

**KANSAS GEOLOGICAL SURVEY
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CONGLOMERATIC LIMESTONES OF THE UPPER
PENNSYLVANIAN CAPTAIN CREEK LIMESTONE AND THEIR
ASSOCIATION WITH THE LOWER SEQUENCE BOUNDARY OF THE
STANTON DEPOSITIONAL SEQUENCE NORTHWESTERN JOHNSON
COUNTY, KANSAS

by

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Introduction

The recognition and interpretation of sequence boundaries in carbonate systems can often be difficult as a result of problems such as the subtle nature of sequence boundaries, the presence of numerous stratigraphic breaks, and the amalgamation of surfaces (Franseen et al, 1990). In this sense, associated stratal geometries and facies patterns can aid in their recognition.

However, much controversy exists as to the origin of carbonate conglomerate units. Some workers interpret these deposits to occur during relative sea-level lowstands (e.g., Sarg, 1988; Hunt and Tucker, 1992) and therefore represent initial deposits overlying sequence boundaries (Sarg, 1988) or just below the sequence boundary (Hunt and Tucker, 1992). Others interpret carbonate conglomerate units as being shed during relative sea-level highstands (e.g., Schlager, 1991) and therefore the sequence boundary lies above the conglomerate unit.

A study was conducted on a conglomeratic limestone, up to 7.5 feet thick, that apparently occurs at the base of Stanton depositional sequence in eastern Kansas. The purpose of this study was to describe, define the limits, and elucidate controls on the development of this conglomerate in the context of its association with the basal Stanton sequence boundary. Also, because many carbonate conglomerate units are associated with petroleum reservoirs, the complexities in the local stratigraphy and nature of the conglomerate unit were considered for their effects on conceptual models for hydrocarbon migration, trapping, and reservoir development.

Geologic Background

This study focuses on the Upper Pennsylvanian Captain Creek Limestone Member of the

Stanton Limestone within the Stanton depositional sequence (Watney et al., 1989), in northwestern Johnson County (Figs. 1 & 2). The Stanton Limestone represents a classic example of a Kansas cyclothem as described by Heckel (1975) but recently has been reinterpreted as a depositional sequence by Watney et al. (1989) (Fig. 2).

Underlying the Captain Creek Limestone is an outside shale, the Vilas Shale, which caps the subjacent Plattsburg depositional sequence. In Johnson County the Vilas Shale ranges in thickness from 8 to 25 feet. The Vilas Shale is thickest in the northern part of the county and thins to the south (O'Connor, 1971). The Vilas Shale is typically a gray mudstone, silty or sandy shale or fine-grained sandstone. Mica and carbonized plant fragments are common. The Vilas Shale represents deltaic sedimentation during a relative low stand in base level (Watney and French, 1988). The upper surface of the Vilas Shale is considered the upper sequence boundary of the Plattsburg depositional sequence (Fig. 2) (Watney et al., 1989).

The Stanton depositional sequence is composed of four lithologic units. From base to top these units are: the Captain Creek Limestone, a middle limestone; the Eudora Shale, a core shale or condensed section; the Stoner Limestone, an upper limestone; and the Rock Lake Shale, an outside shale capped by the upper sequence boundary of the Stanton depositional sequence (Watney et al., 1989). The Captain Creek Limestone is the flooding unit within the Stanton depositional sequence and represents initial carbonate sedimentation during a relative rise in sea level (Watney et al., 1989).

O'Connor (1971) reports the range in thickness of the Captain Creek Limestone in Johnson County from 4.5 to 10 feet, thinnest to the northeast and northwest and thickest to the southwest. We found the thickest Captain Creek Limestone to be 12 feet in the area of Highway

K-10 and Kill Creek valley. In this report the "K-10/Kill Creek area" is designated as an area including the S/2 of secs. 32, 33, 34, T.12S., R.22E. and N/2 of secs. 3, 4, 5, T.13S., R.22E. (Fig. 3).

We propose two submembers for the Captain Creek Limestone. The lower submember is composed of a conglomeratic limestone and upper submember bioclastic lime wacke-packstone. This coarse-grained lower submember, up to 7.5 feet thick, occurs only locally in the K-10/Kill Creek area (Fig. 4). This submember is typically a gray or brown conglomeratic lime grainstone composed of small pebble-sized limestone clasts, bioclasts, and shale clasts. The upper range in grain size is 2.8 dm in diameter. The upper Captain Creek submember is typically a gray to light-brown phylloid, brachiopod, crinoid, and bryozoan lime wacke-packstone. Watney et al. (1989) propose that initial flooding associated with the Stanton depositional sequence began at some time during Vilas Shale deposition. However, based on my observations in the K-10/Kill Creek area, initial flooding appears to be associated with the basal conglomerate submember of the Captain Creek Limestone at the top of the Vilas Shale. Perhaps initial flooding within the Stanton sequence was oscillatory and a minor regression separates initial flooding within the Vilas shale as proposed by Watney et al (1989) and flooding of the upper surface of the Vilas Shale as recognized in this study.

The Eudora Shale is typically 6 to 8 feet thick (O'Connor, 1971) but Newell (1935) reports at least as much as 11 feet in thickness locally. The Eudora Shale is generally composed of a thin, basal, gray calcareous shale overlain by 2 to 4.5 feet of black phosphatic fissile shale and capped by 3 to 6 feet of gray partly calcareous shale (O'Connor, 1971). The black phosphatic shale represents a condensed section which was deposited during maximum rate of

increase in relative sea level and/or during maximum depth of this rise in base level (Watney et al., 1989).

The thickness of the Stoner Limestone averages from 13 to 18 feet (O'Connor, 1971). The Stoner Limestone is commonly a wavy-bedded skeletal/phyllloid-algal wackestone. Cryptic fenestral fabric are locally characteristic of the middle to upper lithologies. This unit represents carbonate aggradation during a relative stillstand and fall in base level (Watney et al., 1989).

The Rock Lake Shale ranges in thickness from 2 to 14 feet. It is typically a shale and sandstone but also includes siltstone, conglomerate, and a thin coal (O'Connor, 1971; Watney et al., 1989). This outside shale represents a relative fall in base level. The upper surface of the Rock Lake Shale is suggested as the upper sequence boundary of the Stanton depositional sequence by Watney et al. (1989).

Previous Studies

Newell (1935) identified a conglomeratic limestone within the Bonner Springs Shale in a section at Penner's ford at the east bluff of Kill Creek, 0.6 mile west of the NE corner of sec. 4, T.13S., R.22E. The "breccia" (Newell, 1935, p. 69) is described as derived from limestone older than the Bonner Springs Shale and possibly representing shoal gravels. Newell's section corresponds to locality CR-1 of this report (Fig. 3). We consider the correlations of Newell at this locality incorrect. The shale below the conglomeratic limestone identified by Newell (1935, p. 100) as Bonner Springs Shale is actually the Vilas Shale and the conglomeratic limestone unit is now correlated as the lower submember of the Captain Creek Limestone instead of a limestone unit within the Bonner Springs Shale. Newell (1935) additionally measured 12 feet of limestone

overlying a thin shale which caps the conglomeratic limestone and correlated this limestone unit to the Plattsburg Limestone. We correlate this limestone unit to the upper submember of the Captain Creek Limestone.

O'Connor (1971) described a 3.5 foot bed of fossiliferous limestone conglomerate about 1 foot from the top of the Bonner Springs Shale on the south side of sec. 33, T.12S., R.22E. in the east bluff of Kill Creek valley. We, however, recognize these conglomerates as the lower submember of the Captain Creek Limestone. Like Newell (1935), O'Connor (1971) identified the Vilas Shale as Bonner Springs in the Kill Creek area near highway K-10. O'Connor (1971) also identified a 5.5-foot-thick bed of gray coarse-grained detrital limestone containing shell fragments, 15 feet above the base of a shale, as a limestone unit within the Bonner Spring Shale. Again, the shale is likely the Vilas Shale and the limestone unit is likely the Captain Creek Limestone. O'Connor (1971) describes a similar sequence near locality SQE-1 (Fig. 3), which includes thick beds of limestone, breccia, and conglomerate exposed along the county road and government railroad in NW1/4, sec. 4, T.13S., R.22E. These limestone conglomerates were correlated incorrectly by O'Connor (1971) as units within the Bonner Springs Shale. We correlate the limestone, breccia, and conglomerate at this locality to the lower submember of the Captain Creek Limestone. O'Connor (1971) did not speculate on the origin of these coarse-grained limestones.

Heckel (1975) studied the Stanton Formation in a regional context but did not address the conglomerates at the base of the Captain Creek in the K-10/Kill Creek area. However, Heckel (1972) and Heckel (1975) bring attention to channels in the Stanton Limestone either filled with calcarenite or lined with calcarenite and filled with sandstone in Woodson and Wilson Counties,

some 80 miles to the southwest of Johnson County. These channels are between 12 to 22 miles long and 0.5 to 1 mile wide and occur between Stanton phylloid-algal buildups.

Prochnow (1982) was the first to place the conglomeratic limestones of the K-10/Kill Creek area within the Captain Creek Limestone. The study was limited, however, addressing only three sections of conglomeratic limestones of the Captain Creek Limestone in roadcuts along highway K-10 just east of the Kill Creek valley. At this locality Prochnow (1982) interpreted the entire Captain Creek as a fining-upward submarine channel-fill sequence. She described the conglomeratic lower submember of the Captain Creek Limestone as a coarse channel lag and wacke-packstones of the upper submember of the Captain Creek Limestone as the top of the fining-upward sequence.

In 1988, under the direction of Paul Enos, the Geology 732 and Geology 932 courses at the University of Kansas Department of Geology studied the conglomeratic limestones of the Captain Creek Limestone in the K-10/Kill Creek area. Results were prepared but never published.

