

**STRATIGRAPHY AND DIAGENESIS OF THE OZAWKIE LIMESTONE  
(PENNSYLVANIAN, VIRGILIAN) IN NORTHEASTERN KANSAS**

by

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Kansas Geological Survey  
Open-file Report  
98-1

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## ABSTRACT

The Ozawkie Limestone Member of the Deer Creek Formation (Pennsylvanian, Virgilian, Shawnee Group) consists of two layers separated by shale in central Kansas outcrop belt, but contiguous further north. In general, each layer of the Ozawkie represents a northward-shallowing sequence. The lower layer of the Ozawkie in the southern region is a fusulinid wackestone. The upper layer is a very fine packstone. In the central area, both layers are coated grainstones to packstones. In the northern area, the Ozawkie is a packstone or rarely grainstone with coated grains, micrite intraclasts, and fenestral porosity.

Features such as laminated micrite crusts, rhizocasts and rhizoliths, prismatic columns, and karst, cap much of each layer of the Ozawkie. This suggests that the Ozawkie was deposited during two episodes of transgression and regression, with subaerial exposure occurring during each regression. Lesser development and lesser extent areally of subaerial features capping the lower layer suggests that the first regression was not as extensive as the second. Shoreline was probably in north Osage County, Kansas, during the first regression, and south of the study area during the second.

Three diagenetic facies are identified in the Ozawkie by which diagenetic environment exerted the greatest influence of the sediments. Facies A, the lower layer in the south, was dominated by the marine phreatic zone. Facies B, the bulk of the Ozawkie, was dominated by the freshwater phreatic zone. Facies C, the uppermost centimeters of each layer, were dominated by the freshwater vadose zone. The Ozawkie incorporates diagenetic aspects of both middle and upper limestones, and could be considered, diagenetically, a mini-cyclothem.

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## INTRODUCTION

The Ozawkie Limestone (Upper Pennsylvanian, Virgilian) is the lowermost member of the Deer Creek Formation (Fig. 1) and is representative of "lower limestones" of Virgilian cyclothem. The Ozawkie Limestone is generally described as a brown-weathering limestone with locally abundant ooids and fusulinids (Moore, 1936; Zeller, 1968). The Ozawkie Limestone crops out from southeastern Nebraska and southwestern Iowa to southern Kansas (Fig. 2). South of Coffey County, Kansas, correlations become difficult due to the apparent splitting of the Ozawkie Limestone and the thickening of intervening shales (O'Connor, 1958; Lamoreaux, 1983). Maples (oral comm., 1995) identified a limestone 20 cm thick as the Ozawkie in mapping Greenwood County (Fig 3).

The goals of this project were to look at the differing lithologies of the Ozawkie Limestone in northeastern Kansas in an attempt to unravel the different depositional environments represented and their distribution, examine the diagenesis of the Ozawkie, and to elucidate the sea-level history surrounding Ozawkie Limestone deposition. A related goal was to further document exposure surfaces reported by Robb (1990) and Robb and Michnick (1991) and to place them in depositional context. The results of this study has applications for other lower limestones, and furthers understanding of a dominant feature of Kansas Pennsylvanian geology, the cyclothem.

A cyclothem is an alternating series of limestones and shales interpreted as deposits of a single rise and fall of relative sea level (Fig. 4). An ideal Missourian cyclothem consists of a thin middle limestone, a core shale, and a thicker upper limestone (Heckel, 1980). A megacyclothem is a combination of cyclothem. An idealized Virgilian megacyclothem consists of a lower, middle, and upper limestone separated by shales and is interpreted to represent deposition from two cycles of relative sea level rise and fall

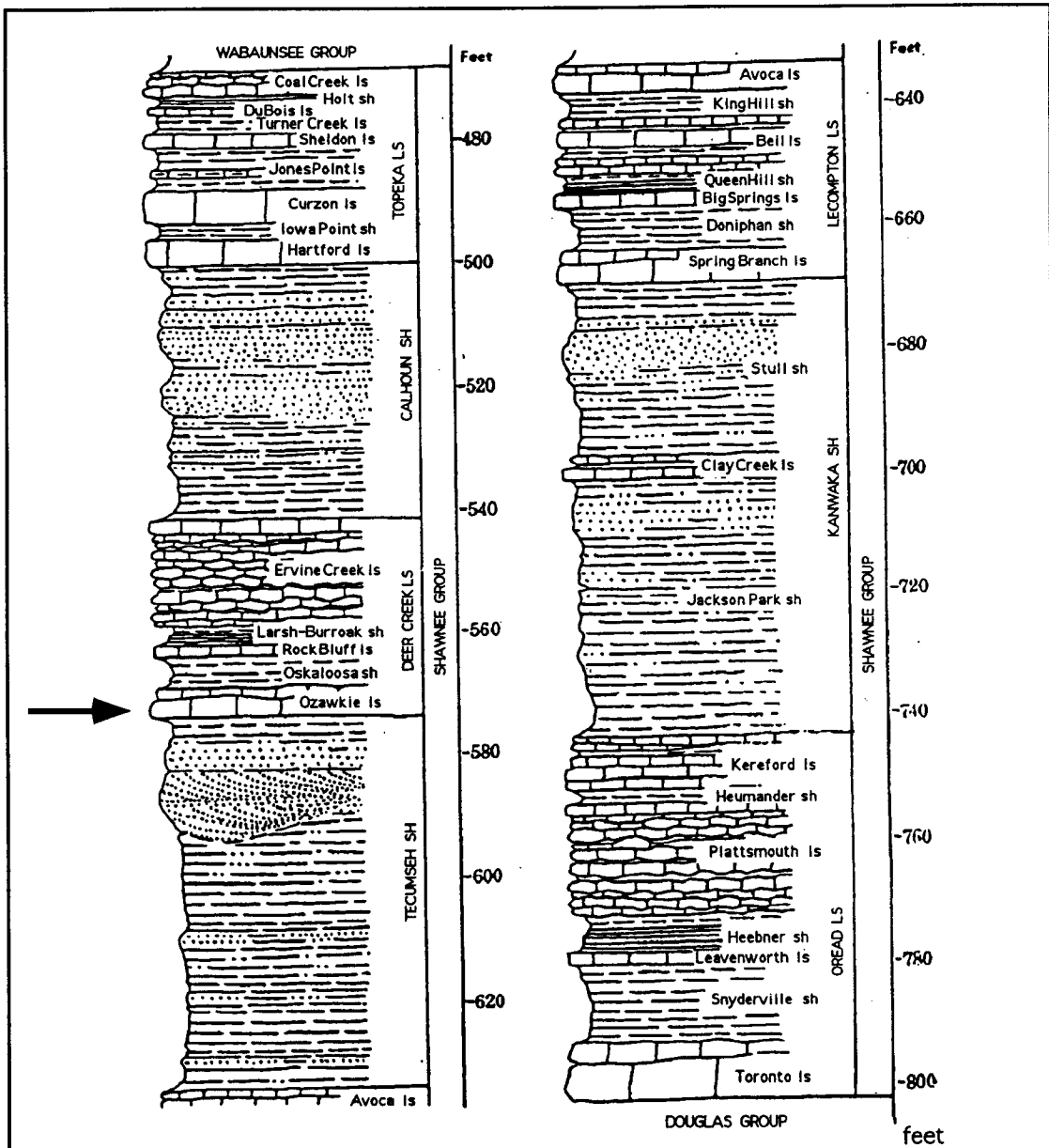


Figure 1. Generalized stratigraphic section of the Shawnee Group (Upper Pennsylvanian, Virgilian) of Kansas showing the Deer Creek Formation and the Ozawkie Limestone (arrow).  
 (modified from Moore et. al. 1949)

Figure 2.

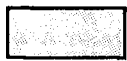
Geologic map of Kansas and adjacent parts of Oklahoma, Missouri, Iowa, and Nebraska.

Legend

Kansas, Oklahoma, and Missouri (from Moore, 1949)



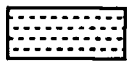
Permian



Post-Shawnee



Shawnee Group (note: Deer Creek in middle)



Pre-Shawnee

Iowa (from Preliminary Geologic Map of Iowa)



Cretaceous



Virgilian (includes Shawnee Group)



Missourian

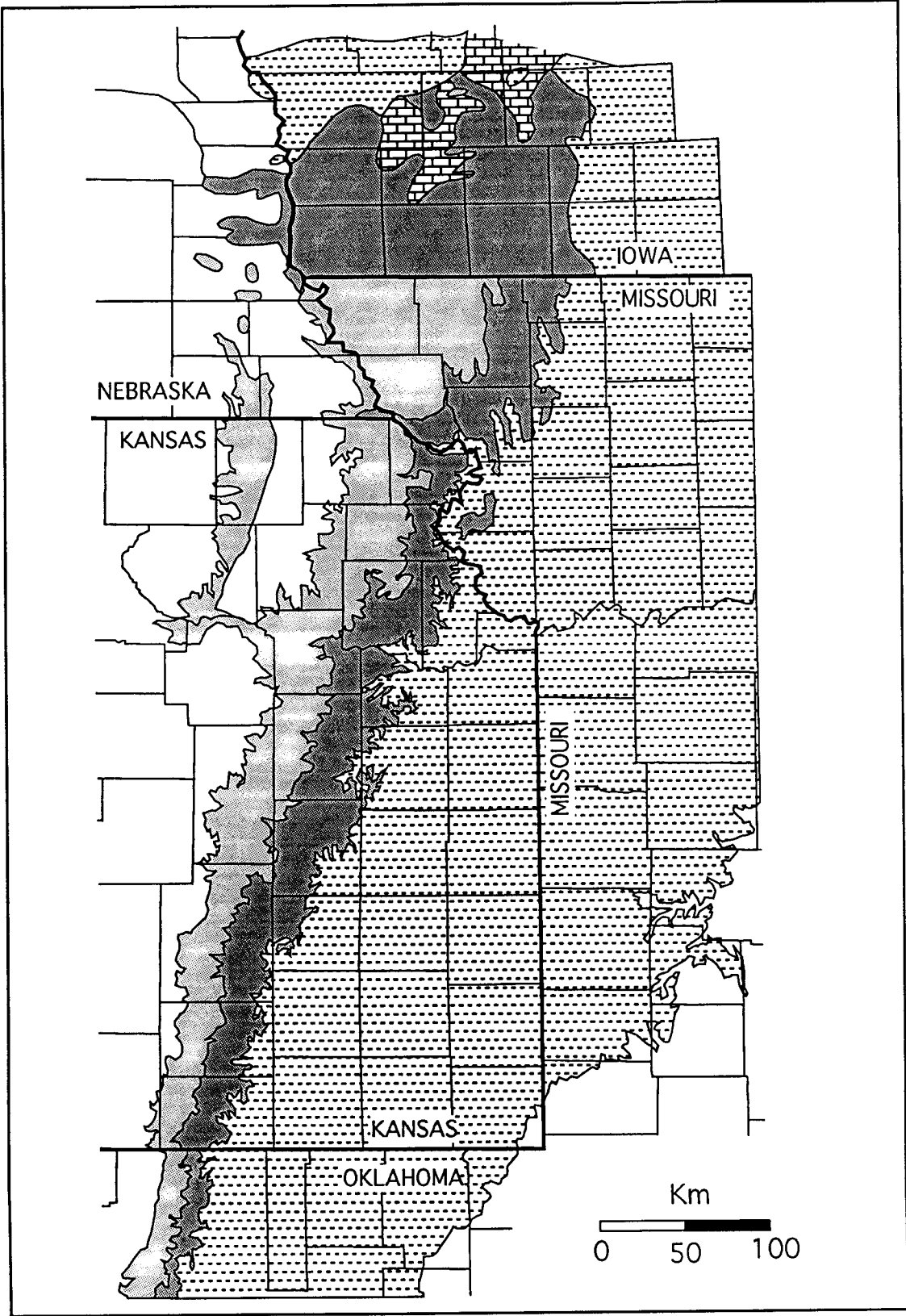
Nebraska



Post-Shawnee (southern Nebraska from Moore, 1949)



Pennsylvanian (from Reed and Burchett, 1964)



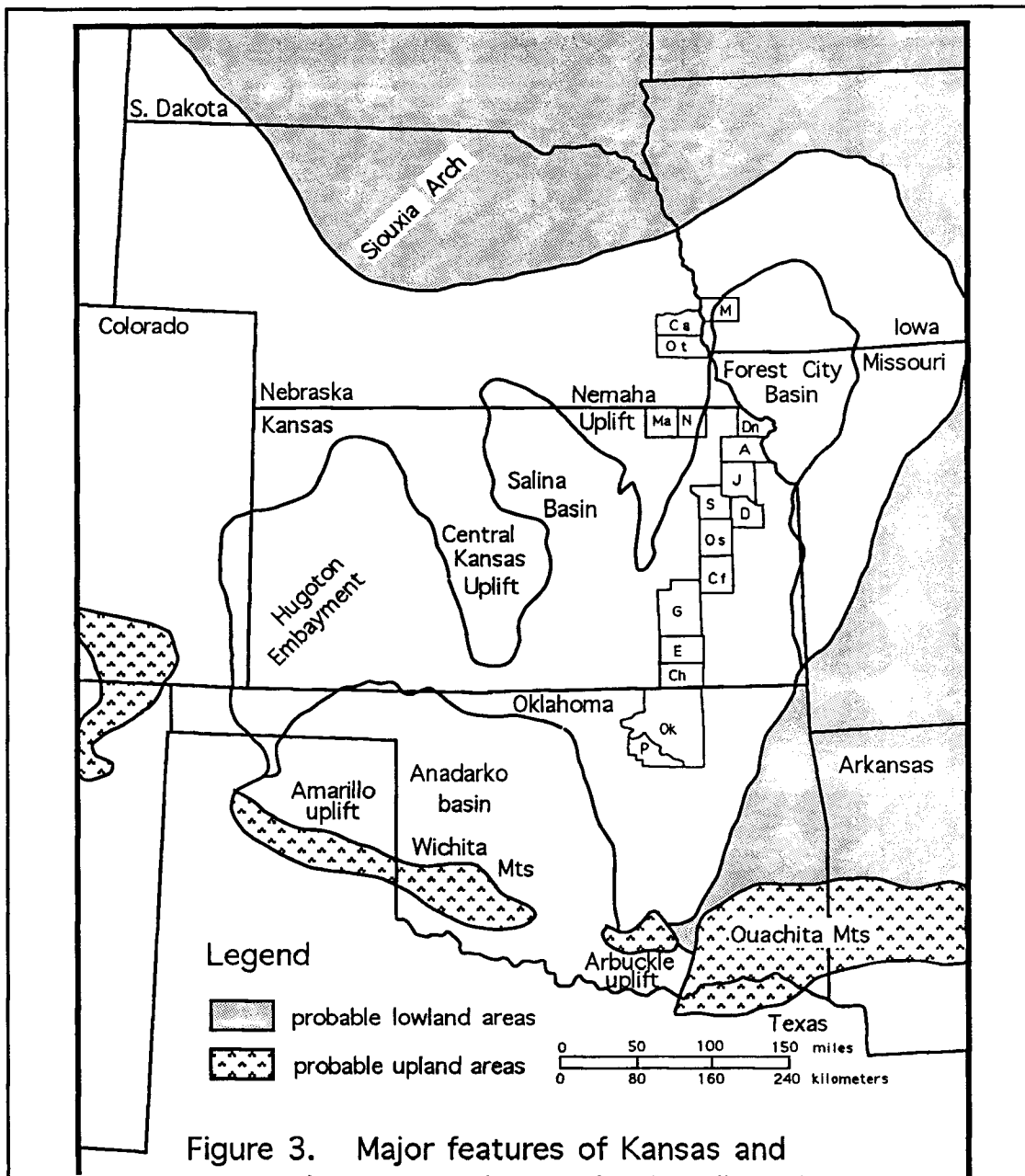
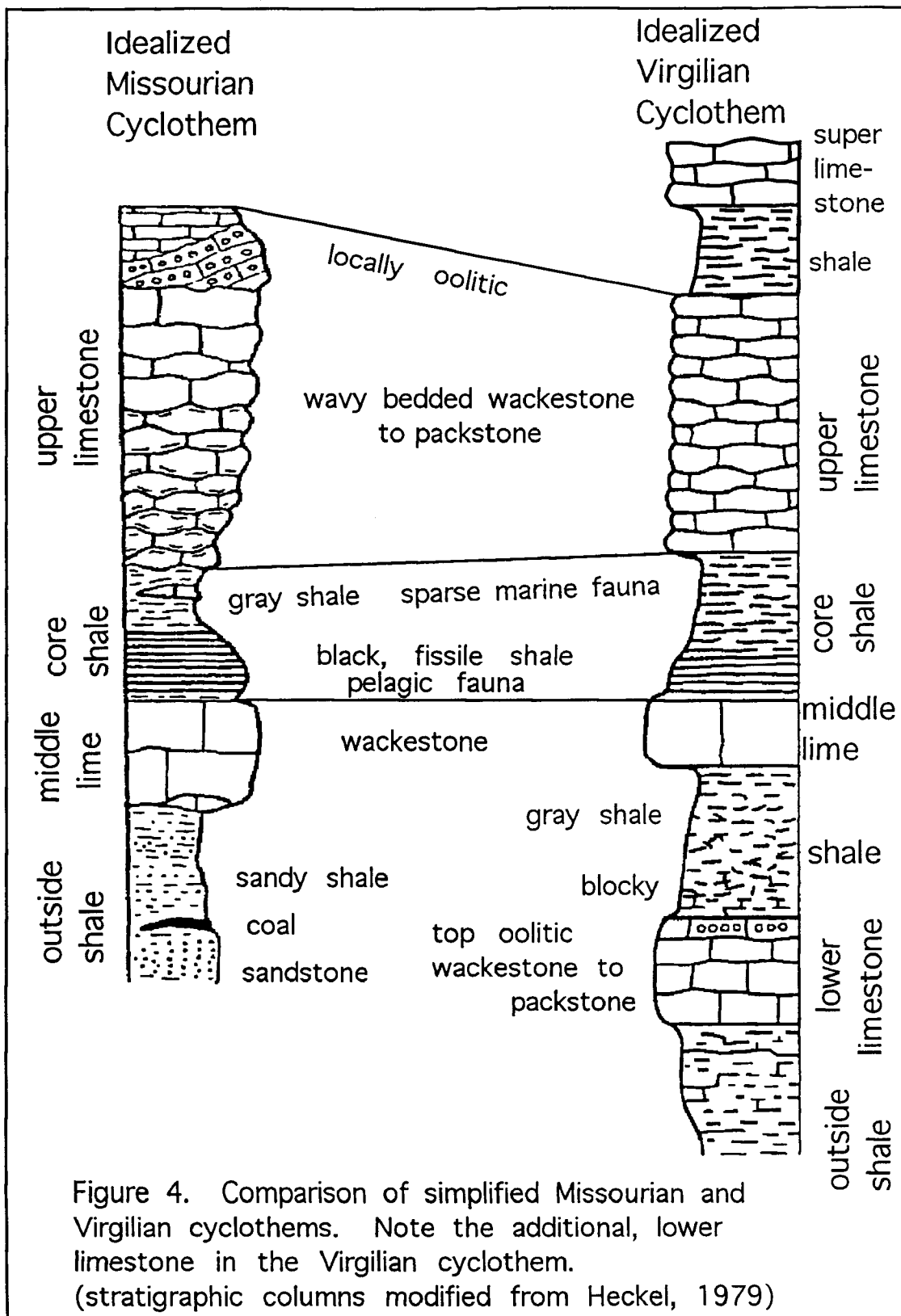


Figure 3. Major features of Kansas and surrounding areas during the Virgilian time. (modified from Troell, 1969)

M is Mills County, Iowa  
 Ca is Cass County, Nebraska  
 Ot is Otoe County, Nebraska  
 Ma is Marshall County  
 N is Nemaha County  
 Dn is Doniphan County  
 A is Atchison County

J is Jefferson County  
 S is Shawnee County  
 D is Douglas County  
 Os is Osage County, Kansas  
 Cf is Coffey County  
 G is Greenwood County

E is Elk County  
 Ch is Chautauqua County  
 Ok is Osage County, Oklahoma  
 P is Pawnee County, Oklahoma



(Heckel, 1980). Various authors (Moore, 1964; Troell, 1969; Heckel, 1979; Lamoreaux, 1983; Blaine, 1990) have suggested factors which may be important in cyclothem deposition, including eustatic sea-level change and rate of change, amount and rate of terrigenous influx, tectonic movements, rate of basin subsidence, compaction of sediments, and time.

Lower limestones are absent in Missourian cyclothems, so Heckel (1980), who worked almost exclusively in the Missourian, considered lower limestones to be "fortuitous." In the Virgilian megacyclothem (Fig. 4), however, lower limestones are a member of equal standing. Understanding how lower limestones relate to cyclothem deposition is important to understanding a major variant of Midcontinent Pennsylvanian cyclothems.

Kansas is interpreted to have been a relatively flat platform episodically covered by a shallow, epicontinental (epeiric) sea during the Pennsylvanian (Lee, 1943). Northeastern Kansas was part of the Forest City Basin (Fig. 3). Shoreline was typically in Nebraska during relative sea-level high stands, and migrated southward into Kansas during relative sea-level lows. Shoreline was also bounded to the west by the Nemaha High in central Kansas and central Nebraska. The platform edge was located in southeastern Kansas and northeastern Oklahoma and more open marine water lay to the south.

Troell (1969) did the first study to specifically examine a lower limestone, the Toronto Member of the Oread Formation (Fig. 1). He noted a thin, widespread *Osagia*-rich zone at the base of the Toronto Limestone, which he interpreted to represent deposition from a rapidly transgressing sea. Subfacies within the Toronto were interpreted to represent deposition resulting from local conditions developed during the inundative phase of the sea, rather than migrating facies tracts. A gradual regression near the end of deposition of the

Toronto allowed tidal-flat or littoral sediments to be deposited in Nebraska and northern Kansas and tidal-flat or delta-influenced sediments to be deposited in Oklahoma and southern Kansas.

Troell (1969, pg. 23) suggested Toronto deposition was followed by a period of non-deposition, with local erosion that incised channels into the Toronto. Troell (1969, pg. 3) further suggested that eustatic change in sea level had the greatest impact in controlling the deposition of the Toronto, rather than basin subsidence or sediment influx.

Joeckel (1994) identified paleosols in the Snyderville Shale (Fig. 1) and the upper Lawrence Formation. The Lawrence paleosol was thickest and better developed in Nebraska, and thinned into Kansas. The thickness of marine sediment between the Toronto and Lawrence paleosol increased from 0 to 170 cm in Nebraska to 3 to 6 m by northeastern Kansas. This suggested that the Toronto transgression occurred south-to-north and involved an appreciable amount of time.

The bulk of the Snyderville Shale consisted of two welded paleosols in southeastern Nebraska and a single paleosol in northeastern Kansas, but otherwise there was little differential development. This suggested that the Snyderville Shale paleosol resulted from a rapid and widespread exposure. The thickness of marine sediment deposited on the paleosol was relatively uniform. The relatively uniform thinness of overlying marine sediment further suggested that the post-Snyderville paleosol transgression was extensive and quite rapid.

#### PREVIOUS WORK

Smith (1894, pg.199) wrote, "In 1892, Mr. H.C. Hoover, of the Geological Survey of Arkansas, found at the government lime-kiln, three miles northwest of Pawhuski, Oklahoma Territory, Osage Agency, a bed of massive limestone about 100

feet thick, lying horizontally on heavily bedded sandstones.” The Deer Creek Formation was initially included within the [now] Pawhuska Limestone in Oklahoma, and Mr. H. C. Hoover went on to become the President of the United States of America.

Moore (1936, pg. 181) appended, “The limestone at the locality indicated is that now called Deer Creek, but the thickness of the main bed that is quarried is only about 10 feet. This suggests a probable typographical error exists in Smith’s description. The term Pawhuska Formation is now applied in Oklahoma to 130 to 180 feet of strata ranging from Lecompton to Topeka.” Moore’s (1964, pg. 317) section three miles from Pawhuska shows 20 feet of limestone total, so the 10 feet must refer only to the quarried limestone bed.

Bennett (1896, pg. 117) recognized the Deer Creek system and defined the type section as the top of the hill at Spencer (SE1/4, sec. 33, T11S, R17E), just east of Topeka, Kansas. The Deer Creek included three limestones and two shales from top to bottom: 4.5 feet of limestone (author’s note: an unusually thin section), 4 feet of black shale, a 2 foot limestone bed, 10 feet of shale, and 6 feet of limestone.

In 1927, Condra recognized two distinct limestones separated by a black shale, and one thin limestone within the black shale, within the Deer Creek around Rock Bluff, Nebraska. Condra named the upper limestone the Ervine Creek and the lower Limestone the Rock Bluff.

Upon examination of the section at Rock Bluff, Nebraska, Moore (1936, pg. 183) stated, “The correspondance of characters is so complete that I had no hesitation in concluding that the Rock Bluff limestone is the “middle Deer Creek” of Kansas, and therefore it seemed apparent that the “lower Deer Creek” member (here termed Ozawkie) was without a geographic name.” The old town of Ozawkie (sec. 29-32, T9S, R18E, Jefferson County, Kansas) is currently under the waters

of Perry Reservoir, but the type section of the Ozawkie Member (NE 1/4, sec. 31, T9S, R18E) remains above water on the north side of state highway 92.

The Ozawkie was not studied in detail in early stratigraphic work on the Deer Creek Formation in the Midcontinent. O'Connor's (1958) work focused on proper identification and correlation of the several Virgilian megacyclothems. B. A. Dickson (1965) constructed a paleo-environmental map of the Deer Creek, but because of the large stratigraphic thickness involved, the interpretations were simply "normal marine lime" over most of the outcrop area.

Moore (1964, pg. 317) reported the presence of the Ozawkie Limestone as far south as sec. 2-T35S-R9E (Chautauqua County) in Kansas and correlated the Deer Creek Formation into northern Oklahoma. Moore identified a limestone at Turkey Run, Oklahoma (from a Newell section) as Ozawkie, though that interval is covered over two intervening sections. Branson (1964, pg. 60) shows a Deer Creek Limestone and an underlying Plummer Limestone of Osage County, Oklahoma (Fig. 3) as correlative with the Deer Creek of southern Kansas.

The Plummer Limestone has since ceased to be used as a stratigraphic name in favor of the Rock Bluff Limestone. For future researchers poring over older documents, a brief review should save some confusion. The Plummer Limestone, defined as a member of the Pawhuska Limestone in Oklahoma, consisted of two, dark blue limestones each about 6 inches (15 cm) thick separated by about 5 ft (1.6m) of dark shale (Moore, 1936, pg. 185). Some older, archival, stratigraphic sections identify the Plummer Limestone in northeastern Kansas as a dense blue, fusulinid-rich, thin limestone and identify the underlying Rock Bluff Limestone as an earthy-brown, oolitic limestone about 5 ft (1.6m) thick. It appears that this Plummer Limestone is the Rock Bluff Limestone of current usage, and what was called the

Rock Bluff is actually the Ozawkie Limestone.

Moore (1964, pg. 341) defined an ecologic community within the upper part of the Ozawkie Limestone Member around the Kansas River Valley (Douglas, Shawnee, and Jefferson Counties). The "Ozawkie-type (*Knightites*)" assemblage consists of abundant small- and medium-sized colonies of *Osagia*, robust gastropods, and a few large, very well-preserved, bivalves. *Osagia* is an algally-coated (perhaps bacterially) particle. Moore attributed this paleobiotope to have lived in marginal parts of a retreating sea. Moore (1964, pg. 341) also remarked that the lower Ozawkie Limestone was a fusulinid-rich rock of "Tarkio-type" considered to represent "culminating marine conditions within the Ozawkie cycle."

Moore (1964, pg. 305) also noted a "Red Eagle-type" assemblage composed of inarticulate brachiopods, conodonts, and ostracodes, present in intra-Ozawkie shale in central Osage County, Kansas. The Red Eagle-type was interpreted to represent deposits from a poorly-oxygenated shallow sea.

Fagerstrom and Burchett (1972) studied six sections of the Ozawkie Limestone in southeastern Nebraska and southwestern Iowa. They note that the Ozawkie is highly variable in lithology and thickness, but the general pattern consists of a cryptalgal layer up to 30 cm thick, overlain by a siltstone to shale up to 60 cm thick, and finally by a silty limestone up to 30 cm thick. Fagerstrom and Burchett (1972) interpreted the Ozawkie depositional environment as ranging from supratidal and intertidal flats to shallow, restricted marine. The Ozawkie pinches out against the Nehawka-Table Rock Arches (equivalent to the Nemaha Arch in Kansas) in Cass County, Nebraska (Fig. 3), which they interpreted as shoreline. Comparison of the cryptalgal structures of the Ozawkie to stromatolites from Shark Bay, Australia, and Andros Island, Bahamas, led them to conclude that the tidal range was at least 20 cm, the maximum height of the stromatolites, and the

paleoslope of the intertidal-supratidal zone was about 3cm/km, the ratio of height of the stromatolites to width of the stromatolite zone.

Lamoreaux (1983) examined the Deer Creek Formation from Jefferson County, Kansas, to Chautauqua County, Kansas. He interpreted the Deer Creek as deposited from a single transgressive-regressive cycle. A thin coal and channel-fill sandstone beds in the underlying Tecumseh Shale suggested that the Tecumseh was fluvio-deltaic deposition (Lamoreaux, 1983). The Ozawkie was considered a transgressive limestone deposited below wave base, but within the photic zone. A local oolite was recognized in Jefferson County, Kansas. The Oskaloosa Shale was interpreted to represent sediment influx from the south in excess of the rate of sea-level rise. Later, sea-level rise exceeded the rate of sediment influx and the Rock Bluff Limestone and Larsh-Burroak Shale were deposited. The top of the Larsh-Burroak Shale and the Ervine Creek Limestone represent regressive deposits in Lamoreaux's scheme.

In Douglas and Jefferson County, Kansas, Robb (1991) and Robb & Michnick (1990) divided the Ozawkie into two facies, a coated grainstone and a lenticular lime mudstone to wackestone, interpreted as local high-energy shoal environments in open marine environment. In Jefferson County, they measured an average paleoflow direction of N47°E in cross-bedded grainstones with a possible second node to the southwest (Fig. 5). To the south and northeast, in Osage and Atchison Counties respectively, Robb and Michnick (1990) identified a single facies, a bioclastic wackestone to packstone, and interpreted it as normal marine. Laminated crusts were reported capping the Ozawkie over the whole study area from Atchison to Osage County, with an intramember crust developed locally in Jefferson, Douglas, and Shawnee Counties. These crusts were interpreted to represent two intervals of

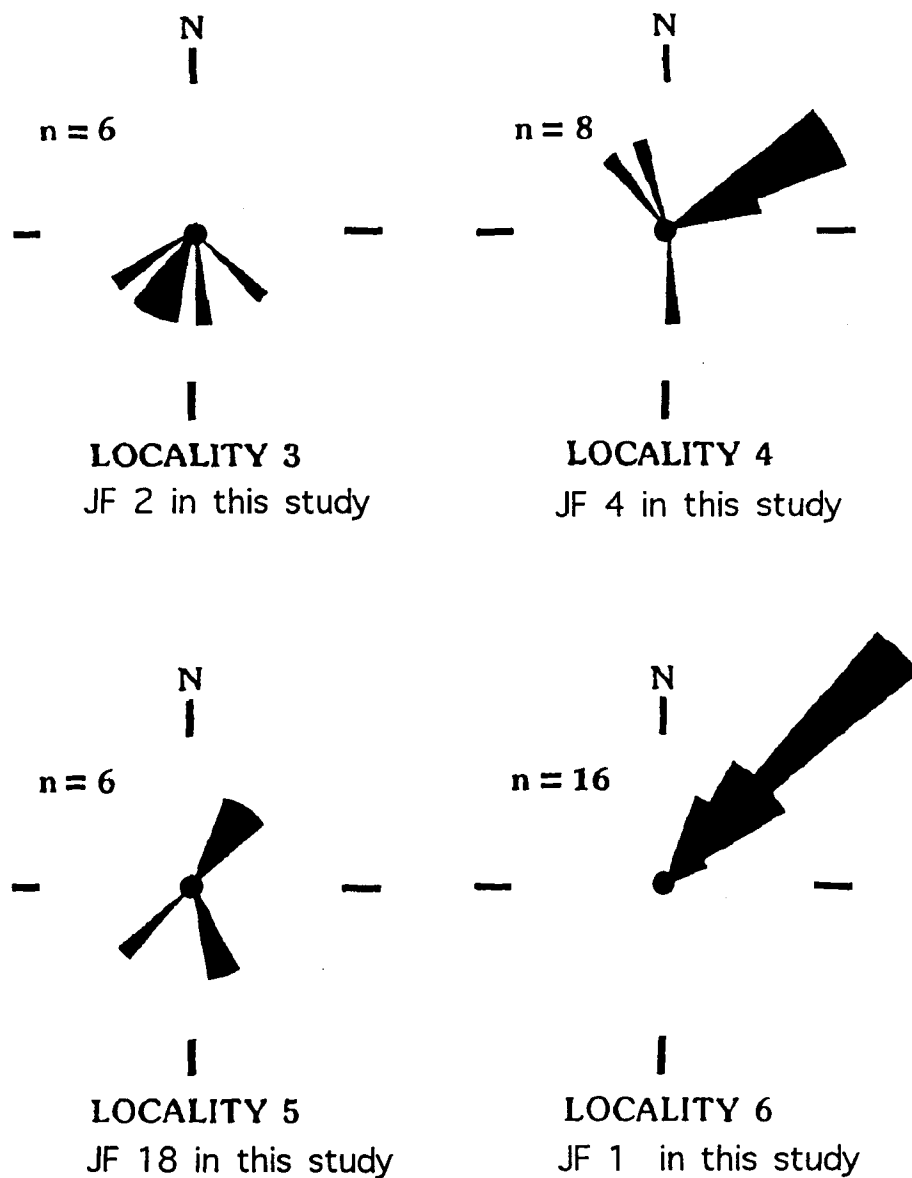


Figure 5. Frequency roses from Robb and Michnick (1990) indicating their paleocurrent data.

subaerial exposure of the topographically higher oolite shoals. Robb (1991) also reported paleosol development in the top of the underlying Tecumseh Shale in Douglas and possibly Jefferson County.

B.M. Conkin (1954) examined conodonts and ostracodes of the Deer Creek Formation. Conkin (1954, pg. 11) interpreted that the Oskaloosa Shale was definitely marine from Osage County, Kansas into Oklahoma. In Coffey County, Kansas, however, she identified a fresh- to brackish-water charophyte (alga) near the top of the Oskaloosa and interpreted brackish- to fresh-water deposition.

#### METHODOLOGY

Forty outcrops and two quarries exposing the Deer Creek Limestone were examined from Doniphan County, Kansas to Osage County, Kansas (Fig. 6). Outcrops were found either through the literature, through outcrop files archived at the Kansas Geological Survey, or by driving down the roads that cross the Deer Creek according to published geologic maps (Ward 1973, Bayne 1973, Winslow 1972, Johnson and Adkison 1967, O'Connor 1992, O'Connor 1955). The two quarries examined were the N.R. Hamm quarry north of Grantville, Kansas (NW1/4, sec. 15, T11S, R17E, Jefferson County), and the Martin Marietta Aggregates quarry at Big Springs, Kansas (SW1/4, sec 26, T12S, R17E, Douglas County). Five cores from Marshall and Nemaha counties, Kansas, that contain the Deer Creek were also examined. Cores are stored at the Kansas Geological Survey Core Facility. All the data from Coffey and Greenwood Counties, Kansas, was collected during a day-long field trip with Chris Maples, who is currently mapping these two counties.

For the purpose of this study, the outcrop belt was divided into a southern, central, and northern area, based on attributes of the Ozawkie (Fig. 6). In the southern area, the

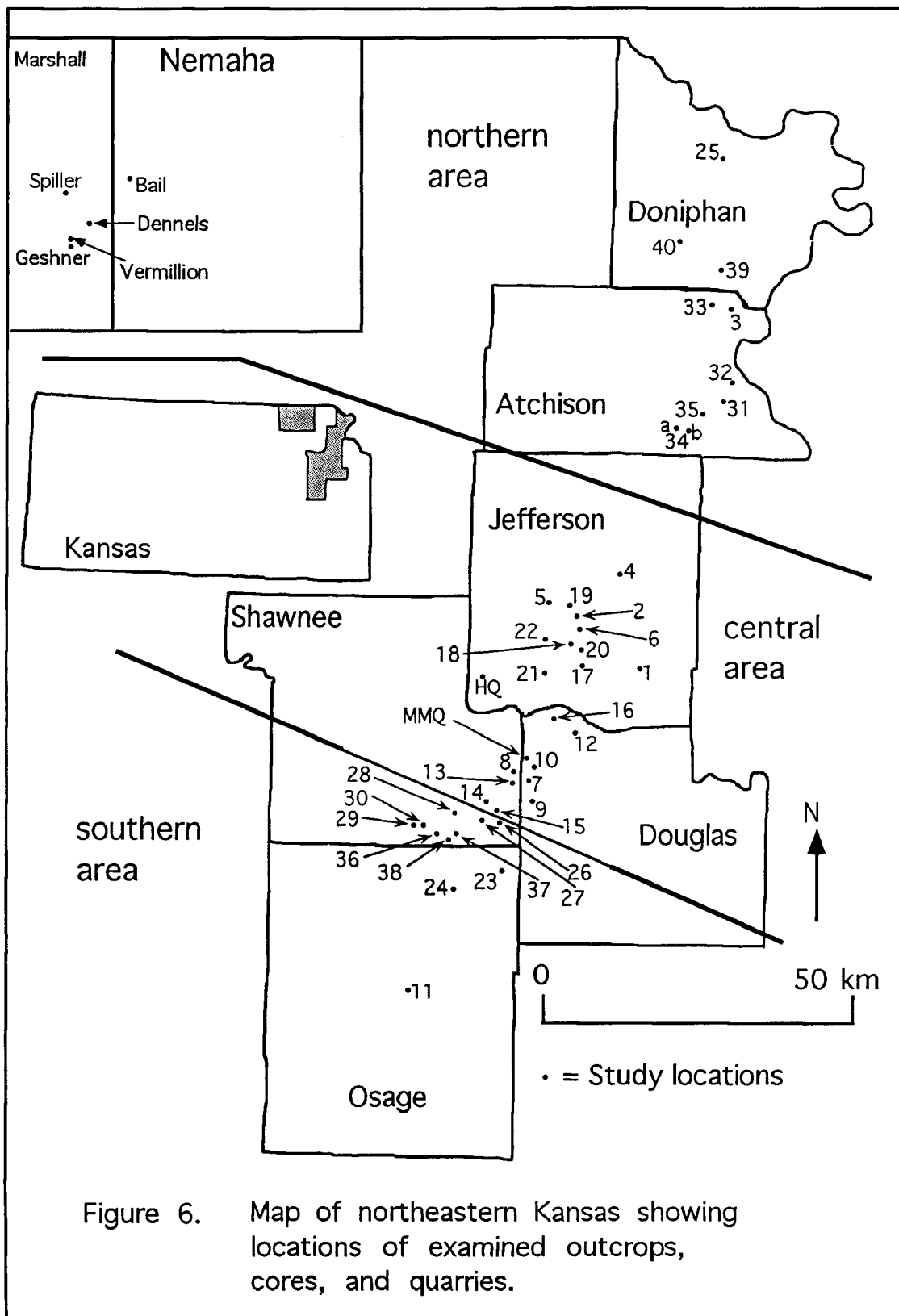


Figure 6. Map of northeastern Kansas showing locations of examined outcrops, cores, and quarries.

