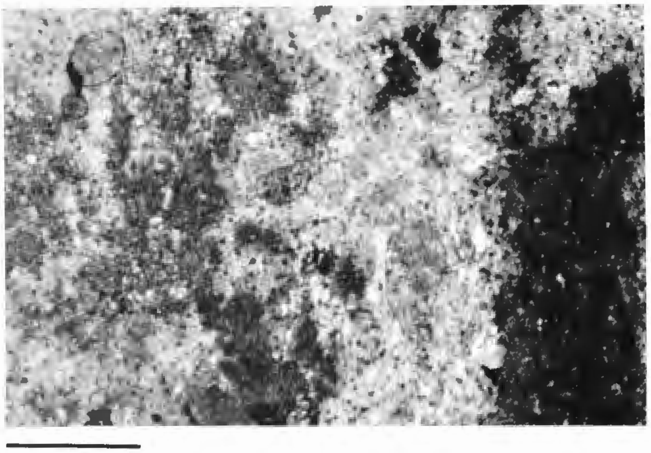

FIGURE 47. Cresswell Limestone Member of the Winfield Limestone. Bioturbation in the Cresswell Limestone caused by burrowing organisms. Note fine-sized opaque grains and pellets or pelloids that produce a clotted appearance in the photomicrograph. Bar scale = 0.5 mm. (35 ×, plane polarized light)

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.