Watney and French (1988) and Watney et al. (1989) reported that the Captain Creek Limestone thins and contains mud-pebble conglomerates at the base on the east bluffs of the Kill Creek valley along highway K-10. They noted that the Captain Creek Limestone is a phylloid-algal wackestone to the west and a more resistant limestone ledge to the east of this anomalous setting.

Methods

Field observations form the foundation of this study. Fourteen stratigraphic sections

were measured and 61 hand samples were collected. Numerous Captain Creek Limestone localities and related outcrops were studied at the reconnaissance level, including 5 outcrops on the Sunflower Army Ammunition Plant. All hand samples were cut, thirty were polished, and 20 thin sections were made. Data for a structural map of the top of the Captain Creek Limestone (Fig. 5) were collected by leveling up or down from known elevations using 7.5 minute topographic maps for 29 localities. Data for an isopach map of the thickness of the lower conglomeratic limestone submember of the Captain Creek Limestone (Fig. 4) were collected by measuring outcrop thicknesses at 13 localities.

Results of Field Methods and Petrography

Allochems such as bivalves, bryozoan, crinoids, gastropods, fusulinids, and minor quartz sand grains are typically associated with the lithoclastic conglomerates of the basal Captain Creek. Lithoclasts are mainly limestone and minor shale and siltstone. Most limestone lithoclasts are lime mudstones. One lithoclast (Fig. 6) from the conglomerate at SQE-1 shows a pattern of concentric cracking that resembles patterns seen in soil glaebules (Goldstein, 1988; Fig. 9) with open pores lined with a laminated crust. These features could represent subaerial exposure of the top of the Vilas Shale or a pre-Vilas Shale limestone unit. Another limestone lithoclast from section SQE-1 contains possible rhizoliths and glaebules.

A structural map of the top of the Captain Creek Limestone shows gradual regional dip westward at about 20 feet per mile (Fig. 5). However, at the K-10/Kill Creek area the dip increases to 80-100 feet per mile into a NE/SW trending syncline. Some 70 feet of counter regional eastward dip occurs on the western flank of the syncline (We consider the anticlinal

nose to the west of the syncline an oil/gas lead.) O'Connor (1971; Fig. 15) mapped a steepening of western dip on the top of the Stanton Limestone in this area but did not map a reversal in regional dip.

The Captain Creek conglomerate thickens into the K-10/Kill Creek area syncline (compare Figs. 4 & 5). The axial trend of the thickened Captain Creek conglomerate is NE-SW (Fig. 4). The Captain Creek syncline, at least in part, may reflect paleobathymetry which may be related to paleostructure. On the east flank of the Captain Creek syncline the Eudora Shale onlaps and pinches out on top of the Captain Creek Limestone in roadcuts along highway K-10 just east of the Kill Creek valley suggesting the presence of positive paleobathymetry during deposition of the Eudora Shale.

In an outcrop along the south side of highway K-10 at locality KC-3, at a locality KF-1 just north of an east-west county road 0.2 miles from the NE corner of sec. 4, T.13S., R.22E., and in quarries on the eastern side of the Sunflower Army Ammunition Plant at localities SOW-3 and SOW-4, algal mound facies are present within the Plattsburg Limestone, which possibly are equivalent to the Spring Hill Limestone Member. This algal mound facies was observed to overlie coarse-grained, cross-bedded lime grainstones in all of these exposures (Fig. 7) except along K-10 where the section below the mound is not exposed. These grainstones are also exposed at the top of a hill along a dirt road just inside the Sunflower Army Ammunition Plant, at locality SOW-1. The grainstone and algal mound facies of the Plattsburg Limestone appear to have accreted on the northwest flank of the Wyandotte Olathe algal mound of Crowley (1969) and could have accentuated paleotopography that already existed on the Olathe mound. The thickening of the conglomeratic limestones of the Captain Creek Limestone corresponds to a

thinning of the Wyandotte Limestone in an interbank area between the Bonner Springs and Olathe algal mounds of Crowley (1969) (Fig. 8). It is suggested, however, that paleobathymetry during Captain Creek Limestone deposition may have been influenced more by the underlying local algal mounds in the Plattsburg Limestone than algal buildups in the Wyandotte Limestone.

Dm-scale relief occurs on the upper surface of the Vilas Shale in a number of outcrops where the contact between the Captain Creek conglomeratic limestone and Vilas Shale is observable, suggesting erosional scour at the base of the conglomeratic limestone by channelized currents. At SQE-1 (Fig. 3 & 9) 0.5 m of this relief is expressed as a broad downcutting into the upper Vilas Shale with onlap of conglomeratic limestone onto the erosional surface. At locality SQE-2 and in exposures just west of KC-1 (Fig. 3) dm-scale relief on the top of the Vilas Shale also occurs with Captain Creek lime wacke-packstones onlapping onto shales of the Vilas Shale at SQE-2 and sandstones of the Vilas Shale (or Captain Creek?) west of KC-1. The elongated geometry of the thickening of the Captain Creek conglomerate (Fig. 4) and the erosional contact with the underlying Vilas Shale is suggestive of a channel-fill deposit.

At the locality mentioned above, just west of KC-1 on the north side of highway K-10, the sandstones that underlie Captain Creek limestones may actually be channel-fill deposits within the lower submember of the Captain Creek Limestone as suggested by Prochnow (1982). Heckel (1972, Fig. 2) mapped a Stanton Limestone channel between two phylloid-algal buildups that is filled with both sandstone and calcarenite.

Two sets of unidirectional planar cross-bedding with opposing dip directions within the conglomeratic limestones occur at locality SQE-1 at the entrance to the Sunflower Quarry. The strike and dip of the upper set of foresets is N40°W; 9°NE and a southerly directed 6° apparent

dip was measured for the lower set (Fig. 3 & 10). At locality BS-1, north of K-10 (Fig. 3), dip directions of bedding within conglomeratic limestones also show bidirectional inclinations on cross-bedding (Fig. 10). However, all measurements at BS-1 are apparent dips due to poor exposure of bedding surfaces. At this locality the predominant dip direction is to the northeast suggesting northeastward dominated flow. Perhaps the bidirectional dips reflect reversing current directions such as a tidally influenced flow regime associated with a tidal channel. Dip directions are roughly parallel to the long axis of the Wyandotte Limestone isopach thin between the Bonner Springs and Olathe mounds (Fig. 8) supporting the hypothesis that the Captain Creek conglomerate was deposited by currents flowing parallel to the long axis of this intermound area.

Phylloid algae are uncommon or absent from the upper submember of the Captain Creek Limestone, within the syncline of the K-10/Kill Creek area (Fig. 5), whereas outside of the syncline these limestones are rich in phylloid algae. This suggests deeper water during Captain Creek deposition within the syncline that excluded light-sensitive biota such as the phylloids. Also, within the syncline encrustations of allochems by foraminifers is common suggesting relatively slow depositional rates and reduced productivity associated with relatively greater water depths. Captain Creek limestones rich in phylloids and containing relatively fewer encrusting foraminifers are relatively common outside of the syncline suggesting relatively higher carbonate productivity and accumulation rates associated with relatively shallow water depths. The upper submember of the Captain Creek thickens outside of the syncline, further suggesting increased productivity and greater accumulation rates outside of the syncline.

As mentioned earlier, a major control in the deposition of basal conglomeratic limestones in the Captain Creek Limestone may have been the paleobathymetry produced by phylloid algal

buildups within the Argentine and Farley Limestone Members of the Wyandotte Formation and the Plattsburg Limestone. Field work concentrated on developing high-order stratigraphic resolution in the intramound area between the Olathe and Bonner Springs algal banks of Crowley (1969) (Fig. 8). In figure 5 of Crowley (1969), an area between Wyandotte algal mounds in the K-10/Kill Creek area appears to be filled in by a thick section of the Bonner Springs Shale which would suggest a filling up of a paleotopographic low in the intermound area by Bonner Springs shale prior to Plattsburg Limestone deposition. However, the map in this figure is based largely on data from Newell (1935). Field work has shown that the stratigraphic correlations of Newell (1935) are incorrect and misleading in this area. There is no evidence of a thick section of Bonner Spring Shale corresponding to a thin Wyandotte Limestone section in this area. The new interpretation of the local stratigraphy contained herein suggests that negative paleorelief may have existed in the intermound area even after deposition of the Bonner Springs Shale.

It is suggested that grainstone shoals of Plattsburg skeletal carbonates developed on the western and northwestern flanks of the Olathe Bank during initial flooding on top of the Wyandotte sequence boundary (Fig. 2). Continuing relative rise in sea level appears to have resulted in algal buildups superjacent to the skeletal shoals. Vilas Shale shales and sandstones appear to onlap a Plattsburg Limestone algal mound at the K-10 exposures just east of the Kill Creek valley and the mound likely influenced local development of Vilas Shale sandstone bodies around the mound.

It is suggested that deposition of conglomeratic grainstones at the base of the Captain Creek was tidally influenced and paleotopography on Wyandotte and Plattsburg algal build-ups

likely caused a constriction and focusing of tidal energies in the Wyandotte intermound area during relative rise in sea level and flooding of the upper sequence boundary of the Plattsburg depositional sequence. Topographic relief on the Plattsburg mound was great enough to preclude deposition of Vilas Shale on its paleotopographic crest, at least at the Plattsburg mound exposure on the south side of K-10 just east of the Kill Creek valley. Deposition of open marine shelf limestones is represented by the upper submember of the Captain Creek Limestone. However, at least a modest local change in water depth is indicated by relatively thinner muddier limestones containing fewer phylloid algae within the axial position of the intermound area. In exposures along highway K-10 just east of the Kill Creek valley, the Eudora Shale onlaps onto the Captain Creek Limestone above the Plattsburg mound and reflects continued paleotopographic influence of the mound during Eudora time. At this locality the limestones of the Stoner Limestone and Captain Creek Limestone appear juxtaposed.