Ozawkie typically consists of two limestone unit with significantly different lithology, separated by shale. The central area is typified by two contiguous limestone layers of similar packstone to grainstone lithology. A gap of about 20 km separates outcrops of the Ozawkie in central Jefferson County from Atchison County and Doniphan County, where exposures are typically poor, but in general the Ozawkie is two contiguous layers with similar peloidal packstone lithology.

Approximately 150 hand samples were slabbed and polished. Approximately 50 thin sections were prepared from slabs that displayed interesting features. Thin sections were polished and left uncovered wherever feasible. Poorly consolidated, weathered, or fractured samples were covered after grinding with 600 grit because they commonly can not take the rigors of polishing.

Polished samples and thin sections were examined using a low-power stereomicroscope and a standard petrologic microscope. Thin sections with abundant cements were stained with Alizarin Red S and potassium ferricyanide (J. A. D. Dickson, 1965).

Data for isopach maps of various members were collected from field observations, literature reports, and well-log files archived at the Kansas Geological Survey. Maps were hand-contoured.

## FACIES

### Tecumseh Shale

The Tecumseh Shale (Fig. 1), which underlies the Ozawkie Limestone, is generally a greenish grey (5GY 6/1) to light olive grey (5Y 6/1), shale containing rippled, thin siltstone layers with mica flakes and sparsely-scattered macerated plant debris commonly along bedding planes. Locally the Tecumseh contains considerable siltstone or fine sandstone with small-scale lenses ranging up to meters wide and tens of centimeters

deep interpreted as channel fills. The Tecumseh ranges from roughly 21 m (70 ft) thick to 15 m (50 ft) thick in eastern Kansas (Moore, 1936).

A thin limestone is locally found within the upper 3m of the Tecumseh. In the southern area, the limestone is a sandy echinoid-clast packstone (OS11) or a lime mudstone with equant spar-filled cracks (SH30). Moore (1964, pg. 322) showed two, 30 cm thick, *Osagia*-rich limestones separated by siltstone in the upper Tecumseh in a section at Jefferson County. Tecumseh cores from Nemaha and Marshall Counties contain a persistent, argillaceous, fossiliferous wackestone. Fossil grains include crinoids, brachiopods, algae, and ostracodes.

In the central area, the top of the Tecumseh is locally calcareous, red or green mudstone, up to a meter thick. Clay slickensides, irregular calcareous nodules, root casts up to 5 cm in diameter and centimeters in length, be red to green in color, and vague prismatic columns are also locally developed. This interval is from 0 to 3m below the base of the Ozawkie. Pebble-sized coated carbonate nodules are incorporated locally into the base of the Ozawkie, even where carbonate is lacking at or near the top of the Tecumseh. The generally poor outcrops in the northern area do not expose any carbonate layer at the top of the Tecumseh. Tecumseh cores from Marshall and Nemaha Counties typically have a sequence of dark-green shale with slickensides, locally overlain by red shale with slickensides, and overlain by a thin, argillaceous wackestone developed within 2 to 3 m of the base of the Ozawkie.

The Tecumseh above the lime mudstone at SH30 contains a rich fauna including crinoids (up to 5cm long preserved), brachiopods, ramose and fenestrate and encrusting bryozoans, echinoids, ostracodes, gastropods, and fusulinids. Cores from Nemaha and Marshall show a different distribution of fossils. Inarticulate brachiopods are found sparsely throughout the

Tecumseh, but increase in number above the thin wackstone layer. Ostracodes are also present sparsely above the wackestone. Johnson and Adkinson (1967) reported sparse fossils in Shawnee and adjacent Jefferson Counties. The base of the Tecumseh contains crinoid columnals, foraminifers, and ostracodes. The upper 3m of the Tecumseh locally contains crinoid columnals, bryozoans, brachiopods, and casts of bivalves and gastropods. The bulk of the Tecumseh is unfossiliferous except for plant fragments.

#### Oskaloosa Shale

The Oskaloosa Shale (Fig. 1), which overlies the Ozawkie, is a brown-grey, calcareous shale. The Oskaloosa is 2 to 4 m thick in northeastern Kansas and reportedly thickens up to 8m in southern Kansas (Moore, 1936). A silty, mottled lime mudstone, 5 cm thick, is present near the top of the Oskaloosa at locality JF1. Above this lime mudstone, the Oskaloosa becomes darker and finely-laminated. Channel-forms filled with siltstone or shale up to several meters wide and 2 meters deep occur within the Oskaloosa.

In Nemaha and Marshall cores, the basal 30 cm of the Oskaloosa is a slickensided green shale containing weathered clasts of the Ozawkie. The middle of the Oskaloosa is generally a siltstone. In the Geshner core, a vertical, hollow, carbonized rhizocast 20 cm long is present. Wispy laminations of bioturbated siltstone and shale are common at the top. The uppermost part of the Oskaloosa is typically a bioturbated, fusulinid-bearing shale. The contact with the overlying Rock Bluff Limestone is either abrupt, or gradational over 3 cm.

#### Rock Bluff Limestone

The Rock Bluff Limestone (Fig. 1) is a dense, fossiliferous, wackestone with conchoidal fracture. The Rock Bluff is pale yellowish purple (10YR 6/2) and weathers very

pale orange (10YR 8/2) to greyish orange (10YR 7/4). In outcrop, it breaks into large, rectangular blocks. The base of the Rock Bluff is burrowed and the top surface is everywhere very flat. The most common fossils include brachiopods, fenestrate bryozoans, gastropods, crinoid segments, foraminifers including fusulinids, phylloid algae, rugose corals, and trilobite fragments. Other particles include pellets and oncoids with phylloid-algal nuclei. Infauna is represented by pellet-packed burrows and mottling. Diagenetic features include vugs, intraparticle porosity, and minor stylolites.

#### Larsh-Burroak Shale

The Larsh Burroak Shale (Fig. 1) is a typical core shale with 30 cm of black, fissile shale with conodonts, sparse fish scales, and fin imprints at the base. The black shale grades upwards into a brown or light-grey, noncalcareous shale. In outcrop, the black shale, which is more resistant to erosion, is exposed and the brown to grey shale is generally covered by vegetation. In Kansas, the Larsh-Burroak averages just over 1 m in thickness.

#### Ervine Creek Limestone

The Ervine Creek Limestone (Fig. 1) is a fossiliferous wavy-bedded wackestone to packstone. The Ervine Creek is a greyish orange (10YR 7/4) rock both weathered and fresh, and is nodular to wavy bedded. The base of the Ervine Creek is commonly flat to slightly wavy, and is typically *Osagia*-rich, with the largest being around 3 centimeters in diameter. In the cores, the uppermost meter of the Ervine Creek contains either one or two, current-laminated, coarsening-upward sequences culminating in coated packstone to grainstone. Common fossils include phylloid-algal fragments, brachiopods, gastropods, fusulinids, other foraminifers, crinoids, ramose and fenestrate bryozoans, corals, and trilobites. Other particles include

pellets and oncoids with phylloid-algal nuclei. Chert is lacking in the Ervine Creek, in contrast to the facies-equivalent and otherwise similar Plattmouth Limestone of the Oread Formation.

### Ozawkie Limestone

The Ozawkie ranges from 0 to 2.3 m thick in the northern and central areas, and approaches 5 m in thickness in the southern area where it includes an intervening shale interval. The Ozawkie Limestone consists of two units, either in contact or separated by a southward-thickening shale. The Ozawkie is lithologically diverse laterally along the outcrop belt, but similar lithologies are present in the upper and lower units. Generally the Ozawkie is a skeletal wackestone in the southern region, a coated packstone in the central region, and a peloidal packstone to lime mudstone in the northern area.

Fresh samples of the Ozawkie ranged from light olive grey (5Y 8/1) to light grey (N7). Weathered samples were approximately dark yellowish orange (10 YR 6/6)

#### *Northern Area*

Exposures of the Deer Creek in the northern area are sparse, due to glacial till and loess deposits from the Missouri River, making it difficult to generalize about the Ozawkie Limestone. The Ozawkie is generally comprised of two layers. The lower layer is a coarse, coated-grain packstone to peloidal wackestone. Micrite clasts up to 2 cm in diameter (average is 2mm) are present at AT 3 (Photo 1). Fossils are rare, but high-spired gastropods, phylloid algal fragments, and thin-shelled brachiopods are present. Near the top of the lower layer fenestrae, sheetcracks, and rhizocasts are common. The top of the lower Ozawkie is very flaggy-bedded where weathered. A calcareous shale, 5 cm thick, locally separates the lower Ozawkie from the upper Ozawkie.

The top layer is a bed of fine peloidal grainstone to

packstone at the base grading upwards to a lime mudstone. The base locally contains in-situ brachiopod and burrows and fenestrae occluded by spar cement. The lime mudstone at the top is flaggy-bedded, displays abundant rhizocasts (Photo 2), rhizoliths with laminated micrite aureoles, fenestrae, clotted micrite, circumgranular cracking, and vague prismatic columns.

In northeast Jefferson County and adjacent Atchison County, the Ozawkie appears to be absent. AT 34a has no hint of Ozawkie present or a break in slope indicating a limestone. The Ervine Creek and Rock Bluff limestone are both present at AT 34b, a break in slope is visible where the Ozawkie should be, but no limestone is exposed. AT 35 has no Ozawkie exposed, but some float within the ditch had a lithology typical for the upper Ozawkie in the area. Well logs from just west of these locales, however, report Ozawkie. Whether these locales represent an area where the Ozawkie was eroded away, never deposited, or merely well covered is uncertain.

### *Cores*

The Ozawkie is also comprised of two layers within cores about 50 km west of the outcrop belt. The exact base of the Ozawkie is difficult to define because the top of the Tecumseh is calcareous shale that grades upward into argillaceous lime mudstone. The lower Ozawkie is typically a lime mudstone to wackestone. Fine, wavy laminae are locally discernible within the mudstone. The base is commonly burrowed and the burrows are filled by a coarse-grained, bedded, coated-skeletal wackestone or packstone. Overall, a fairly diverse fossil assemblage is present including crinoids, fusulinids and other foraminifera, gastropods, algae, and brachiopods. The top of the lower layer has undergone slight in-situ brecciation, creating brecciation porosity, and contains some probable rhizocasts.

The lower layer and upper layer are typically separated by

a 5 cm thick conglomerate of slickensided shale or flat shale pebbles (Photo 3). Other pebbles within the conglomerate include reworked limestone clasts from the lower layer and black shale fragments of unknown origin.

The upper layer is a fine packstone or grainstone. Pisoids up to 3 cm in diameter (Photo 4) and intraclasts up to 1 cm in diameter with internal bedding have been observed at the base of the upper layer. Foraminifers are a very common fossil throughout the upper layer, and near the top typically constitute the dominant fossil grain. Crinoids and gastropods are also present. The top of the Ozawkie has undergone in-situ brecciation. Weathered nodules of the upper Ozawkie are present in the overlying, slickensided green shale of the Oskaloosa. Rhizocasts, rhizoliths, circumgranular cracks, and fenestrae, commonly filled with green shale from above, are common in the upper Ozawkie (Photos 5, 6, 7). In the Dennels core, a karst pit several centimeters wide and filled with green shale penetrates to the base of the upper layer (Photo 3).

### *Central Area*

In the central area, the Ozawkie shows considerable local variability, but a generalized sequence would contain four distinct units. From bottom to top, the lithologies and general characteristics of these layer are : <1> a coarse, coated grainstone to packstone; <2> a poorly-sorted floatstone to rudstone with thin, discontinuous laminated crusts at the top; <3> a coated grainstone to packstone; and <4> a poorly-sorted floatstone with laminated crusts. Common fossils in the packstone to grainstones include large gastropods, ramose and fenestrate bryozoans, fusulinids, and crinoid stems. A calcareous shale, commonly with medium prismatic peds (Buol et. al., 1973) up to 30 cm thick (localities DG12, SH13, and JF1 (Photo 8)), overlies the Ozawkie.

The lower coated grainstone to packstone (<1>) contains

oids and abundant coated grains, commonly up to 4 mm in size, typically with whole fossil or bioclast cores. Coated caliche pebbles, presumably reworked from the top of the Tecumseh Shale, up to 10 mm in diameter are also present at some localities. In the southern part of the central area, fusulinids and echinoid ossicles are the dominant particles. A small lens of large brachiopods in growth position is present in the lower coated-grain packstone unit at locality JF5.

Locally, clasts within the middle floatstone (<2>) can be fitted together suggesting auto-brecciation or at least minimal movement for big clasts (Photo 9). Irregular clasts of a thin, laminated, micrite crust are now randomly oriented at JF5 (Photo 10). However, in some localities (JF2, JF16, and JF18) the rudstones clasts are well rounded.

The upper coated grainstone to packstone (<3>) has ooids and abundant coated grains up to 2 mm in diameter. Whole fossils are rare, although large gastropods are present in the most ooid-rich outcrops.

The upper floatstone (<4>) contains clasts of light- and dark-grey lime mudstone and coated grainstone. The source of the coated grainstone clasts is very likely the lower layers of the Ozawkie Limestone. Dark-grey lime mudstone is not present within the Ozawkie in this area, so the source of these clasts is unclear. Clast size ranges up to 20 cm in diameter, and at localities JF1 and JF20 the coarser clasts are concentrated near the top. The contact between the floatstone and the underlying coated grainstone appears erosional with locally up to 15 cm of relief (Photo 11).

Within both the middle and upper floatstones are laminated crusts, rhizocasts and rhizoliths, sheetcracks, circumgranular cracking, and solution pipes (Photos. 12 and 13). The crusts are up to several cms thick and consist of fine, wavy laminae. Elongate, spar-filled rhizocasts with micrite aureoles are very abundant within the crusts and also commonly

penetrate into the underlying lithology. Clotted micrite, irregularly-shaped peloids clumped together, are also common. The crusts clearly truncate the underlying lithology, thicken into local lows attaining thickness of 5 cm or more, and coat vertical to overhanging surfaces (Photo 13).

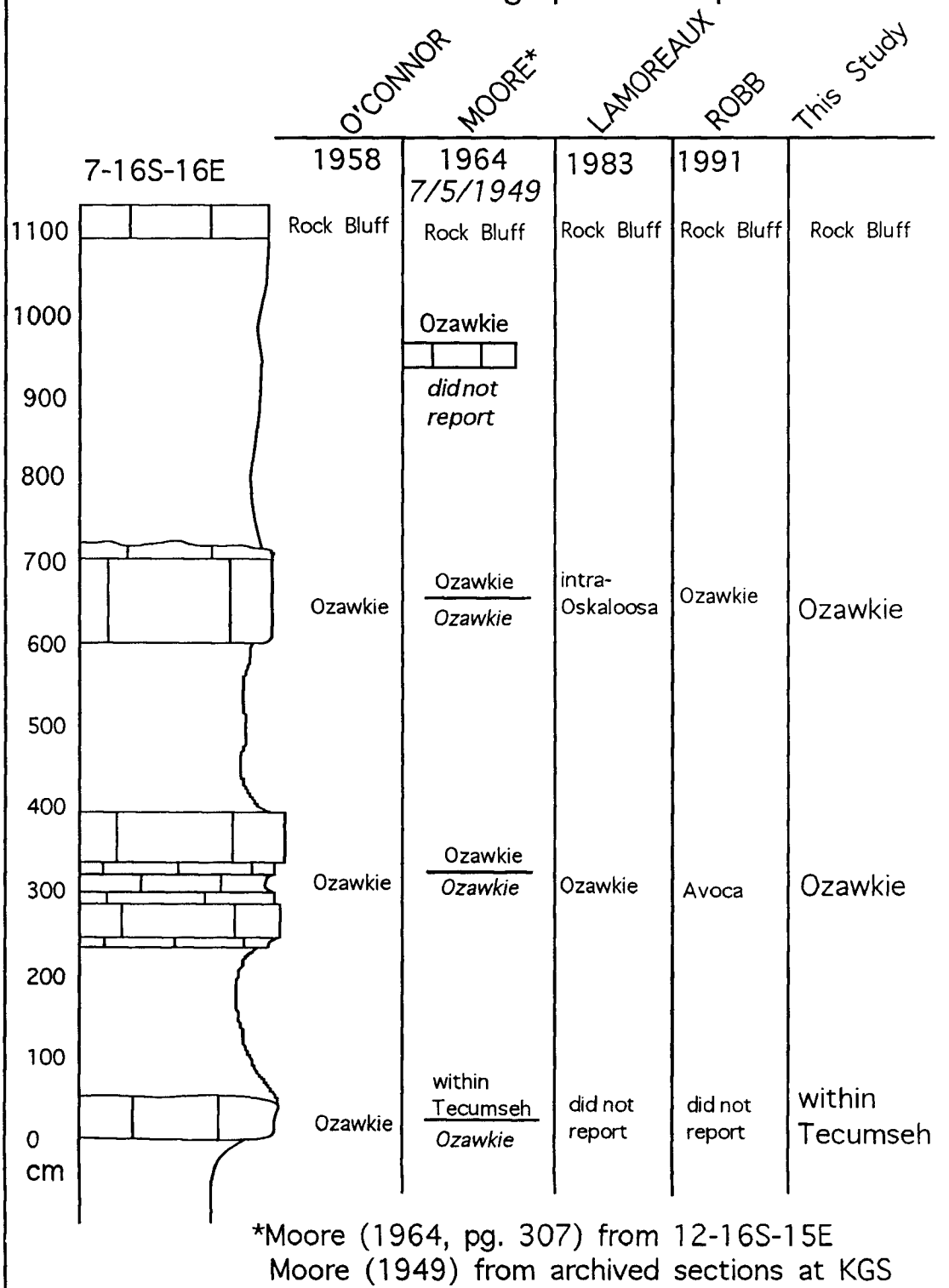
### *Southern Area*

In Osage County and southern Shawnee County, the Ozawkie consists of two limestone intervals separated by a calcareous shale which attains a thickness of 2 meters. Where the shale is lacking, contrasting lithologies of the layers signal the onset of subdivision. The uppermost unit is a fine-grained, skeletal packstone. The lowermost unit is a coarse-grained fusulinid wackestone or packstone. At OS 23, a bed of brachiopods in growth position, 30 cm thick, separates the two units.

In central Osage County two limestones are attributed to the Ozawkie (Fig. 8) based on correlation to the north, and a third limestone is attributed to the Tecumseh. The uppermost limestone is a skeletal packstone with abundant, subangular fossil fragments. Common identifiable fossil fragments include brachiopod spines and trilobites. The intervening shale has thickened to about 130 cm at OS11. The lower limestone is a flat-bedded, brownish grey (5YR 5/1) wackestone with abundant small fusulinids, other foraminifers, broken brachiopod shells, oncolitically-coated grains, fitted pellets and pellet-filled burrows.

South of the study area, in Coffey County, the Ozawkie is generally very poorly exposed and facies change significantly (Maples, oral communication, 1995). Three limestones are recognized between the Oskaloosa Shale and the Beil Limestone of the Lecompton Formation. The uppermost limestone, directly beneath the Oskaloosa Shale, is a silty limestone with abundant thin-shelled brachiopods, both broken and whole. The lower

Figure 7. Section at sec 7, T16S, R16E, Osage County, and various stratigraphic interpretations.



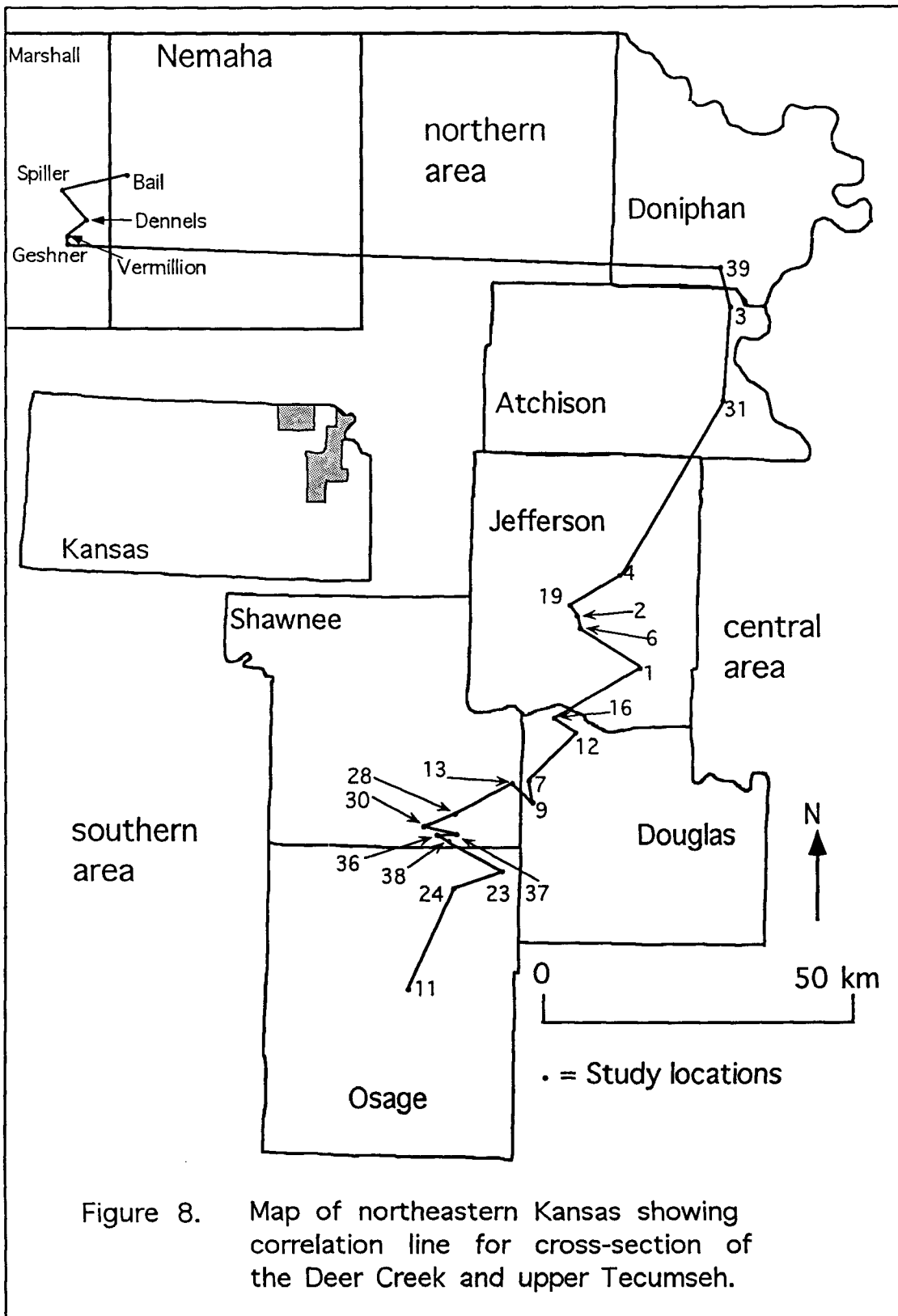
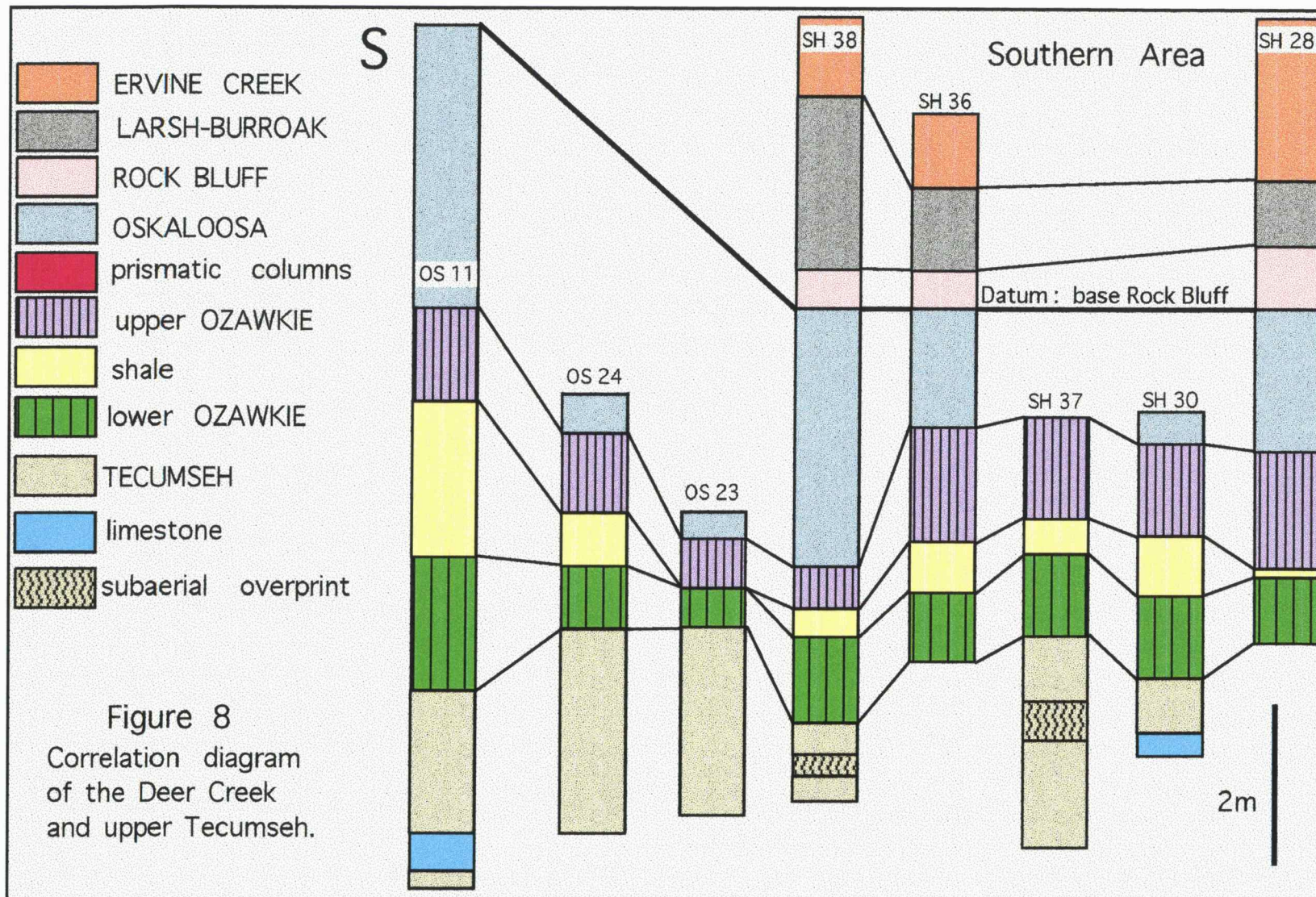
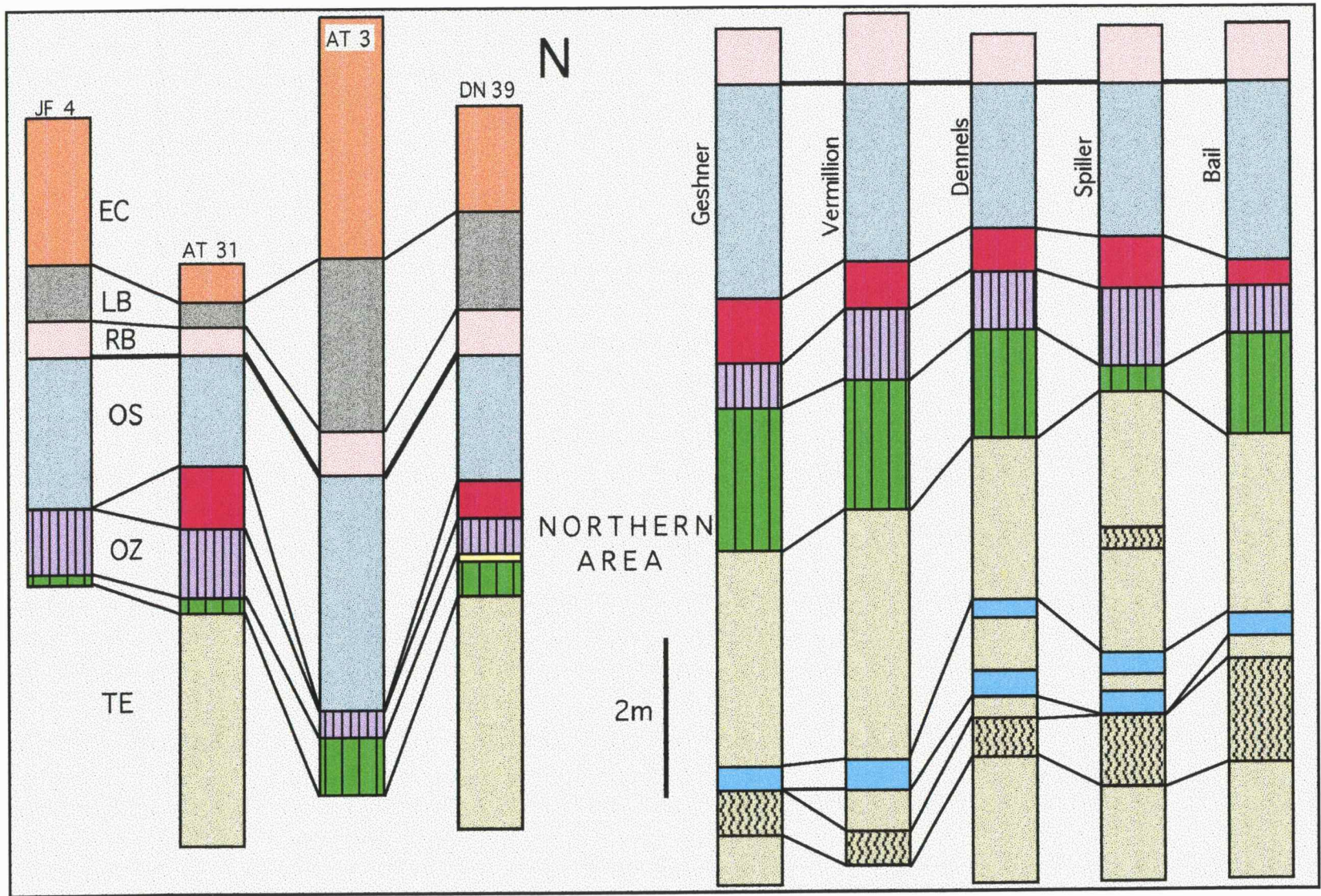
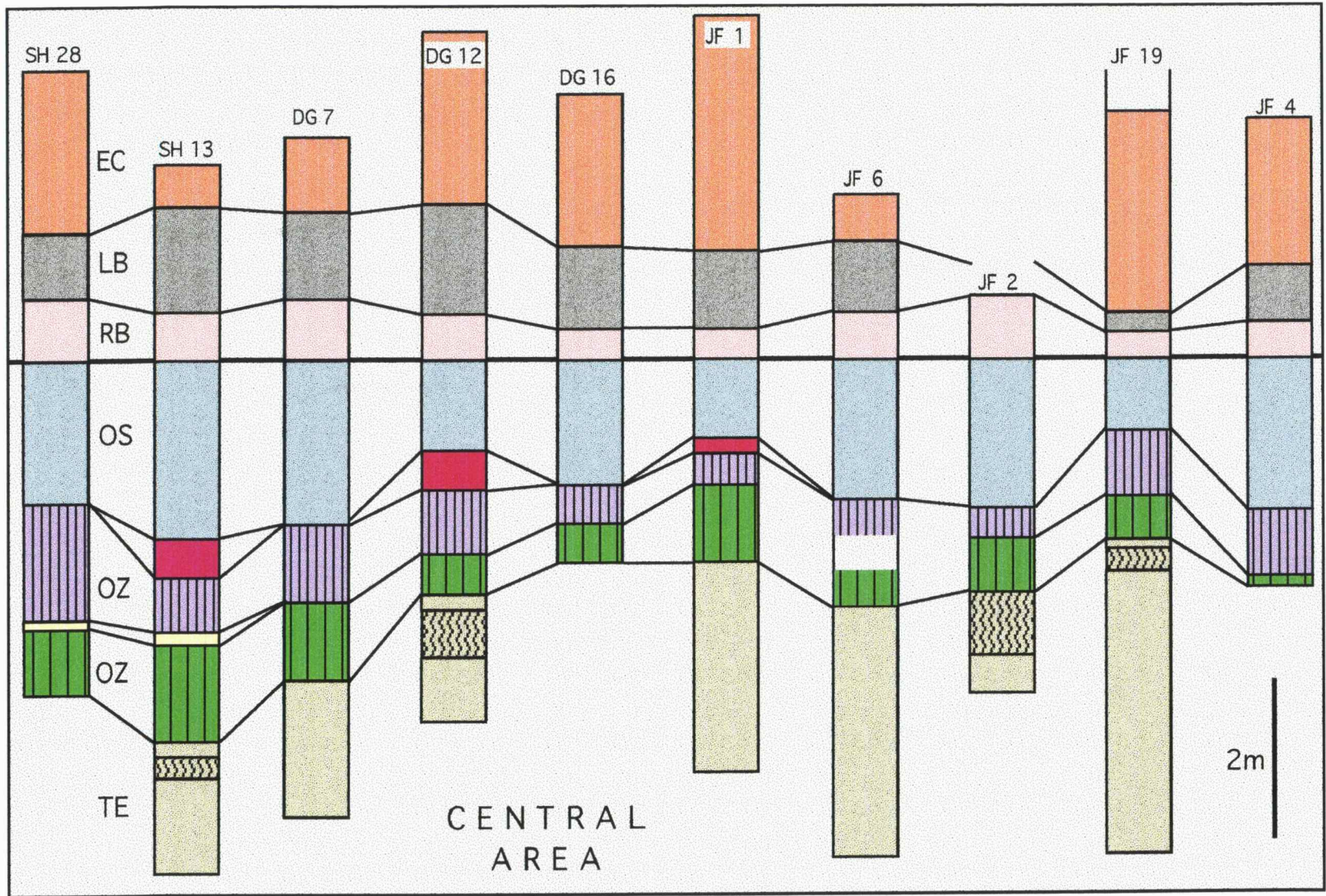


Figure 8. Map of northeastern Kansas showing correlation line for cross-section of the Deer Creek and upper Tecumseh.







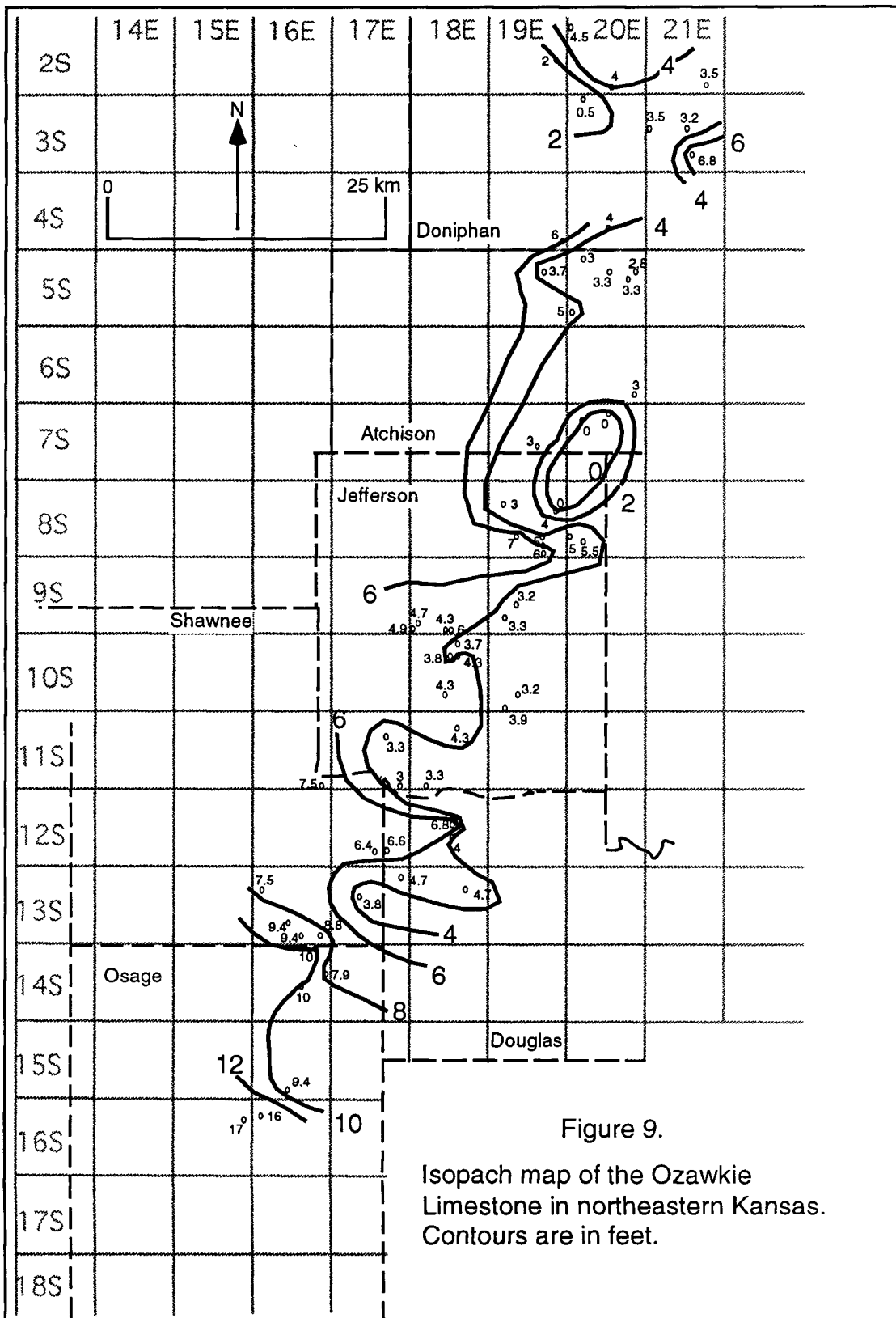


Figure 9.