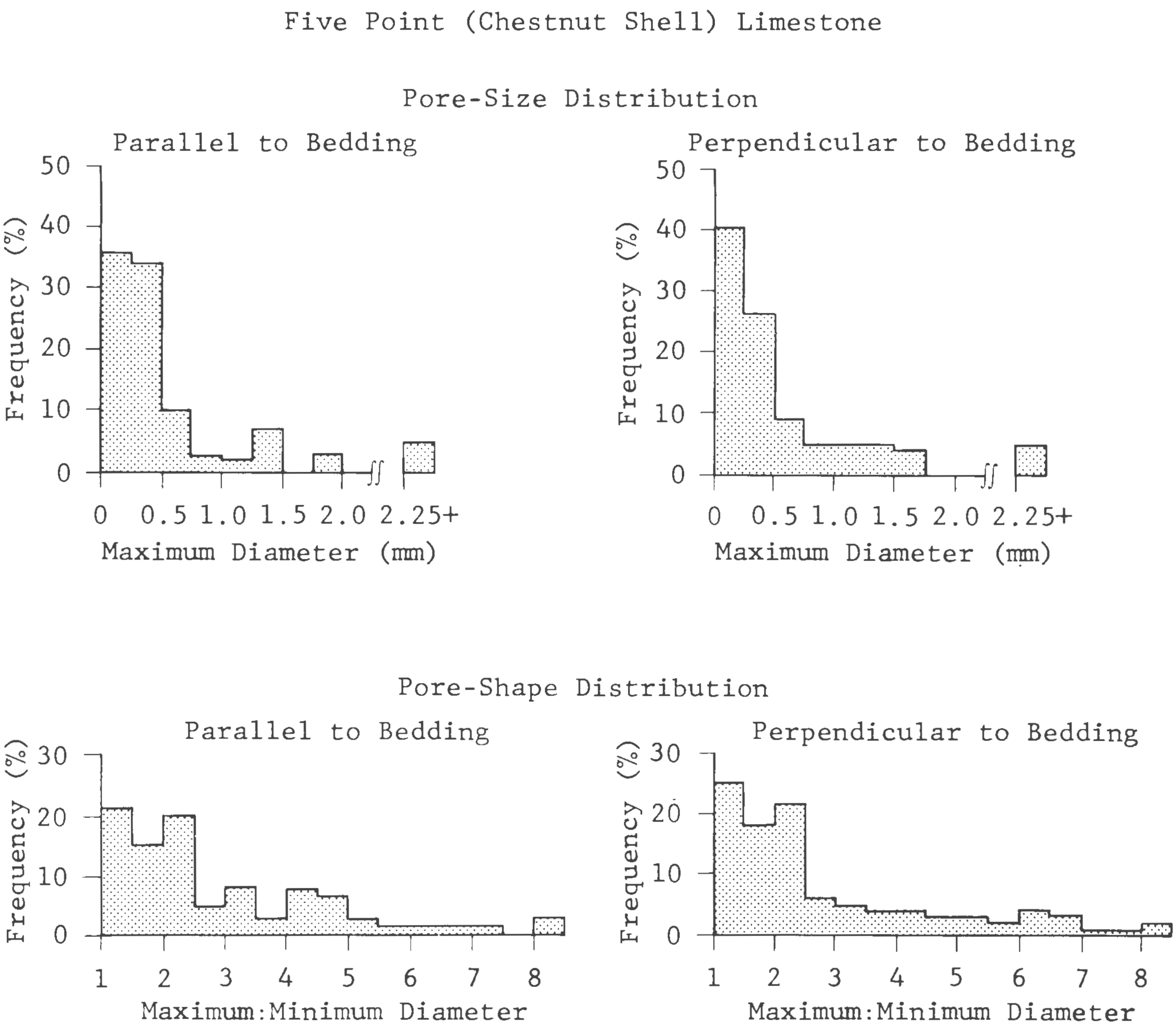

FIGURE 48. Histograms showing pore-size and pore-shape distributions of currently quarried Kansas building limestones.

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.

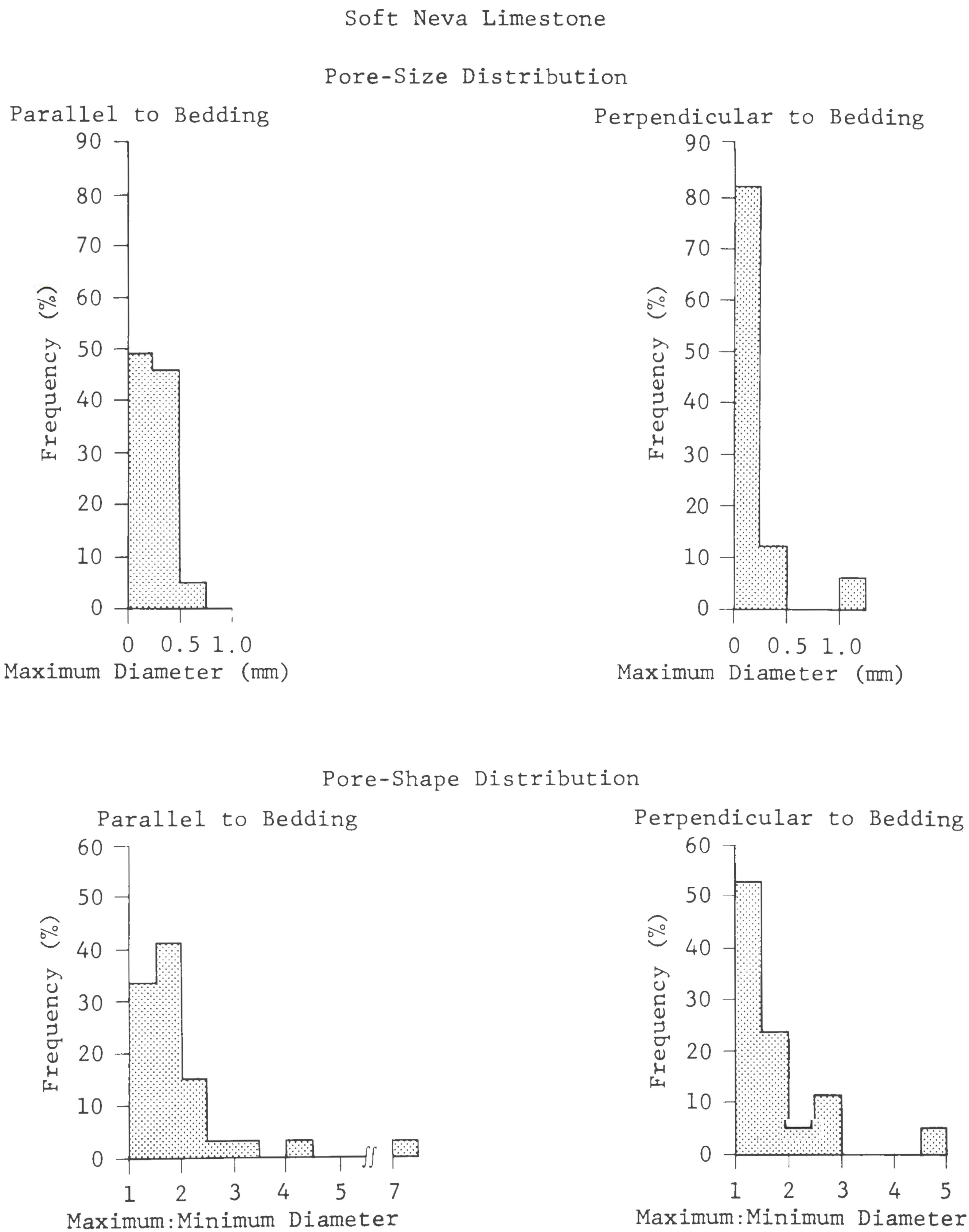

FIGURE 48, cont.