A tidal channel-fill deposit similar to the Captain Creek deposit described herein has been described in Missourian age outcrops in the uppermost Wolf Mountain Formation of north-central Texas by Erxleben and Cleaves (1982). The Texas example represents a tidal channel that scoured into underlying terrigenous mudstone and sandstone units of the Wolf Mountain Shale. The tidal channel-fill is composed of calcite-cemented coarse pebbles, sand, and fossil debris up to 2 inches in diameter. The fill is rich in broken Myalina shells, crinoids, rock fragments, and ferruginous claystone concretions. Erxleben and Cleaves (1982) speculate the source of carbonate allochems to be a carbonate bank a few miles downdip of the outcrop. The channel is about 13 feet deep. Fifteen feet of sandy and silty mudstone overlies the tidal channel, representing reworked relict deltaic facies from a transgressive marine shelf

environment that preceded overlying "offbank" Winchell Limestone deposition. Like the upper submember of the Captain Creek Limestone the overlying Winchell carbonates are thinly and unevenly bedded phylloid-algal crinoidal wackestone. Erxleben and Cleaves (1982) suggest this tidal channel-fill deposit in the uppermost Wolf Mountain Formation indicates tidal activity immediately prior to the initial transgression that resulted in deposition of the thick Winchell offbank carbonate. This example from Texas offers some similarities to the Captain Creek conglomeratic limestone.

Exploration Concepts

Between the Bonner Springs and Olathe algal banks of the Wyandotte Limestone in Johnson County stratigraphic variations occur at a small scale and lend to exploration geologists multiple scenarios for petroleum traps and charge histories in a midcontinent setting that is often viewed as having a simplicity similar to a layered cake. My preliminary stratigraphic investigation of the Kansas City and Lansing Groups of the Late Pennsylvanian indicates that locally the limestone members of the Wyandotte, Plattsburg and Stanton Limestones may be vertically juxtaposed. In the study area, shales that normally are interbedded between limestone units are instead observed to onlap onto positive paleotopography with the shales absent in crestral areas, creating a situation where potential reservoirs are stacked and potential seals are absent. This produces a situation in which hydrocarbon migration pathways would locally be across multiple formation boundaries and would not be constrained by shale horizons that would normally limit migration within individual limestone (reservoir) units. Similar complexities in local stratigraphy of other areas could allow migration of hydrocarbons into the downdip

margins of thick mounds bypassing the mound (highest hydrocarbon volume storage potential) and migrate further into vertically juxtaposed thinner limestones with less storage capacity, less attractive seismic expression, and less attractive risk analyses. Also, clastic wedges within outside shales could potentially act as thieves to migrating hydrocarbons on the updip flanks of mounds such as in the relationship between sandstones of the Vilas Shale and limestones of the Plattsburg at the K-10/Kill Creek area. This would produce a potential stratigraphic play in outside shales on the updip sides of underlying mounds which, because of structural position, may not normally be a primary exploration objective. Also, topographic lows between algal mounds may contain shoestring-type reservoir geometries in transgressive limestones (eg., Captain Creek conglomerate) although migration of hydrocarbons into these structurally depressed deposits could be a problem. Porous grainstone bodies, such as in the lower Plattsburg represent potential reservoir facies within the mound-margin. The overlying muddy moundfacies and laterally adjacent shales could act as seals for the potential grainstone reservoirs that developed on downdip margins of algal buildups.

Conclusions

- 1) The Captain Creek conglomerates may have been deposited as a tidal channel fill in a bathymetrically constricted area between the Bonner Springs and Olathe algal mounds during a relative sea-level rise.
- 2) It is suggested that his paleobathymetry was the result of stacking of Argentine, Farley and Plattsburg algal mounds.
- 3) Because of the erosional nature of the lower surface of the lower Captain Creek

conglomeratic channel-fill, this surface is considered the sequence boundary between Plattsburg and Stanton depositional sequences.

4) Multiple stacking of Late Pennsylvanian algal mounds can combine to form complex stratigraphic hydrocarbon traps and migration pathways.

Recommendations

1) Determine if the Captain Creek conglomerate is identifiable on the approximately 100 water well logs on the sunflower Ammunition Plant property. This could aid in local correlations and in delineation of the geometry of the conglomerate unit.

2) Take a core in the Kill Field area (SE, SE, sec. 33) in order to confirm the relationship between the Captain Creek conglomerate and the Plattsburg mound.

3) Investigate Stanton outcrops in the Olathe-Stilwell intermound area and Stanton Limestone structural lows mapped by (O'Connor, 1971; Fig. 15) for similar stratigraphic developments. Perhaps conglomeratic limestone at the base of the Captain Creek also exists in these areas. If so, more could be learned about the deposition of the conglomeratic limestone and its relationship to the lower sequence boundary of the Stanton Depositional Sequence.

4) Future workers should question the correlations of Newell (1935), some stratigraphic calls are incorrect and misleading. For example, in section 27 on page 100 (Newell, 1935) Newell's 53 feet of Bonner Spring Shale actually consists of 6 feet of Captain Creek conglomerate, 25 ft of Vilas Shale, 8 feet of Plattsburg Limestone, and only 14 feet of Bonner Spring Shale.

Acknowledgements

Paul Enos and Jeff Johnson provided valuable discussions of Stanton stratigraphy. Students contributions to a draft report from the 1988 Geology 732 and Geology 932 courses at the University of Kansas Department of Geology provided valuable insight into the complexities of the Stanton stratigraphy.

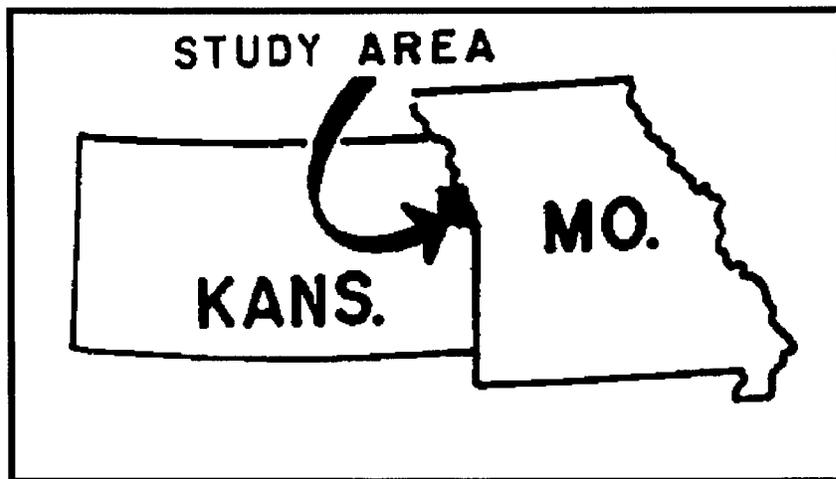


Figure 1. Location map of study area.

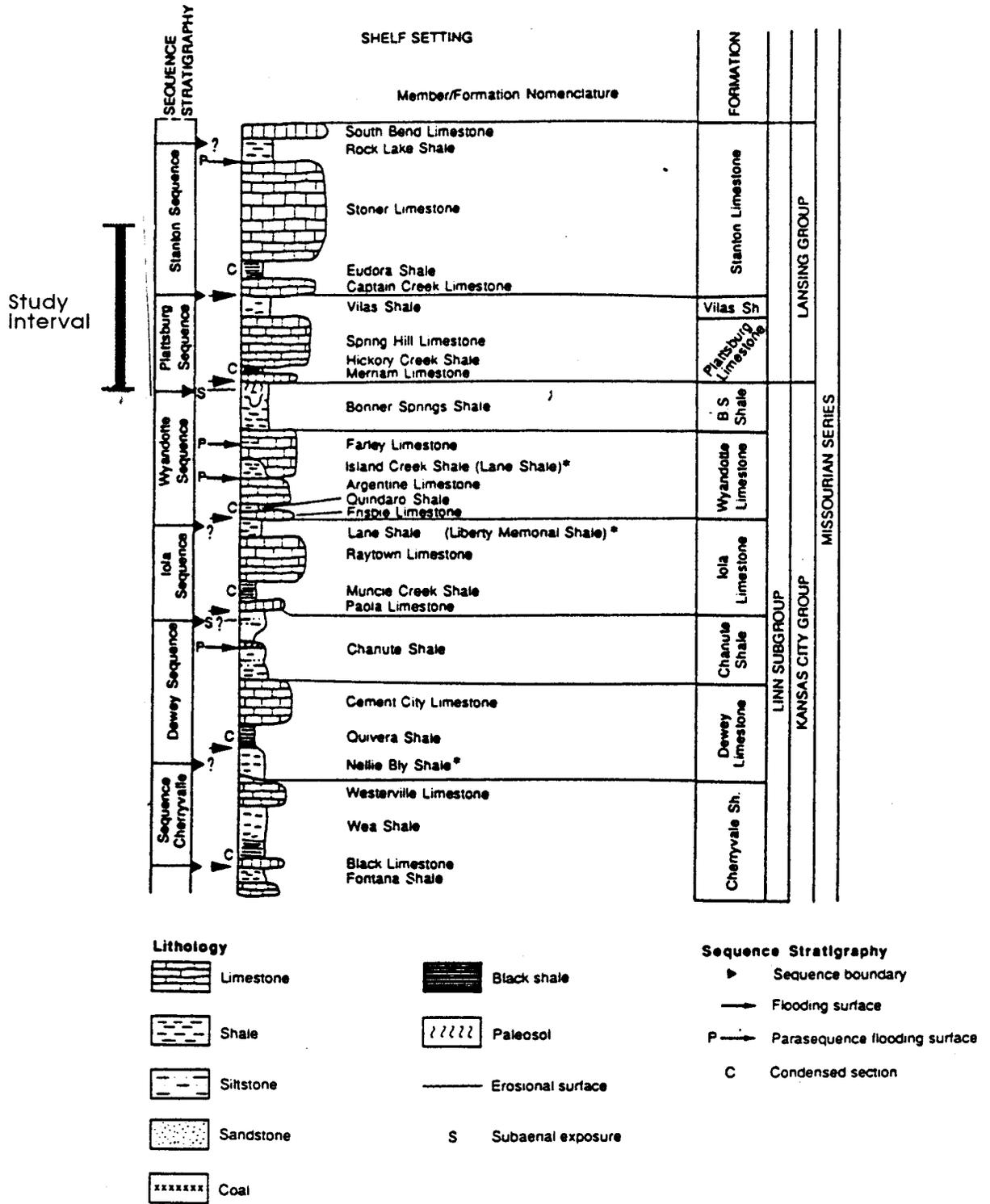


Figure 2. Stratigraphic section of Kansas City-Lansing Groups (from Watney et al., 1989).