Isopach map of the Ozawkie Limestone in northeastern Kansas. Contours are in feet.

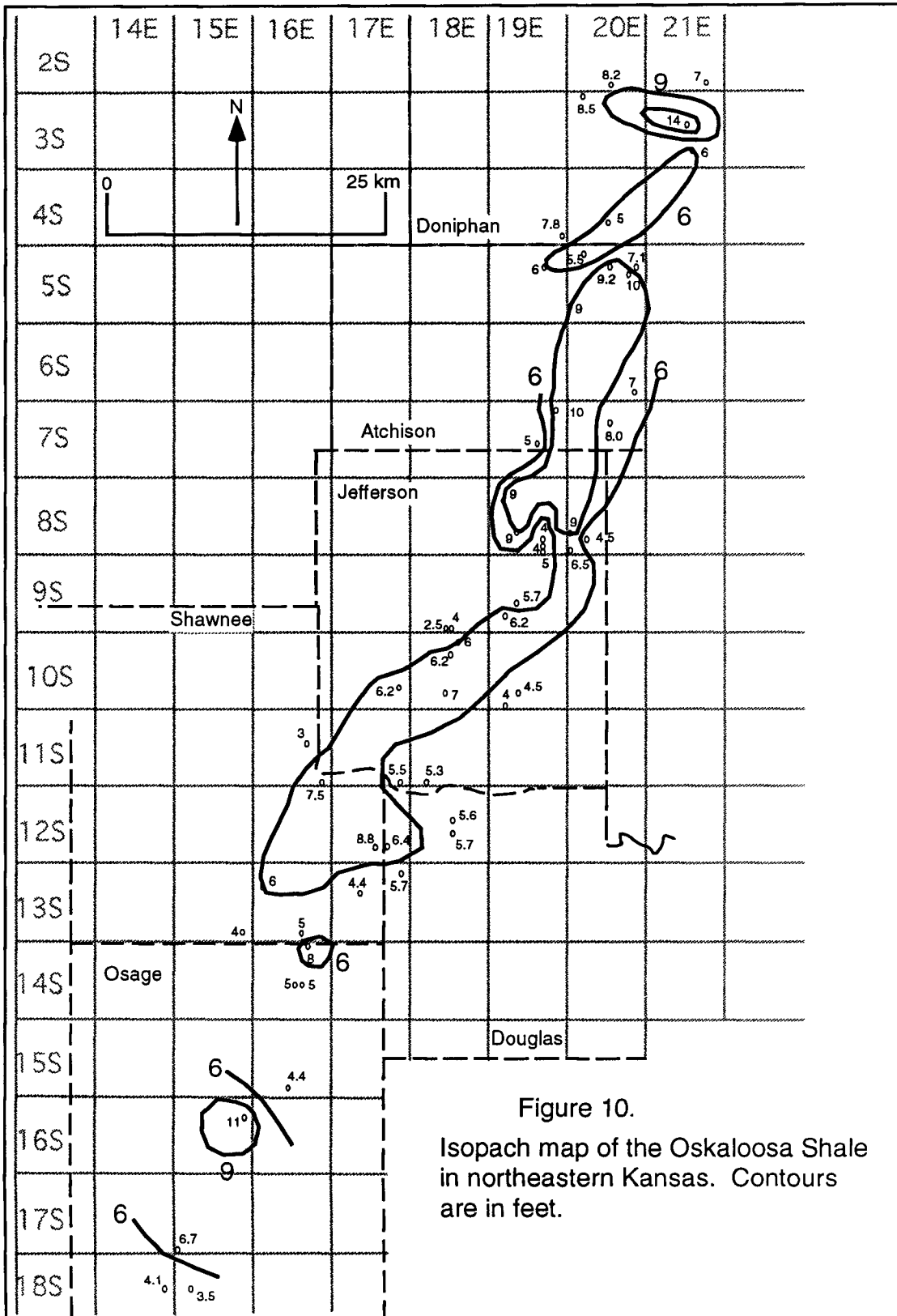


Figure 10.

Isopach map of the Oskaloosa Shale in northeastern Kansas. Contours are in feet.

Nebraska border though 120 km to the west of the outcrop belt, and its lithology is highly variable. However, Moore, Frye, Jewett, and O'Connor (1951), decided that the Ost was too patchy in occurrence to warrant subdivision of the Tecumseh in Kansas. Naming the limestone may also imply a time-equivalent or genetic origin which may not be the case.

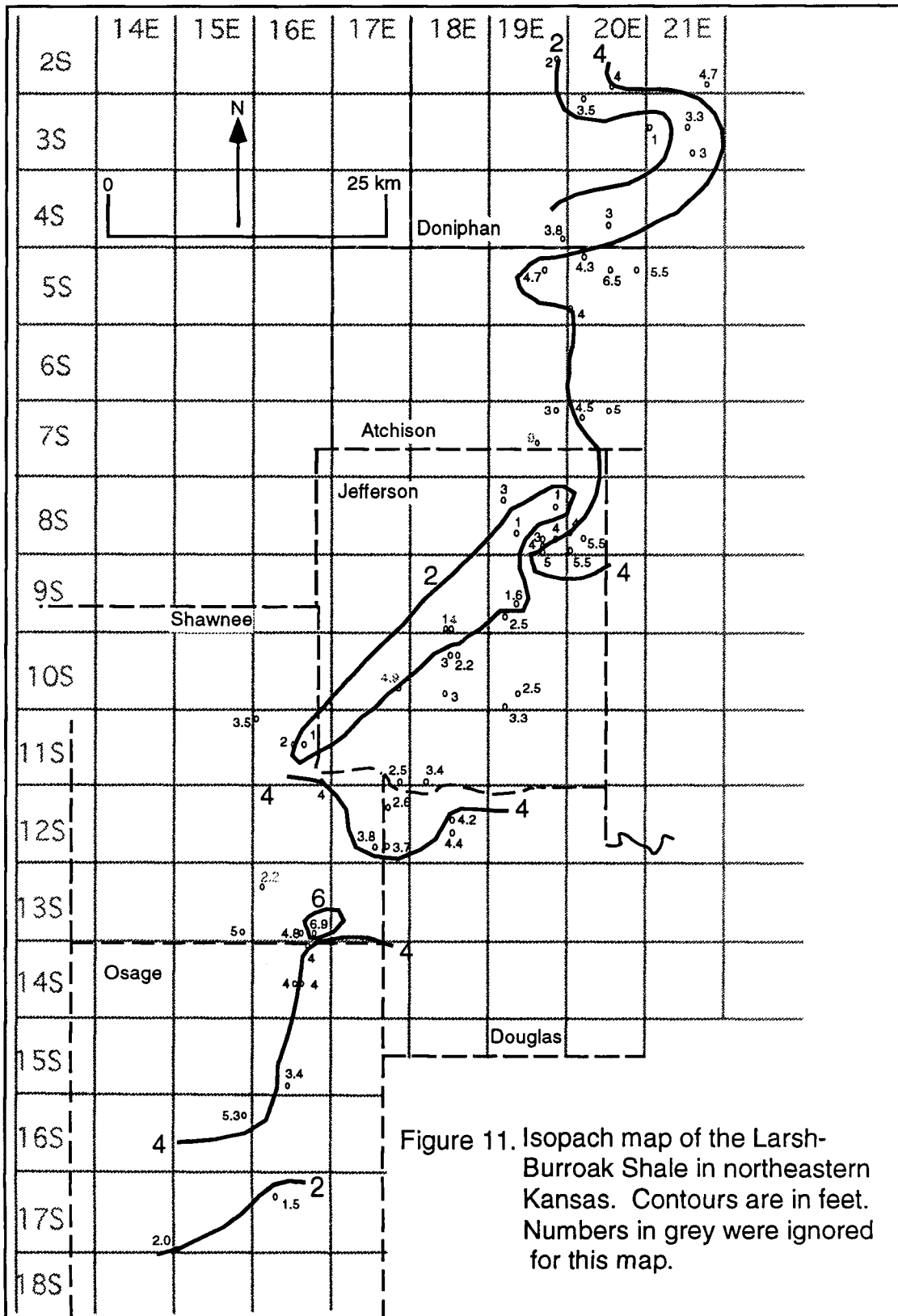
#### THICKNESS DATA FOR THE DEER CREEK FORMATION

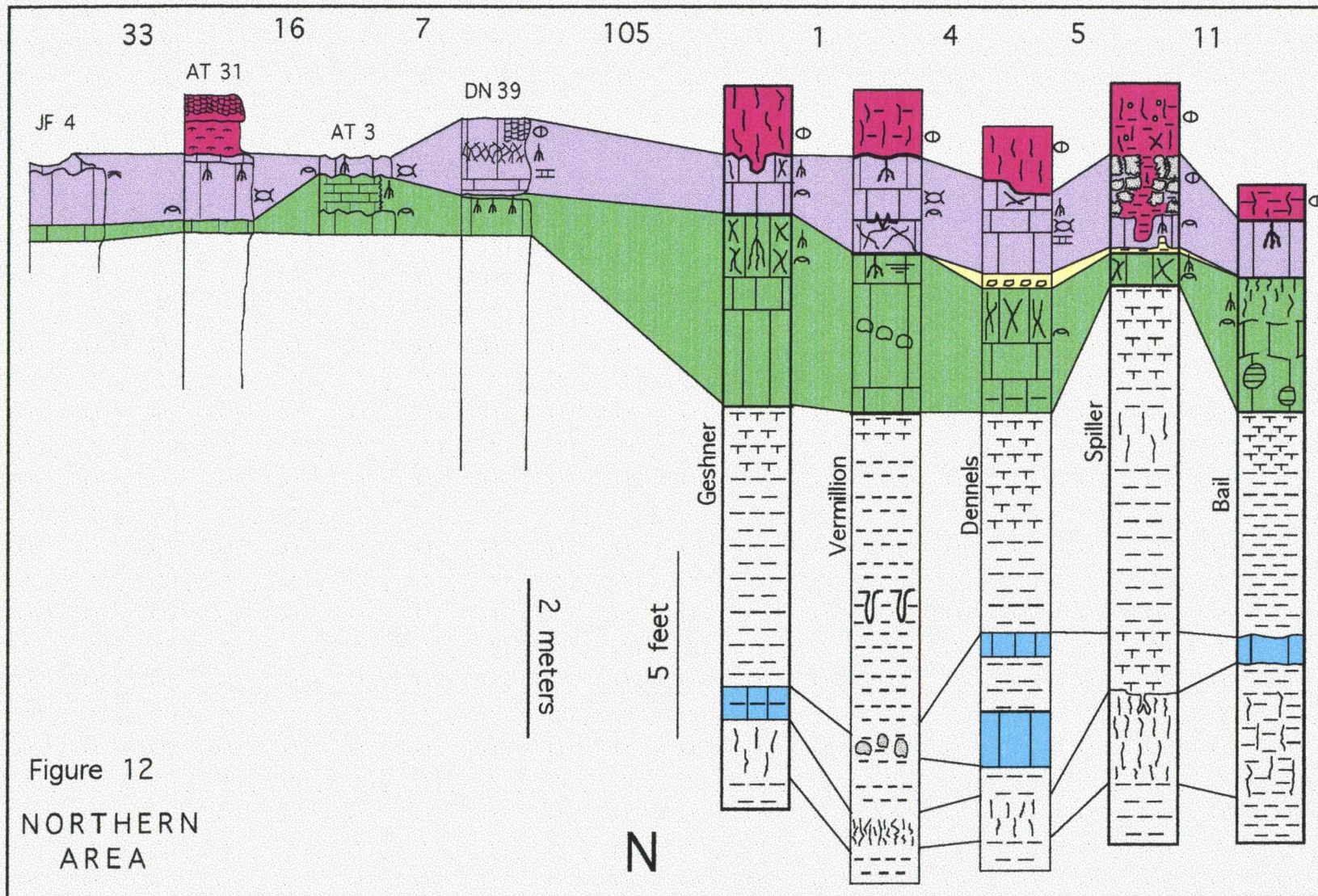
Isopach maps for the Ozawkie Limestone (Fig. 9), Oskaloosa Shale (Fig. 10), and Larsh-Burroak Shale (Fig. 11) members were constructed in an attempt to determine if paleotopography played a significant role in deposition of the Deer Creek Limestone. The outcrop belt is a relatively linear feature, and reliable subsurface data are too few to alleviate that problem, which makes it difficult to construct isopach maps. At best I would suggest that thickness generalities are valid, but a better areal distribution of points is sorely needed. An isopach of the Tecumseh would have been key to determining if paleotopography played a role in Ozawkie deposition, but too few reliable thickness points were available.

Thickness values of the Ozawkie increase greatly in the southern area, but this is caused by an intervening shale being tallied with the limestones for a total. Figure 11 was contoured ignoring 4 points that were significantly different from immediately nearby points.

Z-values, an individual point's difference in thickness from the average in standard deviations, were calculated for the Ozawkie, Oskaloosa, and Larsh-Burroak. The correlation coefficient calculated for the Ozawkie versus Oskaloosa is 0.15 and for the Ozawkie versus Larsh-Burroak is 0.13.

Correlation coefficients from -1.00 to -0.3 and from +0.3 to +1.00 are the standard cutoff for a recognizable correlation. The closer the value is to either -1.00 or +1.00, the stronger the correlation. In this case, with correlation coefficients very





close to zero, the thickness in one unit has no relation to the thickness of the other unit.

## DEPOSITIONAL HISTORY OF THE TECUMSEH AND OZAWKIE

### *Tecumseh Shale*

Shale of the lower Tecumseh contains a sparse assemblage of crinoids, fusulinids, and ostracodes (Johnson and Adkison, 1967) that indicate marine deposition during the retreat of the Avoca sea.

The middle of the Tecumseh is an unfossiliferous shale with channel-fill siltstones to fine sandstones. Both Moore (1964) and Lamoreaux (1983) report thin coals present near the upper Tecumseh, but do not give specific locations. Moore (1964) showed a coal in his idealized diagram of the Deer Creek megacyclothem, and drew a coal-like symbol in his sections of the Deer Creek at location 6-17S-16E (Osage County, Kansas). Archived stratigraphic sections at the Kansas Geological Survey, however, do not include any Tecumseh sections containing a coal. No coals were found in this study. Plant material is abundant along bedding planes though suggesting a nearby source. The middle of the Tecumseh likely represents deposition from a deltaic system, cut by channels, adjacent to vegetated swamps.

Silty, calcareous mudstone with prismatic columns, carbonate nodules, and rhizocasts are locally present in the southern and central region up to a meter from the top of the Tecumseh. Nemaha and Marshall county cores of the Tecumseh contain red or green slickensided shale between 2 and 3m from the top. Sparse fossils are even present in the Bail core in the slickensided shale. These features represent a widespread subaerial exposure and paleosol development overprinted onto the Tecumseh (Fig. 12, Fig. 13).

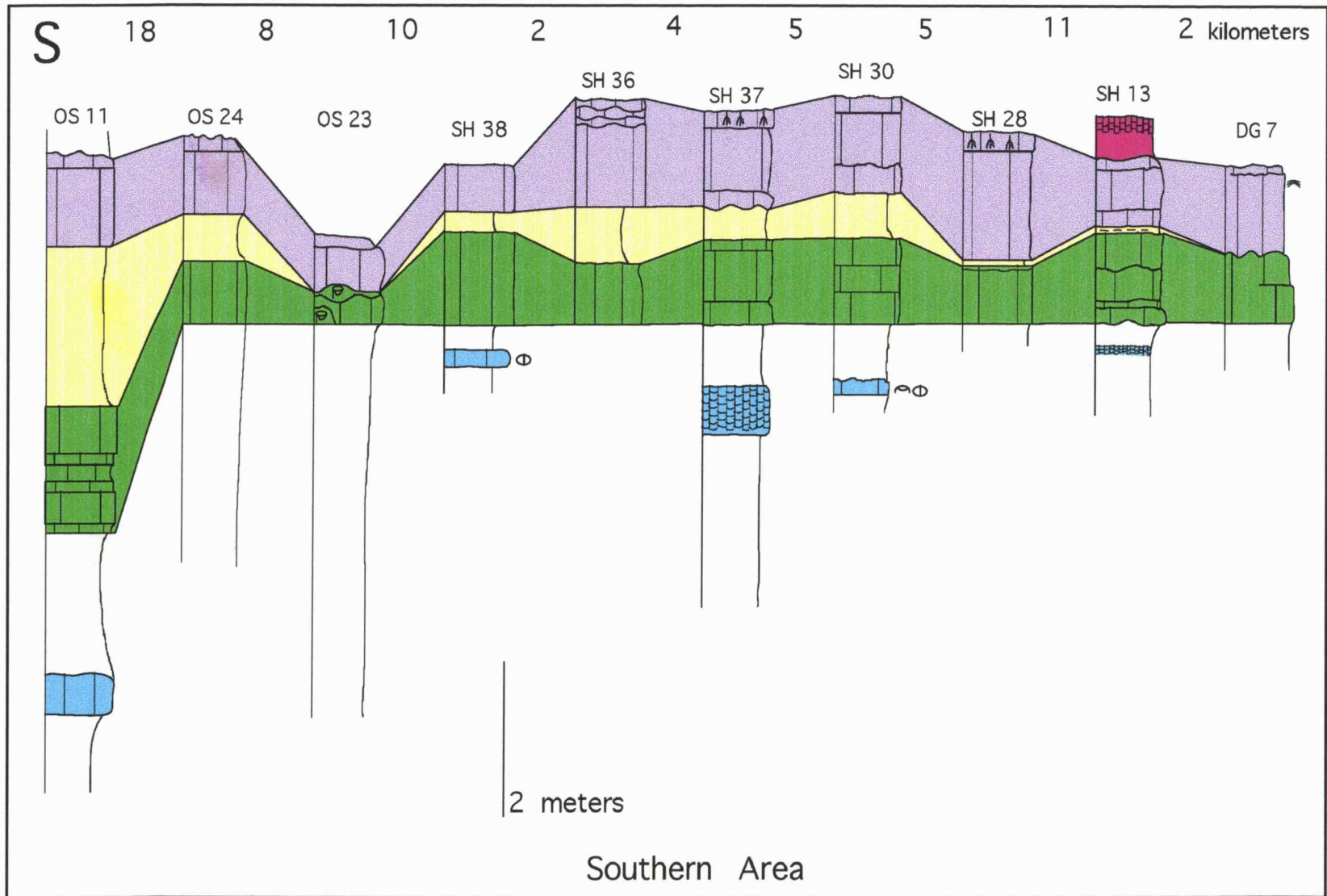
A thin, argillaceous, skeletal wackestone caps the

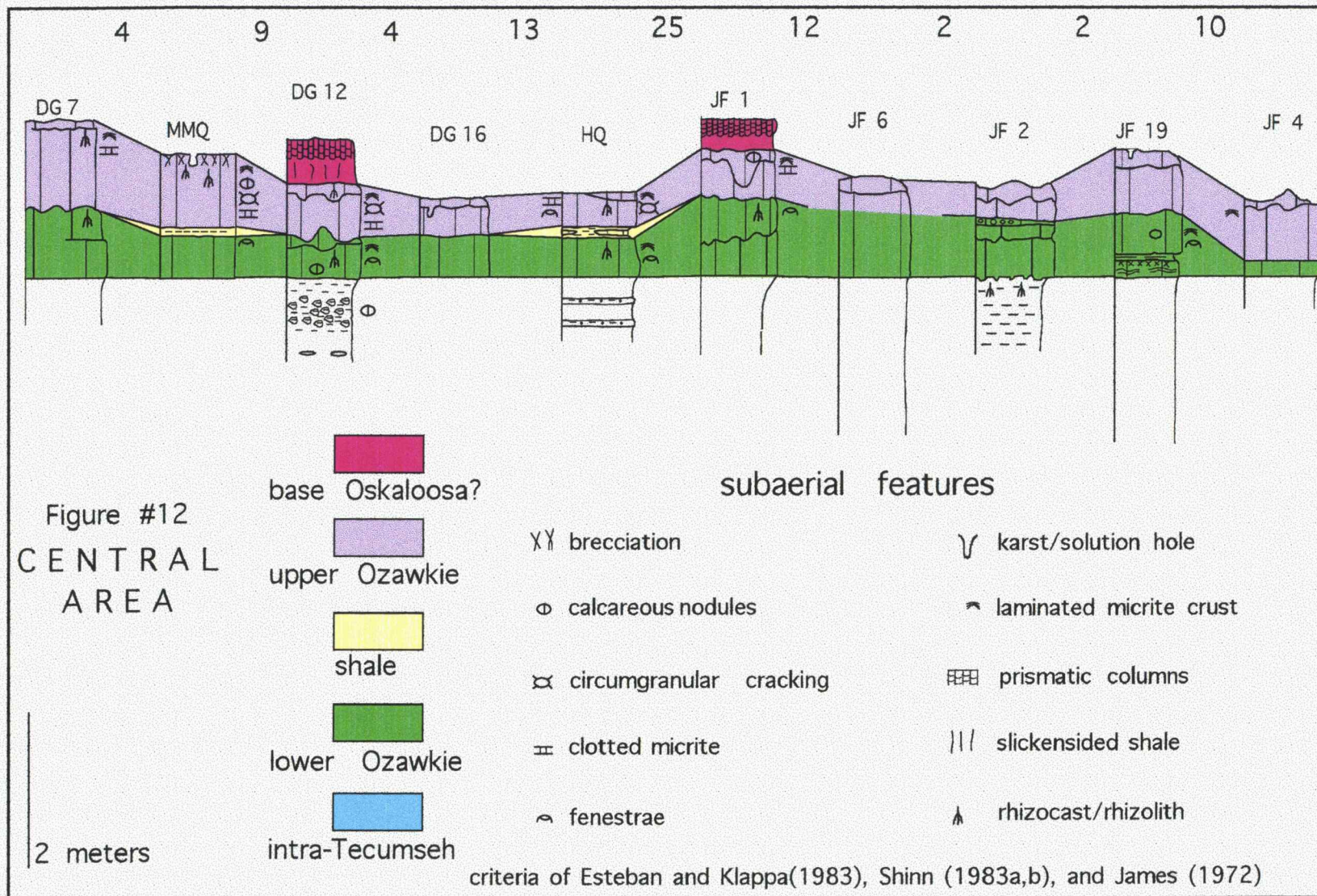
Figure 13.

Chart showing types of features present at each locality and level of confidence in recognition.

<u>FEATURE</u>	<u>CONFIDENCE LEVEL</u>
RI = rhizolith	! = definitely
Rc = rhizocast	+ = most likely
MI = laminated micrite crust	- = possible
Mc = clotted micrite	
F = fenestrae	
Cc = circumgranular cracking	
N = caliche nodules	
K = karst/solution hole	
P = prismatic columns	
S = slickensides	
cover= covered	
No OZ= Ozawkie not present	
poor= poorly exposed	

	<u>TECUMSEH</u>	<u>lower OZAWKIE</u>	<u>upper OZAWKIE</u>
Bail	S!	Rc!, F+	R!l, S!
Spiller	S!	Rc-, F!	R!l, Rc+, S!, N!, F!, K-
Dennels	S!	F!	Rc+, Mc!, Cc!, S!, N!
Vermillion	S!	Rc+	Rc!, F!, S!, Cc+, N+
Geshner	S!, Rc+	Rc+, F!	Rc+, F!, S!, N!
DN 25	cover	poor	poor
DN 40	cover	poor	MI-
DN 39	cover	Rc+	Rc!, P+, N+, Mc+
AT33	cover	poor	P-
AT3	cover	Rc+, F!	Rc!, R!+, F!, Cc+
AT 32			Rc+, P-
AT 31			P!, Rc!, R!+, F!, Cc+
AT 34a,b 35		noOZ	NoOz
JF 4	cover		MI-
JF 19		MI+, F-	K-
JF 5	cover	Rc+ MI! F! Cc+	poor
JF 2	Rc!	poor	poor
JF 6		poor	poor
JF 22		poor	poor
JF 18	cover	MI+, Cc+	MI+
JF 20	cover	MI+, N+	Rc!, MI!, Cc+, Mc+
JF 1		Rc+, F+	P!, MI!
JF 17	cover	poor	poor
JF 21		poor	poor
HQ		MI! , F!, Rc-	Rc!, MI!, Cc!, Mc!, F!
DG 16	cover		K-
DG 12	N+, Rc-	Rc+, F!, MI+, N-	P!, R!+, Rc+, MI!, Cc+, Mc+
MMQ	cover	F!	R!l, Rc+, MI!, Mc!,Cc!, N+,K!,F!
DG 10	cover	poor	poor
SH 8	cover	poor	poor
DG 7	cover	Rc-	MI!, R!+, Rc+, Mc+
SH 13	P+		P!
DG 9	cover	Rc-	Rc+
SH 14	cover	poor	poor
SH 15	cover	poor	poor
SH 26	cover	poor	Rc-, poor
SH 27	cover	poor	poor
SH 28	cover	Rc!	Rc!, P-
SH 30	N+, F!		Rc!
SH 29	cover	poor	Rc+
SH 37	P!	Rc!	Rc!
SH 36	cover	poor	poor
SH 38	N+	Rc+	Rc+
OS 23		Rc-	Rc+, P-
OS 24			P-
OS 11			Rc-, P-





paleosol in the Nemaha and Marshall cores. A thin limestone is also present at OS11 (echinoid-clast packstone) and SH30 (lime mudstone with equant spar-filled cracks), and reported by Moore (1964, pg. 322) in Jefferson County (Osagia-rich), where an underlying paleosol overprint in the Tecumseh is lacking. A sparse amount of inarticulate brachiopods and ostracodes are present in the shale above the wackestone, and a rich fauna is present in the shale above SH30.

This suggests a widespread transgression occurred following the paleosol which locally deposited a limestone. The sandy echinoid-clast packstone likely represents either a high-energy strand-line of a transgressing sea or perhaps a tidal channel. The lime mudstone at SH30 was likely deposited in a supratidal environment and was occasionally dessicated. The fauna above the limestone is indicative of a marginal marine setting.

Within the central region of this study, caliche nodules from the Tecumseh's paleosol are incorporated into the lower Ozawkie, and the base of the Ozawkie is locally in contact with the paleosol. At JF1, no paleosol is present in the Tecumseh, yet caliche clasts are incorporated into the lower Ozawkie. This suggests that some pre-Ozawkie erosion occurred which stripped some to all of the marine deposition off and locally removed the paleosol.

In summary, initial deposition of the Tecumseh in northeastern Kansas occurred in a marine setting. As the regression following the deposition of the Lecompton Formation proceeded, the Tecumseh was deposited in a deltaic system adjacent to subaerially-exposed, vegetated areas. Paleosols were commonly developed locally. Relative sea-level then rose and the upper part of the Tecumseh was deposited in a marine setting. In the central region, pre-Ozawkie erosion may have removed the marine deposition and locally the underlying paleosol.

### *Ozawkie Limestone*

The Ozawkie Limestone represents deposition from generally shallowing environments along a south to north trend.

#### Lower Ozawkie

In the southern area, the lower Ozawkie grades northward from a fusulinid wackestone to a coated, skeletal packstone. Fossils are well-preserved, the assemblage is varied, med and pellets are abundant, and burrows are common. This would suggest that the lower Ozawkie was deposited from a relatively quiet, subtidal environment. Rhizocasts are locally superimposed at the top of the lower Ozawkie in the northern part of the southern region. The shale that separates the lower and upper Ozawkie contains a normal marine fauna at the base, passes into a restricted-to-brackish fauna in the middle, and returns to a normal marine fauna at the top. This suggests that a relative sea-level drop occurred. The lower Ozawkie in southern Shawnee County was likely subaerially exposed, Osage County was likely still submarine, but close enough to shoreline that water composition was affected.

In the central area, the lower Ozawkie is generally a coarse, coated, skeletal packstone to grainstone with locally abundant ooids and a diverse fossil assemblage. Coated nodules of the Tecumseh Shale incorporated into the base indicate some pre-Ozawkie erosion. The lower Ozawkie most likely represents deposition from an agitated, subtidal environment. A floatstone to rudstone with clasts typical of the lower Ozawkie (Photo 3) may be developed at the top of the lower layer. Features such as laminated micrite crusts, rhizocasts, circumgranular cracking, and fenestral porosity are present. It appears that following deposition of the lower Ozawkie, a relative sea-level drop and subaerial exposure occurred.

In the northern area, the lower Ozawkie is generally a peloidal, fenestral packstone or a coated packstone. Fossils are rare and the assemblage is limited. The top of the lower layer contains abundant rhizocasts, fenestrae, and is muddier. The lower Ozawkie in cores is very similar. The base is gradational with the marine sediments of the upper Tecumseh, but the lower unit is generally a burrowed to laminated lime mudstone. The upper part of the lower layer is slightly brecciated and rhizocasts may be present. The wavy laminations are most likely stromatolitic layers that would have been continuous across the cores had subsequent brecciation not occurred. This suggests that both the northern area and the cores represent quiet, possibly semi-restricted, shallow marine to intertidal or supratidal deposits.

The top of the lower Ozawkie in the north and central areas, and an intervening shale in the southern area, record a significant change in depositional environment caused by a relative sea-level drop. Subaerial features cap the lower Ozawkie in Shawnee County and northward, and are lacking in Osage County and southward. The base of the shale overlying the lower Ozawkie at OS11 contains a diverse fauna typical of normal marine conditions. Towards the middle, the shale's fauna grades into a limited two-fossil assemblage, a thin-shelled brachiopod and one foraminifera, and likely represents a brackish-water environment. The shale passes gradationally again into a diverse fauna at the top which is normal marine. This strongly suggests that shoreline, located in Nebraska during the bulk of Ozawkie deposition, migrated southward to around the border of Shawnee and Osage Counties. North of shoreline, the Ozawkie was subaerially exposed. To the south was still submarine, but apparently the remaining basin was too restricted to allow influx of enough normal marine water, and freshwater runoff altered the water quality. Relative sea-level rise which marked the beginning of deposition of the

upper Ozawkie, restored normal marine conditions.

### Upper Ozawkie

In the southern area, the upper Ozawkie is a fine-grained packstone with abundant skeletal grains. Coated grains are rare. The upper Ozawkie likely represents deposition from a high energy, subtidal environment. Generally a lime mudstone with abundant rhizocasts caps the Ozawkie. Locally, poorly developed prismatic columns are discernible in the mudstone.

In the central area, the upper Ozawkie is generally a coated packstone to grainstone with abundant skeletal grains, ooids, cross-bedding, and local mud layers (Photo 11). The bulk of the upper Ozawkie represents deposition from an agitated, subtidal to intertidal environment. Pisoids or fining-upward sequences present at the base of the upper Ozawkie likely represent early deposition from a transgressing sea. The cross-bedding likely was created in tidal channels and the mud layers probably represent storm-deposits. Brecciation and jumling of the lower crust and abundance of fenestrae and rhizoliths/rhizocasts at JF5 (Photo 10) represent a supratidal to intertidal environment developed during this transgression. The top of the Ozawkie contains abundant rhizocasts and rhizoliths, laminated micrite crusts and clotted micrite, circumgranular cracking, and karstic cavities (Photos 12, 13). Prismatic columns commonly cap the Ozawkie Limestone in the central area (Photo 8).

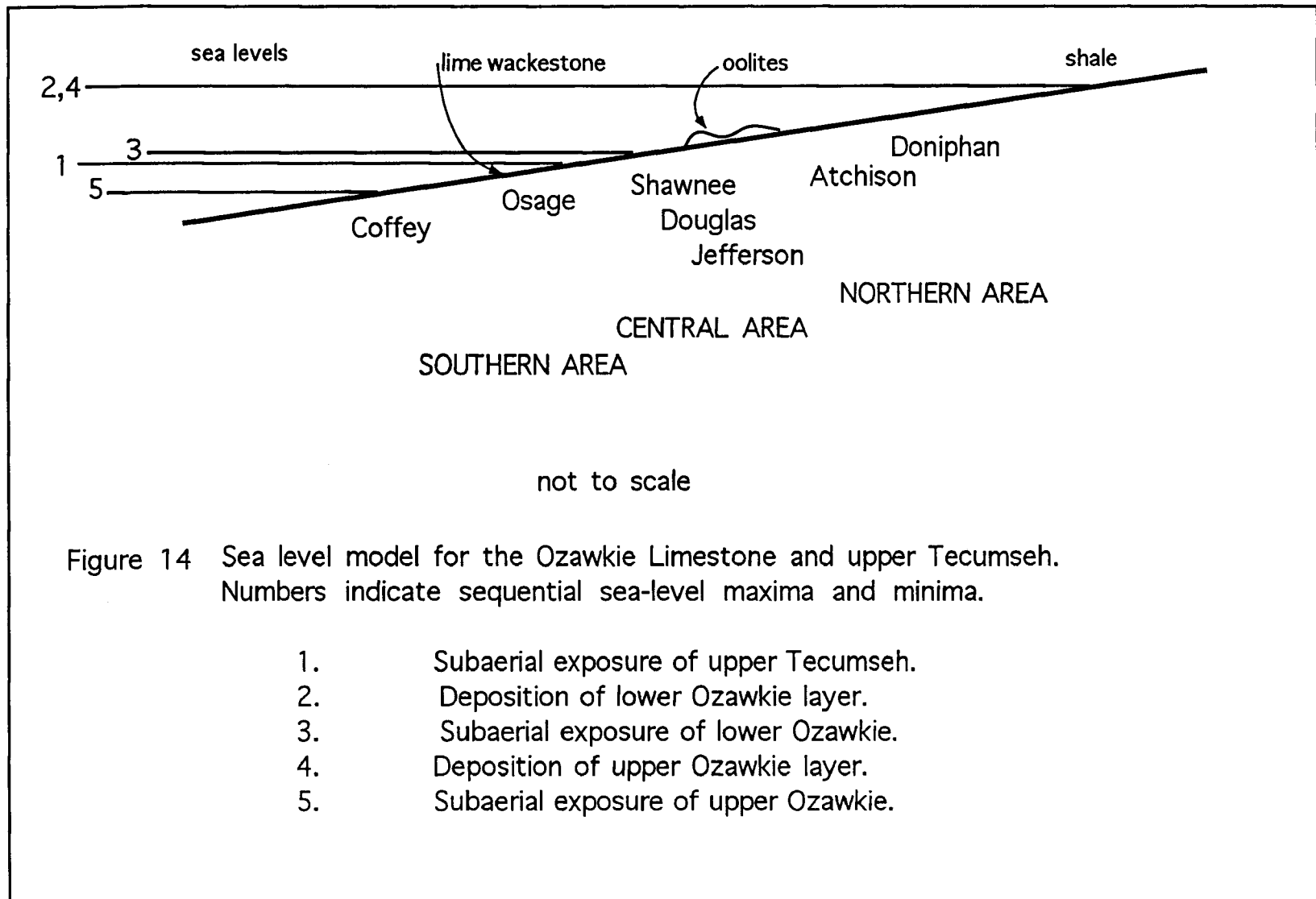
In the northern area, the upper Ozawkie is typically a peloidal wackestone to packstone. Rhizocasts, rhizoliths, circumgranular cracking, fenestrae, and poorly developed columns, are common. Brachiopod lenses and burrows are present at the base of the upper layer. The upper Ozawkie likely represents deposition from a shallow subtidal environment initially, and later deposition from an intertidal to supratidal environment. At isolated locales, the Ozawkie is

absent. It is likely that the Ozawkie was eroded away either during subaerial exposure following deposition, or channels developed during deposition of the Oskaloosa removed it.

In cores, the base of the upper Ozawkie typically contains large, asymmetrically-coated pisoids, and grades upwards into a fine-grained skeletal wackestone to packstone. The top of the Ozawkie also contains pisoids and abundant foraminifera. Karstic cavities or rhizocasts, filled with green shale from above, extend throughout the upper Ozawkie. Brecciation porosity, rhizoliths and rhizocasts, clotted micrite, and circumgranular cracks are also common. The top of the Ozawkie is typically autobrecciated and nodules of the Ozawkie are incorporated into the overlying, slickensided green shale. The base of the upper Ozawkie records a very shallow, restricted environment of deposition during a transgressing sea. The bulk of the upper Ozawkie represents deposition from a relatively quiet, subtidal environment. The top of the Ozawkie has characteristics of deposition from shallow, quiet, restricted marine waters. Supratidal and intertidal features seem to be overprinted. This would suggest that relative sea-level fell and subsequent subaerial exposure occurred, as opposed to an autocyclic build-up to sea level.

The upper unit of the Ozawkie follows the general trend of shallowing from south to north. The proposed depositional environments of the upper Ozawkie are very similar to those proposed for the lower Ozawkie: subtidal in the southern region, agitated subtidal to perhaps intertidal in the central region, and intertidal to supratidal for the northern region and cores.

In summary, the Ozawkie Limestone was deposited from two cycles of transgression and regression (Fig. 14). During the first transgression, the southern area was a quiet subtidal environment, the central area was an agitated subtidal to intertidal environment, and the northern region and cores was an intertidal to supratidal environment. Sea-level then



relatively dropped. Based on lack of subaerial exposure criteria, the most likely location for shoreline during maximum regression is the northern part of the southern area, or somewhere in northern Osage to southern Shawnee County. During the second transgression, very similar depositional environments were established. The southern area was generally agitated subtidal, the central area was agitated shallow marine to intertidal, and the northern area was intertidal to supratidal. Relative sea-level fell following deposition and shoreline must have migrated south of Osage County, based on subaerial features capping the Ozawkie over the entire study area. By central Coffey County, Maples (oral comm. 1995) identified a clearly subtidal Ozawkie with no overprinted subaerial features. This suggests that the maximum extent of regression was somewhere in central Coffey County, Kansas. Subaerial features from the second exposure event are much more abundant and better developed than features from the first exposure event (the top of the lower Ozawkie). This suggests that the second exposure event was of greater duration than the first one.

This second exposure event is the beginning of deposition of the Oskaloosa Shale. In core, where modern weathering is absent, this relationship is more clear. The slickensided shale contains weathered but identifiable nodules of the upper Ozawkie. The upper Ozawkie was deposited, then subaerial features were overprinted, and finally the upper Ozawkie was weathered and incorporated into the slickensided shale. In the Geshner core, a carbonized rhizocast is preserved 0.5m above the slickensided shale, or a full 1.5m above what is coherent Ozawkie, further suggesting that the subaerial exposure was within the Oskaloosa. The well-developed prismatic columns noted in the central area are likely similar in origin. Marine fossils at the top of the Oskaloosa, immediately underlying the Rock Bluff Limestone, indicate that sea-level relatively rose

during the end of Oskaloosa time.

#### DIAGENESIS OF MISSOURIAN CYCLOTHEMS

For idealized Missourian cyclothems, Heckel (1983) postulated that general patterns of diagenesis can be predicted from the interpreted sea level history of cyclothems. Each limestone deposited in the cyclothem should experience a different order of diagenetic environments.