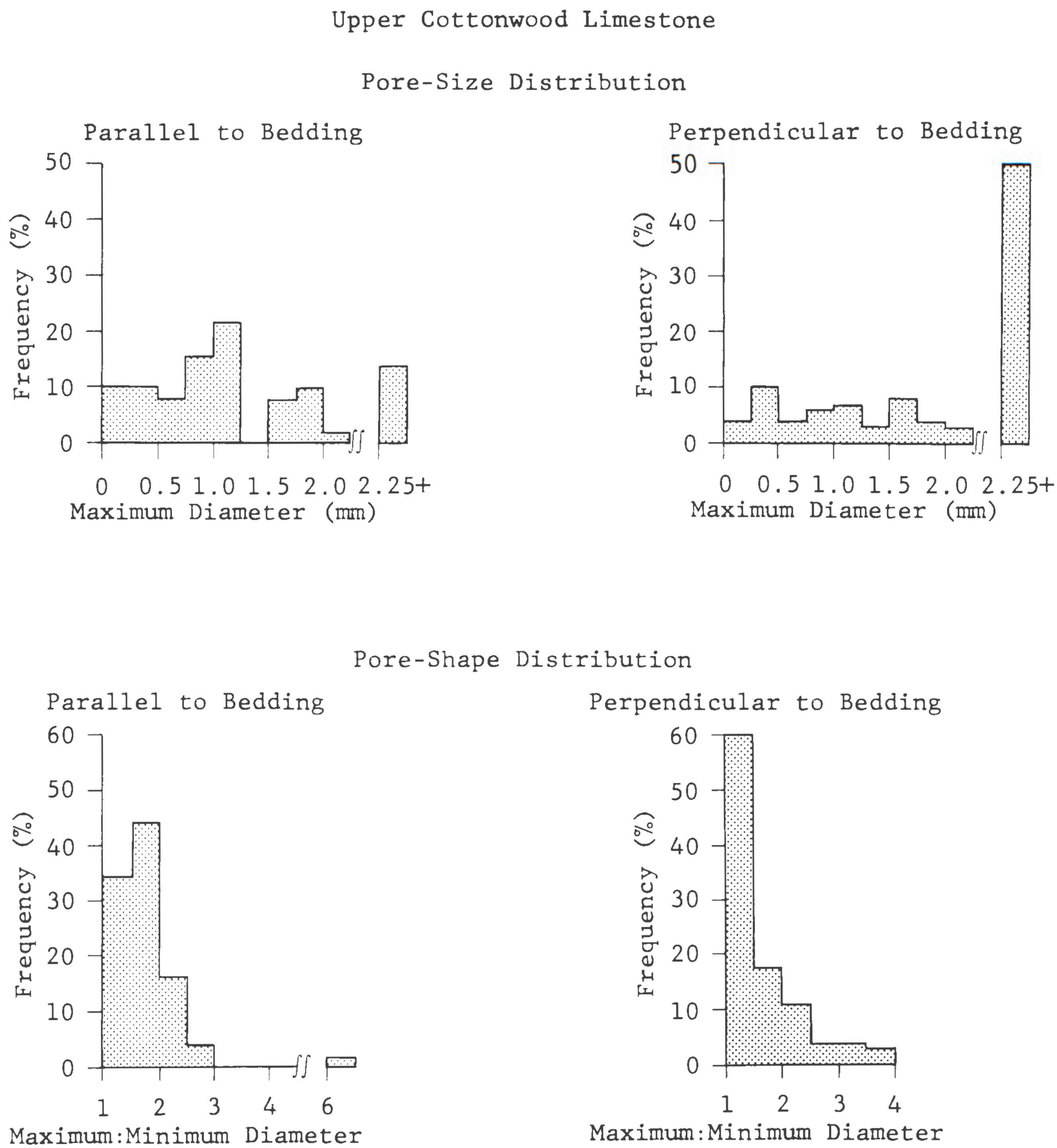

FIGURE 48. cont.