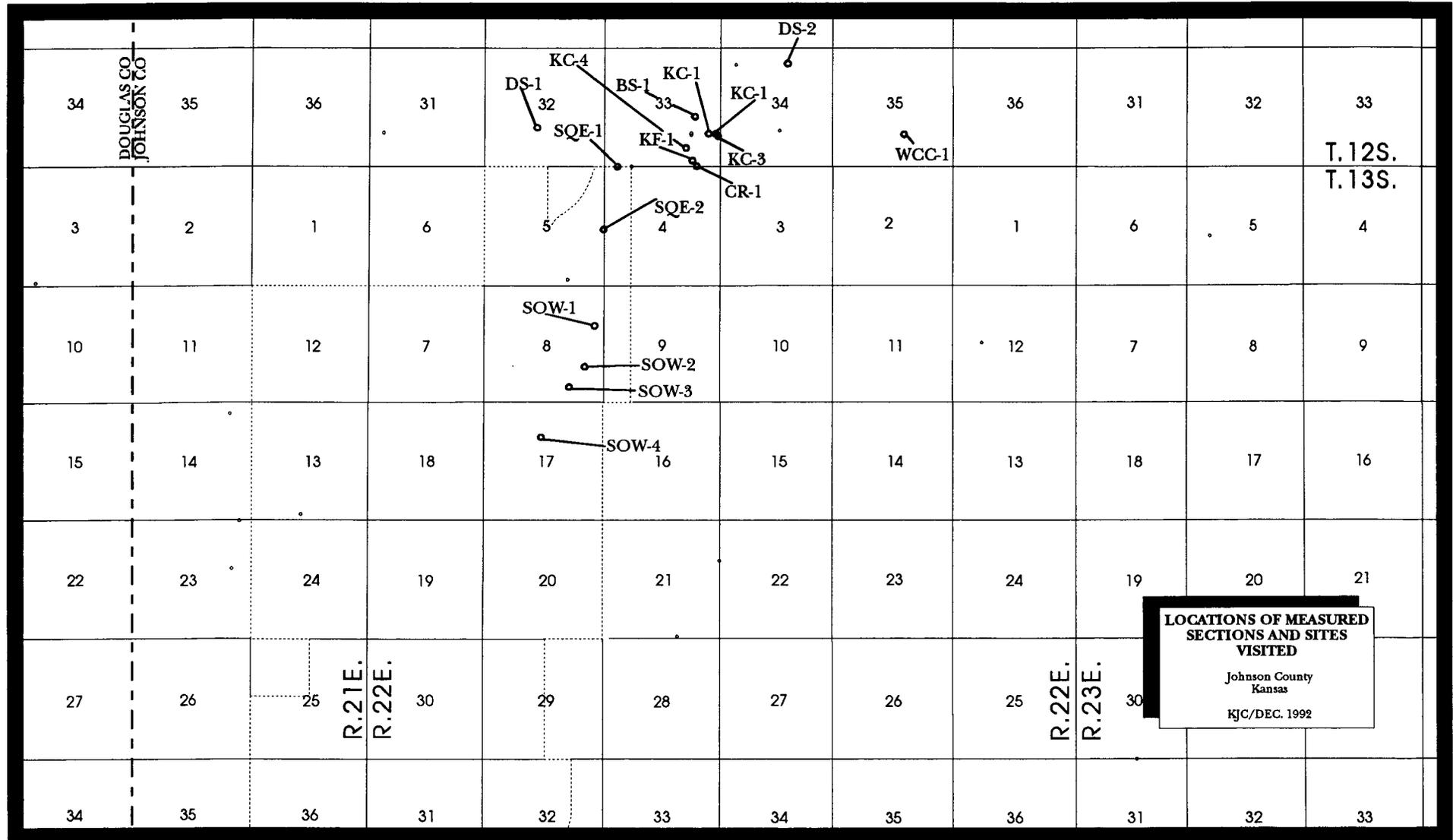


Figure 3. Locations of measured sections and reconnaissance sites. Undesignated open circles are reconnaissance sites.

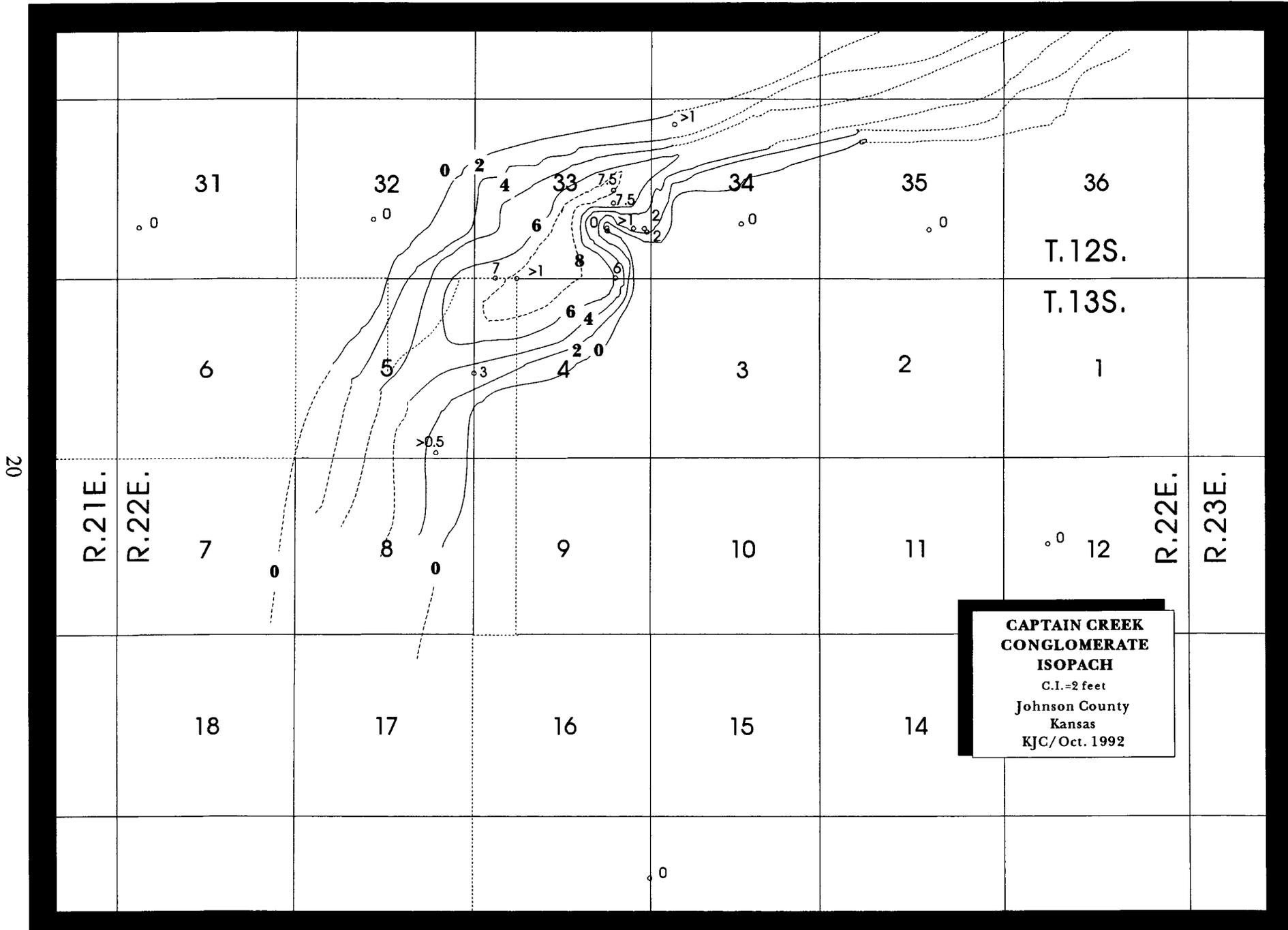


Figure 4. Isopach map of thickness of conglomeratic limestones of the lower submember of the Captain Creek Limestone.