Transgressive limestones, the middle limestones, are characterized by overpacking of grains, neomorphism of originally unstable grains (ooids, green algae, and molluscs), and ferroan calcite and ferroan dolomite. This indicated movement from the marine phreatic zone into the deeper-burial connate zone with compaction occurring before much cementation. The core shales acted as "seals" and minimized the penetration of meteoric water into the middle limestone during diagenesis of the upper limestones.

Regressive limestones, the upper limestones, were characterized by early cement rims, large-scale leaching of unstable grains with common collapse of micrite envelopes, followed by pervasive cementation by ferroan calcite and ferroan dolomite. This indicated movement from the marine phreatic zone to meteoric waters. During the following transgression, deeper connate water from below would slowly move back into the upper limestone.

Railsback (1984) recognized five diagenetic zones in his study of a Missourian cyclothem (Dennis Formation). Diagenetic facies were based on varying degrees of preservation of unstable carbonate grains such as phylloid algae, ooids, and molluscs.

Facies A consisted of rocks where all originally unstable grains were lacking relict internal structure. Facies A was the uppermost portion of the upper limestone, was thickest to north closest to paleoshoreline, thinnest to the south, and was

interpreted to represent the rocks spending the most time in an unsaturated meteoric-phreatic and vadose environment.

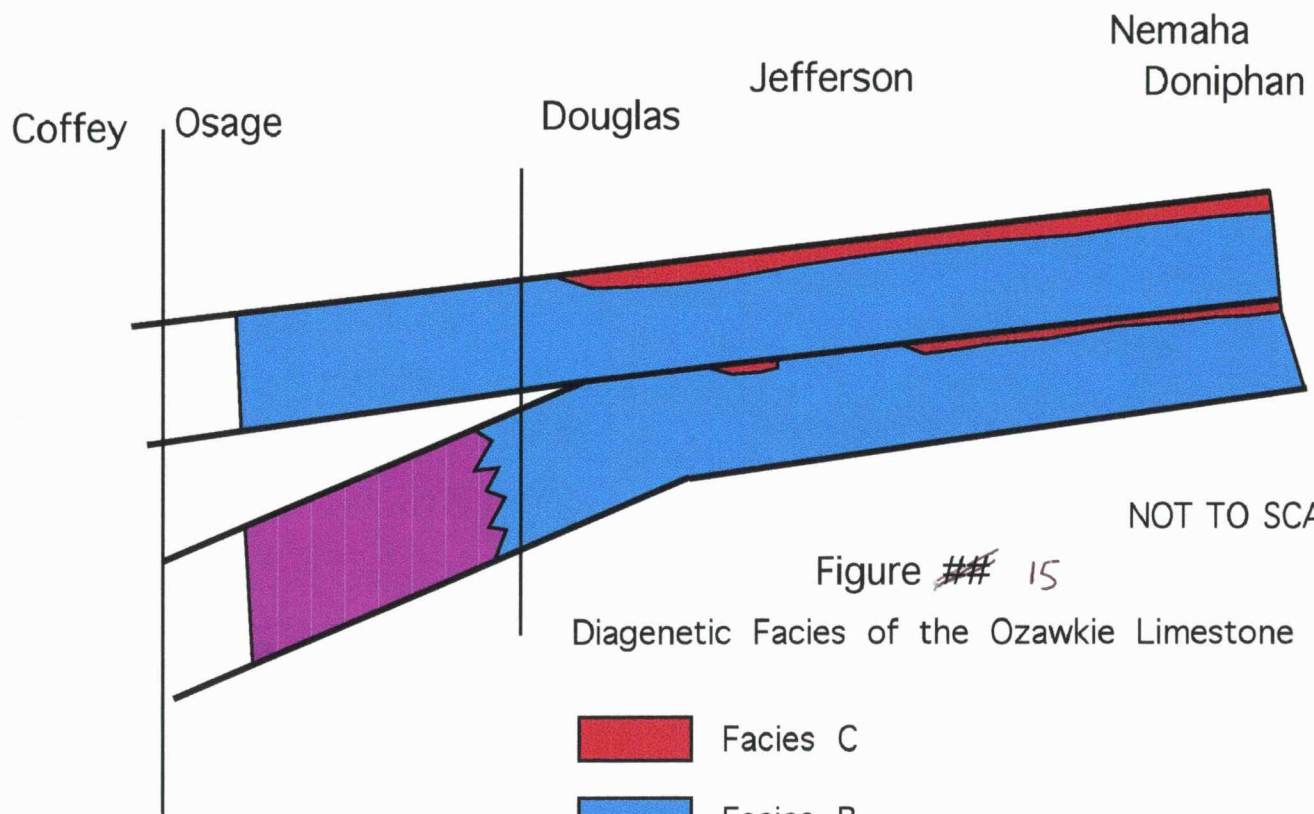
Facies B and C consisted of rocks with progressively more preservation of unstable grains. B and C were found below A, but above the base of the upper limestone, and were interpreted as rocks spending the most time in the unsaturated- and saturated-meteoric phreatic environments respectively.

Facies D consisted of rocks with unstable grains preserved with some internal structure, and a fitted fabric with many interpenetrating grain contacts. D was found at the southermost extent of the upper limestone and the entire middle limestone. Facies E consisted of rocks with mostly a microdolomite matrix with few unstable grains and crushed shells. E was found at the base of the upper limestone throughout all but the southermost part of the study. Both Facies E and D were interpreted as spending the most time in the stagnant, saturated marine-phreatic environment.

A comprehensive study has not been done on a Virgilian Cyclothem. It is likely that the diagenesis of the upper and middle limestones are similar to their Missourian counterparts (Fig. 3). Lower limestones, which have no Missourian equivalent, do not fit into this scheme.

## DIAGENETIC FEATURES OF THE OZAWKIE LIMESTONE

The Ozawkie Limestone can be roughly divided into three diagenetic facies based on the diagenetic environment which had the greatest impact (Fig. 15). These facies are differentiated by the types of porosity-occluding cements present, presence or absence of syntaxial overgrowths on echinoderm fragments, and on differing preservation of originally unstable aragonite grains such as phylloid algae and gastropods.



NOT TO SCALE

Figure ~~##~~ 15

Diagenetic Facies of the Ozawkie Limestone

- Facies C
- Facies B
- Facies A

Facies A is present in the lower Ozawkie in the southern region. Facies B is the bulk of both the lower and upper Ozawkie. Facies C is uppermost cap of the lower and upper Ozawkie.

#### Facies A

Facies A consists of those rocks where mostly equant cement occluded the pores, outlines of grains are heavily micritized, and some early compaction occurred.

Skeletal grains are mostly unbroken, but pellets preserved in burrows are slightly flattened and the mud matrix is mottled. Where in contact, skeletal grains are sutured.

Primary cement is only present as intraparticle porosity, most common in fusulinids. Echinoid grains do not display early syntaxial rims of cement. In very well preserved fusulinid chambers, typically in the central ones, PB Fe-rich calcite lines the chamber, otherwise PE Fe-rich calcite occludes the chamber. In some chambers, however, NE dolomite cement is present. NE dolomite is patchily present replacing the muddy matrix and may also have replaced shell material.

All original aragonite has been replaced. While preservation is poor, rare grains still show original texture, and micrite envelopes are unbroken, suggesting that slow replacement of aragonite occurred following early compaction.

#### Facies B

Facies B consists of those sediments with pore-reducing isopachous cements and later pore-occluding equant cement, general dissolution of originally unstable aragonite grains, and presence of early syntaxial rims. Coarse grainstones and packstones, with abundant and large interparticle spaces, allowed for the best examination of the diagenetic sequence.

Uncoated echinoid grains typically have early cement

syntaxial, Fe-rich calcite rims. Otherwise, the initial primary cement is PB calcite lining the grains. The blades are typically terminated crystals of calcite, but display several different compositional zones as revealed by staining with Alizarin Red S and potassium ferricyanide (Photo 14). Around echinoid grains, Fe-rich cement is apparent, otherwise an Fe-rich calcite base ranges from continuous to rarely present. A growth band of Fe-poor calcite syntaxially overgrows the Fe-rich base and is continuous. Spectacular samples may show a second band of Fe-rich calcite (Photo 15). A continuous band of Fe-rich calcite comprises the rest of the isopachous rim.

In about one quarter of the thin sections from this facies, bladed dolomite with common pyrite inclusions overgrows the calcite. When pore space is limited, this dolomite band may have occluded the pore.

After the isopachous rim precipitated, originally unstable grains such as ooids, mollusk shell fragments, and phylloid algae grains were dissolved. Most previous structure is gone, suggesting that the aragonite was leached away leaving a mold rather than being slowly replaced. The best example of this is in Photo 7 where later green shale filtered down and reduced the mold of a gastropod. Ooids may have some structure intact indicating that both processes, dissolution and replacement occurred.

PE Fe-rich calcite generally occludes the remaining pore space with patchily present NE rhombic dolomite. Rare locations have dolomite occluding the pore space.

### Facies C

Facies C consists of those rocks which show features such as laminated micrite crusts, clotted micrite, rhizocasts and rhizoliths, karst holes, and circumgranular cracks. Facies C is typically confined to the uppermost centimeters of the two units of the Ozawkie.

The crusts range from mm's to cm's thick, are comprised of wavy laminations of micrite, and generally thicken into local lows and thin around highs. Crusts commonly cut into underlying lithology, may overhang edges, and several generations of crust may be present. Clotted micrite is commonly found in the crust too. Circumgranular cracks around grains, now occluded, are commonly found in the upper few centimeters underlying a micrite crust.

Rhizocasts are generally 1mm in thickness and several cm's long. Micrite aureoles surround what was a hollow tube, but is now occluded by spar. Some locations have isopachous rims of calcite in the casts before occlusion. When found associated with crusts, rhizocasts are found in the crust and extend into the underlying lithology. Rhizolith preservation varies from carbonized traces defining a tube, to pyrite-filled tubes with micrite aureoles.

#### DIAGENESIS OF THE OZAWKIE LIMESTONE

In summary, Facies A is dominated by Fe-rich calcite and NE dolomite, has undergone slight compaction, and echinoderm grains do not have syntaxial overgrowths. Facies B displays isopachous rims of compositionally-zoned calcite and rare dolomite, Fe-rich calcite or dolomite pore-occluding cement, aragonite has been leached and/or replaced, and echinoderm grains have syntaxial overgrowths. Facies C is characterized by features such as rhizocasts, laminated micrite crusts, and clotted micrite.

Longman (1980), in a summary paper, proposed criterion for recognition of different nearsurface diagenetic environments. The marine phreatic environment is recognized by lack of leaching of grains, isopachous fibrous aragonite or Mg-rich calcite cements, polygonal boundaries between isopachous cements, and no syntaxial overgrowths on echinoderms. The freshwater phreatic environment is

characterized by leaching of originally aragonite grains and replacement by equant calcite, isopachous bladed calcite, and syntaxial overgrowths on echinoderms.

Facies A most likely represents sediments where the marine phreatic diagenetic environment exerted the greatest influence. While slight compaction clearly occurred early, stylotized grain boundaries against mud suggests some early cementation. The mud was at least semi-lithified before compaction.

Facies B represents sediments that were influenced the most by the freshwater phreatic environment. The local distribution of Fe-poor calcite in otherwise isopachous calcite rims, and very rare meniscus (?) cements indicate that some time elapsed in the freshwater-vadose zone, where the pores were not completely filled with water. The presence of compositional zones of calcite, plus dolomite with pyrite, suggests that pore-fluid chemistry was subject to relatively rapid changes.

Facies C displays features formed in the freshwater-vadose environment usually associated with subaerial exposure, and were created in two different situations. The first situation is that the subaerial features are approximately synchronous with deposition. This situation can be recognized by features such as fenestrae and rhizocasts being coincident with grain boundaries and bedding, implying that the sediments were not yet lithified. The second situation is that subaerial features are later in the diagenetic history, and cut into underlying lithology and diagenetic facies. In these cases, rhizocasts and micrite crusts cut indiscriminately across grains, matrix, and any previous cements. When subaerial exposure occurred, syndepositional or post-depositional, is local in nature.

## IMPLICATIONS OF DIAGENESIS

The diagenesis of the Ozawkie is consistent with the sea-level history interpreted from depositional features, and has further implications for diagenetic models of Virgilian Cyclothems.

Certain locations in the central and northern areas show where facies C cuts into facies B. If sea-level relatively dropped, it would be expected that freshwater-vadose features would cut into or form over freshwater-phreatic features. The lower layer in the southern area was dominated by the marine phreatic zone, whereas the upper layer shows freshwater-phreatic dominance. That is consistent with the idea that the regression which followed deposition of the lower Ozawkie was less extensive than the regression which accompanied deposition of the upper Ozawkie.

The Ozawkie limestone seems to incorporate diagenetic features from both middle (transgressive) limestones and upper (regressive) limestones of cyclothem models.

Railsback's study showed that both sea-level history and paleotopography play a role in diagenesis of upper limestones. Topographically-higher parts experience greater influence of meteoric water than topographically-lower parts. Middle limestones were affected mostly by sea-level history. This is logical because the sea level is at the relative highest stand for a long period of the cyclothem deposition, hence all the middle limestone is under marine waters.

In the Ozawkie, part of the lower unit was never subjected to freshwater, and diagenetically resembles a middle limestone. If the diagenetic aspect of this study had been extended further south into Coffey County, Kansas, it is likely that some of the upper layer would resemble a middle limestone diagenetically too. The remainder of the Ozawkie diagenetically resembles an upper limestone. Freshwater exerted the greatest diagenetic influence, and the extent and abundance of subaerial features suggest that

paleotopographically-higher parts were to the north.

In this regard, lower limestones can be considered a mini-cyclothem unto themselves.

### CONCLUSIONS

- 1) Both layers of the Ozawkie Limestone member of the Deer Creek Formation generally represent northward-shallowing depositional environments: quiet, subtidal environments in the southern region; active, shallow environments in the central area; and semi-restricted, shallow to supratidal environments in the northern area.
- 2) The Ozawkie was deposited from a series of two transgressions and regressions. Regression following deposition of the lower layer moved shoreline into northern Osage County, Kansas. The post-Ozawkie regression likely moved the shoreline south of the study area.
- 3) During maximum sea-level regressions, the Ozawkie Limestone was subaerially exposed in the central and northern areas leading to creation of subaerial features such as laminated micrite crusts, rhizocasts and rhizoliths, prismatic columns, sheetcracks, clotted micrite, and karstic cavities. Subaerial features capping the lower layer of the Ozawkie are less developed and less extensive areally than features capping the upper layer, supporting that the first regression was less extensive and of shorter duration than the second regression.
- 4) Three diagenetic facies are identified in the Ozawkie. Facies A, found in the lower layer in the southern part of the study, represents sediments which were influenced the most by marine phreatic water. Facies B, the remaining bulk of the lower and upper Ozawkie, represents sediments where

the freshwater phreatic zone exerted the greatest diagenetic influence. Facies C, the uppermost centimeters of each of the Ozawkie's layers, represents sediments which were influenced the most by the freshwater vadoze zone.

The Ozawkie incorporates diagenetic features of both middle and upper limestones in Heckel's (1980) and Railsback's (1983) diagenetic schemes for cyclothems. The Ozawkie, in this case, diagenetically resembles a complete mini-cyclothem.

- 5) Subaerial exposure also occurred near the top of the Tecumseh Shale. Where the base of the Ozawkie is erosive, the subaerial exposure in the Tecumseh is in contact (or possibly eroded away) with the base of the Ozawkie. Otherwise, up to 3 meters of shale may be between them.

## ACKNOWLEDGMENTS

I would like to thank my advisors, Paul Enos, Bob Goldstein, and Ernie Angino, for reviewing this project and making many great suggestions for improvement, both of the text and the science. I also need to thank the Panorama Society of the KU Museum of Natural History and the Kansas Geological Foundation for financial support during the field work portion of this project. The Kansas Geological Survey has also been invaluable in allowing me to utilize their equipment, access to cores and work space, the well log library, and archived stratigraphic sections.

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## APPENDIX A. Location of outcrops

Locality JF 1 : NW 1/4, SW 1/4, sec 32, T10S, R19E.

Oskaloosa 7.5'

Exposed along east and west side of HWY 59, 5 miles north of Williamston, KS.

Locality JF 2 : SW 1/4, SE 1/4, sec 3, T10S, R18E. Ozawkie 7.5'

Exposed on west side of road, just south of old school.

Locality AT 3 : NE 1/4, NE 1/4, sec 14, T5S, R20E. Atchison West 7.5'

Poorly exposed along east and west sides of HWY 7, about 3.6 miles north of Atchison, KS, or 2.1 miles south of the Doniphan County line.

Locality JF 4 : SW 1/4, SW 1/4, sec 21, T9S, R 19E.

Oskaloosa 7.5'

Exposed along east and west sides of HWY 59, 1.9 miles north of Oskaloosa (Junction HWY 92), KS, or just north of intersection of HWY 59 and County Road 404.

Locality JF 5 : NE 1/4, NE 1/4, sec 31, T9S, R18E. Ozawkie 7.5'

Exposed only along north side of HWY 92, just east of Perry Reservoir. Likely the type section of the Ozawkie Limestone.

Locality JF 6 : NE 1/4, SE 1/4, sec 10, T10S, R18E.

Ozawkie 7.5'

Tecumseh and Ozawkie poorly exposed along east side of road. Rock Bluff, Larsh-Burroak, and Ervine Creek in ditch.

Locality DG 7 : SW 1/4, SE 1/4, sec 26, T12S, R17E. Clinton  
7.5'

Exposed along north and south sides of County Road  
442 at a sharp bend to the north, 1.8 miles west of  
Stull, KS.

Locality SH 8 : SE 1/4, SE 1/4, sec 22, T12S, R17E.  
Richland 7.5'

Poorly exposed along north and south sides of County  
Road 442, 3.7 miles west of Stull, KS.

Locality DG 9 : SW 1/4, NW 1/4, sec 1, T13S, R17E.  
Poorly exposed on east side of road.

Locality DG 10 : SW 1/4 SW 1/4, sec 29, T12S, R18E.  
Clinton 7.5'

Exposure of Lecompton Limestone on north and south  
sides of County Road 442, 0.6 miles east of Stull, KS.

Locality OS 11 : SW 1/4, SW 1/4, NE 1/4, sec 7, T16S,  
R16E. Lyndon NW 7.5'

Exposed along east and west sides and underneath  
bridge along service road of US 75 at Carbolyn State  
Park.

Locality DG 12 : NW 1/4, NW 1/4, sec 22, T12S, R18 E.  
Perry 7.5'

Exposed along north and south sides of I-70,  
approximately 8 miles west of the West Lawrence  
Interchange.

Locality SH 13 : NW 1/4, NE 1/4, sec 34, T12S, R17E.  
Richland 7.5'

Exposed along north and south side of road.

Locality SH 14 : SE 1/4, SE 1/4, sec 33, T12S, R17E.  
Richland 7.5'

Poorly exposed on south side of road.

- Locality SH 15 : NW 1/4, NW 1/4, sec 3, T13S, R17E.  
Richland 7.5'  
Very poorly exposed in ditch along east side of road.
- Locality DG 16 : SE 1/4, sec 32, T11S, R18E. Perry 7.5'  
Exposed along north and south sides of road  
approximately 2.9 miles west of Lecompton.
- Locality JF 17 : NE 1/4, NE 1/4, sec 10, T11S, R18E. Perry  
7.5'  
Ozawkie Limestone exposed along south side of road.  
Rock Bluff, Larsh- Burroak, and Ervine Creek only  
exposed in ditch.
- Locality JF 18 : S1/2, sec 28, T10S, R18E. Ozawkie 7.5'  
Exposed along west side and in the dead end road. If  
conditions are wet, consider parking off paved road  
and walking. Very poorly maintained road.
- Locality JF 19 : SW 1/4, SE 1/4, sec 33, T9S, R18E.  
Ozawkie 7.5'  
Exposed along north and south sides of road. Further  
up the hill is an exposure of the Topeka Limestone.
- Locality JF 20 : SE 1/4, NE 1/4, sec 3, T11S, R18E.  
Exposed along west and east sides of road.
- Locality JF 21 : SE 1/4, SE 1/4, sec 7, T11S, R18E. Perry  
7.5'  
Poorly exposed in road and ditch on east and west side  
of road.
- Locality JF 22 : NW 1/4, NW 1/4, sec 25, T10S, R17E.  
Ozawkie 7.5'  
Poorly exposed along northwest side of road north of  
marina, and on north side of road leading into  
Delaware State Park.

Locality OS 23 : NE 1/4, NE 1/4, sec 9, T14S, R17E.

Overbrook 7.5'

Exposed on west side of road.

Locality OS 24 : Center, sec 13, T14S, R16E. Overbrook 7.5'

Exposed along north and south side of road.

Locality DN 25 : Center, sec 34, T2S, R20E. Doniphan County

Map

Poorly exposed on road leading uphill east of Fanning,  
just east of HWY 7.

Locality SH 26 : NE 1/4, NE 1/4, SW 1/4, sec 16, T13S,  
R17E.

Poorly exposed on west side of asphalt road. Rock  
Bluff is not exposed. Ervine Creek is exposed  
approximately 1/2 mile to the north.

Locality SH 27 : NW 1/4, NW 1/4, NW 1/4, sec 16, T13S,  
R17E.

Poorly exposed on east side of road.

Locality SH 28 : SE 1/4, SE 1/4, SE 1/4, sec 7, T13S, R16E.

Ozawkie is well exposed on north and south sides of  
road. Other units only exposed on north side of road.  
Tecumseh is covered underneath the Ozawkie, but  
exposed in the creek below.

Locality SH 29 : NW 1/4, NW 1/4, NE 1/4, sec 28, T13S,  
R16E.

Exposed in creek on south side of asphalt road.

Locality SH 30 : NE 1/4, NE 1/4, NE 1/4, sec 28, T13S, R16E.

Ozawkie is very well exposed on west side of road.

Locality AT 31 : Center, W 1/2, sec 36, T6S, R20E.

Exposed along north side of road near powerline. Base  
of Lecompton Limestone very well exposed in creek  
immediately to the south.

Locality AT 32 : NW 1/4, SE 1/4, sec 24, T6S, R20E.

Ozawkie and upper Tecumseh exposed along east side of HWY 73. Ozawkie total thickness is 85 cm.

80-85 lime mudstone with rhizocasts and caliche nodules.

50-80 fine coated packstone

10-50 fine coated grainstone to packstone with brachiopods

0-10 muddy, coated packstone

Locality AT 33 : SW 1/4, SW 1/4, sec 11, T5S, R20E.

Very poorly exposed on west side of road. Rock Bluff is represented in float only. The Ervine Creek is exposed at the top of a rise approximately 1/4 mile to the north.

Ozawkie very weathered, 155 cm thick total.

75-155 massive bed

40-75 wavy bedded

0-40 massive bed

Ozawkie likely originally a packstone.

Locality AT 34A : NW 1/4, NW 1/4, sec 8, T7S, R20E.

Poorly exposed on south side of paved road.

2+ meters of Ervine Creek. Base is very flat, otherwise wavy bedded.

1.4 meters of Larsh Burroak. Float of black shale.

40 cm of Rock Bluff

No Ozawkie present, but suggestive float.

Locality AT 34B : SE 1/4, NW 1/4, sec 16, T7S, R20E.

North of bend of paved road. Ervine Creek poorly exposed on south side of road.


Across a cow fence, in a small stream cut valley there is about 1.5 meters of Ervine Creek exposed before cover. Beneath the Ervine Creek is a second bench with exposure of the Rock Bluff Limestone. About 2 meters below the Rock Bluff bench is a break in slope, but no exposure of limestone.

- Locality AT 35 : SE 1/4, SW 1/4, sec 3, T7S, R20E.  
Exposed on north and south side of road.  
2+meters of Ervine Creek  
1.6 meters of cover (Larsh Burroak)  
40 cm of Rock Bluff  
Ozawkie absent
- Locality SH 36 : NE 1/4, NE 1/4, NE 1/4, sec 34, T13S, R16E.  
Exposed along south side of steeply sloping road.  
Exposure is especially poor at base of slope with some slumping.
- Locality SH 37 : NW 1/4, NW 1/4, NW 1/4, sec 36, T13S, R16E.  
Very well exposed along south and north side of country road. South side scheduled for demolition in summer of 1997 to prevent rock falls onto road.
- Locality SH 38 : SE 1/4, NE 1/4, sec 35, T13S, R16E.  
Poorly exposed on west side of road and along creek bank.
- Locality DN 39 : NW 1/4, NE 1/4, sec 27, T4S, R20E.  
Exposed on north side of road on bend west of small country church.
- Locality DN 40 : SE 1/4, SW 1/4, sec 7, T4S, R20E.  
Very poorly exposed on south side of road (liberal definition of road applied here, though under active reconstruction). Ervine Creek is exposed at top of hill. No exposure of Rock Bluff present. Ozawkie is present as float. Overturned boulders suggest that the Ozawkie is 70 cm thick here.
- Locality HQ: Hamm Quarry NW 1/4, sec 15, T11S, R17E.  
East side and north side of abandoned pit. Salty trucks beware: rumor has it that horses in pit like to lick the paint on vehicles.

Locality MMQ: Martin Marietta Aggregates SW 1/4, sec 26,  
T12S, R17E.  
Examined in north section of western pit. Entire Deer  
Creek should be available in either west pit or east pit at  
most times.

# SYMBOLS FOR SECTIONS

## SEDIMENTARY STRUCTURES



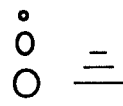
burrow



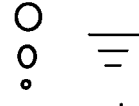
fenestra



geopetal




fining-upward



coarsening-upward



cross-bedding



cross-bedded silt with clay drapes





laminated silt/clay



channel-form

## DIAGENETIC FEATURES

root cast or rhizolith      crusted clast

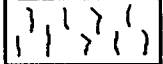


stylolite




laminated micrite crust


## LITHOLOGIC




slickensided shale




calcareous shale



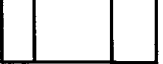
shale




black fissile shale




siltstone



limestone

























brecciation









prismatic columns

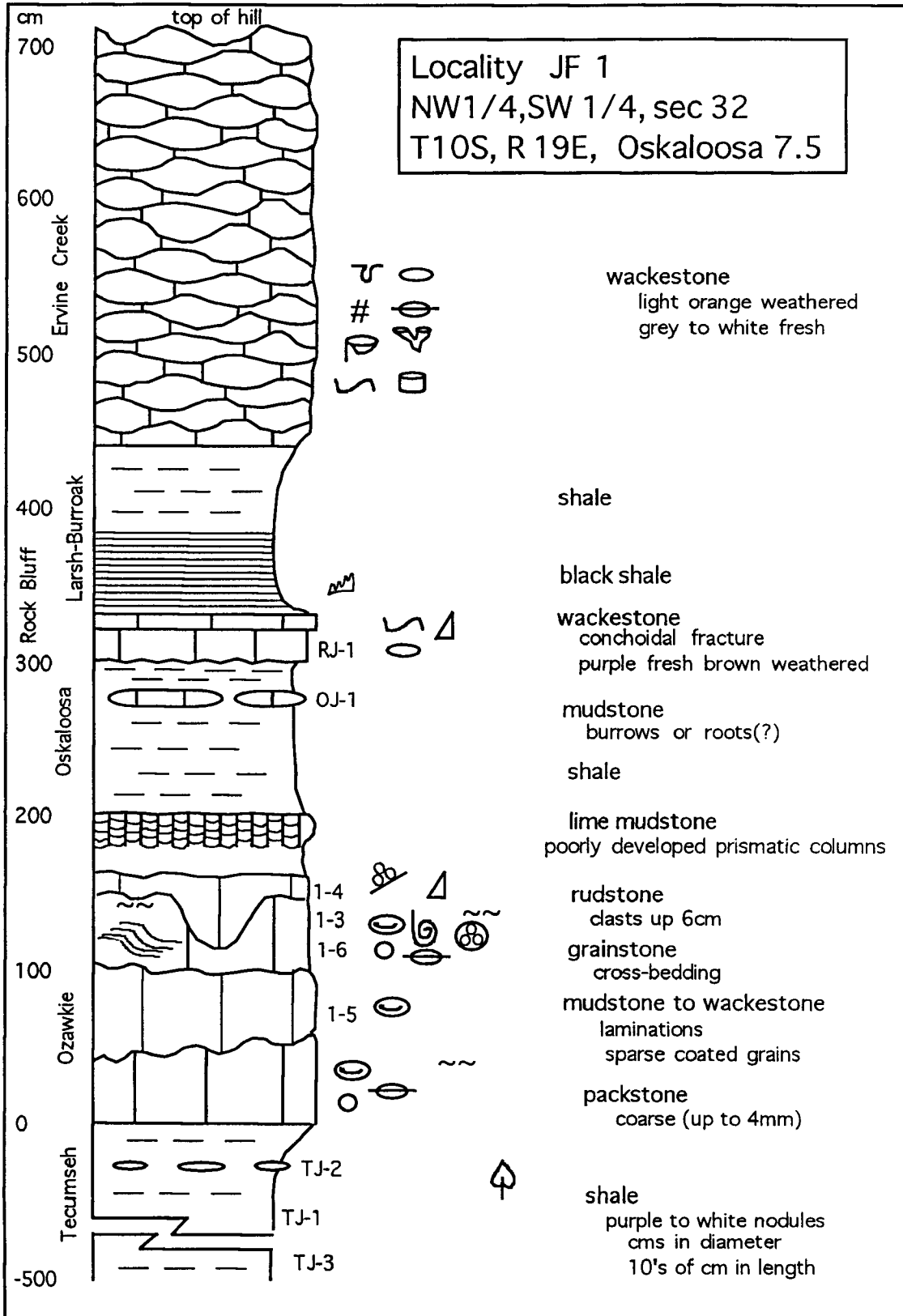
# SYMBOLS USED

## FOSSILS

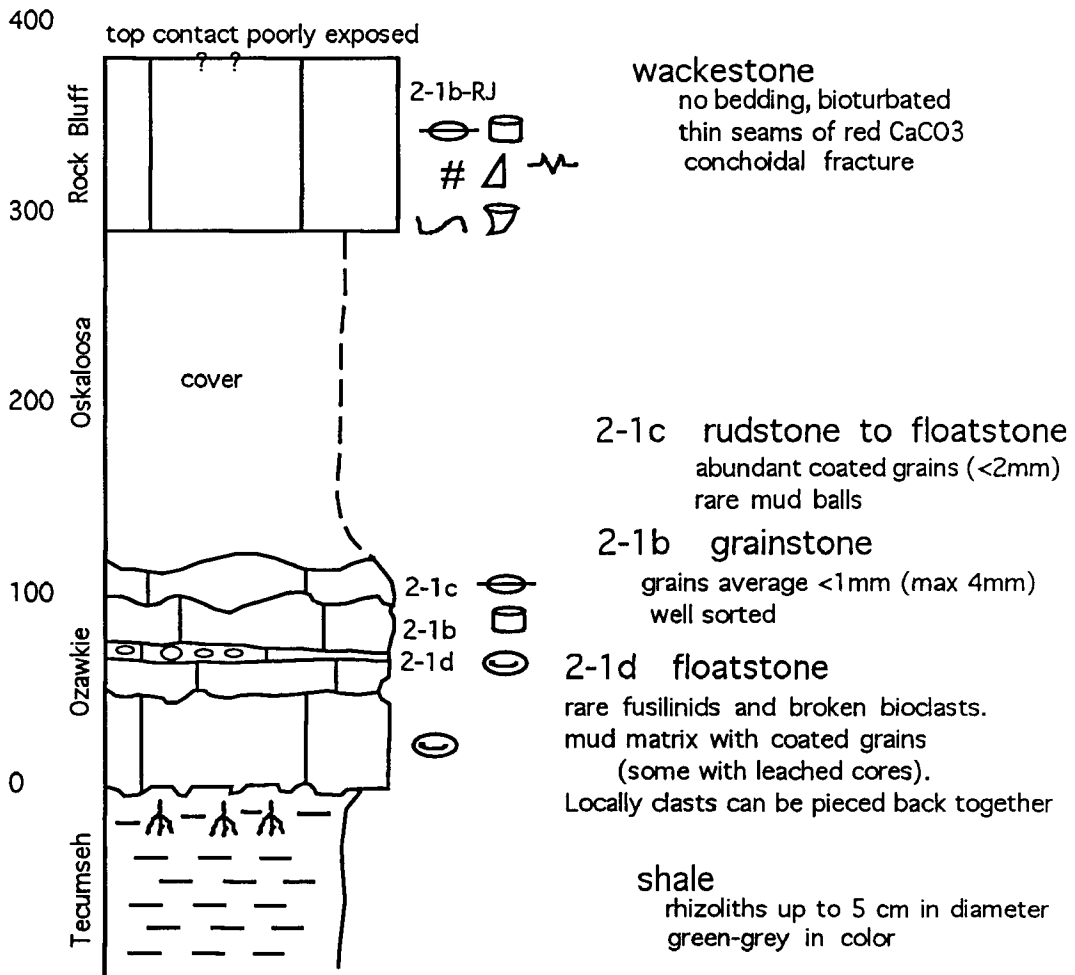
 plant fragments	 general shell fragments	 brachiopod	 fenestrate bryozoan	 ramose bryozoan
 encrusting bryozoan	 coral	 gastropod	 fusulinid	 coiled foram
 biserial foram	 crinoid	 echinoid spine	 echinoid	 sponge
 trilobite	 ostracode	 encruster	 <i>Osagia</i>	 phylloid alga
 conodont				 algae general

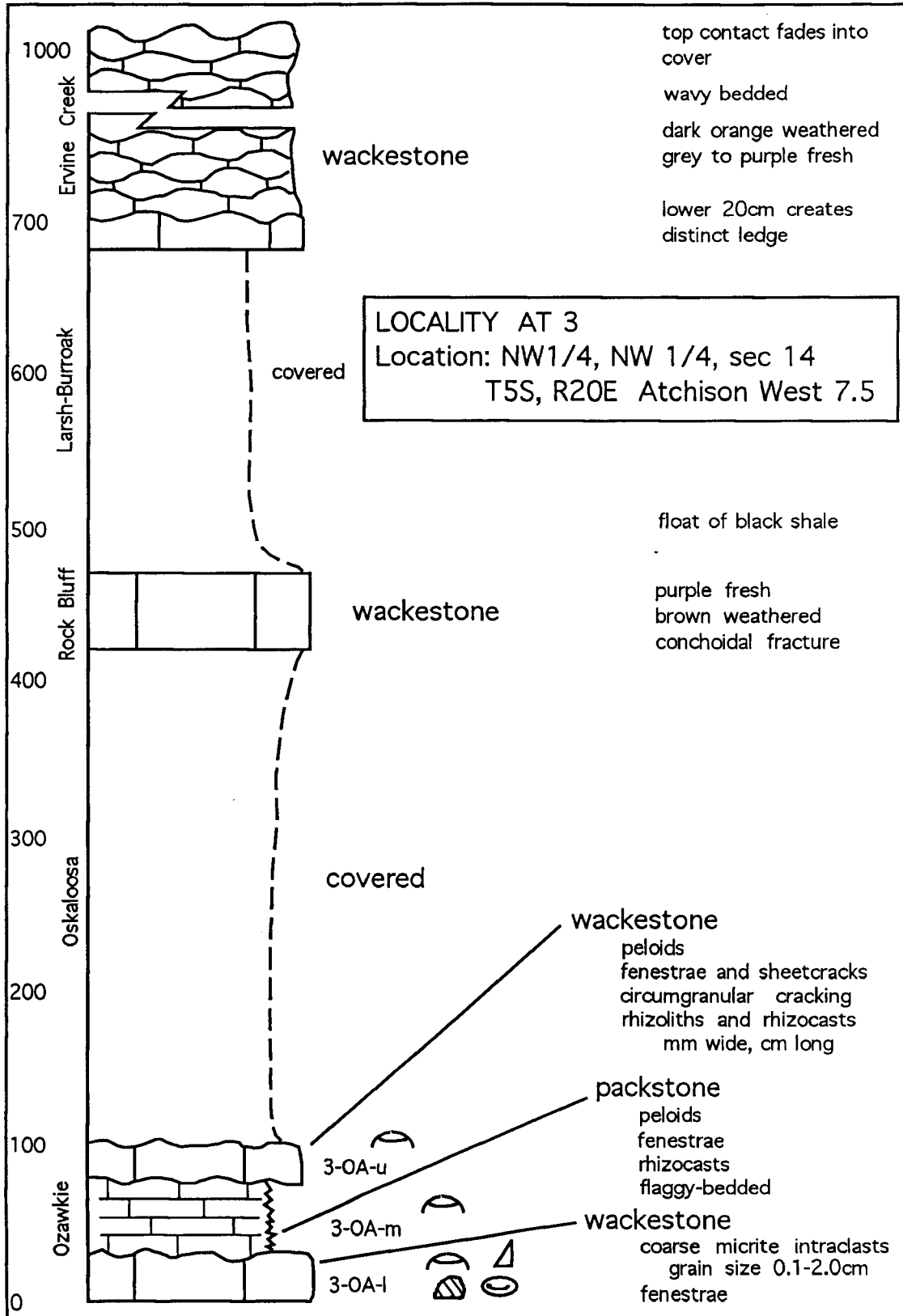
## PARTICLES

 oncolite	 intraclast	 ooid	 coated grain	 peloid	 pisoid
---	---	---	---	---	---

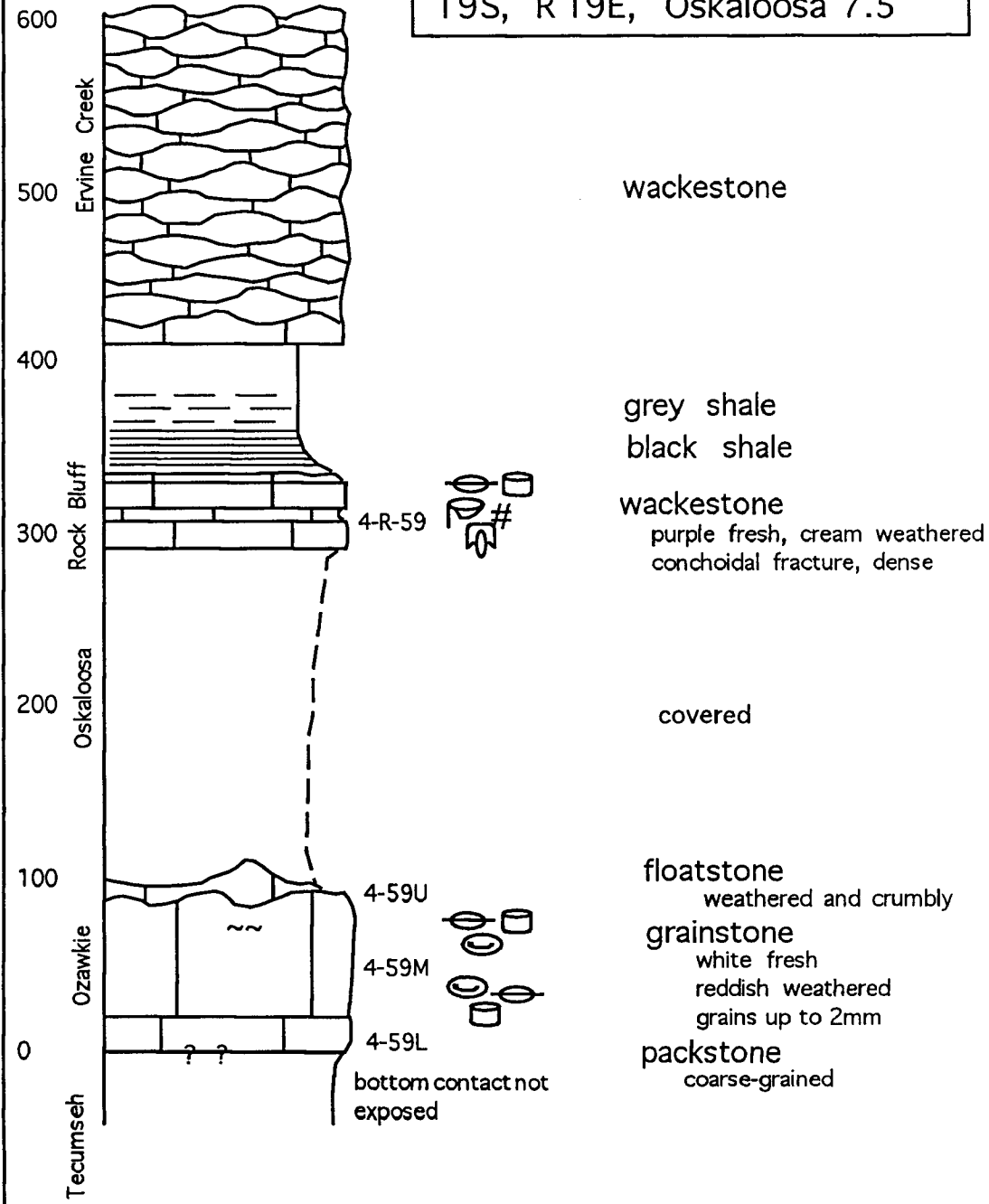


LOCALITY JF 2  
 SW1/4, SE 1/4, sec 3  
 T10S, R18E, Ozawkie 7.5

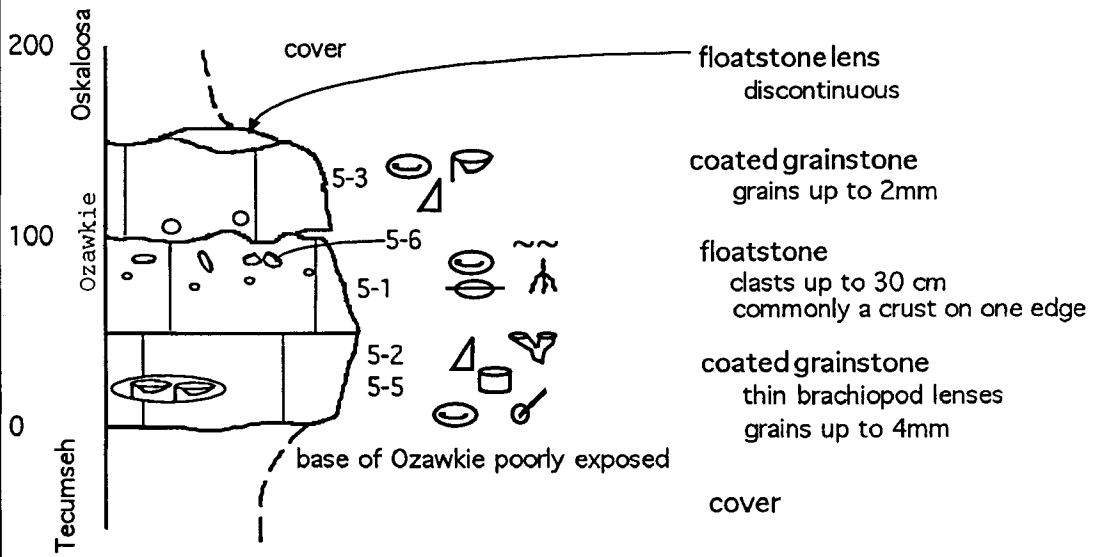




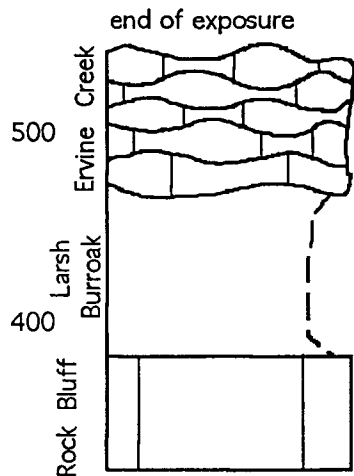
LOCALITY JF 4  
 NE 1/4, NE 1/4, sec 29  
 T9S, R 19E, Oskaloosa 7.5