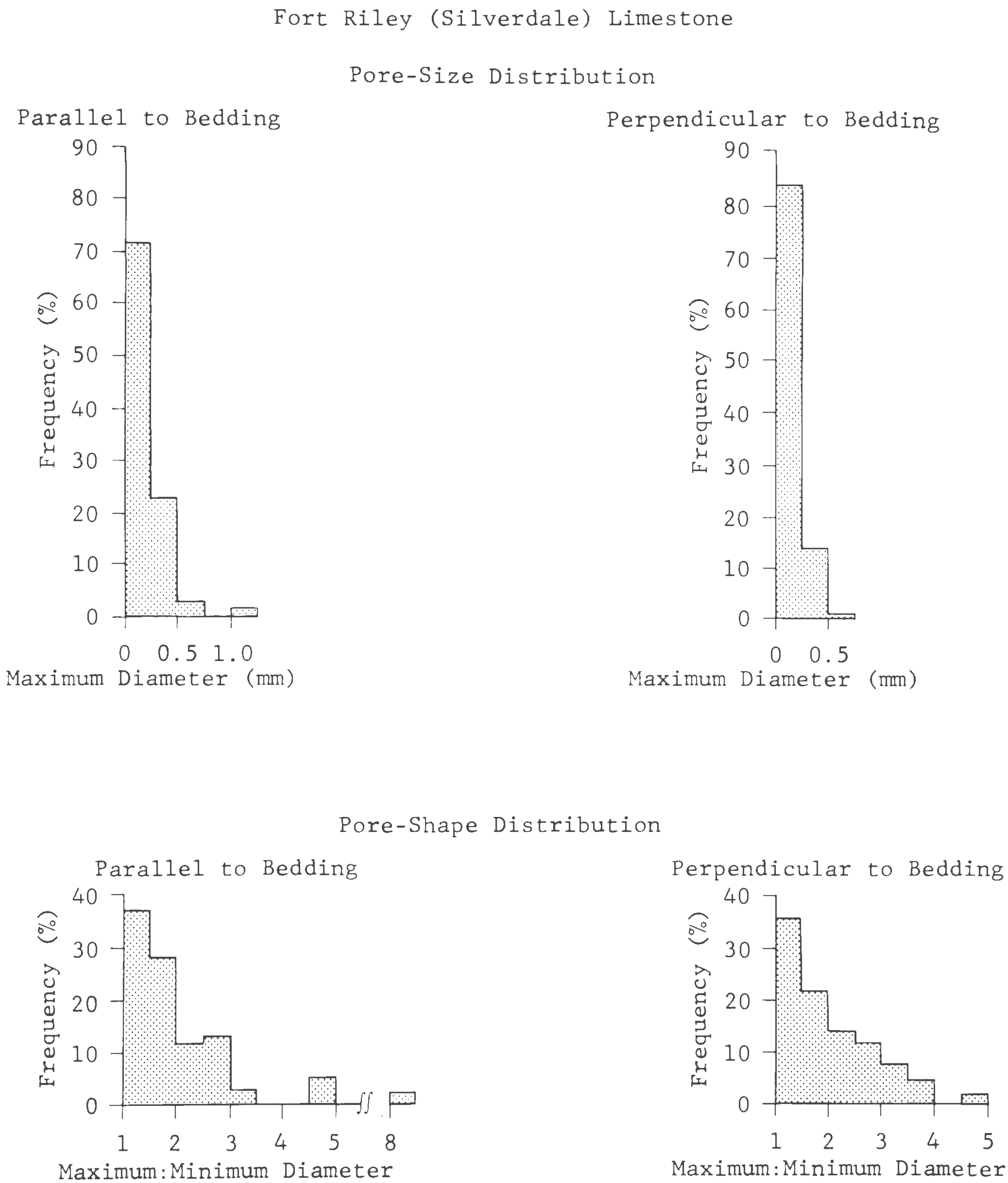

FIGURE 48. cont.