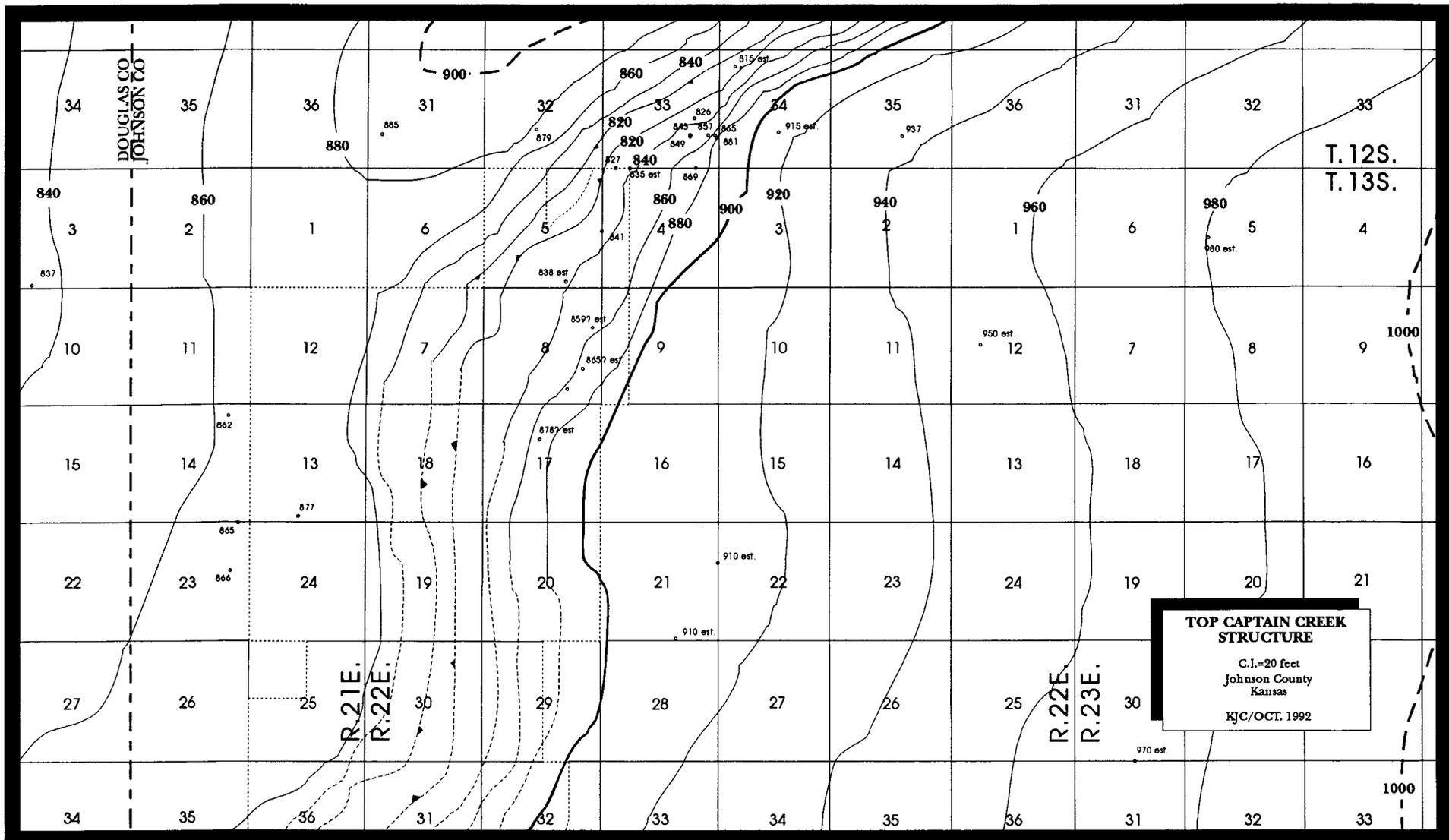


Figure 5. Structure map on the top of the Captain Creek Limestone. Elevations relative to sea level.

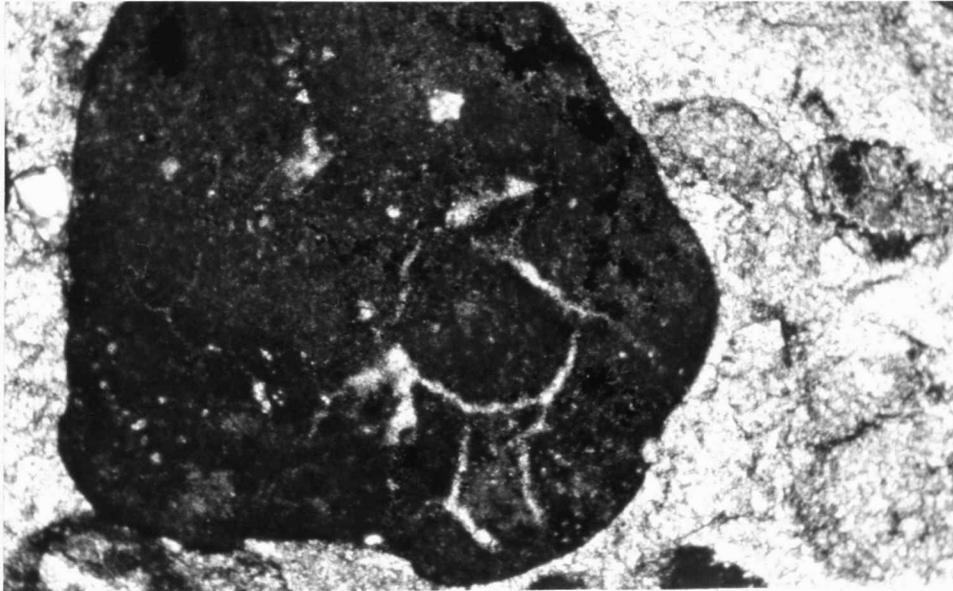


Figure 6. Limestone lithoclast from the lower submember of the Captain Creek Limestone.

Note concentric cracking within lithoclast suggesting subaerial exposure of this lithology prior to Captain Creek deposition.

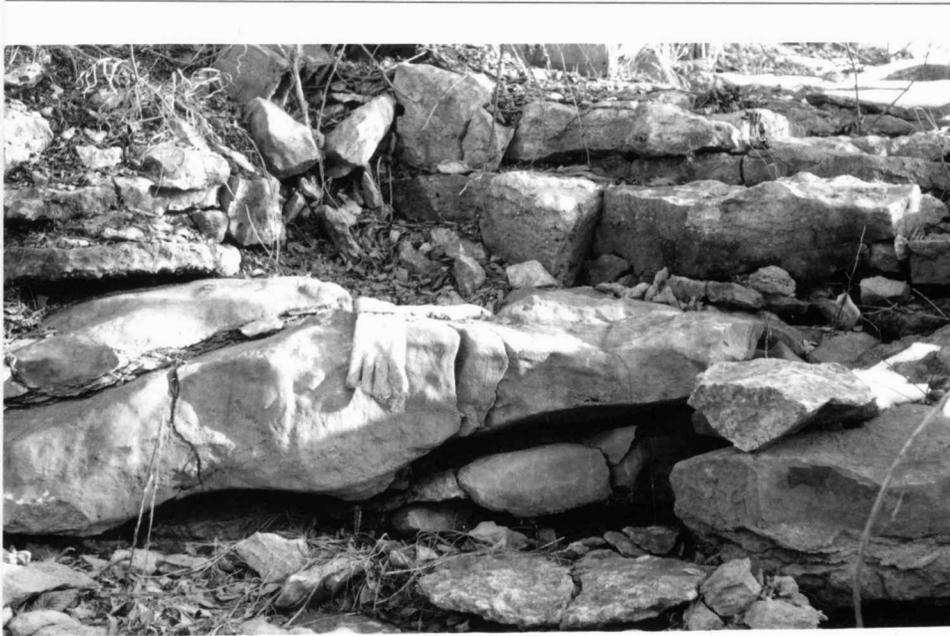


Figure 7. Outcrop photo of grainstones at base of Plattsburg mound at Kill Field. Grainstone beds dip towards the left (west). Overlying the grainstones are horizontal beds composed of phylloid packstones forming the base of a phylloid mound. Glove for scale.