LOCALITY JF 5  
 NE 1/16 - sec 31  
 T9S - R 18E



LOCALITY JF 6  
 1/4 NE - 1/4 SE  
 sec 10 - T10S - R 18E



wackestone to packstone

covered

wackestone

exposed only in east ditch of road

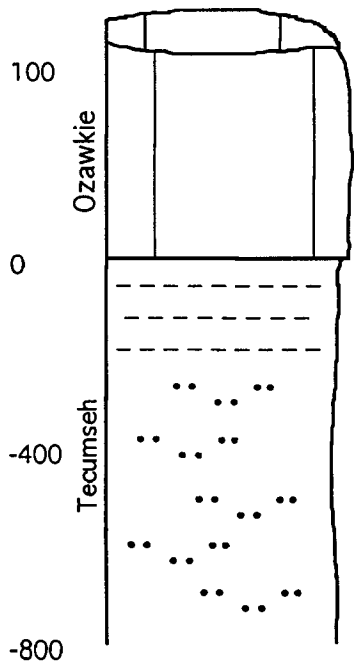
300

Oskalboosa  
 ?  
 (thickness unknown due to slumping)

covered

best guess for thickness is less than 200 cm, based on an older outcrop description

200



floatstone

massive and deeply weathered

coated grainstone

Neither the top nor bottom contacts are exposed well

100

0

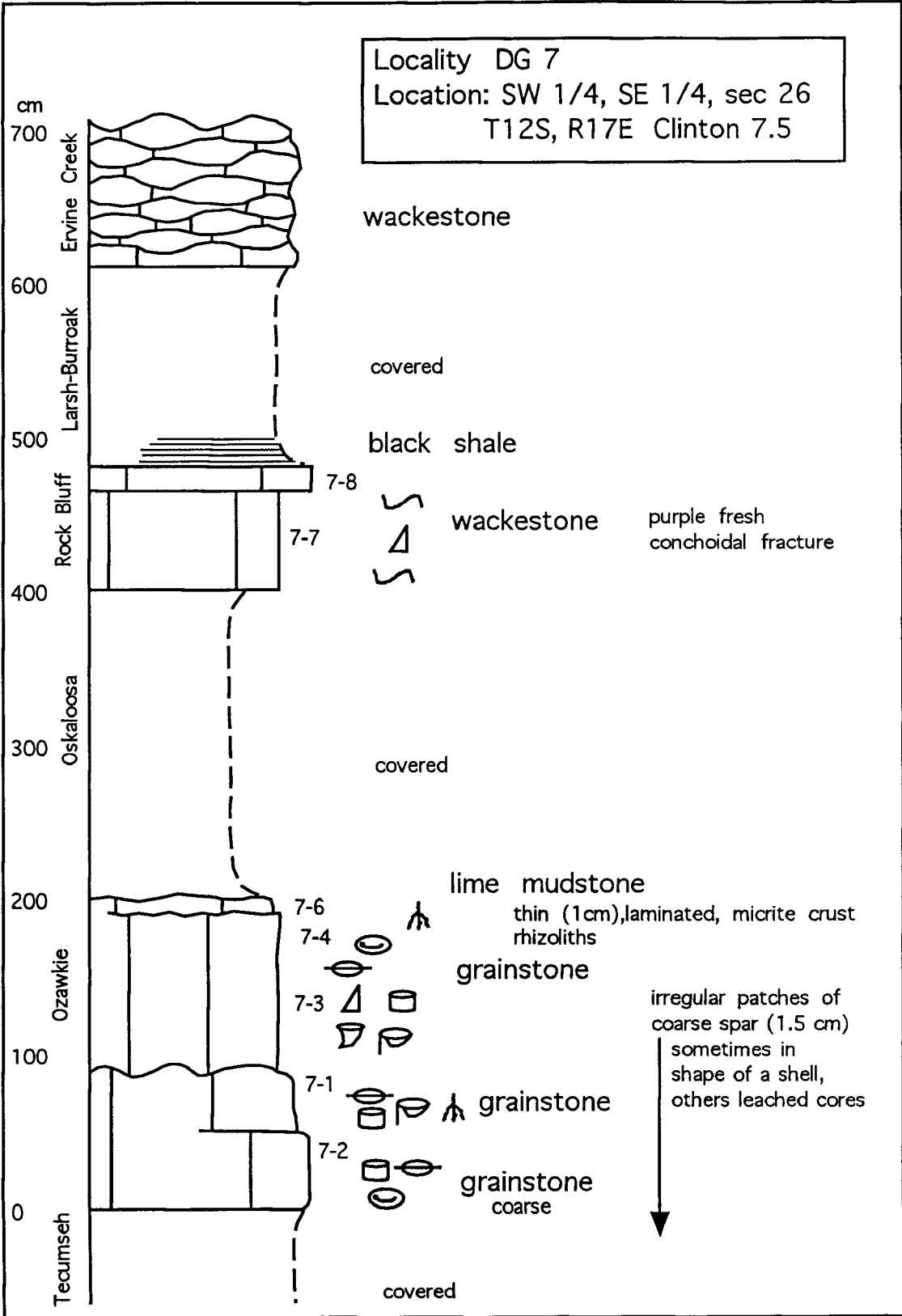
grey shale

-400

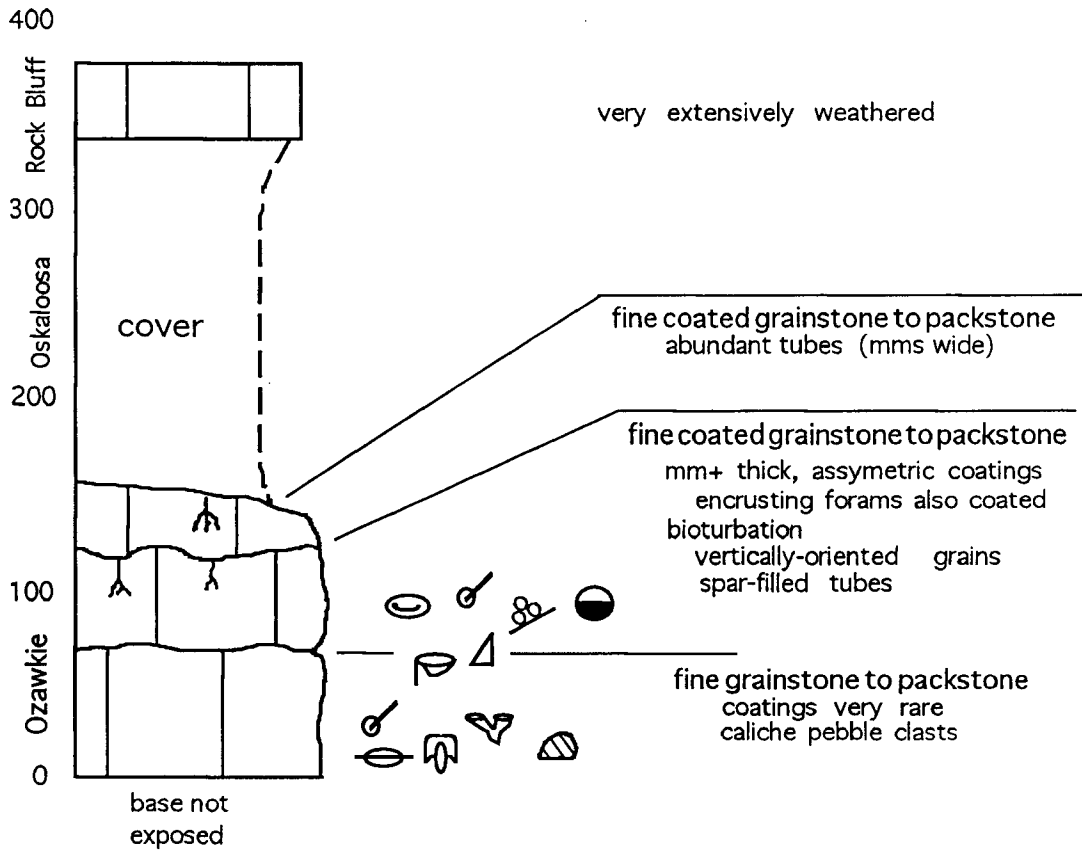
siltstone to fine sandstone

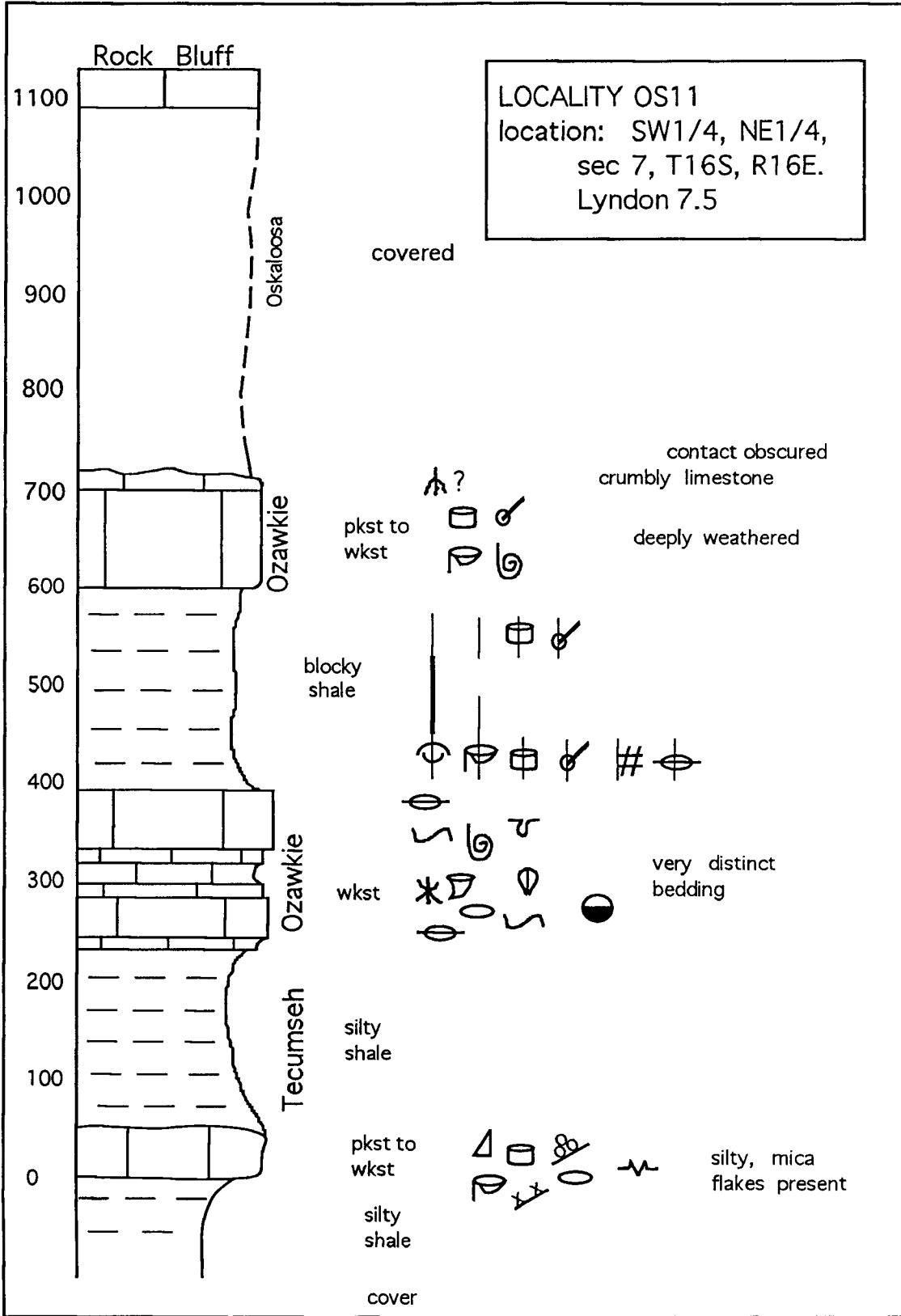
-800

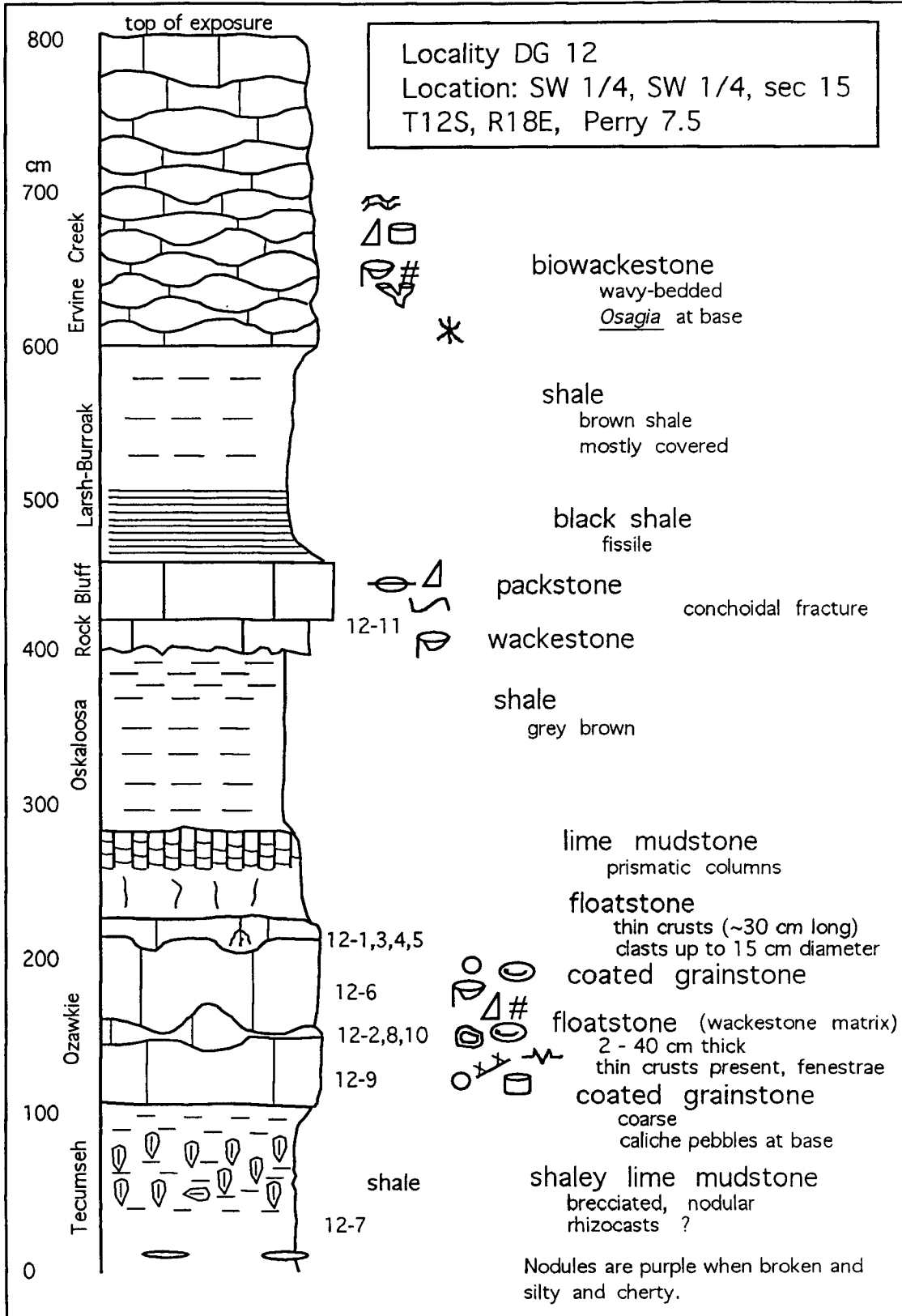
Locality DG 7  
 Location: SW 1/4, SE 1/4, sec 26  
 T12S, R17E Clinton 7.5

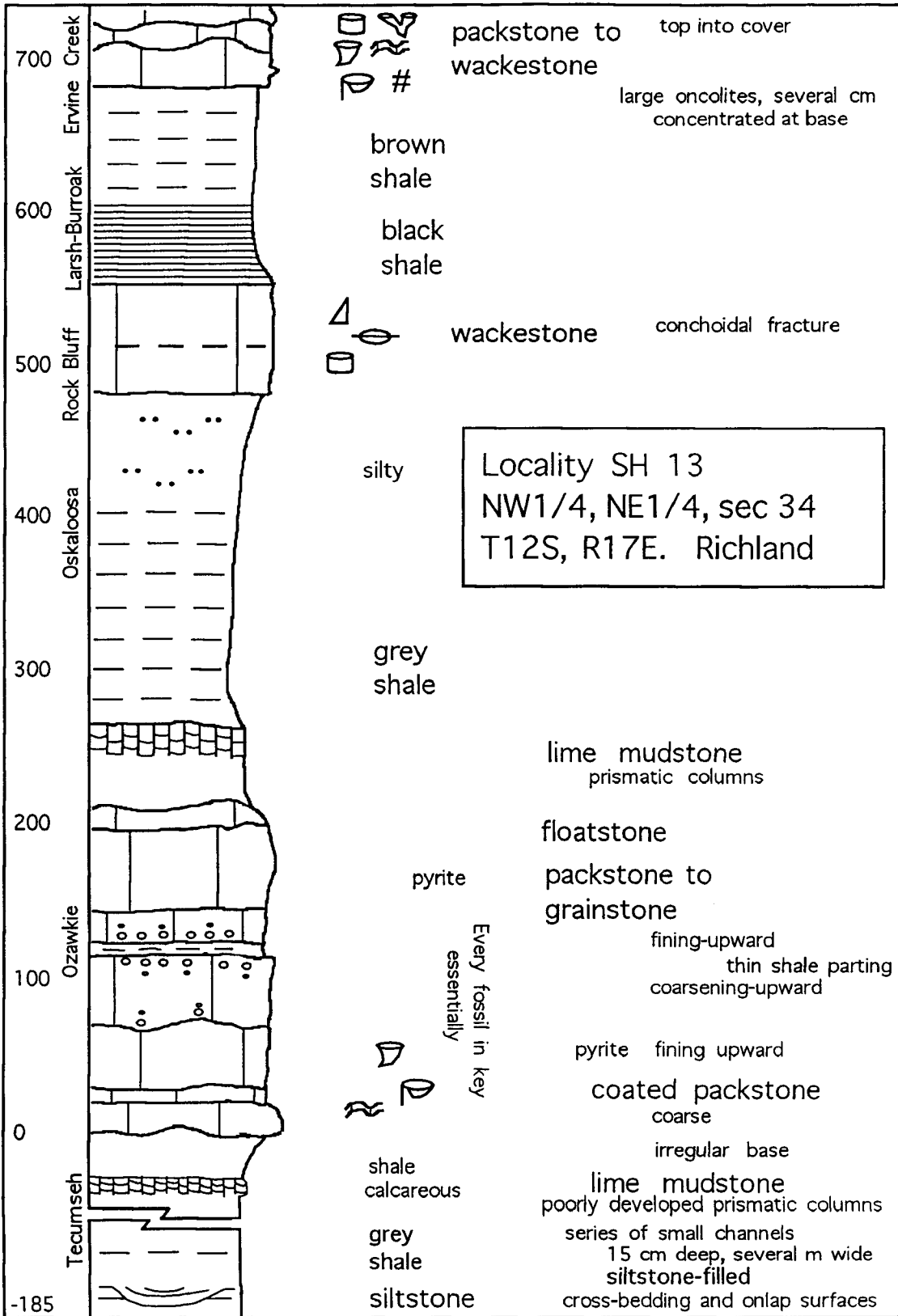


Locality DG 9  
SW-NW- sec 1  
T13S - R17E

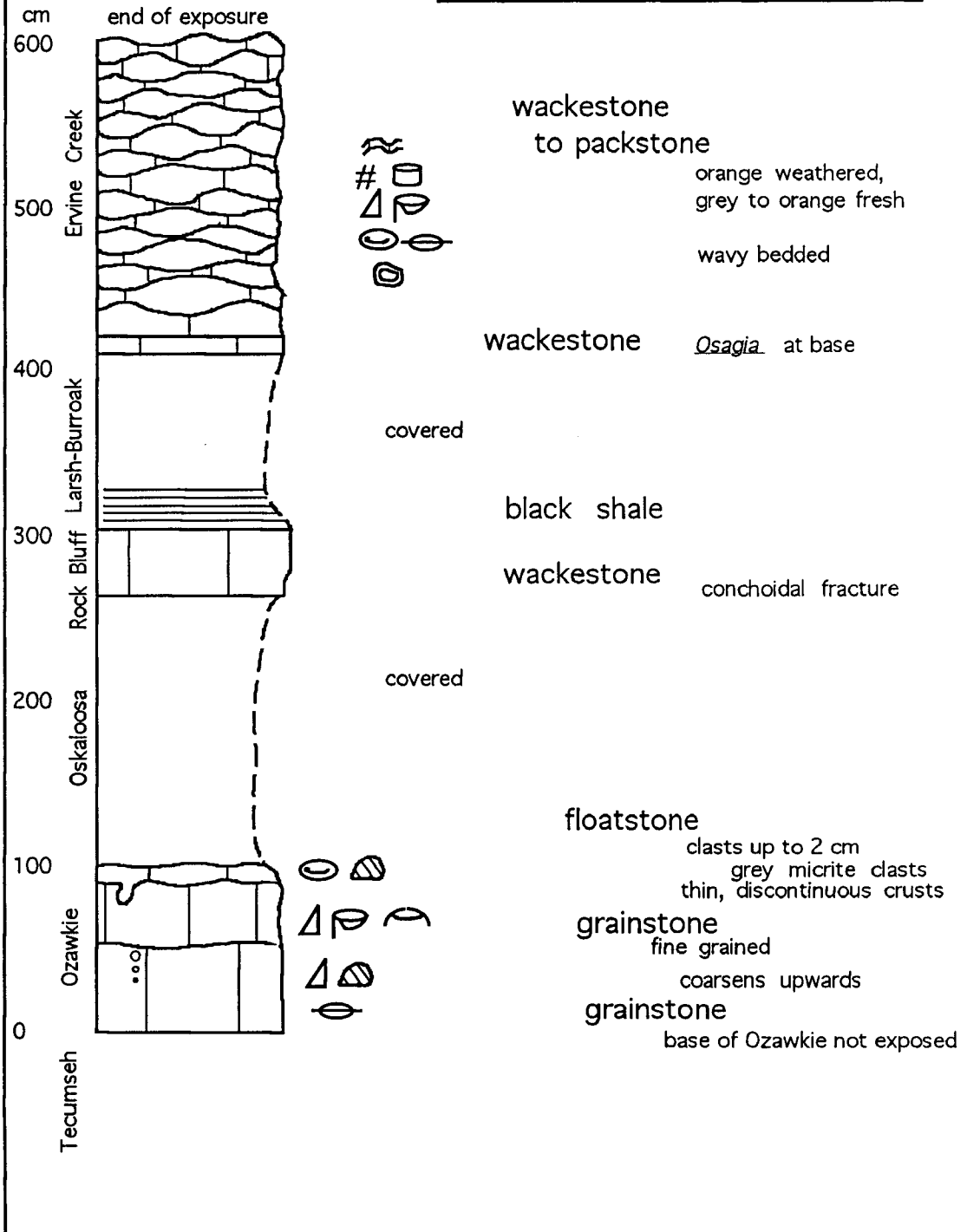




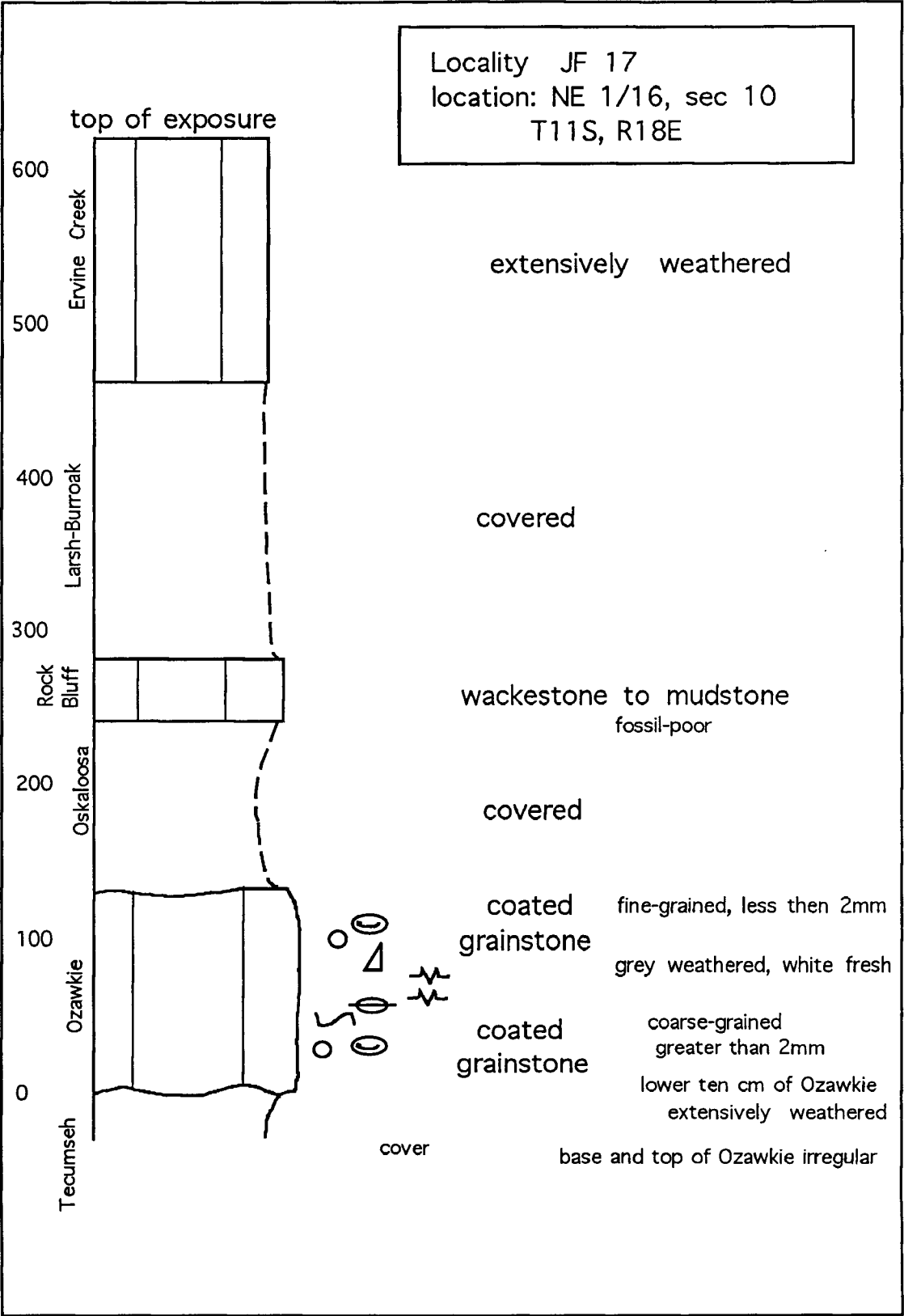




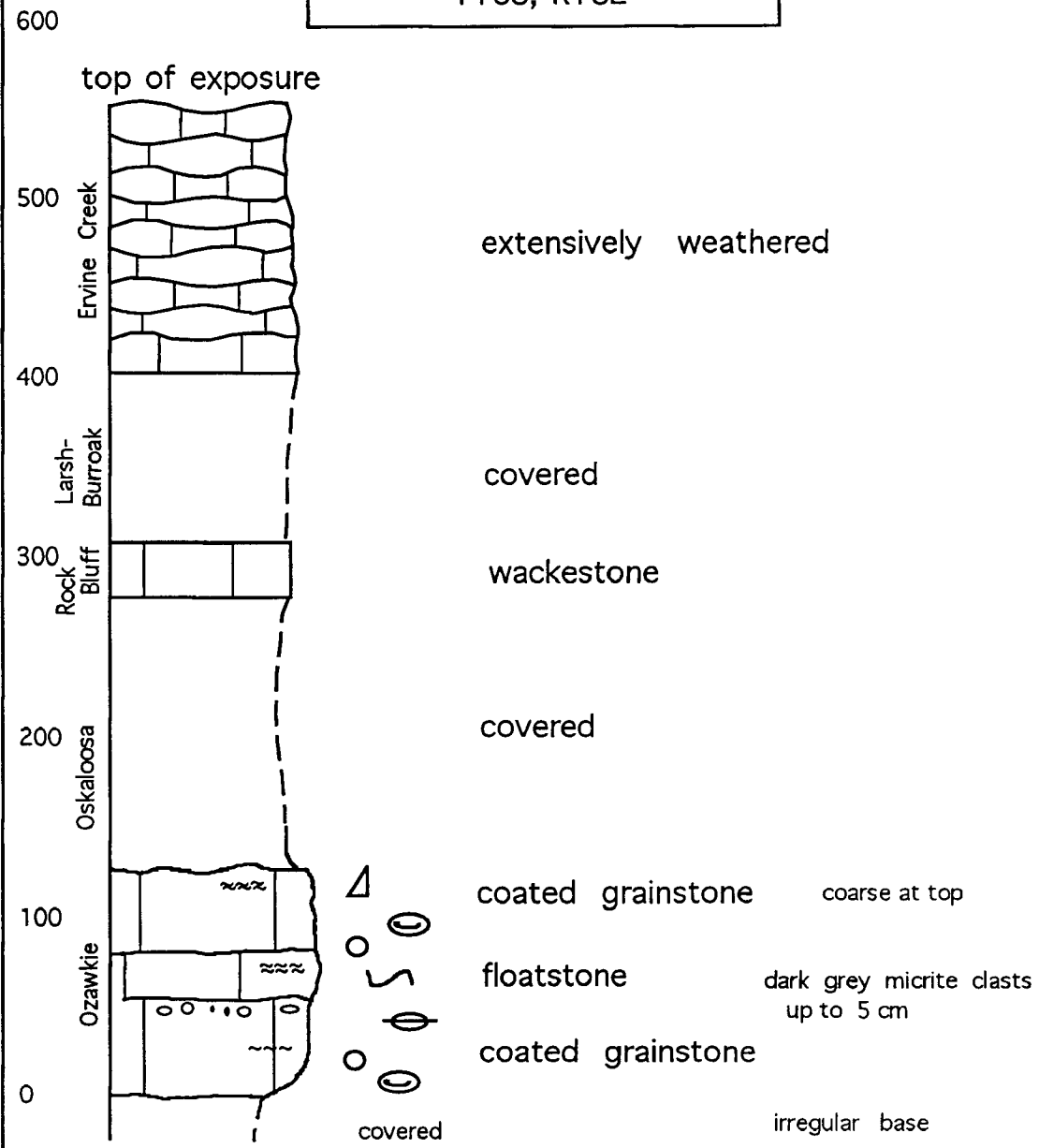
Locality DG 16  
 location: SE 1/4, sec 32,  
 T11S, R18E



Locality JF 17  
 location: NE 1/16, sec 10  
 T11S, R18E

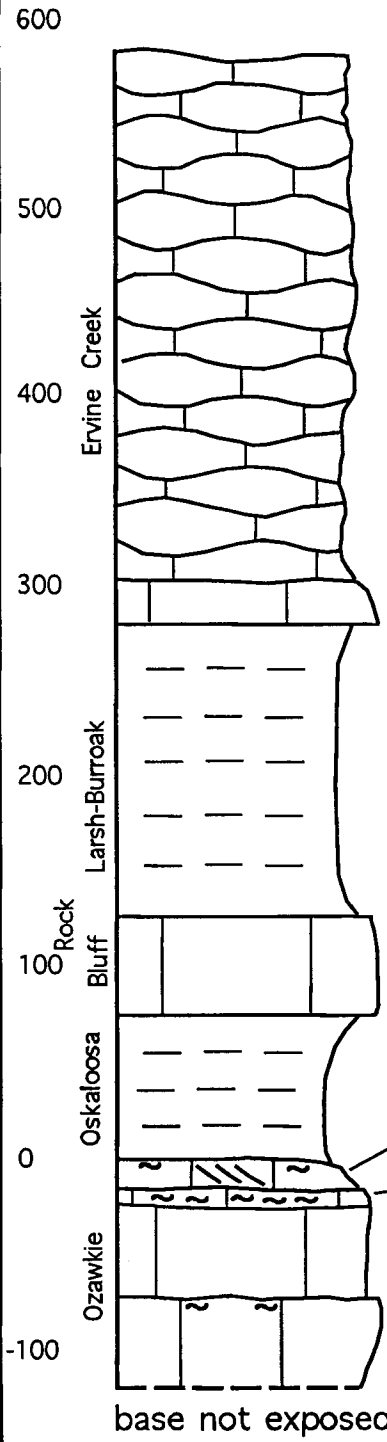


Locality JF 18  
 location: S 1/2, sec 28,  
 T10S, R18E





Locality JF 20  
 SE 1/4, NE 1/4  
 sec. 3, T11S, R18E



wackestone

shale

no hint of black shale

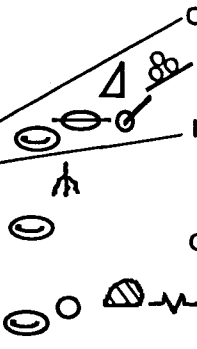
wackestone

coarse coated grainstone  
 coarsens up, cross-bedding  
 laminated micrite at very top  
 dolomite cement