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PORE-SIZE DISTRIBUTION OF HARD NEVA LIMESTONE

Maximum Diameter (mm)	Freq.	%	Freq.	%	Freq.	%	Sum. Freq.	Avg. %
	Parallel to Bedding							
	HN-1		HN-2		HN-3			
0.00-0.24	1	100	2	33	1	100	3	43
0.25-0.49			3	50			3	43
0.50-0.74			1	17			1	14
0.75-0.99								
							7	100
	Perpendicular to Bedding							
0.00-0.24	1	100					1	50
0.25-0.49								
0.50-0.74								
0.75-0.99			1	100			1	50
							2	100

PORE-SHAPE DISTRIBUTION OF HARD NEVA LIMESTONE

Ratio of Maximum to Minimum Diameter	Freq.	%	Freq.	%	Freq.	%	Sum. Freq.	Avg. %
	Parallel to Bedding							
	HN-1		HN-2		HN-3			
1.00-1.49			2	33	1	50	3	33
1.50-1.99			3	50			3	33
2.00-2.49			1	17			1	11
2.50-2.99	1	100					1	11
3.00-3.49					1	50	1	11
							9	99
	Perpendicular to Bedding							
1.00-1.49			1	100			1	50
1.50-1.99								
2.00-2.49	1	100					1	50
2.50-2.99								
3.00-3.49								
							2	100

PORE-SIZE DISTRIBUTION OF SOFT NEVA LIMESTONE

Maximum Diameter (mm)	Freq.	%	Freq.	%	Freq.	%	Sum. Freq.	Avg. %
	Parallel to Bedding							
	SN-1		SN-2		SN-3			
0.00-0.24	1	20	4	67	14	50	19	49
0.25-0.49	3	60	2	33	13	46	18	46
0.50-0.74	1	20			1	4	2	5
0.75-0.99								
1.00-1.24								
							39	100
	Perpendicular to Bedding							
0.00-0.24	1	50	8	80	5	100	14	82
0.25-0.49	1	50	1	10			2	12
0.50-0.74								
0.75-0.99								
1.00-1.24			1	10			1	6
							17	100

PORE-SHAPE DISTRIBUTION OF SOFT NEVA LIMESTONE

Ratio of Maximum to Minimum Diameter	Freq.	%	Freq.	%	Freq.	%	Sum. Freq.	Avg. %
	Parallel to Bedding							
	SN-1		SN-2		SN-3			
1.00-1.49	3	60	2	33	8	29	13	33
1.50-1.99	2	40	2	33	12	43	16	41
2.00-2.49			1	17	5	18	6	15
2.50-2.99					1	4	1	3
3.00-3.49					1	4	1	3
3.50-3.99								
4.00-4.49					1	4	1	3
4.50-4.99								
≈								
7.00-7.49			1	17			1	3
							39	101
	Perpendicular to Bedding							
1.00-1.49	2	100	5	50	2	40	9	53
1.50-1.99			2	20	2	40	4	24
2.00-2.49			1	10			1	6
2.50-2.99			1	10	1	20	2	12
3.00-3.49								
3.50-3.99								
4.00-4.49								
4.50-4.99			1	10			1	6
							17	101

PORE-SIZE DISTRIBUTION OF
FUNSTON (ONAGA) LIMESTONE

Maximum Diameter (mm)	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Sum. Freq.	Avg. %
PARALLEL TO BEDDING										
	O-207		O-191		O-202		O-192			
0.00-0.24	24	53	29	47	15	52	8	21	76	43
0.25-0.49	18	40	19	31	7	24	11	28	55	31
0.50-0.74	1	2	8	13	5	17	4	10	18	10
0.75-0.99			3	5			5	13	8	5
1.00-1.24			2	3	2	7	3	8	7	4
1.25-1.49							3	8	3	2
1.50-1.74	2	4	1	2			3	8	6	3
1.75-1.99										
2.00-2.24										
2.25-2.49							2	5	2	1
									175	99
PERPENDICULAR TO BEDDING										
0.00-0.24	26	46	26	48	22	54	21	37	95	45
0.25-0.49	22	39	23	43	12	29	16	28	73	35
0.50-0.74	4	7	2	4	3	7	7	12	16	8
0.75-0.99	3	5	1	2	3	7	5	9	12	6
1.00-1.24	1	2					1	2	2	1
1.25-1.49	1	2					2	4	3	1
1.50-1.74			2	4	1	2	1	2	4	2
1.75-1.99							1	2	1	
2.00-2.24										
2.25-2.49							3	5	3	1
									209	99

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

			PORE-SIZE DISTRIBUTION		PORE-SHAPE DISTRIBUTION	
Limestone	Sample Number		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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