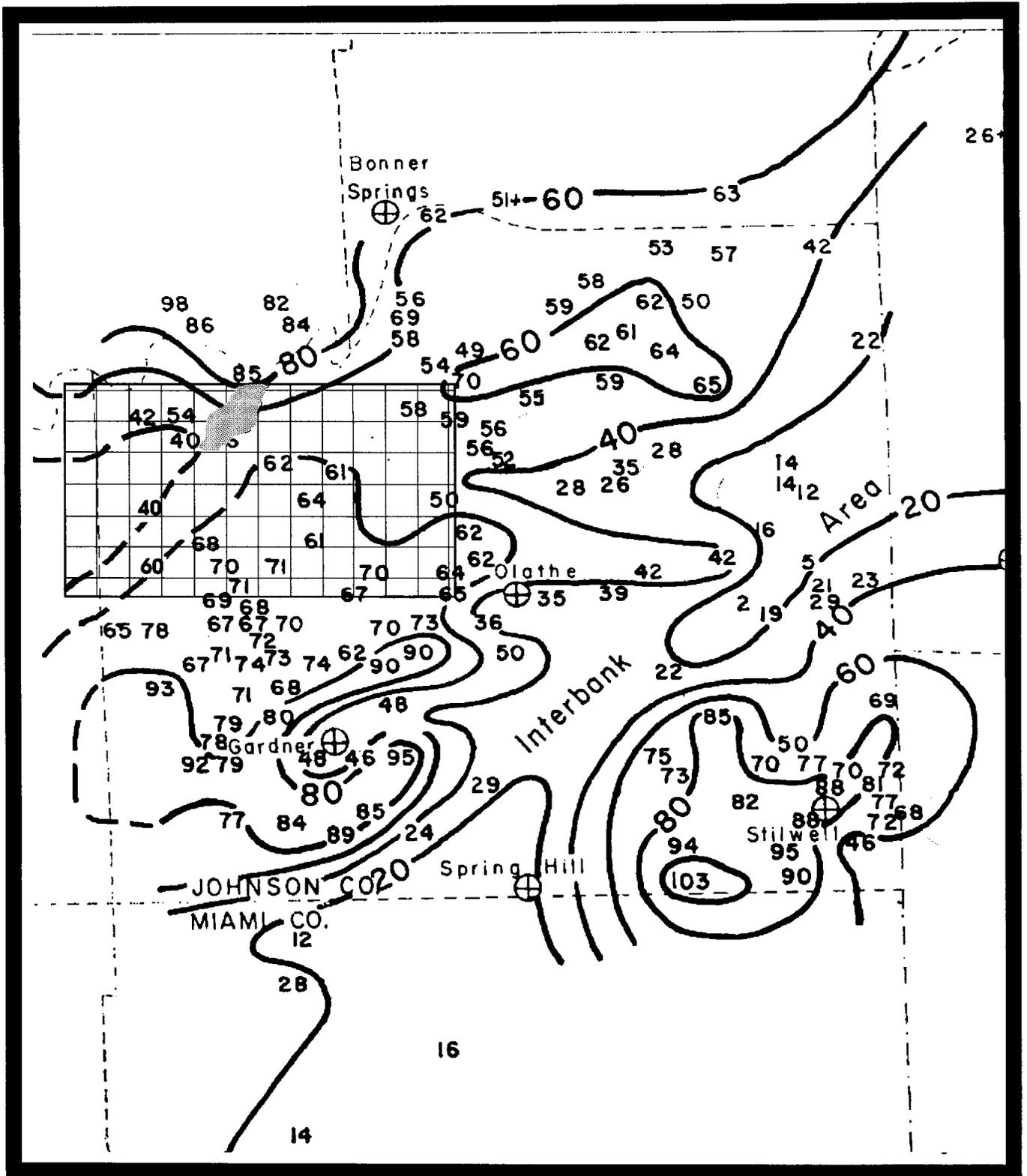


Figure 8. Isopach map of the thickness of the Wyandotte Limestone and showing outline of Township and Range sections in study area that are included in Figs. 3 & 5. Stippled area is location of conglomeratic limestone of the lower submember of the Captain Creek Limestone. The conglomerate is located approximately in an intermound area between Bonner Springs and Olathe aglal mounds. Modified after Crowley (1969).

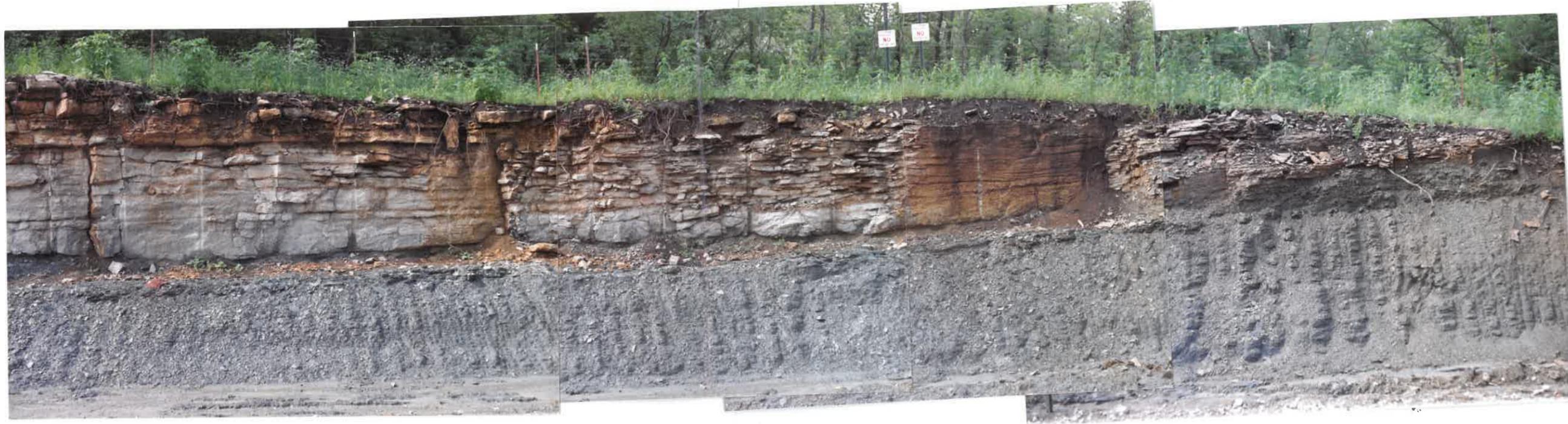


Figure 9. SQE-1 location. Vilas-conglomerate contact showing 0.5m of relief on surface.

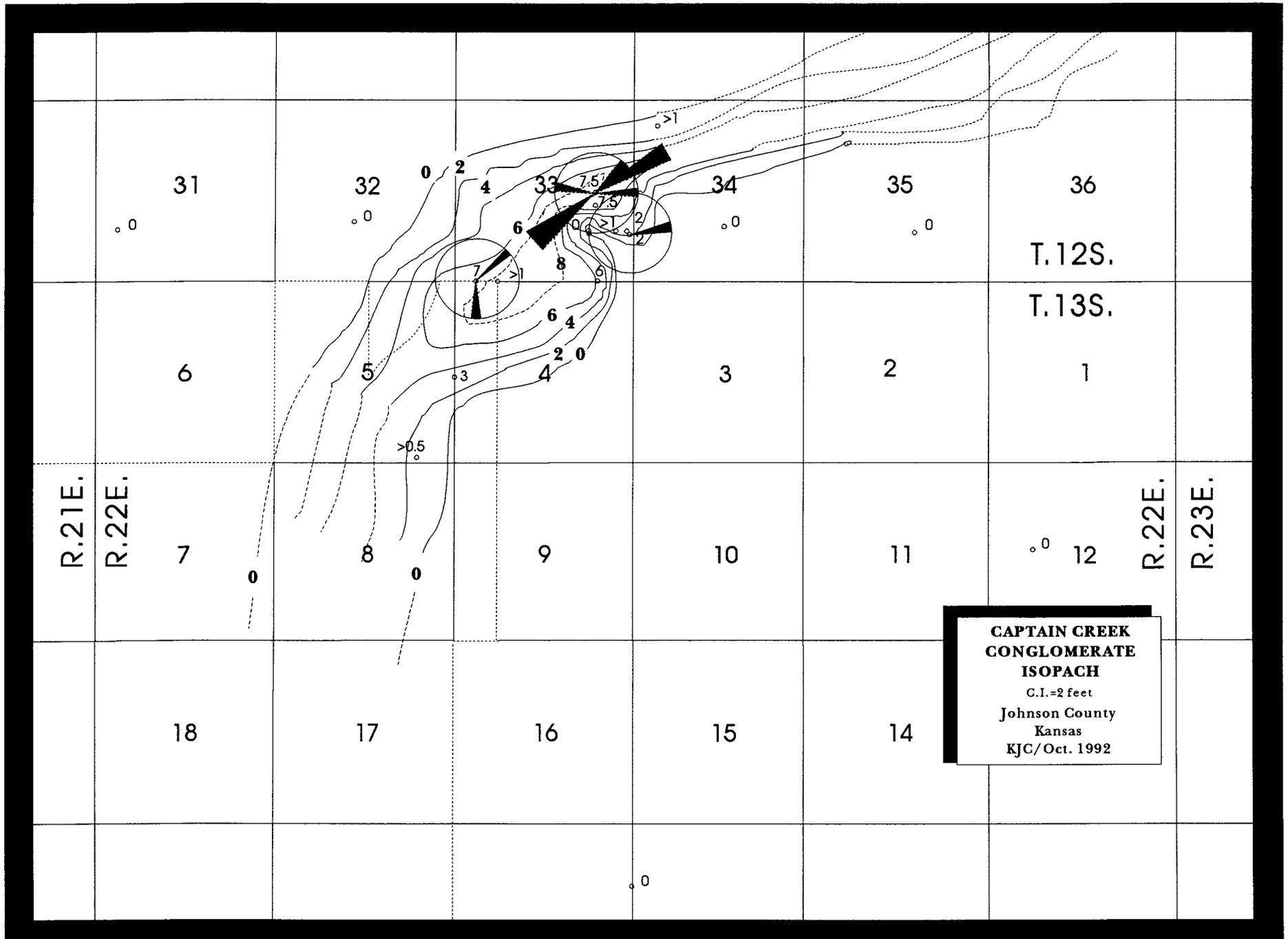


Figure 10. Dip directions of lower conglomeratic limestone member of the Captain Creek Limestone. The bimodal distribution is suggestive of tidal currents.