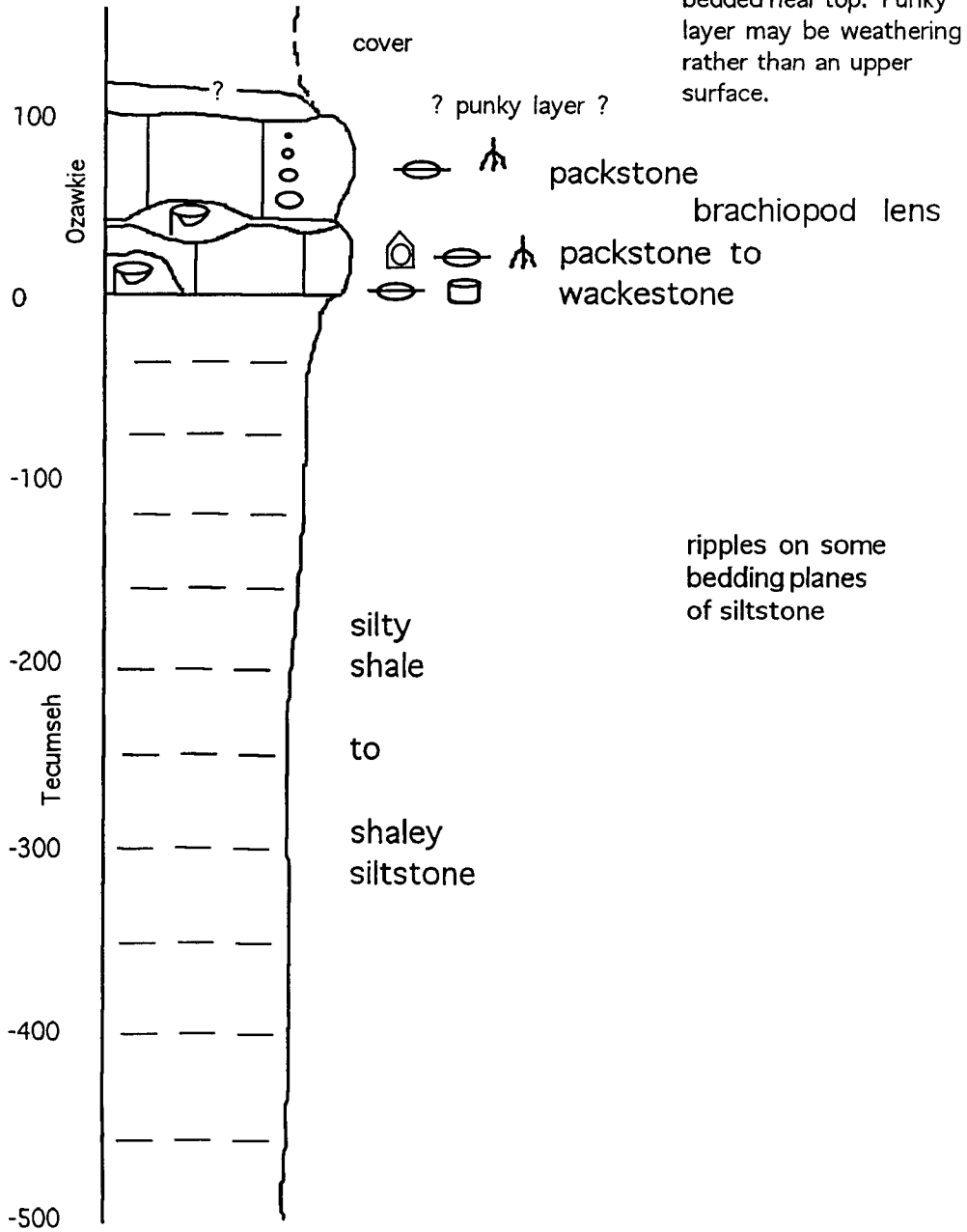
mudstone and packstone  
 rhizocasts, rhizoliths  
 laminated and clotted micrite  
 pyrite abundant

coated grainstone  
 cross-bedding

coated grainstone  
 patches with lime mud in pores  
 dolomite common

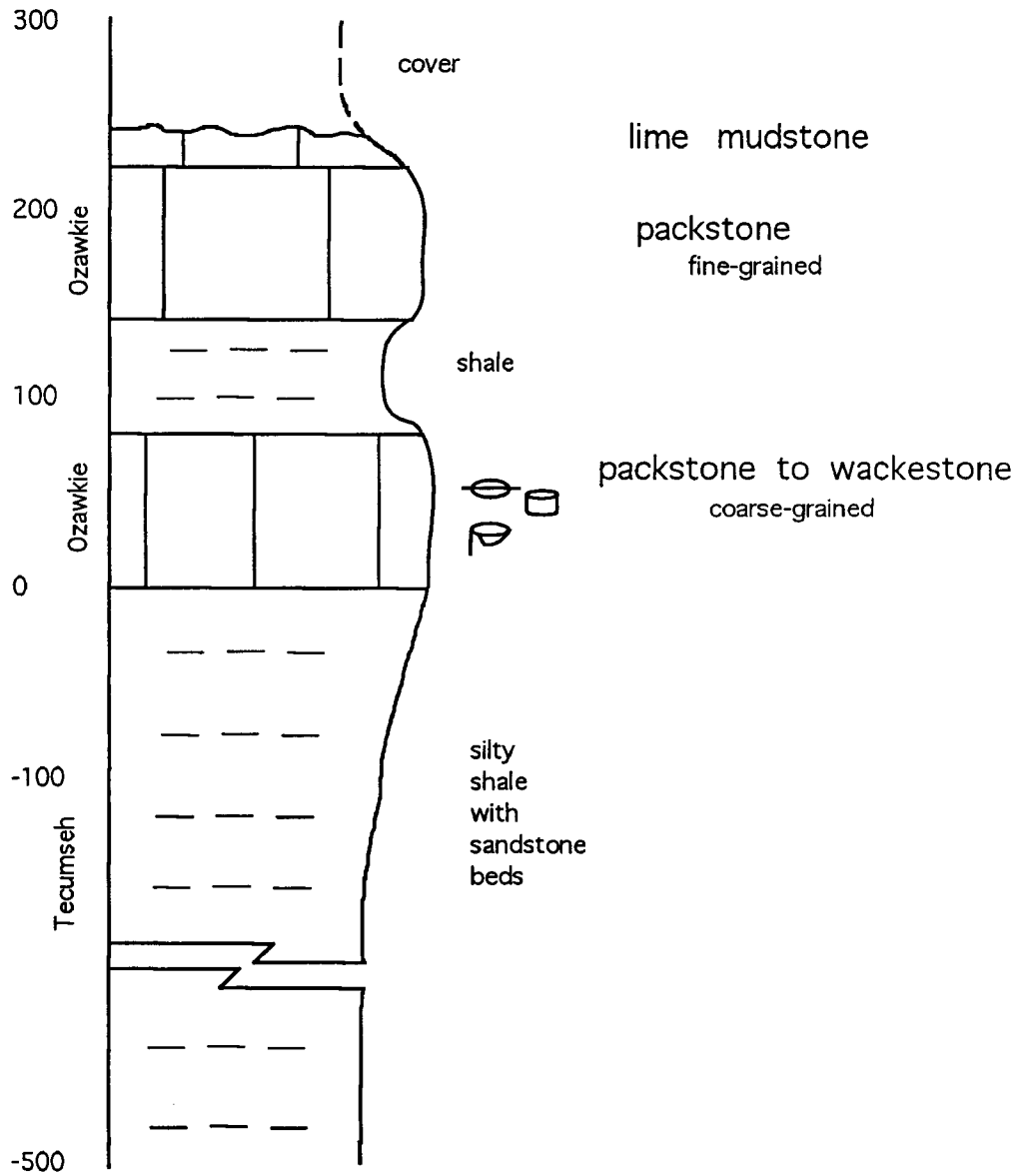


LOCALITY OS23:  
 location: NE1/4, NE1/4  
 sec 9, T14S, R17E.  
 Overbrook 7.5

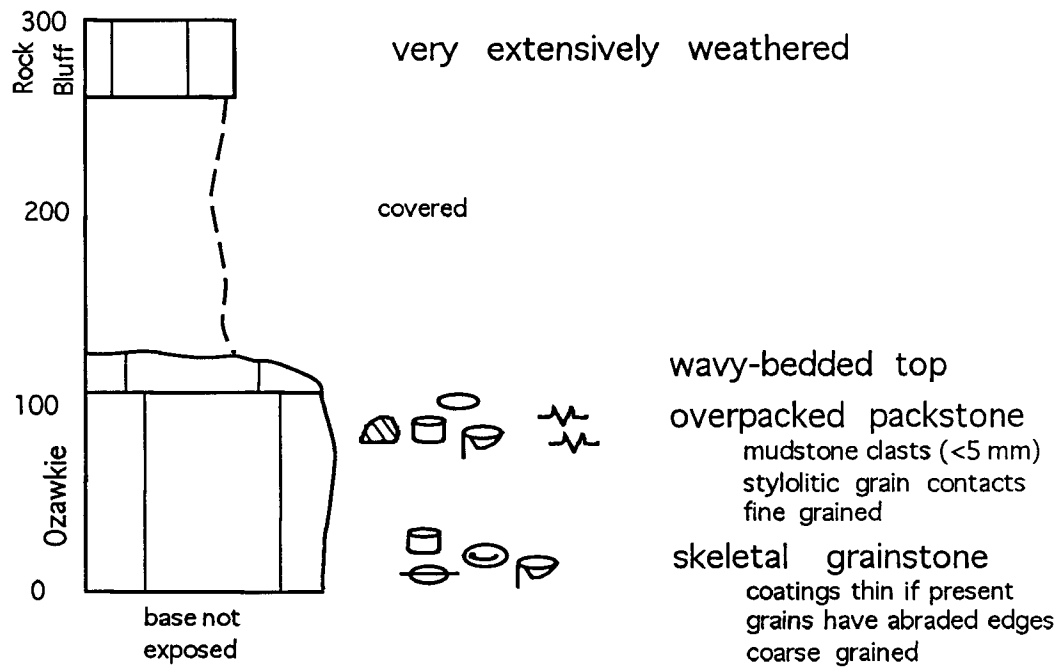


LOCALITY OS24

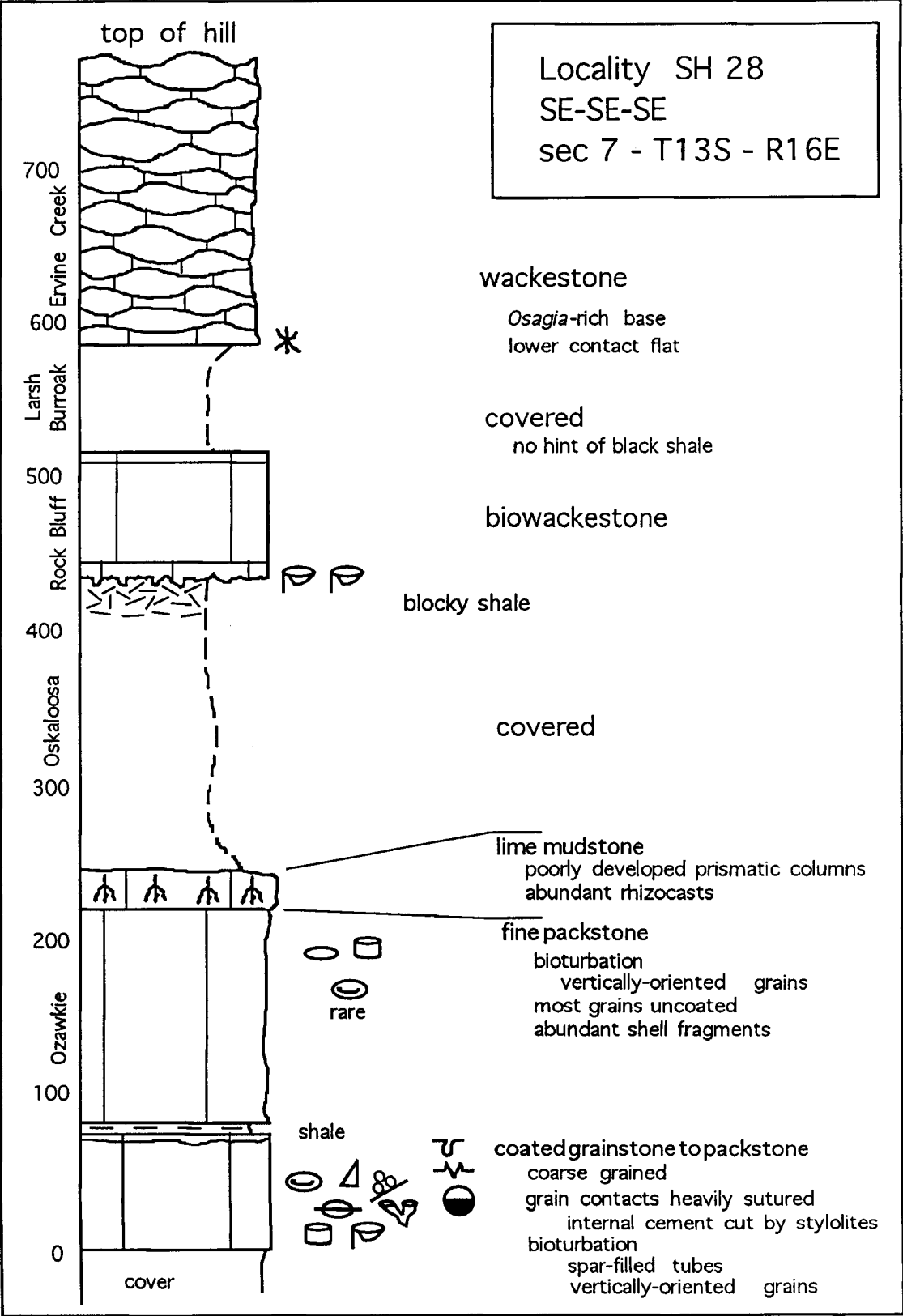
location: center, sec 13,  
T14S, R16E.  
Overbrook 7.5



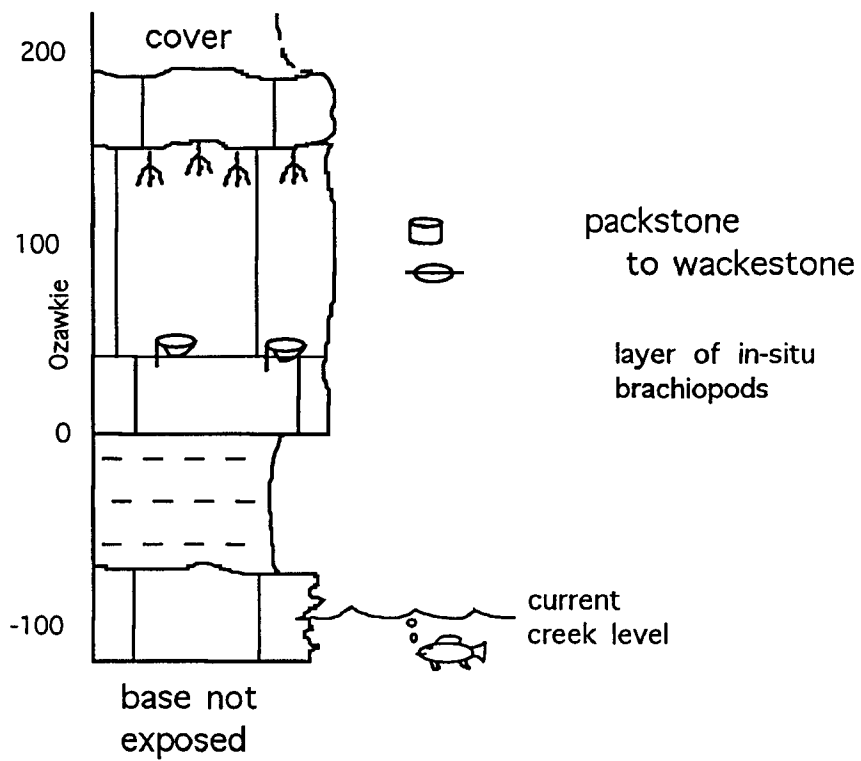
Locality SH 27  
NW-NW-NW  
16-T13S-R17E



Locality SH 28  
SE-SE-SE  
sec 7 - T13S - R16E



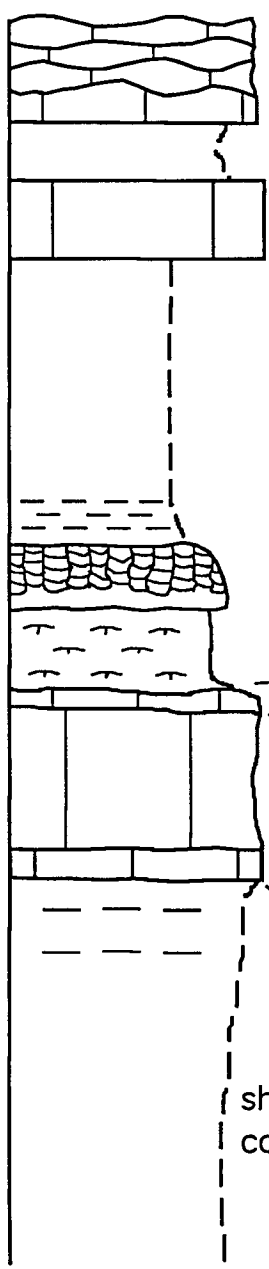
Locality SH 29  
NW-NW-NW  
sec. 28 - T13S - R16E





Locality AT 31  
 Central W1/2  
 36 - T6S - R20E

500  
 Ervine Creek  
 400  
 Rock Bluff  
 300  
 Oskalooosa  
 200  
 100  
 Ozawkie  
 0  
 Tecumseh



slumping near top, but  
 Larsh-Burroak is thin  
 here.

skeletal wackestone

cover

wackestone

cover

blocky shale  
 prismatic columns

calcareous shale

packstone  
 root tubes  
 1mm wide and 5 cm wide  
 laminated micrite aureoles  
 filled by shale from above  
 circumgranular cracking  
 fenestrae

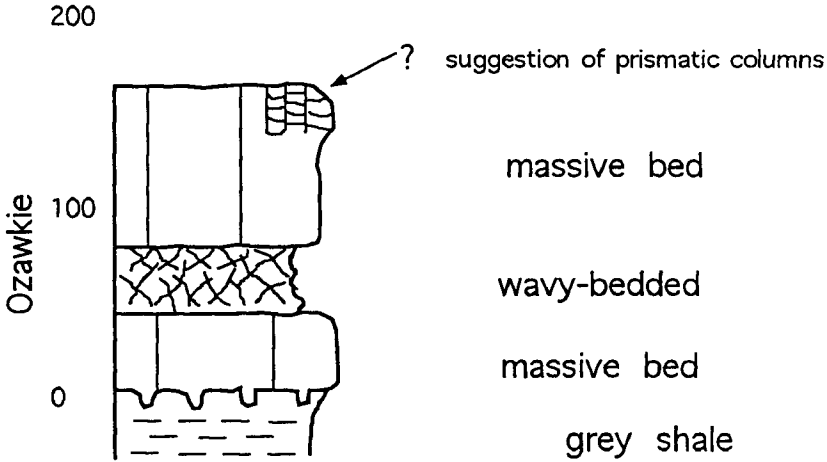
grainstone to packstone  
 fine, well sorted and rounded  
 burrows or fenestrae  
 internal sediment reduced  
 occluded by coarse spar

grainstone to packstone  
 coarse  
 burrows occluded with spar

shale and  
 cover

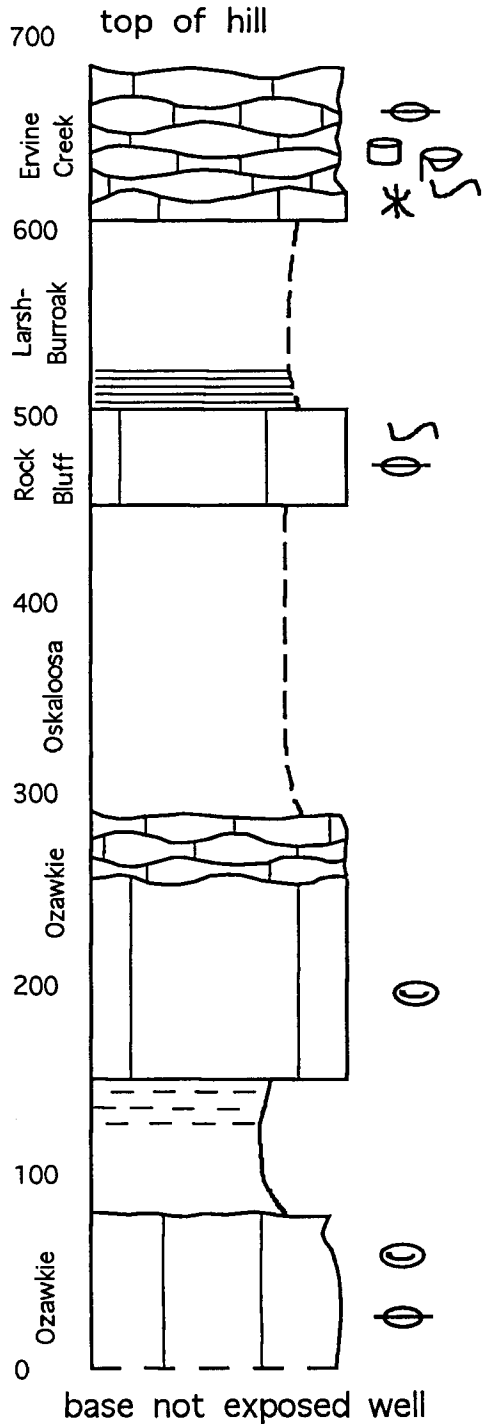
Locality AT 33  
SW - SW  
11 - T5S - R 20E

Ervine creek is exposed in road approximately 400 meters north. Rock Bluff is present only in float.



Ozawkie is deeply weathered. The Ozawkie was most likely a packstone, but grains are too weathered to determine origin.

Locality SH 36  
 NE - NE - NE  
 34 - T13S - R16E



wackestone

covered

black shale

wackestone

covered

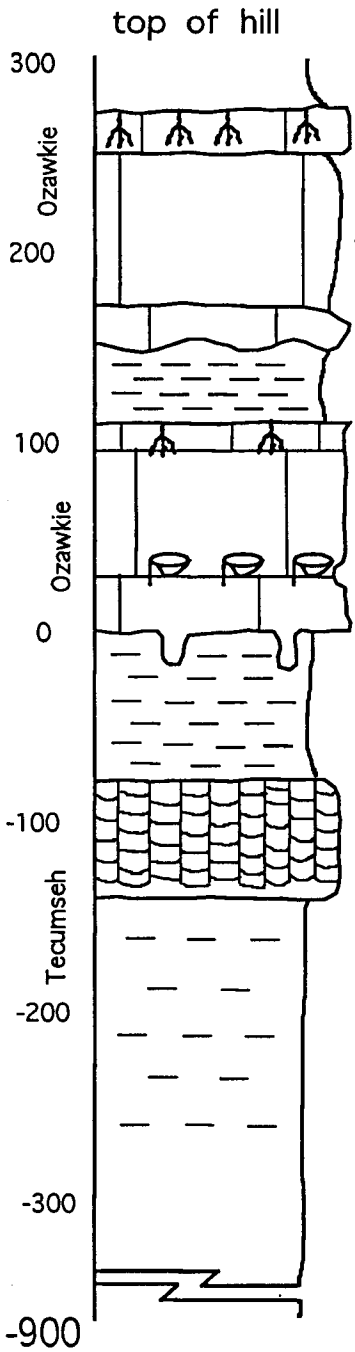
weathered

coated packstone  
 fine-grained

Ozawkie weathered, some  
 slumping but measurements  
 are fairly accurate.

coated packstone  
 coarse-grained  
 fusulinid-rich

Locality S H 37  
 NW - NW - NW  
 36 - T13S - R 16E



mudstone  
 mottled-texture

wackestone  
 bioturbation

shale  
 yellow, non-fissile

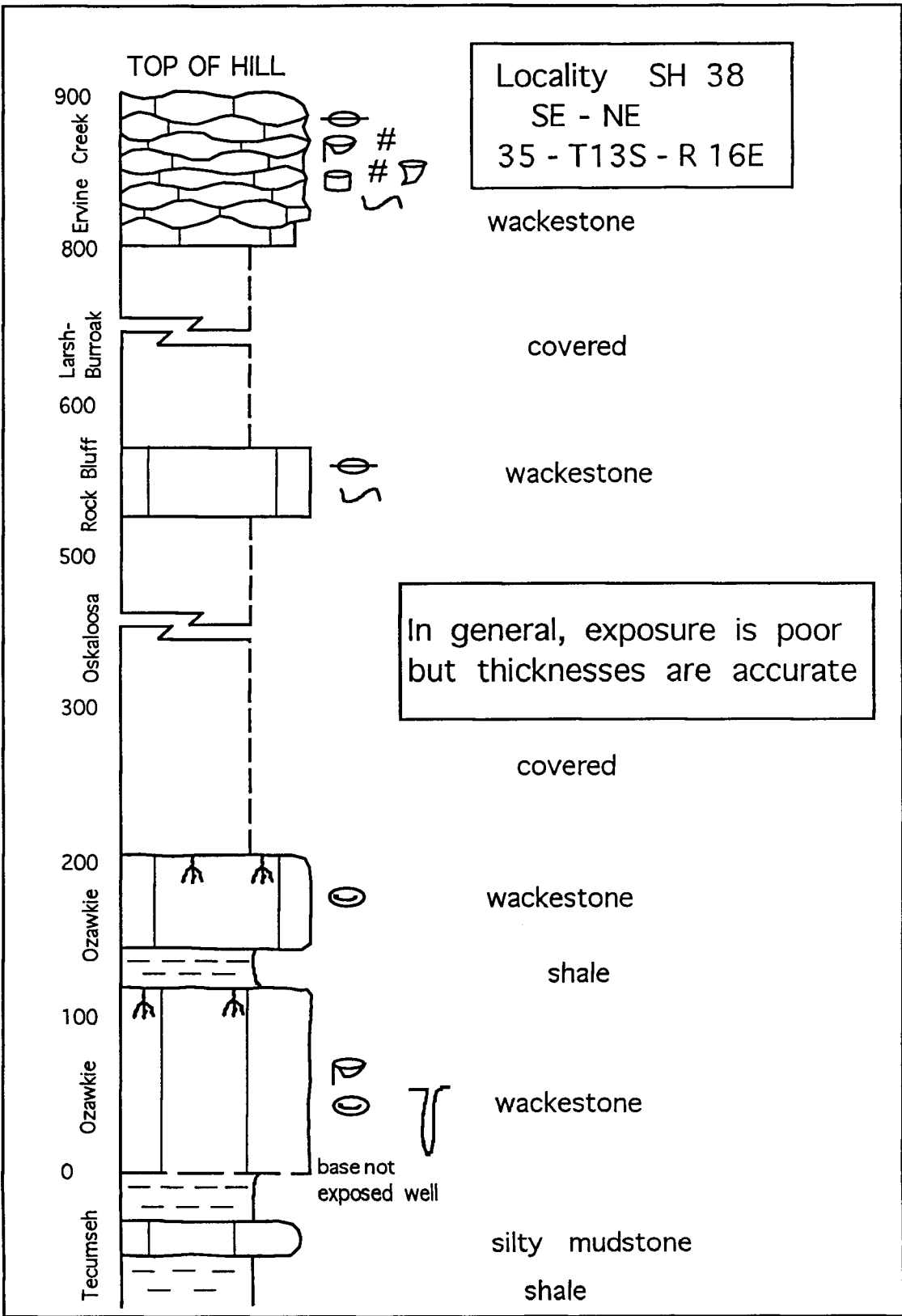
fusulinid wackestone

1. large burrows  
 5 cm wide, 50 cm deep  
 reduced, reverse grading fill  
 occluded by spar
2. small burrows  
 2 mm wide, 10 cm deep

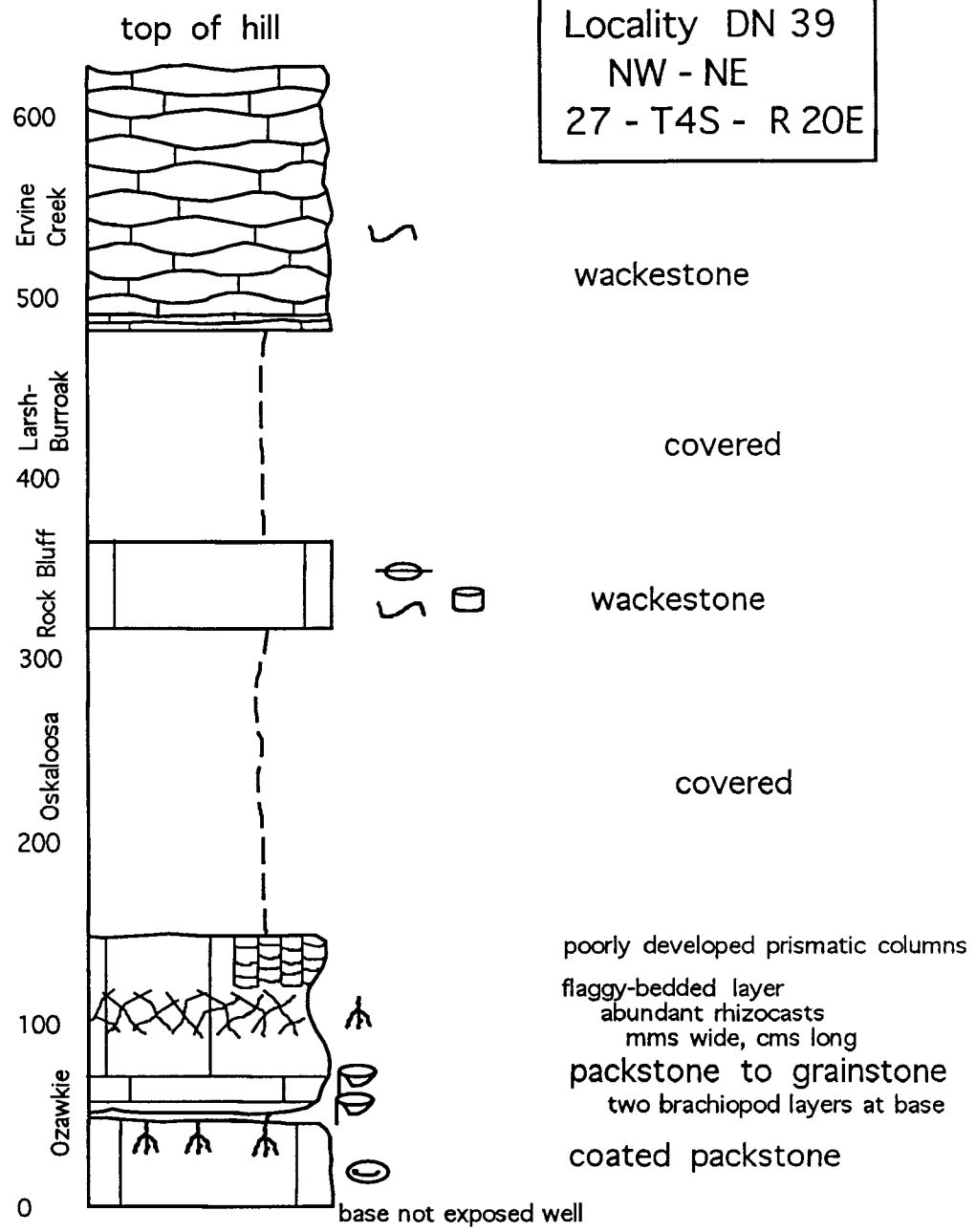
shale  
 blocky, non-fissile  
 dark grey

silty lime mudstone  
 prismatic columns

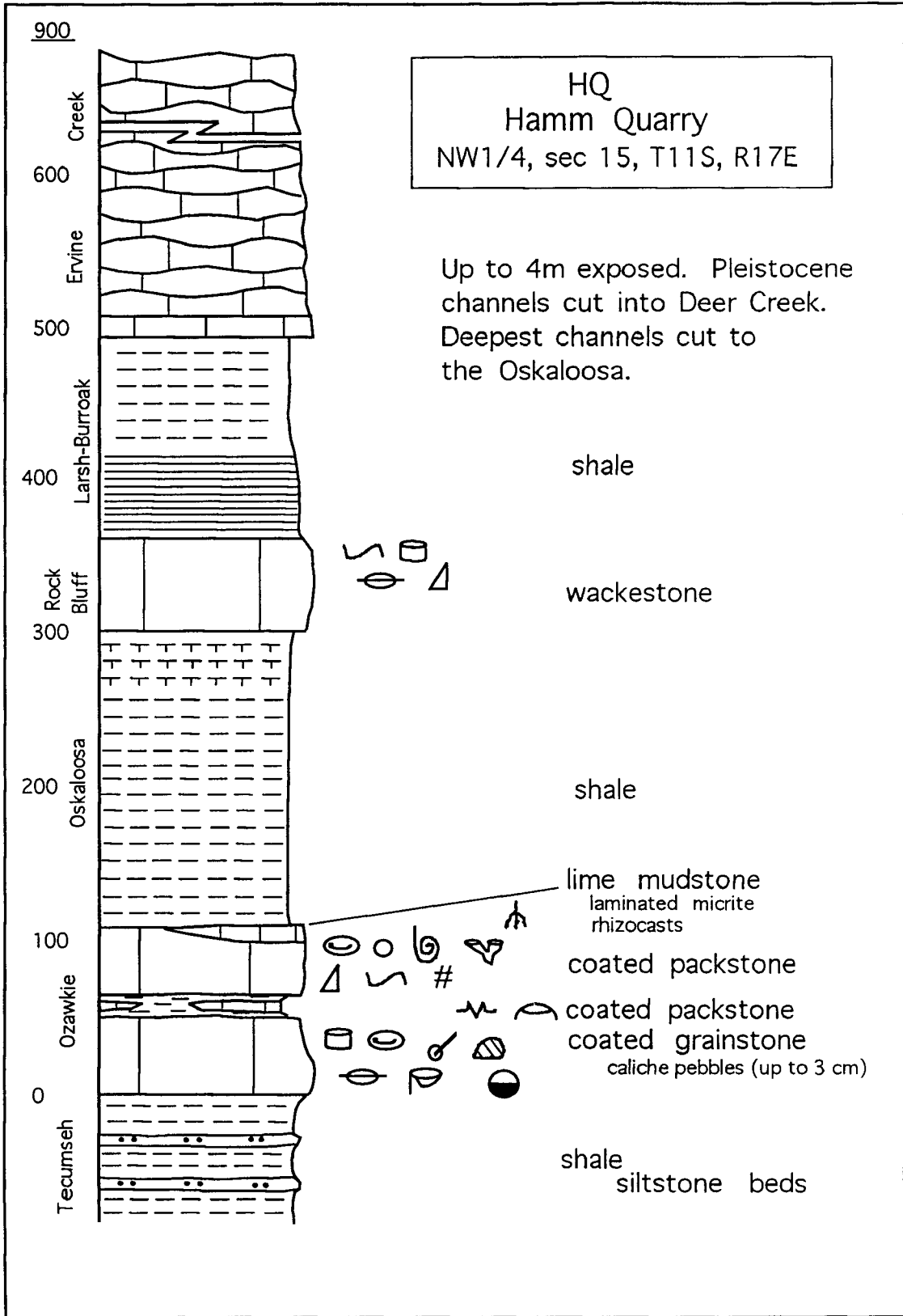
shale  
 grey  
 rare finely laminated silt and clay

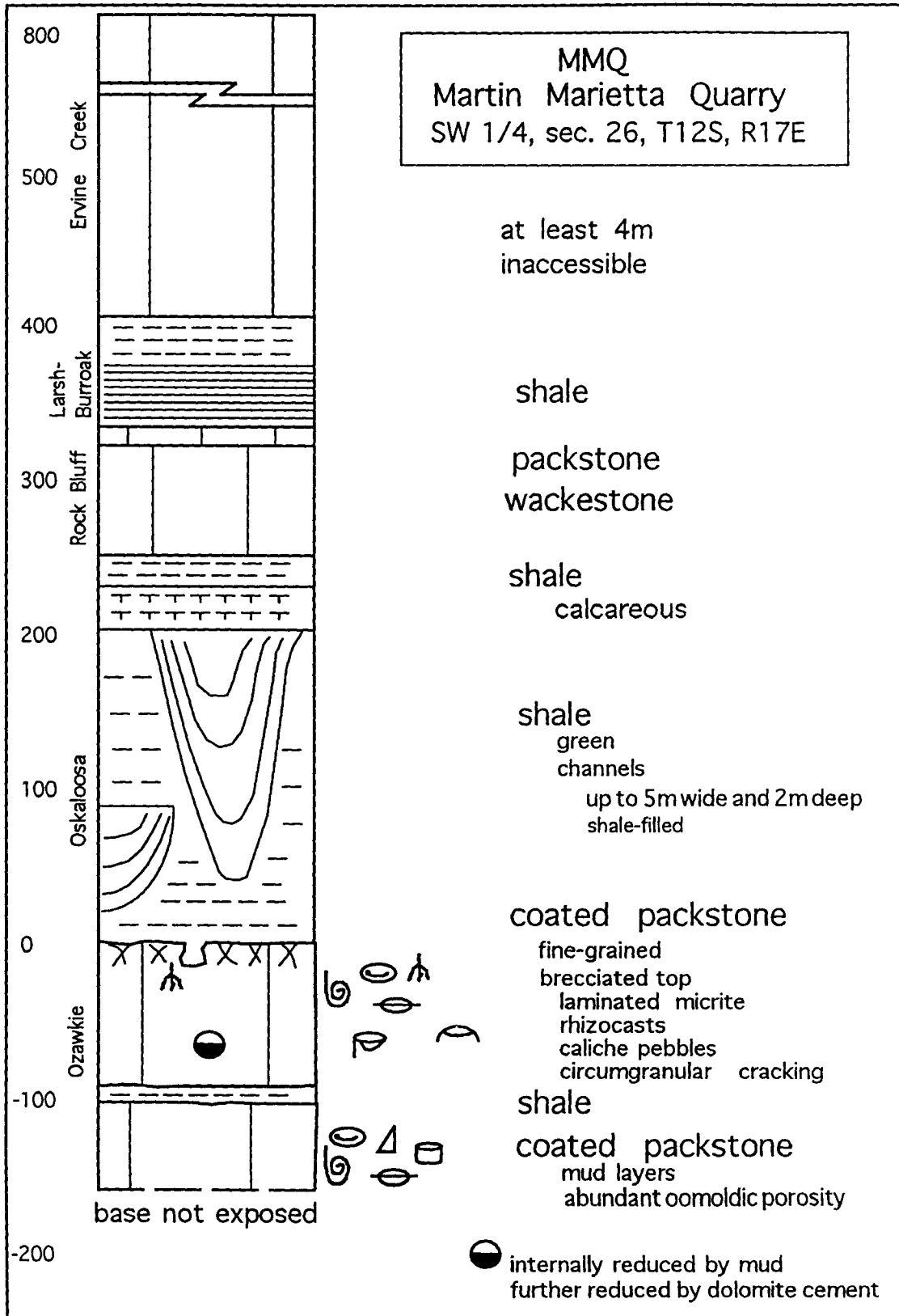


Locality DN 39  
 NW - NE  
 27 - T4S - R 20E



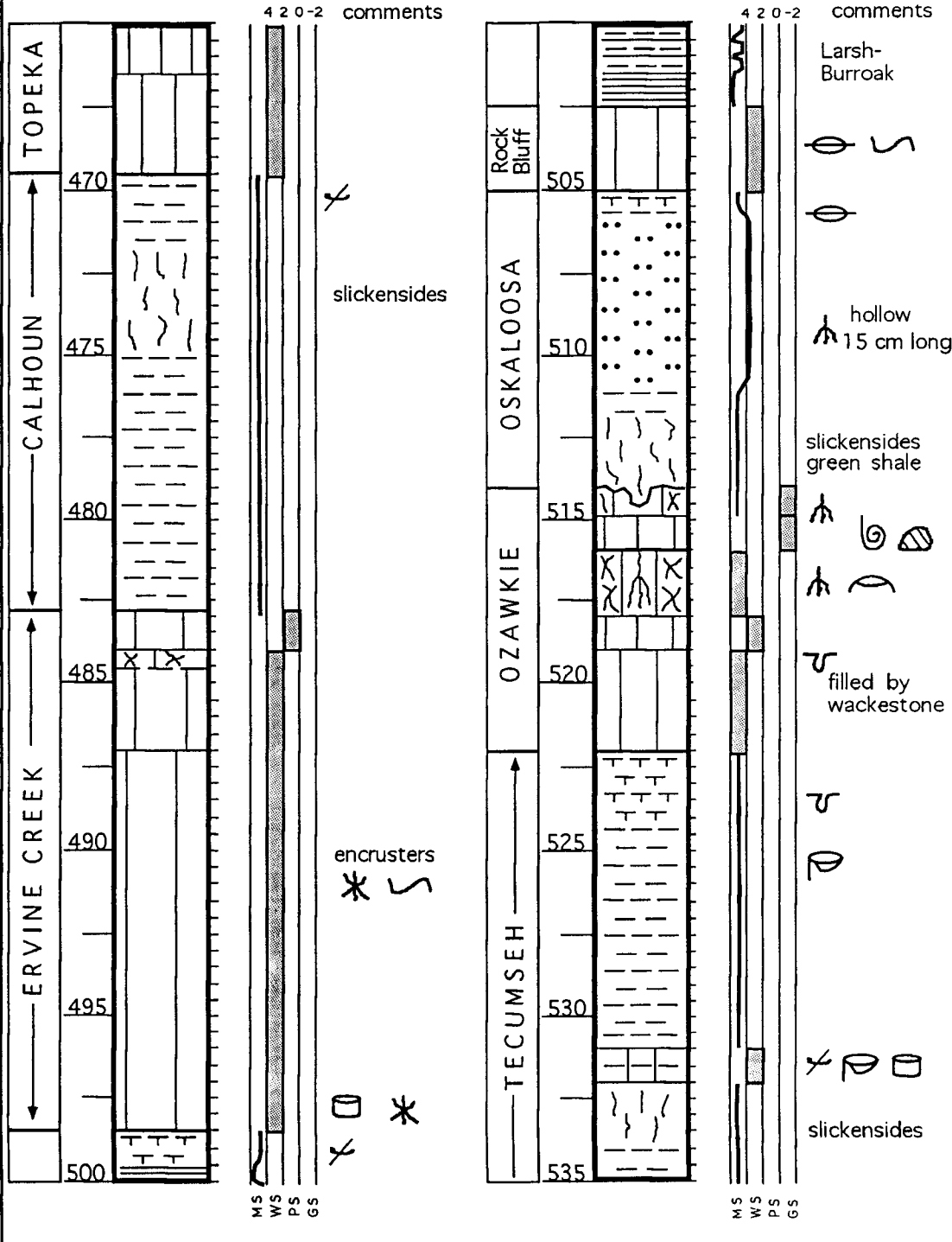
Tecumseh Exposed sporadically in ditch, where present typically a fine-grained, micaceous sandstone to coarse-grained siltstone.