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APPENDIX I

FOSSILS

ALGAE

- III STROMATOLITE
- ☉ DOMAL STROM.
- ☼ DIGITATE STROM
- ⊙ GREEN, CODIACIAN
- ⊗ GREEN, DASYGLAD
- A CORALLINE
- ☐ ENCRUSTING CRALLING
- ☐ PHYLLOID
- PLANTS, MISC.
- ♂ ♀ LEAVES
- ♀ FRAGMENTS
- ♂ ROOTS

FORAMINIFERA

- ⊙ GENERAL
- ⊙ PELAGIC
- ☼ ENCRUSTING
- ⊙ COILED
- ∇ BISERIAL
- ⊙ FUSULINID
- ⊙ MILIOLID
- SPONGES
- Y SPICULE
- ⊙ STROMATOPOROID
- ☼ STROM, DIGITATE
- WORMS
- ∞ GENERAL
- ☼ ENCRUSTING

CORALS

- ⊙ GENERAL
- ⊙ COLONIAL
- ∇ SOLITARY
- ψ BRANCHING
- BRYOZOANS
- ⊙ GENERAL
- # FENESTRATE
- Y RAMOSE
- ☼ ENCRUSTING
- BRACHIOPODS
- ⊙ GENERAL
- ◁ SPIRIFER
- ◁ PRODUCTID
- ⊙ LINGULID

MOLLUSKS

- ∇ CEPHALOPODS
- ∇ NAUTILOID
- ∇ GASTROPOD
- ∇ BIVALVE
- ∇ OYSTER
- ∇ RUDIST
- ∇ RADIOLITE
- ∇ CAPRINID
- ∇ REQUENID
- ECHINODERMS
- ★ GENERAL
- ⊙ CRINOID
- ♂ SPINE
- OSTRACODE
- ⊙ GENERAL



M BARNAL

USE 1/16" SCALE 1 in = 1 meter

SITE

Section: De Soto 1 (DS-1)

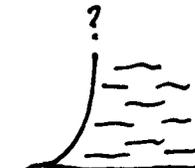
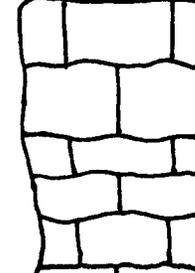
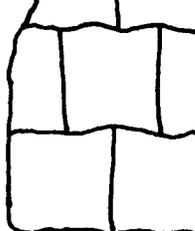
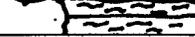
Location: center of S1/2 sec. 32, T12S, R22E, Johnson Co., KS

Name: KJC

Scale: 1 inch = 1 meter

Date: 6/26/92

Elevation: base section approx. 870 ft.

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
EUDORA SHALE	3-4		FISSILE	BLACK SHALE							IS DK-BROWN SHALE AT BASE OF CAPTAIN CK SAME AS MIDDLE CAPTAIN CREEK SHALE AT SQE-1? (EUDORA) COVERED WITH SHALE FLOAT
CAPTAIN CREEK LIMESTONE	2		DM-SCALE UNDOLOSE BEDS	PATLIND WCK-PEKSTN	✓ A ⊙ # A C R		GRAY-LT BRWN	GRAY TO ORANGISH BRWN	UP TO 3 CM "V CRSE"		DS-1-25 A. MISSOURIENSE
	1		DM-SCALE UNDOLOSE BEDS MIN-SCALE LAMINATIONS BY BLOCKY BEDS	BLOCKY WCK-PEKSTN	A ⊙ #		GRAY-LT BRWN	GRAY-ORANGISH BRWN	UP TO 3 CM "V CRSE"		DS-1-1.6 DS-1-1.0
VILAS							DK BRWN GRAY				DS-1-0.3 DS-1-0.2 DS-1-0.1 BELOW SURFACE

Section: DS-2 (exposure in creek)
 Location: NE 1/4, sec. 34, T12S, R22E, Johnson Co., KS
 Name: KJC
 Scale: 1 inch = 1 meter
 Date: 8/19/92
 Elevation: top Wyandotte Limestone approx. 832 ft.

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS		
							FRESH	WEATHERED					
PLATSBURG LIMESTONE	3			COVERED									
				thin-scale wavy bedded	weakened	08		orange brown	orange brown		PERMANENT FE-OXIDE	DS-2-2.8 EXPOSURE IS FLOAT	
BONNETT SPRINGS	2			CLAYSTN				DK GRAY TO BROWN	BROWN			SHALE POORLY EXPOSED	
				1-15cm THICK FOSTON X-BEDS	SANDY LIME CRUST AT TOP	08 09			BROWN AT TOP	GRAY			
					SSTN			MACROCLIP FLAT PEBBLE INTRACANTS	GRAY			WELL CEMENTED HARD	DS-2-1.0
				FOSTON X-BEDS 1-15cm	SSTN			MACROCLIP	GRAY	GRAY		SOFT POORLY CEMENTED	DS-2-0.6
				COVERED									
WYANDOTTE LIMESTONE				COVERED							DS-2-0.1 ALGAL MOUND		

Section: SQE-1

Location: east side of Sunflower Quarry entrance; NW1/4, NW1/4, sec. 4, T13S, R22E,
 Name: KJC Johnson Co., KS

Scale: 1 inch = 1 meter

Date: 6/25/92

Elevation: base section 809.4 ft

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
EUDORA ?	6										
CAPTAIN CREEK LIMESTONE	5		MASSIVE 2 BEDS	BIOBLAST WEXSTN	90R B#?		DK GRAY DK BROWN	ORANGE BROWN	UP TO SMALL PEBBLE SIZE - FIDER THAN LOWER UNIT		← SQE-1-5.3
	4		MASSIVE	BIOBLAST WEXSTN	90R B#?		DK GRAY	DK GRAY- ORANGE BROWN	BIOBLASTS UP TO SMALL PEBBLE SIZE		← SQE-1-4.7
	3		SLIGHTLY FINGER TO BLOCKY	SANDY SHALE	♀	MICALON	BROWN TO DK GRAY	BRWN TO DK GRAY	CLAY TO V. FINE SAND SIZE	↳ GOTHITE ↳ NODULES	← SQE-1-4.0 Y N 40°N 9°NE ← SQE-1-3.7
VILAS SHALE	2		1-3 DM THICK BEDS	CONGL BIOBLAST LIME SPALSTN	90R B#?	VILAS SHALE & LSTN MINOR QZ & SAND O	GRAY GRAY TO DK GRAY	ORANGE BROWN	UP TO 2.5 DM FLAT PEBBLES O F VILAS SHALE PEBBLES AND 3/16 INCH.		← SQE-1-2.9 APPARENT DIP 6° SOUTH
	1		VERY THINLY LAM HORIZ	MUDSTN W/ MINOR INTERLAMS OF SLTY & SSTN	plant FRAGS	CARBONALON PLANT FRAGS	GRAY GRAY		MAINLY CLAY; UP TO FN SAND SIZE	FUSSE V. MINOR PIRITZ	← IRREGULAR & COLONIAL CONTACT W/ O.S M RELIEF SQE-1-2.1 SQE-1-2.0

Section: SQE-2

Location: 0.57 miles south of Sunflower Quarry entrance; center westline sec. 4, T13S, R22E,

Name: KJC

Johnson Co., KS

Scale: 1 inch = 1 meter

Date: 7/1/92

Elevation: base section approx. 835 ft

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
CAPTAIN CREEK LIMESTONE	2		COVERED								
	1		MASSIVE	BIRLINGTON WCK-SCALE BEDS	#9	0.2% SAND	GRAY TO ORANGISH BROWN	ORANGISH BROWN	V. FINE Fossils UP TO 5cm		◀ SQE-2-1.3 TRACE Qtz SAND
			MASSIVE	BLOCKY MM-LAM. SLTY SHALE	BIRLINGTON WCK-SCALE BEDS	#9	SHALE LITHO. FLINT	ORANGISH BROWN	ORANGISH BROWN	LITHOLOGICAL UP TO 3cm	● NODULES
			MASSIVE	MM-LAM. SANDY MARL	COOL BROWN LITHO. CONSTR.	LITHO. SLABS	OLIVE-GREEN	BROWN-ORANGISH BROWN	LITHOLOGICAL UP TO 10cm		◀ SQE-2-0.4 TRACE Qtz SAND

Section: Kill Creek 1 (KC-1)
 Location: E1/2, SE1/4, sec. 33, T12S, R22E, Johnson Co., KS
 Name: KJC
 Scale: 1 inch = 1 meter
 Date: 6/26/92
 Elevation: approx. top Captain Creek Limestone 857 ft

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
STOWER LIMESTONE	6			LIME STONE							
	5										
EUDIRA SHALE	4			FISSILE SHALE			BLACK				
	3										
CAPTAIN CREEK LIMESTONE	2.8			BIOLAST PEWEE STNS							KC-1-2.8 KC-1-2.7 DM-SCALE FINING UPWARD SEQUENCES
	2.7										
	2.0										
	0.8										
	0.4										
0.05					TAN			KC-1-0.8 KC-1-0.4 KC-1-0.05			
								KC-1-0.4 KC-1-0.05			
								KC-1-0.05			

Section: Kill Creek 2 (KC-2)
 Location: SE1/4, sec. 33, T12S, R22E, Johnson Co., KS
 Name: KJC
 Scale: 1 inch = 1 meter
 Date: 8/25/92
 Elevation: top Captain Creek Limestone 865 ft

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
STANLEY LIMESTONE	7			LSTN							
EUDORA SHALE	5-6		COVERED	FLOAT OF LIMESTONE NODULE REPLACING BORROWS							
CAPTAIN CREEK LIMESTONE	4			NEKSTN	98	MISC. CARBONATE	GRAY	GRAY			
	3	0.5-2 CM SCALE BEDS		BIOCLAST PERKSTN	69		ORANGE BROWN TO GRAY	ORANGE BROWN TO GRAY	UP TO 4 CM BIOCLASTS		
	2	IRREG. BEDDING WAVY		MILD MUDDY NEAR TOP	98						
VILLAS SHALE	1			SANDY SHALES BETA	#	NODULES					
		1-10mm RIPPLE TRONCHES IRREG. FLASER LAMS. OSCILLATED RIPPLE X-RIPPLE LAMS		COAL BULLAS CRUSTS	800		BROWN	DK GRAY			
				SANDSTN W/ V. THIN SHALE PARTINGS	8	ABUNDANT MICA	LT BROWN	LT BROWN	FN		
				WHISPY LAMS		CARBONIZED PLANT FRAGS					

Y ≈ E-W STRIKE
 ≈ 2-3.5° N DIP

◀ KC-2-1.5

AT LEAST 2.5cm LOCAL RELIEF IN ETCHED TOP VILAS

◀ KC-2-0.3

Section: Kill Creek 3 (KC-3)
 Location: SE1/4, sec. 33, T12S, R22E, Johnson Co., KS
 Name: KJC
 Scale: 1 inch = 1 meter
 Date: 8/26/92
 Elevation: top Captain Creek Limestone 881 ft

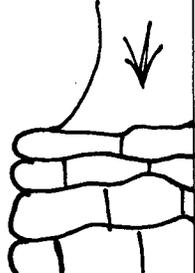
FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
SPONGE LIMESTONE	3			FLAT STRATIFIED LSTN							
CAPTAIN CREEK LIMESTONE	2		DM SCALE WAVY BEDS	BIOCLAST WCK-REACTN	 1 PPK BED FULLY RICH		DK GRAY TO LT BRN	DK GRAY TO LT BRN			
CAPTAIN CREEK LIMESTONE	1		DM SCALE LAMS	SANDY MDSLN	 CARBONIFEROUS PLANT		GRAY TO OLIVE GREEN	GRAY TO OLIVE GREEN		NODULES	
			DM-DM SCALE BEDS	SMALL BIOHERM WCK-REACTN	 CARBONIFEROUS PLANT		DK GRAY-BRN	DK GRAY	UP TO 4cm CLASTS		
WAS SHALE			MM SCALE LAMS	MDSLN	 CARBONIFEROUS PLANT		GRAY	LT GRAY-LT BRN			

± 10° NE UNIT THICKEN TO EAST

Section: KC-4 (east bank of Kill Creek)
 Location: SE 1/4, sec. 33, T13S, R22E, Johnson Co., KS
 Name: KJC
 Scale: 1 inch = 1 meter
 Date: 8/28/92
 Elevation: base section 803 ft.

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
SPRING HILL LIMESTONE (?)	3		FLAGE PARTINGS 3mm - 1.5m WAVY IRREG FRIPPLE LAMS	BIOCLAST CRUSTAL	# A B O		LT BRWN- ORANGE BRWN	DK GRAY	CRS UP TO SMALL PEBBLE SIZE	WEATHERED IRON OXIDE COMMON	KC-4-2.9 KC-4-2.3
	2		5-10 mm LAMS COMMON	BIOCLAST CRUSTAL	# A B O		TAN TO ORANGE BRWN & YELLOW BRWN	DK GRAY TO LT BRWN	CRS UP TO LARGE PEBBLE SIZED GLASTS	BRWN WEATHERED IRON OXIDE COMMON	KC-4-1.7 KC-4-1.4
	1		0.5-5.0 DM BEDS WAVY IRREG CONTACTS			# A B O					

Section: KC-5 (east bank of Kill Creek)
 Location: SE 1/4, sec. 33, T13S, R22E, Johnson Co., KS
 Name: KJC
 Scale: 1 inch = 1 meter
 Date: 8/28/92
 Elevation: base section 794 ft.

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
MERRIAM LIMESTONE (?)	1			BIGGEST COASTAL	✕ R # O		LT BRWN	GRAY	MED. CRZ	WELL CEMENTED	← KC-5-0.2

Section: West Cedar Creek 1 (WCC-1)
 Location: SE 1/4, sec. 35, T12S, R22E, Johnson Co., KS
 Name: KJC
 Scale: 1 inch = 1 meter
 Date: 6/26/92
 Elevation: base Captain Creek Limestone approx. 930 ft

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
VILAS SHALE	1 - 2			COVERED BY GRAY SLTY MUDSTN IN FLOAT							
CAPTAIN CREEK LIMESTONE	3 - 4			DM-SCALE BEDS SHALY STN	PHOLID WCK-PCNSTN #1 #2 #3	INTERCRIST	GRAY-LT BRWN ORANGISH BRWN	BRFF-GRAY-ORANGISH BRWN	UP TO 3 CM 'COSE		WCC-1-4.4 A. MISSOURI USE WCC-1-3.2
LEWIS SHALE	5			COVERED BY BLACK FOSSIL SHALE FLOAT							WCC-1-2.3

HWY LEVEL

Section: Sunflower Ordnance Works (SOW-1)
 Location: NE 1/4, sec. 8, T13S, R22E, Johnson Co., KS
 Name: KJC
 Scale: 1 inch = 1 meter
 Date: 9/11/92
 Elevation: top Plattsburg Limestone 849 ft

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
PLATTSBURG LIMESTONE	4						GRAY	LIGHT BROWN	FID SAND TO LARGE PEBBLE SIZE TYPICAL 1-2mm	MOLDIC GRAINS MANY CLASTS ALTERED TO GOETHITE	◀ SOW-1-4.0
	3										◀ SOW-1-2.1
	2										◀ SOW-1-1.4
	1										◀ SOW-1-0.9
											SHALE CRIP II ◀ BELOW SOW-1-0.1

Section: CR-1

Location: south line, SE 1/4, sec. 33, T12S, R22E, Johnson Co., KS

Name: KJC

Scale: 1 inch = 1 meter

Date: 8/20/92 to 8/21/92

Elevation: base Spring Hill Limestone 807.6 ft (section measured along county road and does not represent true stratigraphic thickness)

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
VILAS SHALE	0			COVERED							
	1		10-15 CM SCALE LAMS W/SHALTY PARTINGS IRREG-WAVY LAMS & X-LAMS BIOLUST LIME CRUSTA SMALL SCALE X-LAMS	SSTN		MICACEOUS LT BRWN	LT BRWN	V FINE-MED	WELL CEMENTED	CR-1-6.7 CR-1-6.6	
VILAS SHALE	4		MICACEOUS MUDSTONE LAMS SLIGHTLY FISSILE			MICA BRWN	BRWN			POORLY EXPOSED	
	3					CARBONACEOUS PLANT FRAGS					
SPRING HILL LIMESTONE	1		1-2 DM THICK HORIZ BEDS 1 CM THICK LAMS UPPER 1/4	BIOLUST CRUSTA		MED BRWN MED BRWN	MED BRWN	CR - V SMALL PEBBLE SIZED 3 MM LARGEST		CR-1-0.6	

Section: CR-1

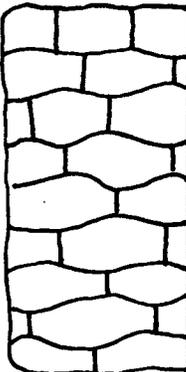
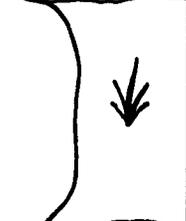
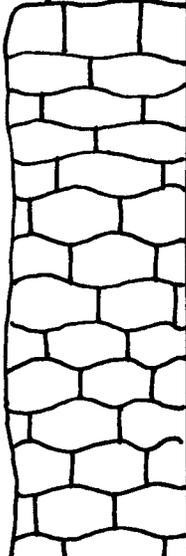
Location: south line, SE 1/4, sec. 33, T12S, R22E, Johnson Co., KS

Name: KJC

Scale: 1 inch = 1 meter

Date: 8/20/92 to 8/21/92

Elevation: base Spring Hill Limestone 807.6 ft (section measured along county road and does not represent true stratigraphic thickness)

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
											TOP OF HILL
STONER LIMESTONE	22 21			BIOCLUST WCK-PEKSTN	♡ ♡ ⊖		BRWN	BRWN ORANGE BRWN			
EUDORA? SHALE	20 19										
CAPTAIN CRIBER LIMESTONE	18 17			DM SCALE BEDS WCKSTN	♡ ♡ ⊖ ♡ ♡ ⊖		LT BRWN LT GRAY	GRAY BRWN			◀ CR-1-18.6
				BIOCLUST WCKSTN	♡ ♡ ⊖ ⊖		BRWN	GRAY BRWN			

Section: KF-1

Location: SE 1/4, sec. 33, T12S, R22E, Johnson Co., KS

Name: KJC

Scale: 1 inch = 1 meter

Date: 8/21/92 to 8/22/92

Elevation: top Spring Hill Limestone 804 ft (section does not represent true stratigraphic thickness)

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
VILAS SHALE	8			Covered							
	7										
	6										
	5										
	4										
	3										
	2										
	1										
SPRING HILL LSTN				BIOCLASTS			GRAY TO LT BROWN	GRAY TO LT BROWN	CRS TO SMALL PEBBLE BIOCLASTS		627' WEST OF NEXT OUTCROP IN SECTION
											◀ KF-1-0.7 ◀ KF-1-0.3

Section: KF-1

Location: SE 1/4, sec. 33, T12S, R22E, Johnson Co., KS

Name: KJC

Scale: 1 inch = 1 meter

Date: 8/21/92 to 8/22/92

Elevation: top Spring Hill Limestone 804 ft (section does not represent true stratigraphic thickness)

FORMATION MEMBER	METERS	LITHOLOGIC PROFILE	SED. STRUCTURE	ROCK NAME	FOSSILS (ORDER OF ABUNDANCE)	PARTICLES	COLOR		GRAIN SIZE	DIAGENESIS	REMARKS
							FRESH	WEATHERED			
2 PLATS BEREA LIMESTONE?	16										
	15										
	14										
	13		DM SCALE BEDS IRREG.	PHYLLOID ROCKS	Nφ φ # φ	LT GRAY TO LT BRN W/ GRAY BASE	GRAY TO LT GRAY			GEOTITES AUTOBREXIA	← KF-1-13.8
	12		FOCUSSED DIPS 12° NW LARGE SCALE X-BEDS DM-SCALE BEDS IRREG.	INTERBED OF MUDST. & BIOLAST CRUSTS	φ φ#			BROWN	DK GRAY TO BROWN	FN-CRSE UP TO SMALL PEBBLE SIZE	← KF-1-12.4 ← KF-1-12.0
	11										← KF-1-11.0 ← KF-1-10.7
	10										← KF-1-9.8
	9										← KF-1-9.1
											← CROP STARTS 627' EAST OF LOWER SPRING HILL LIMESTONE