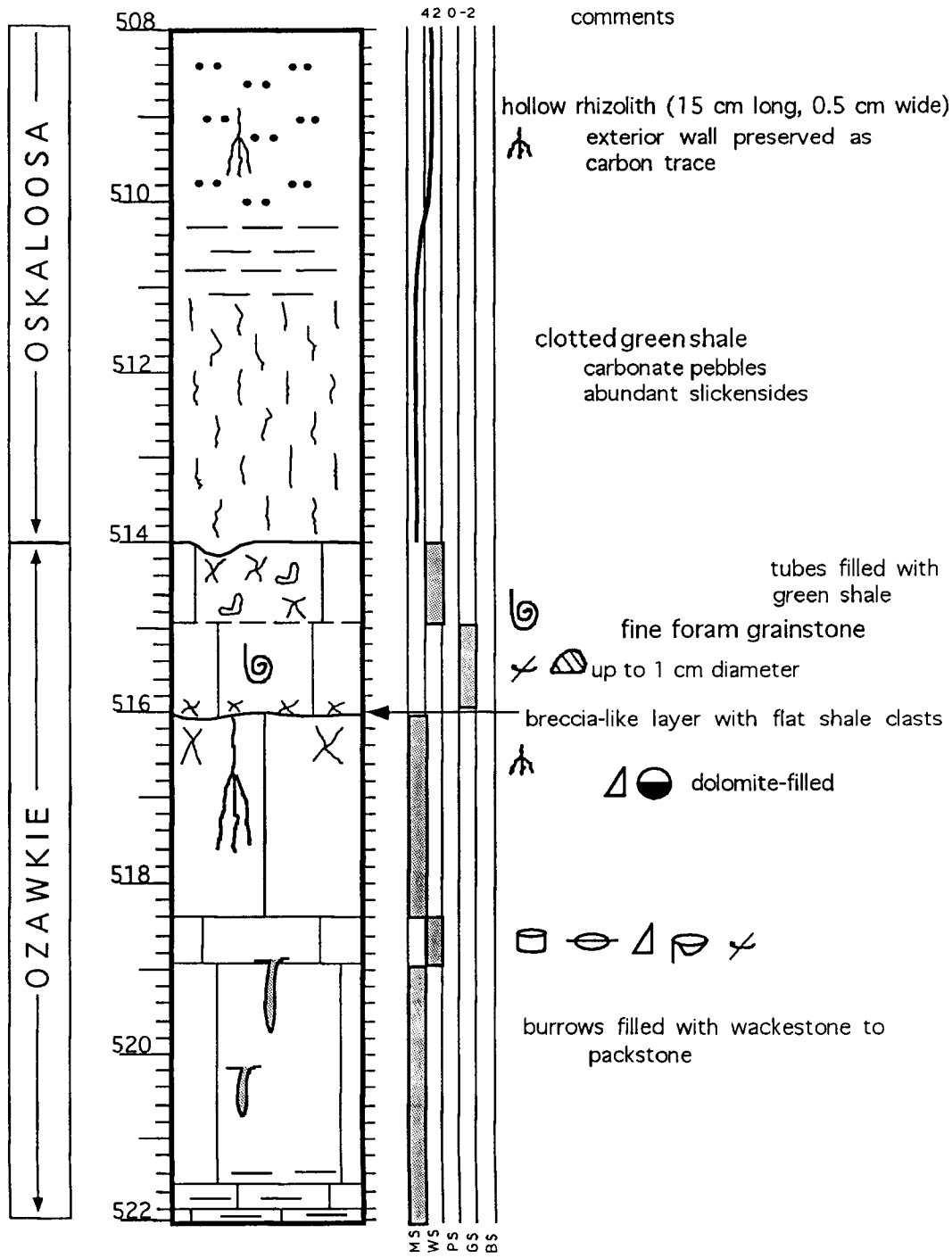
Operator Texas Gulf  
 Lease Geshner VC - 81 - 1  
 Location 12 - 4S - 9E

feet depths 465' to 535'  
 page \_\_\_\_\_



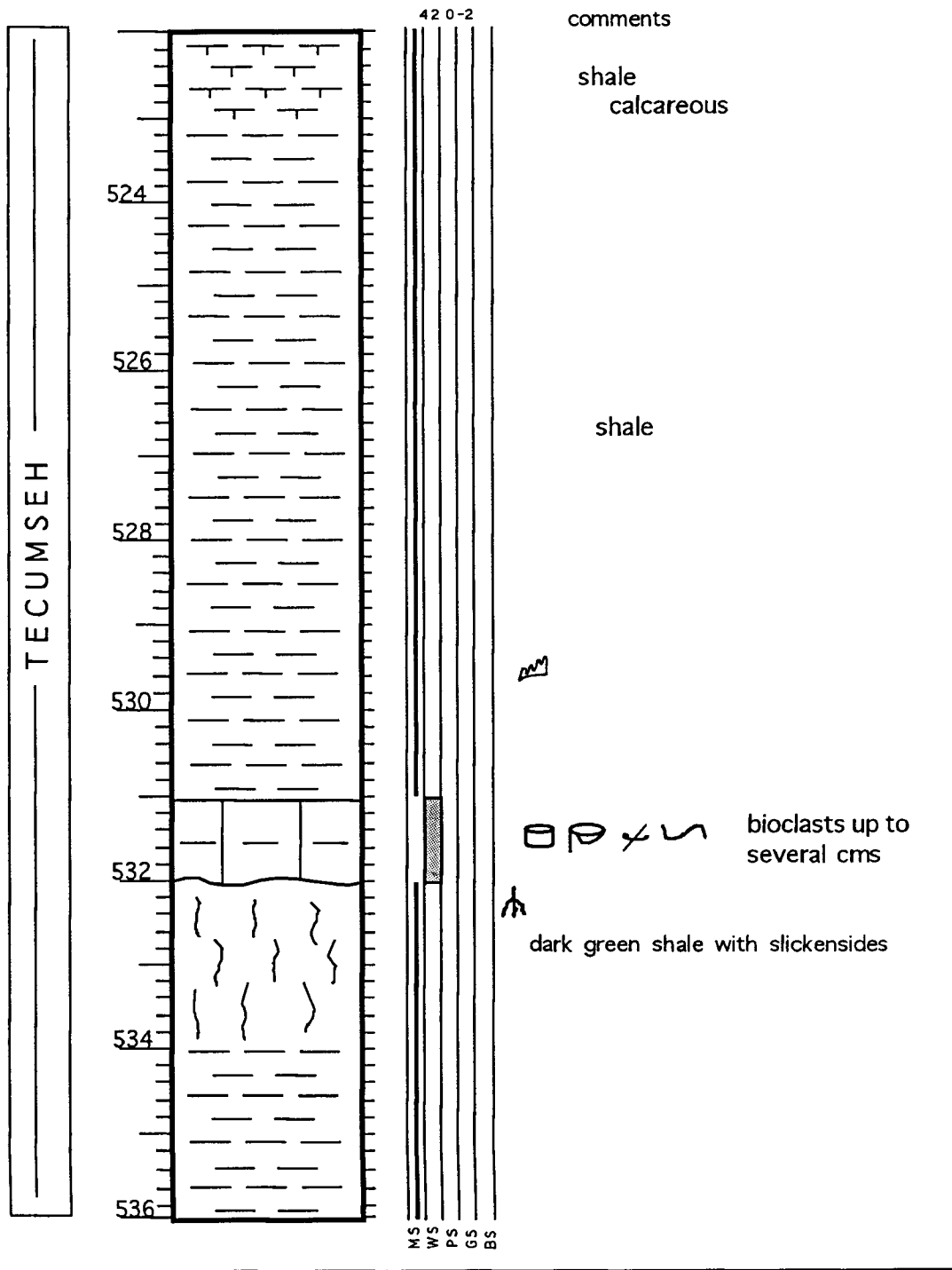
Operator Texas Gulf  
 Lease Geshner VC 81-1  
 Location 12 - 4S - 9E

page \_\_\_\_\_  
 depths 508' to 522'  
 feet



Operator Texas Gulf  
 Lease Geshner VC 81-1  
 Location 12 - 4S - 9E

page \_\_\_\_\_  
 depths 522' to 536'  
 feet



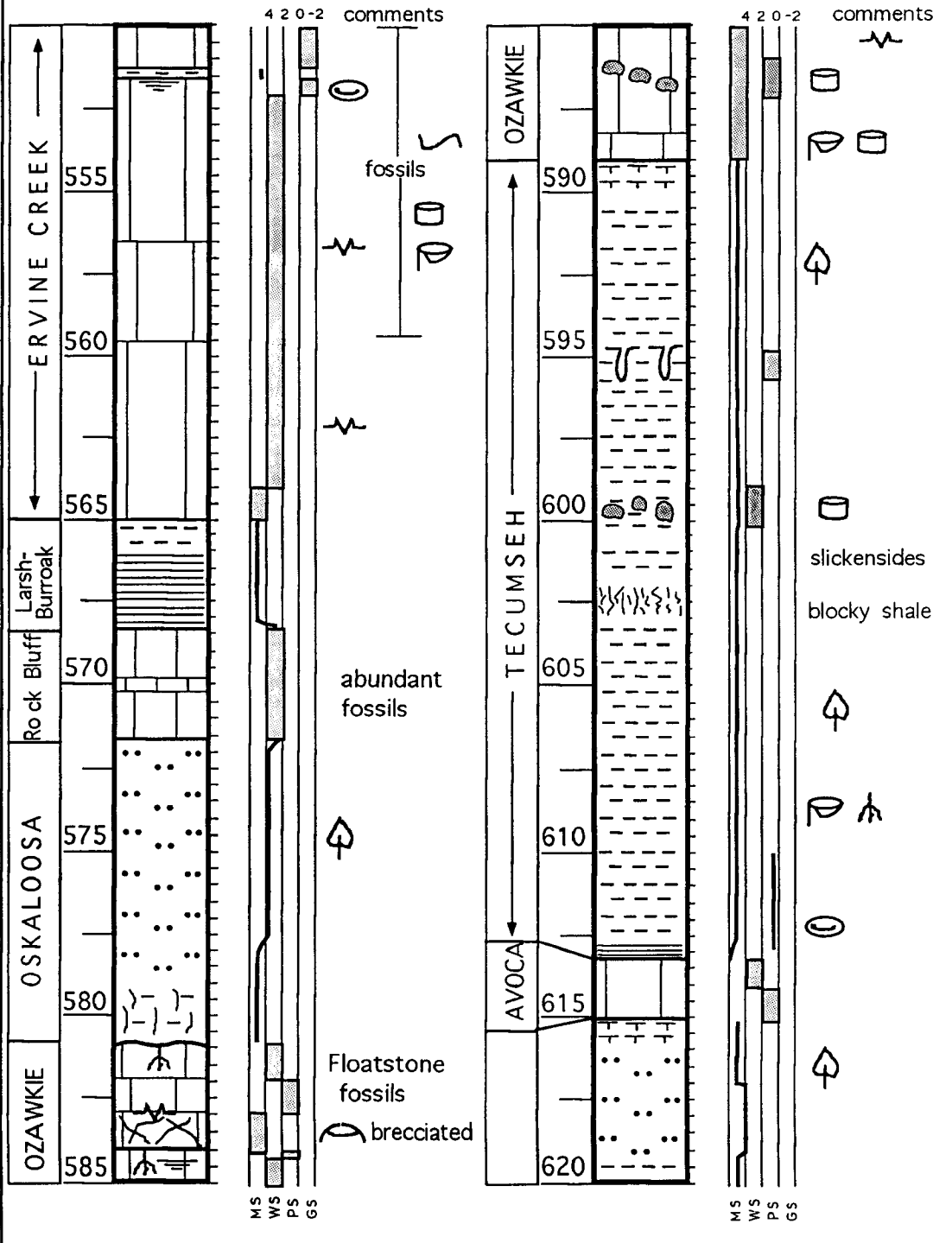
Operator Houston Oil and Mineral

Lease #1 Vermillion

Location 1 - 4S - 9E

feet depths 550' to 620'

page \_\_\_\_\_



Operator Houston Oil and Mineral

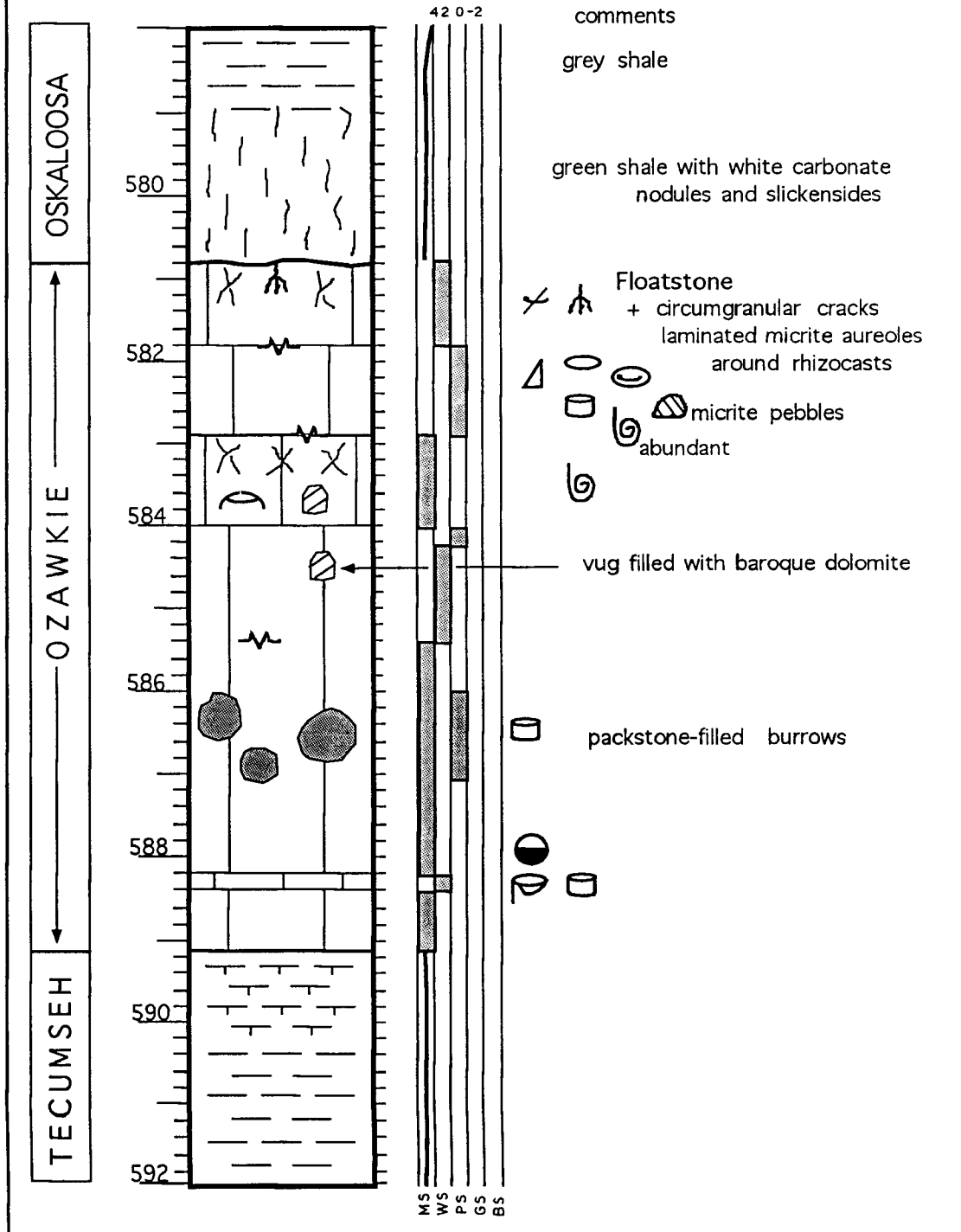
page \_\_\_\_\_

Lease #1 Vermillion

depths 578' to 592'

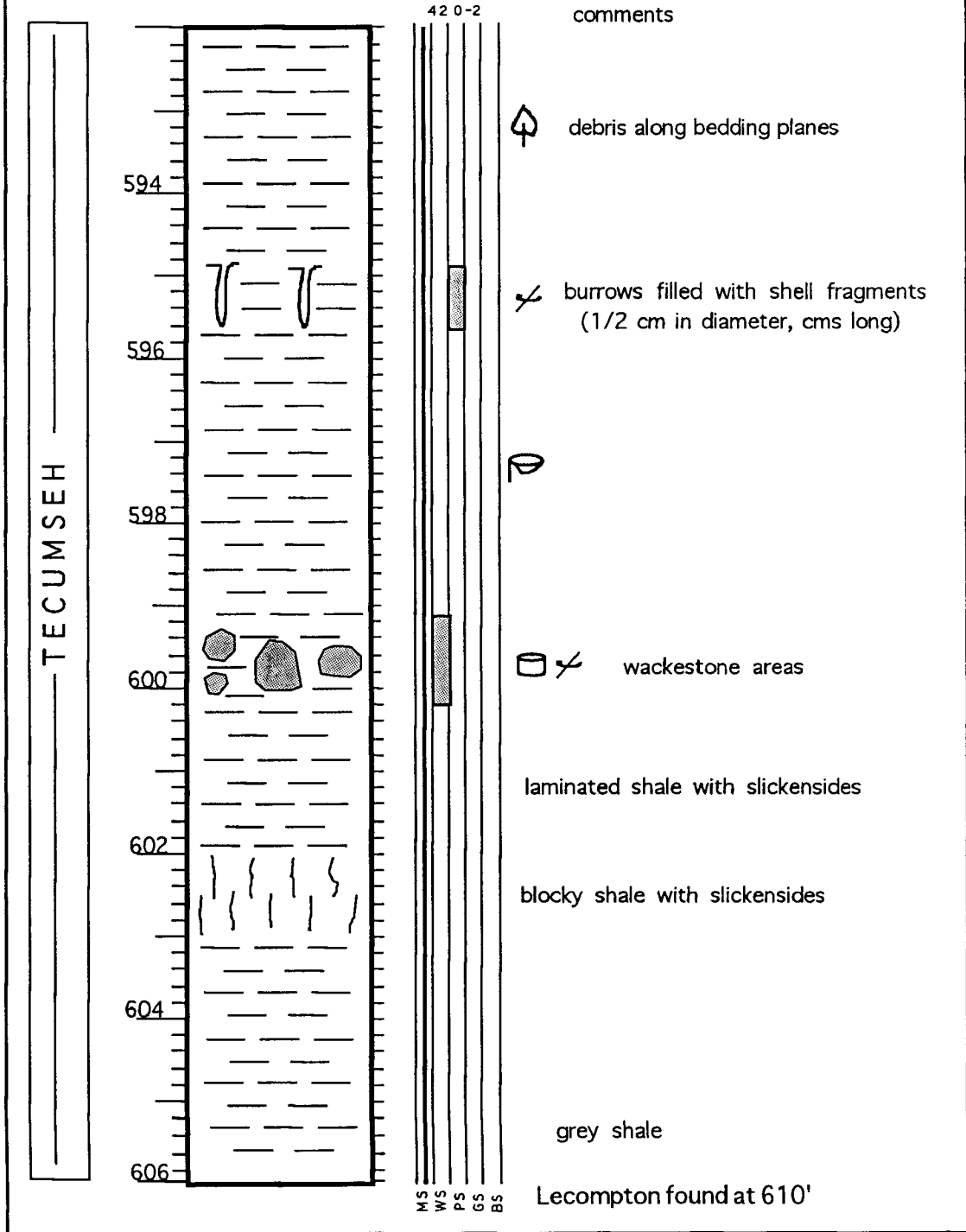
Location 1 - 4S - 9E

feet



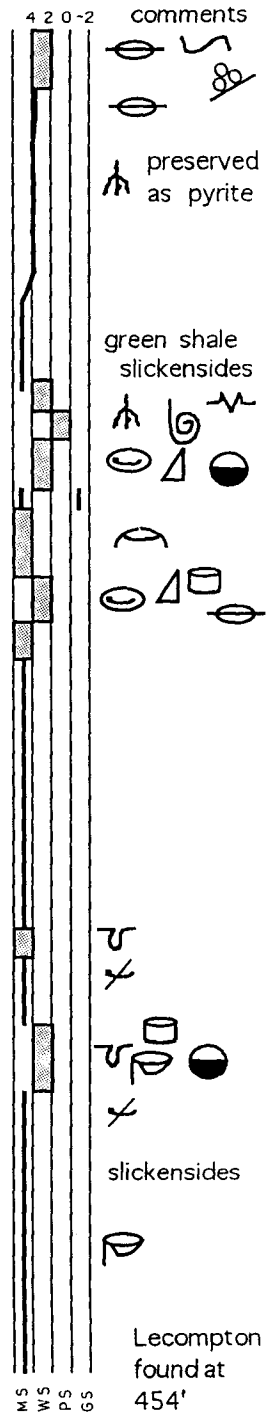
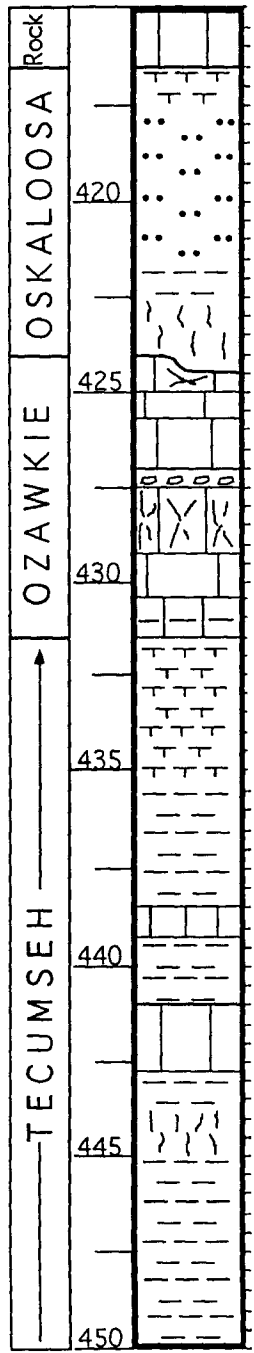
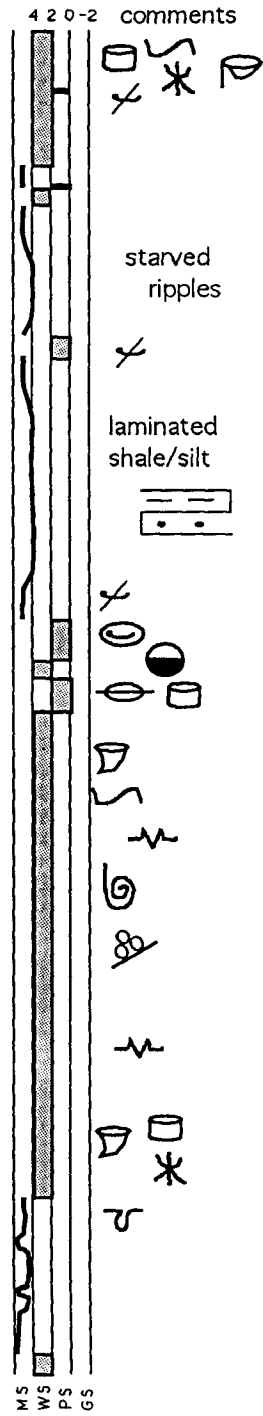
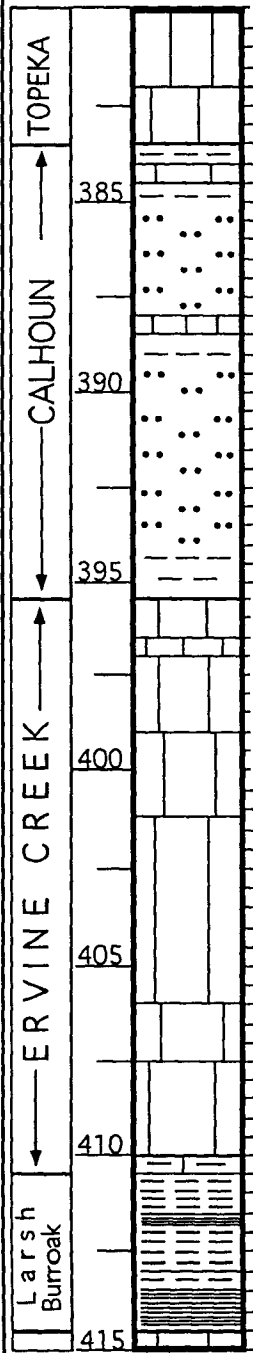
Operator Houston Oil and Mineral  
 Lease #1 Vermillion  
 Location 1 - 4S - 9E

page \_\_\_\_\_  
 depths 592' to 606'  
 feet



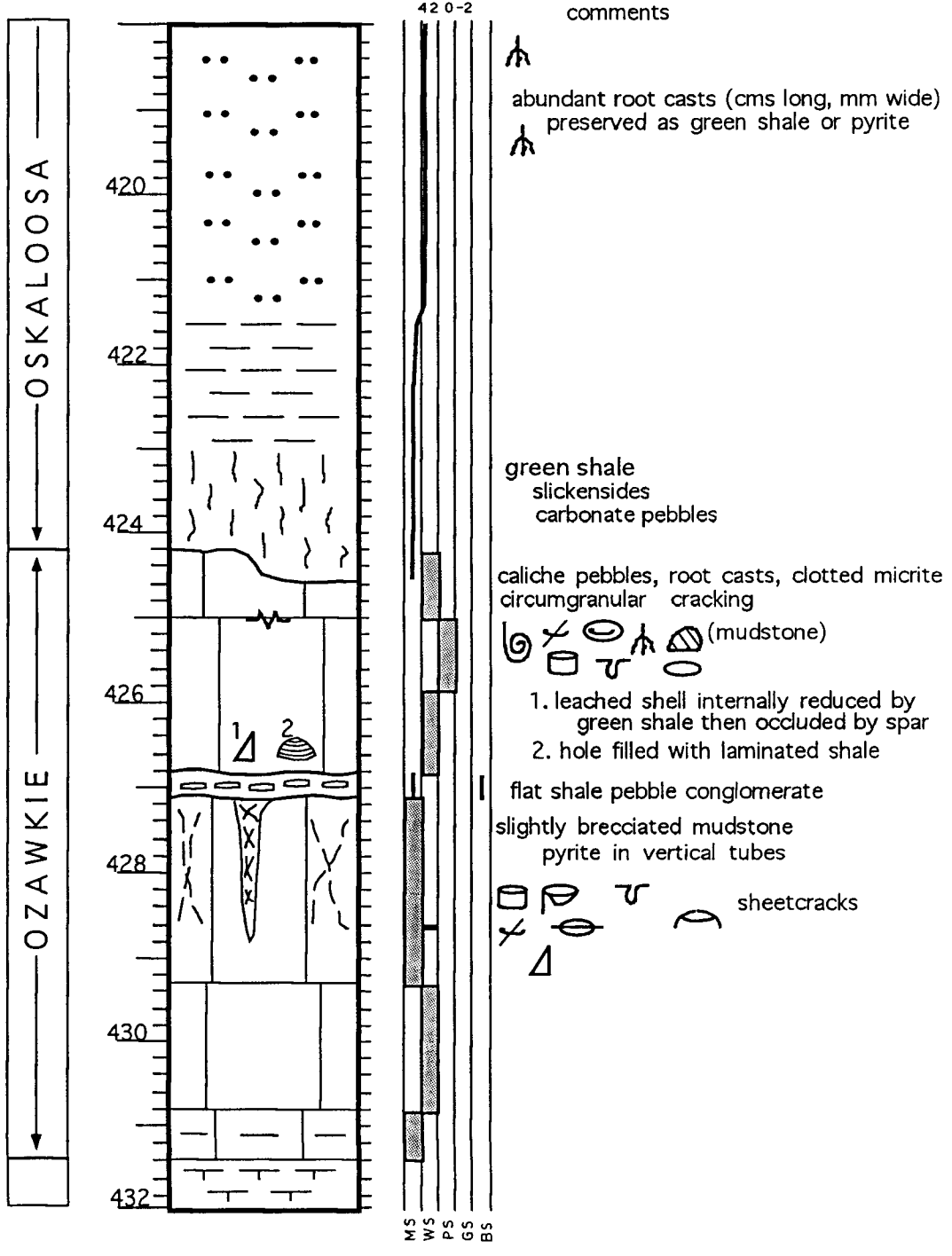
Operator Texas Gulf  
 Lease Dennels JD 81-1  
 Location 27 - 3S - 10E

depths 380' to 450'  
 page \_\_\_\_\_



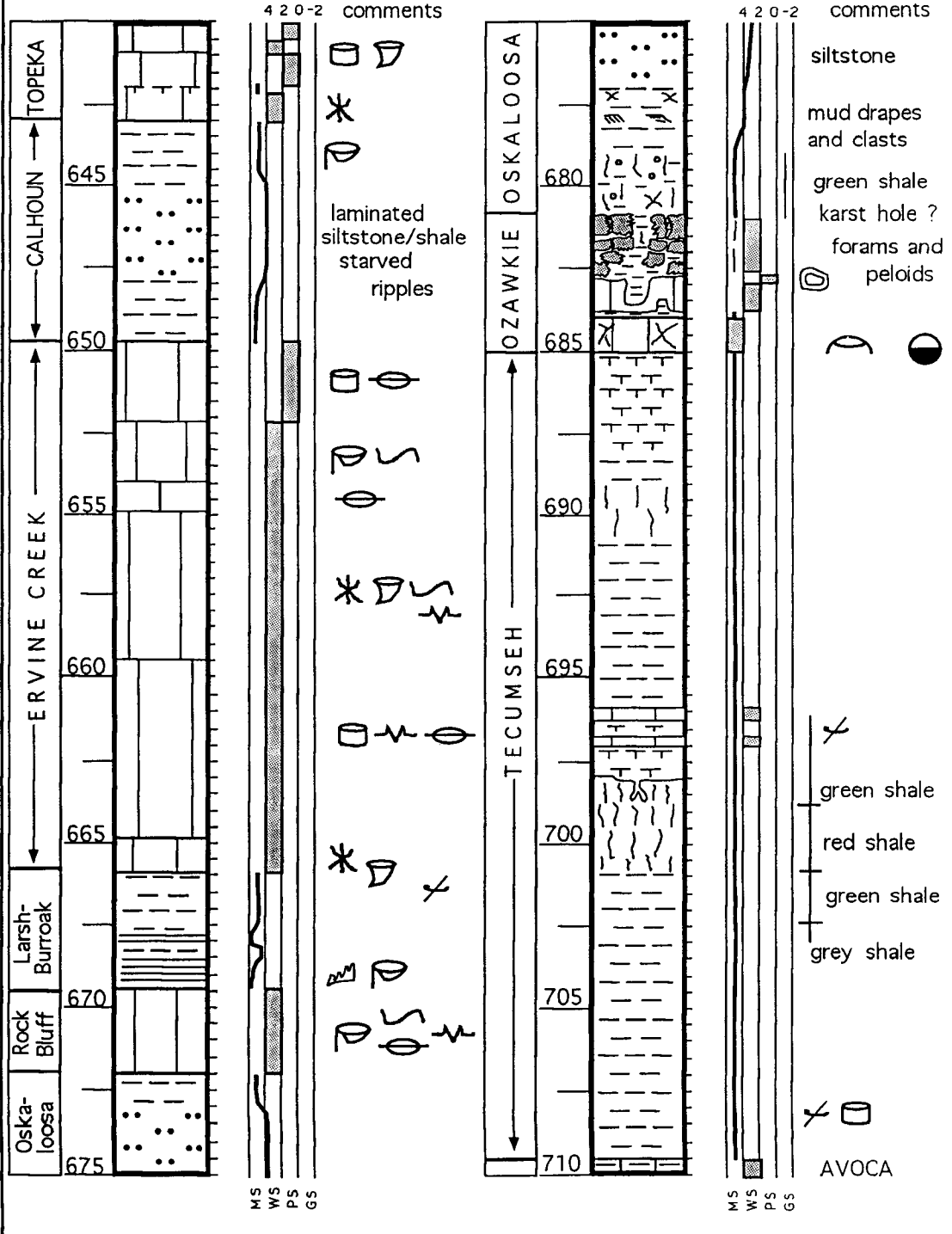
Operator Texas Gulf  
 Lease Dennels JD 81-1  
 Location 27 - 3S - 10E

page \_\_\_\_\_  
 depths 418' to 432'



Operator Texas Gulf  
 Lease Joe Spiller 81-1B  
 Location 11 - 3S - 9E

feet depths 640' to 710'  
 page \_\_\_\_\_



4 2 0-2 comments

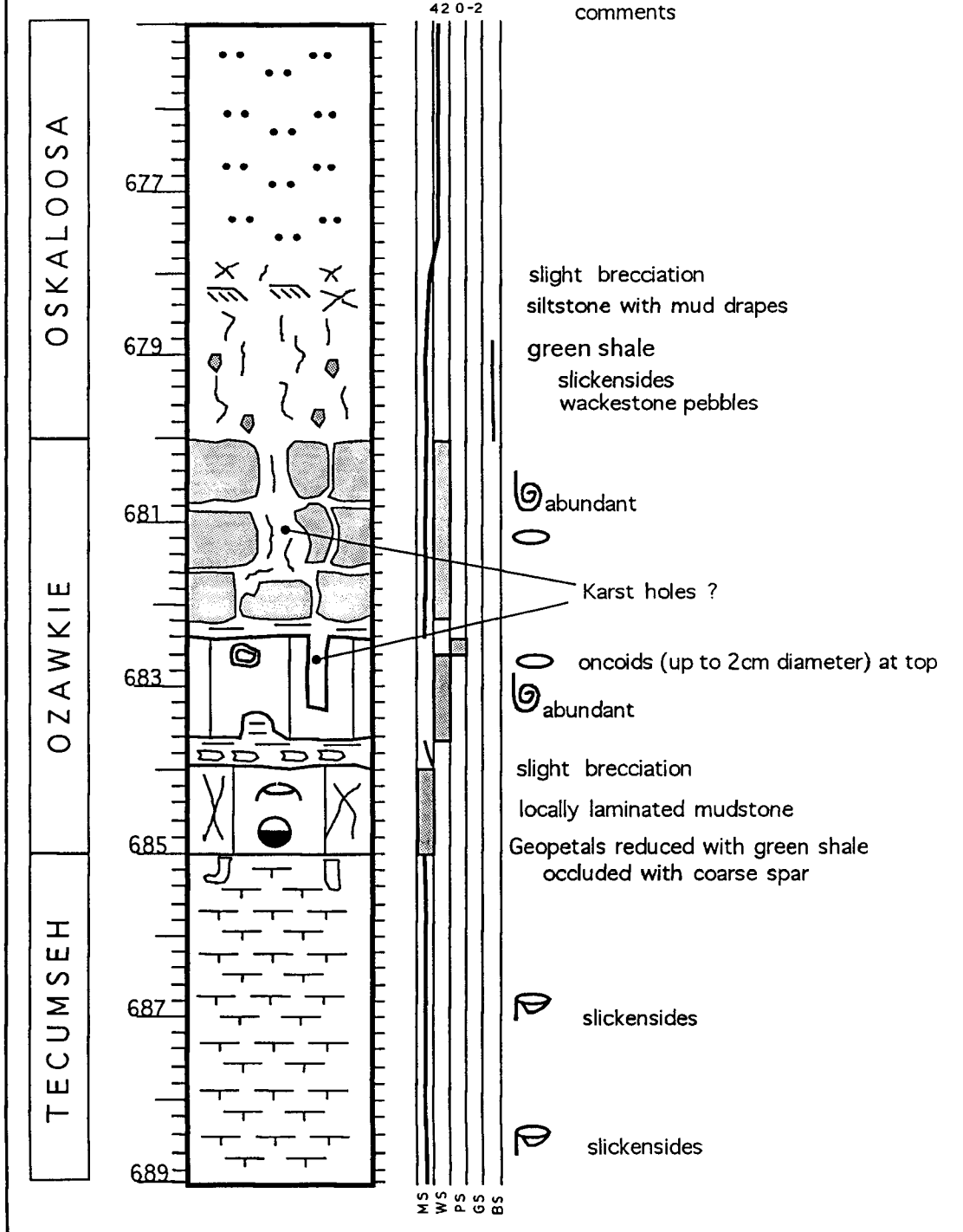
4 2 0-2 comments

MS  
WS  
PS  
GS

MS  
WS  
PS  
GS

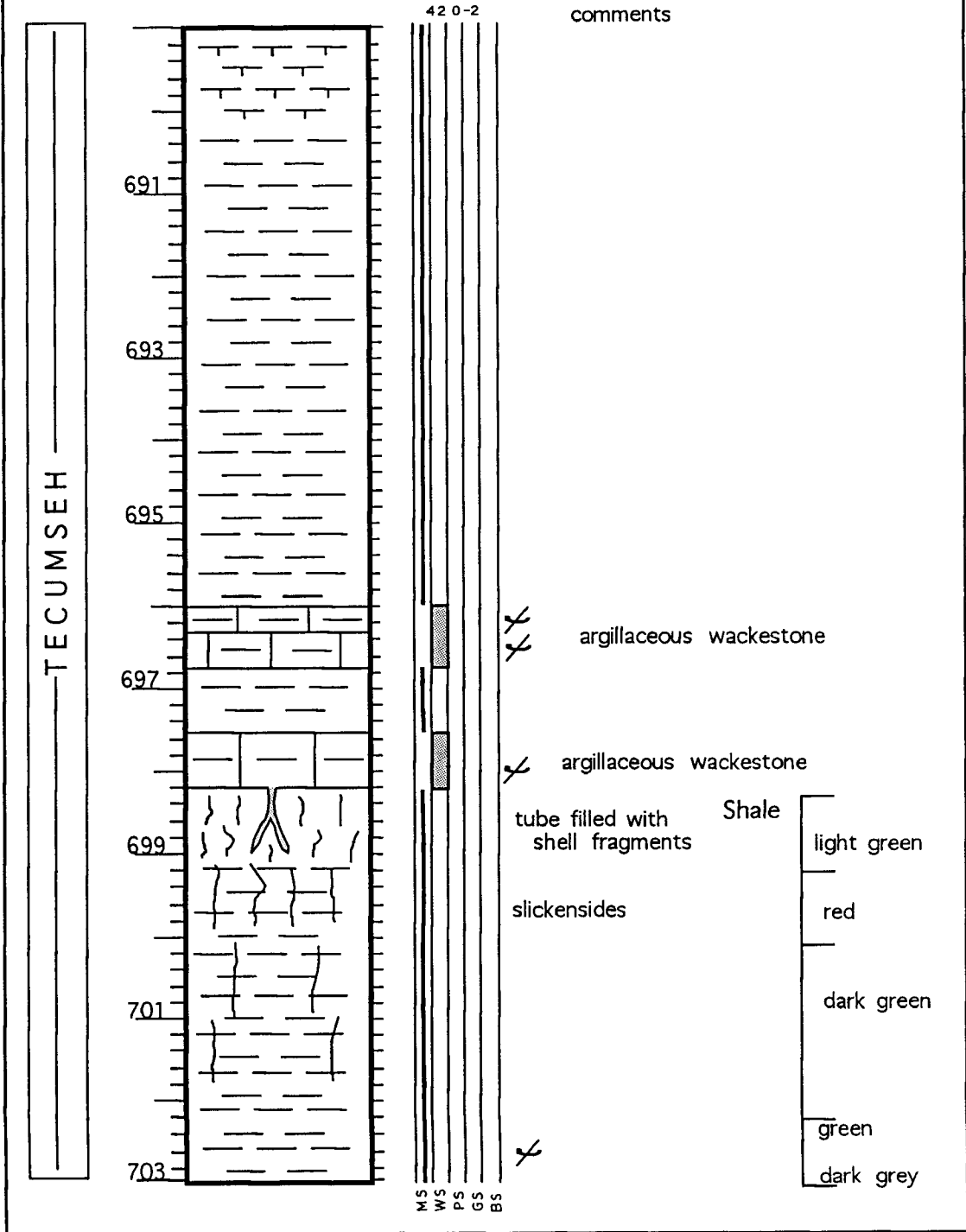
Operator Texas Gulf  
 Lease Joe Spiller 81-1B  
 Location 11 - 3S - 9E

page \_\_\_\_\_  
 depths 675' to 689'  
 feet



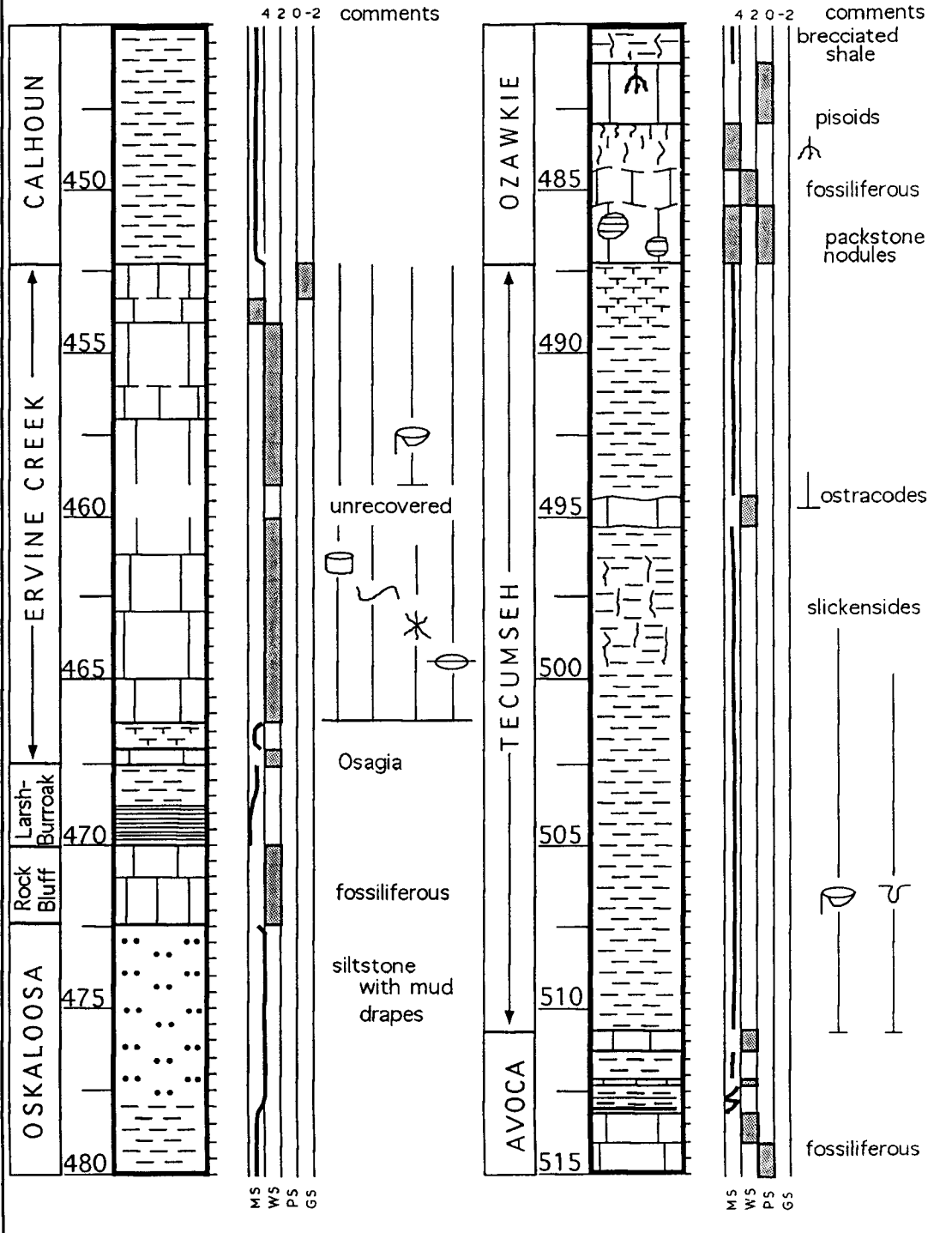
Operator Texas Gulf  
 Lease Joe Spiller 81-1B  
 Location 11 - 3S - 9E

page \_\_\_\_\_  
 depths 689' to 703'  
 feet



Operator Houston Oil and Mineral  
 Lease #1 Bail  
 Location 33 - 2S - 11E

feet depths 445' to 515'  
 page \_\_\_\_\_



Operator Houston Oil and Mineral

page \_\_\_\_\_

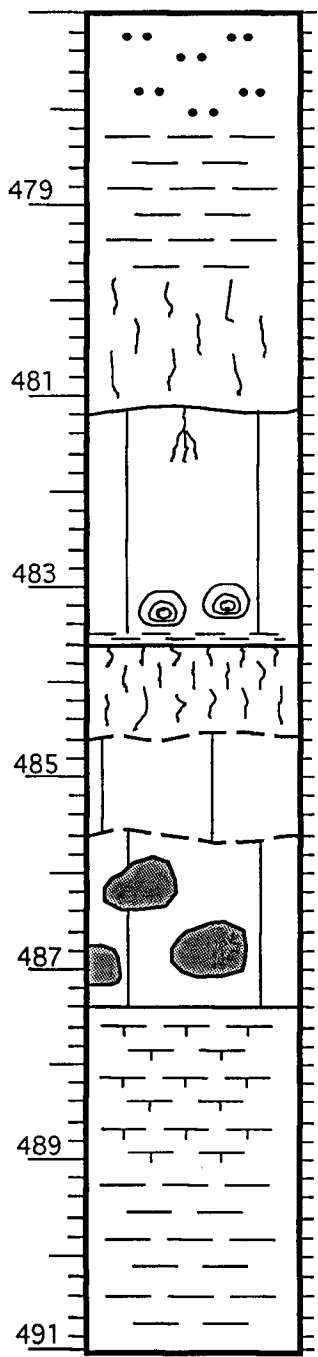
Lease #1 Bail

depths 477' to 491'

Location 33 - 2S - 11E

feet

OSKALOOSA  
OZAWKIE  
TECUMSEH



comments

grey siltstone with mud drapes

grey shale

shale  
green, brecciated  
slickensided

rhizolith (0.5 cm in diameter)

packstone  
fine-grained  
abundant foraminifera

pisoids (up to 3 cm in diameter)

shale break (green)



shale break (green)

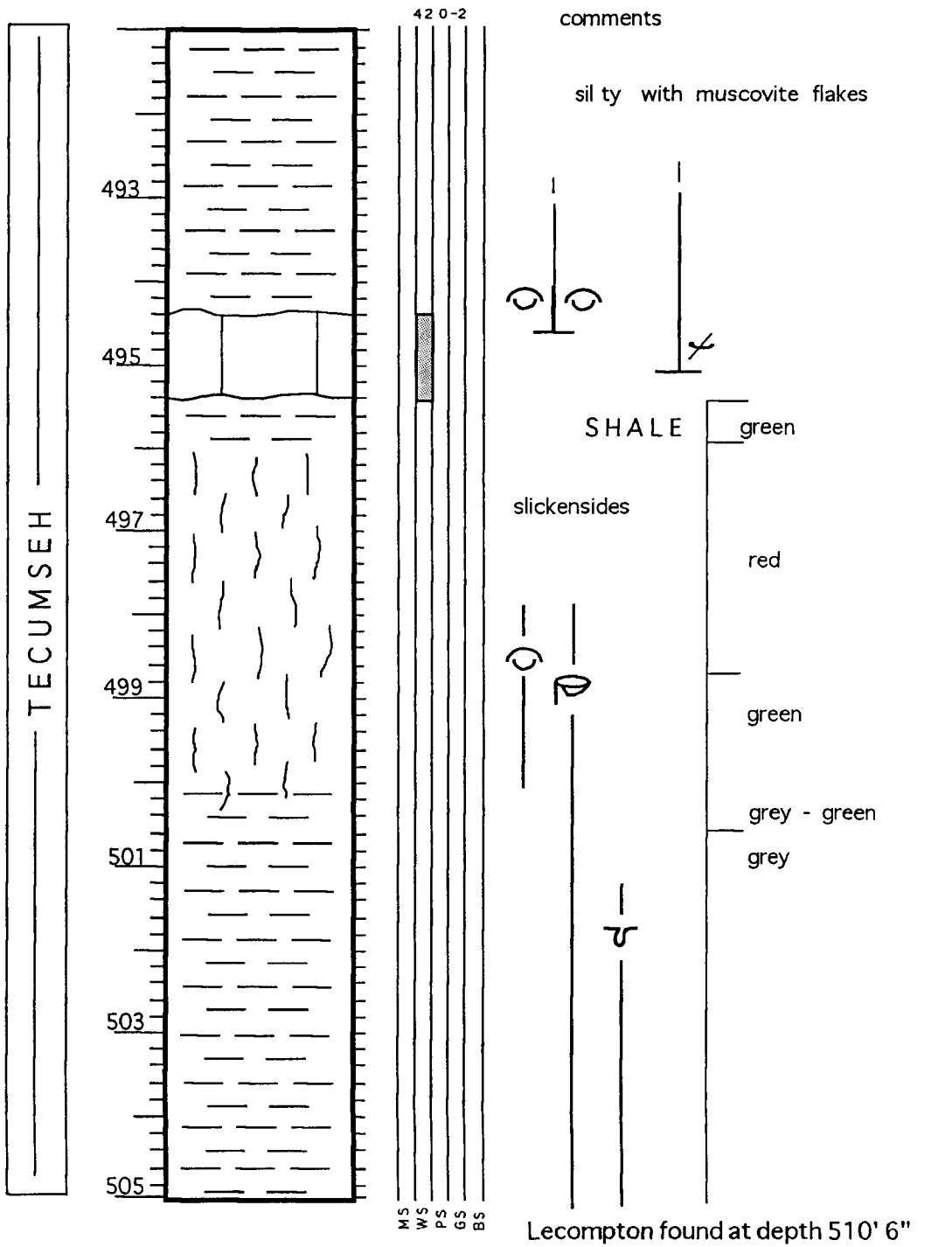
coated packstone burrow-fill  
bedding



shale  
silty with muscovite flakes

Operator Houston Oil and Mineral  
 Lease #1 Bail  
 Location 33 - 2S - 11E

page \_\_\_\_\_  
 depths 491' to 505'  
 feet



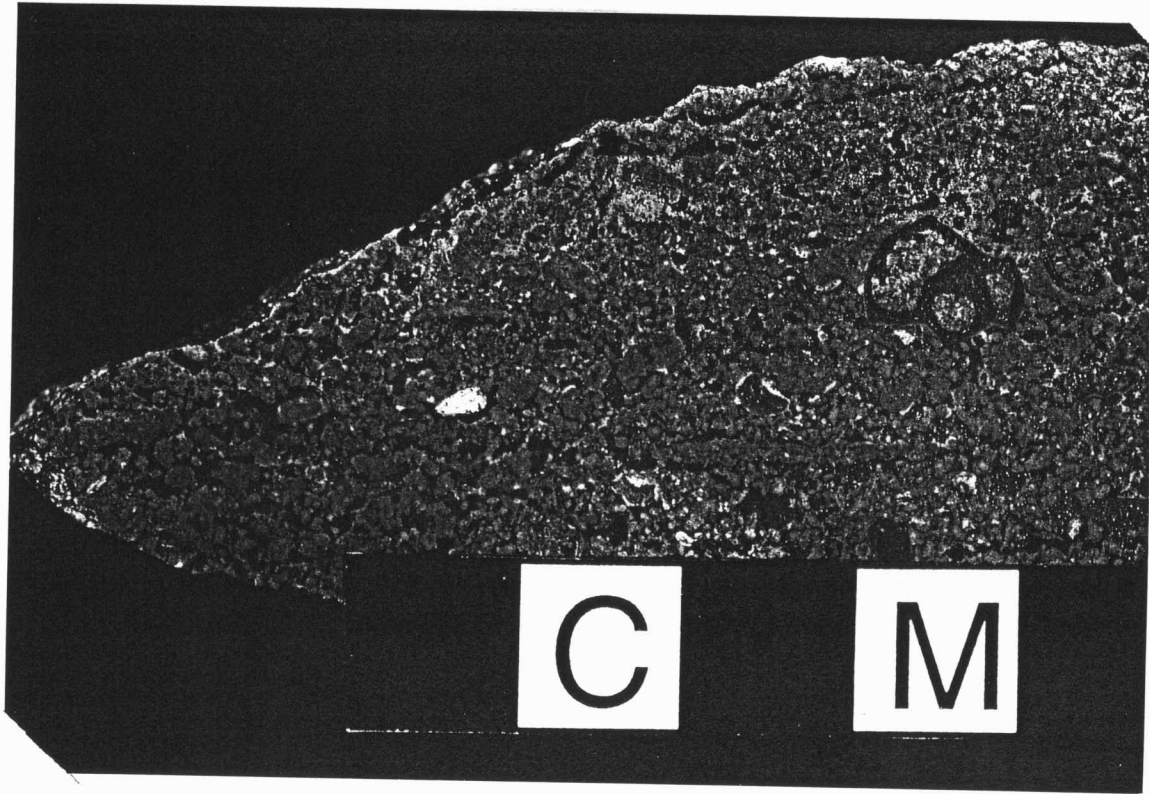


Photo 1. Photograph of fenestral porosity and brecciated fabric within the Ozawkie Limestone at Locality AT3.

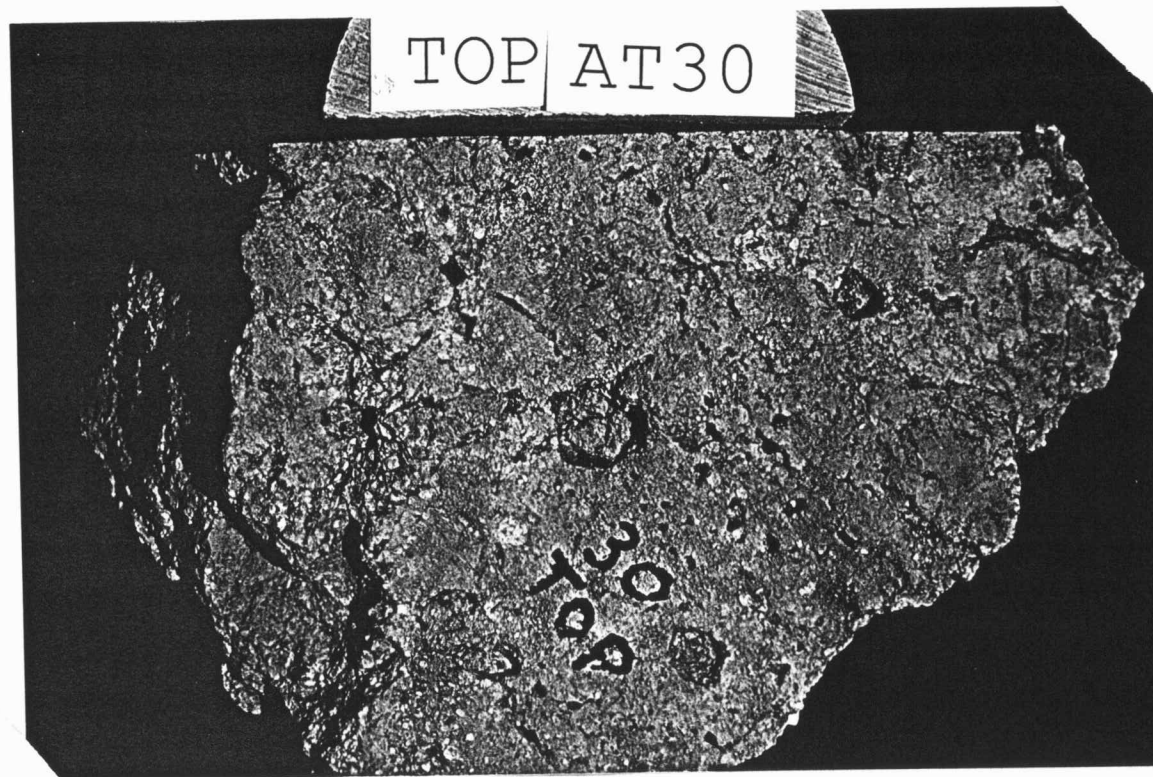


Photo 2. Rhizocasts present on the top of the upper Ozawkie at AT30  
Lettering is 1 cm high.

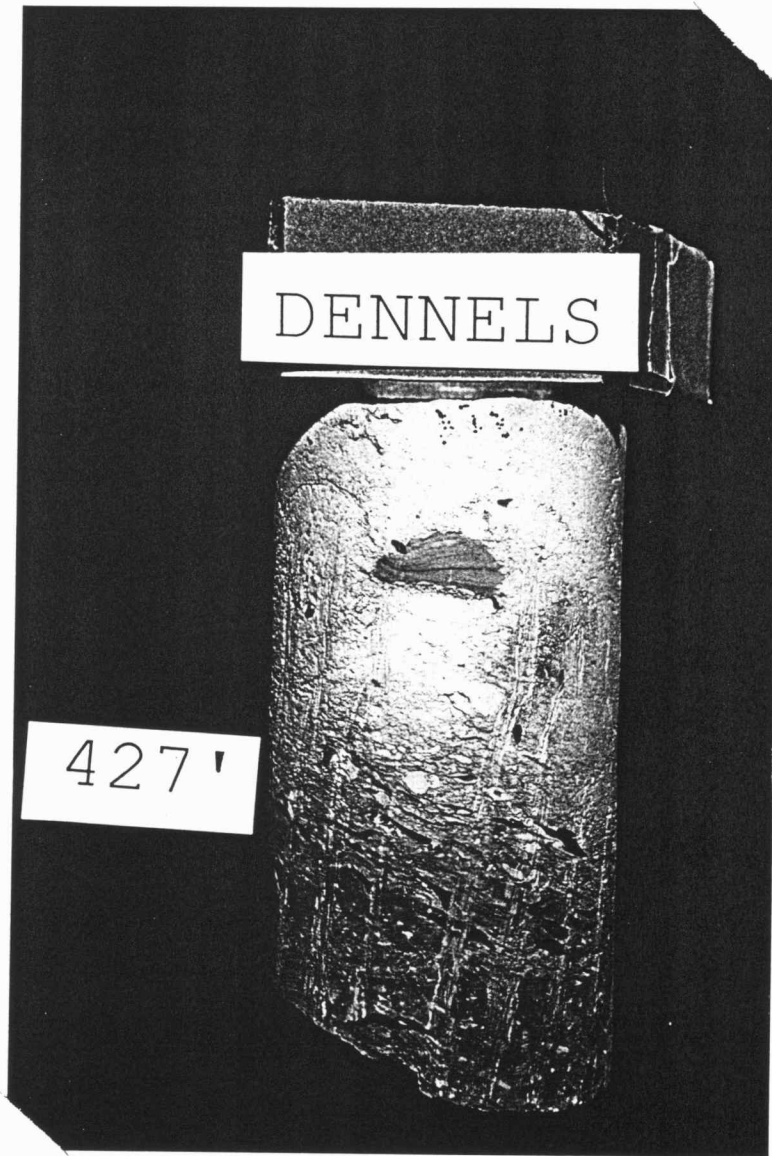


Photo 3. Photograph of laminated shale in a karst hole in the upper Ozawkie, and the flat-shale pebble conglomerate that separates the upper and lower Ozawkie. Lettering is 1 cm high.

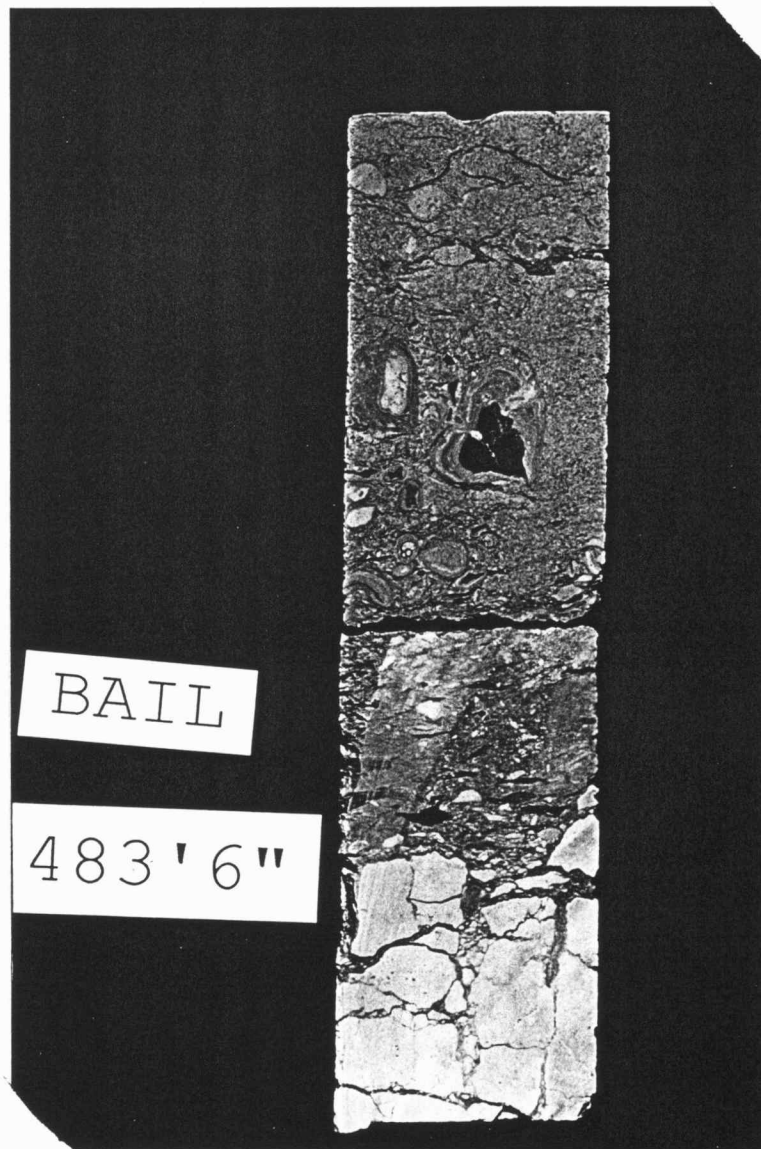


Photo 4. Oncoids at the base of the upper Ozawkie, above the conglomerate, in the Bail core. Lettering is 1 cm high.

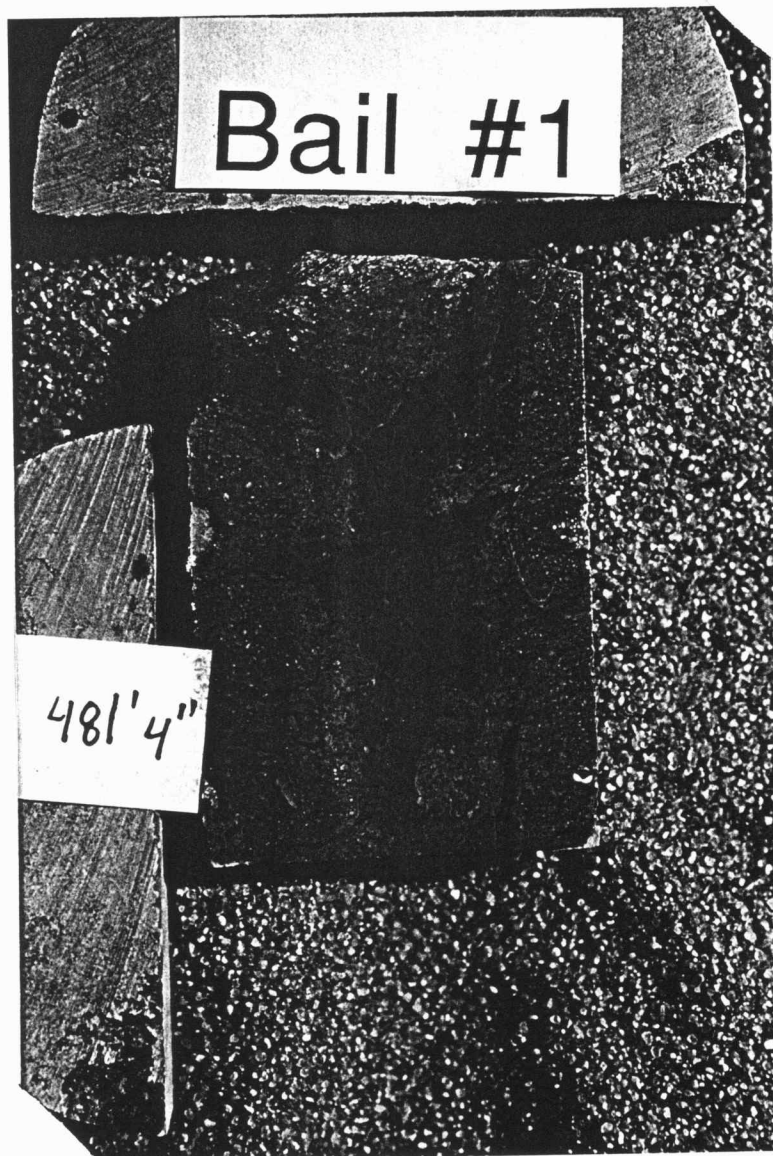


Photo 5. Potential rhizolith in the uppermost Ozawkie in the Bail core.  
Photographed wet. Lettering is 1 cm high.

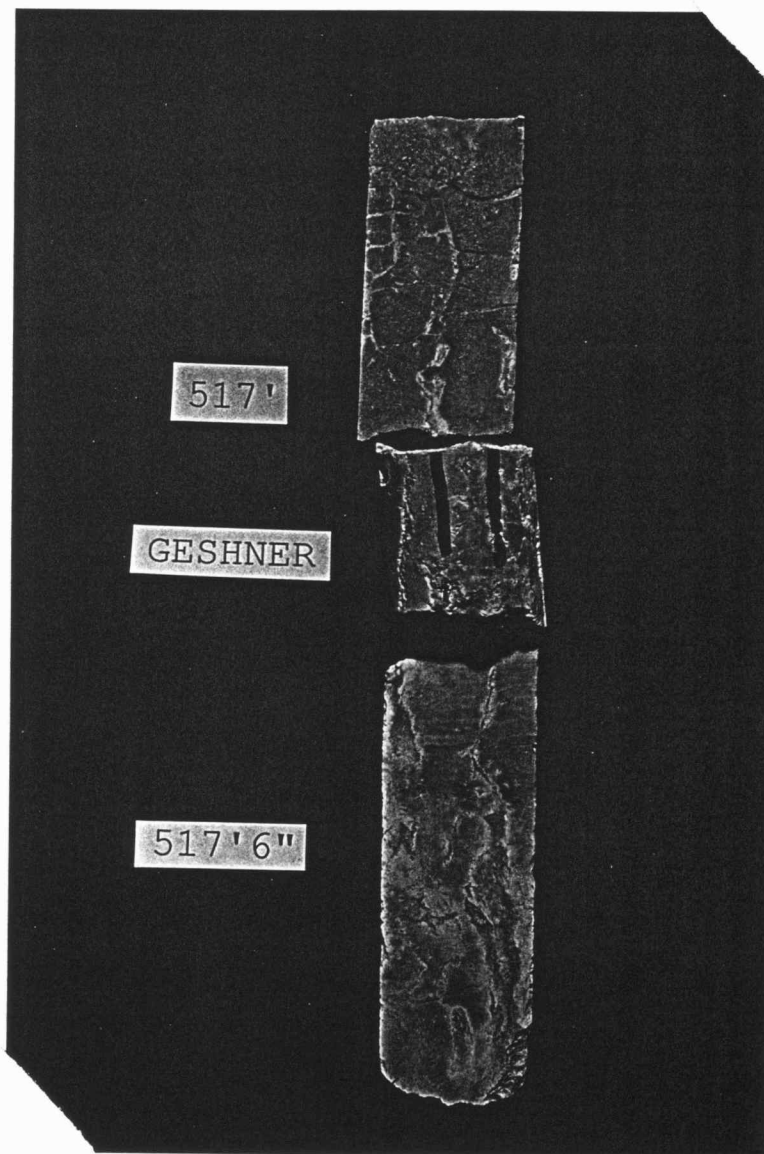


Photo 6. Potential rhizocasts in the lower Ozawkie in the Geshner core. Lettering is 1 cm high.

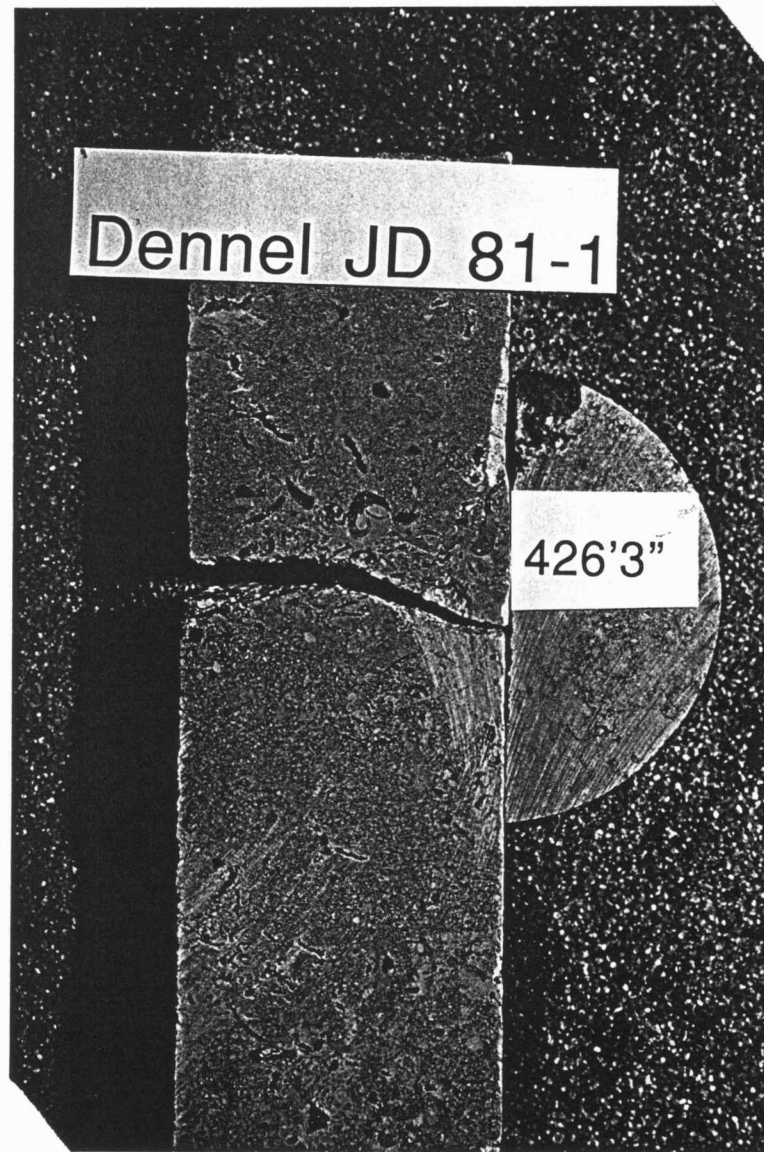


Photo 7. Moldic porosity reduced by green mud from above and occluded by spar cement in the upper Ozawkie in the Dennels core. Lettering is 1 cm high.

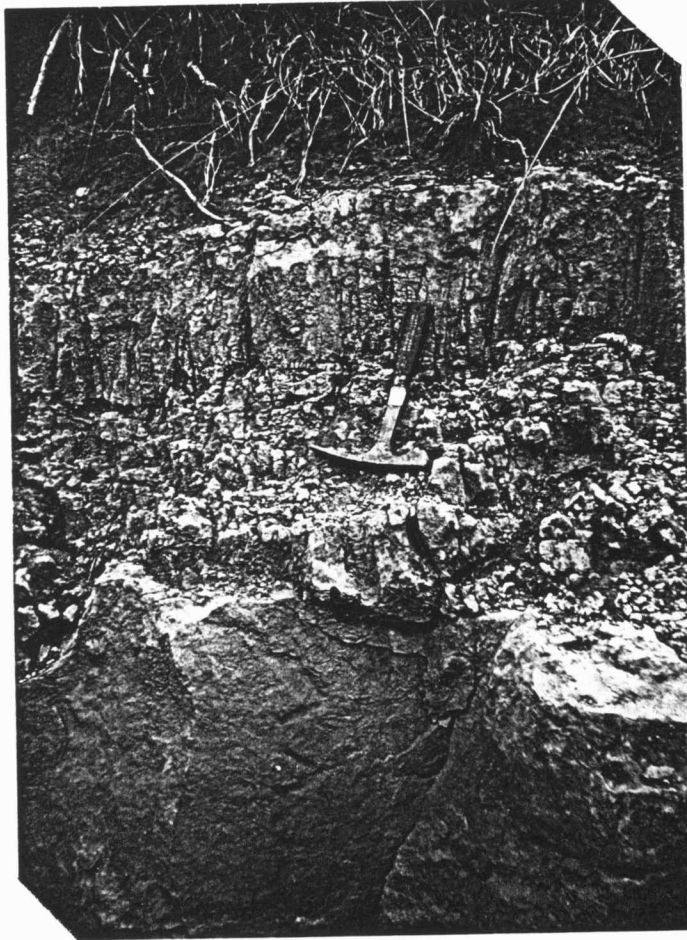


Photo 8. Photograph of prismatic columns capping the Ozawkie Limestone at DG12. Hammer is 30 cm long.



Photo 9. Photograph of middle floatstone at Locality JF5. Clasts can be fitted back together within the scale of the outcrop. Hammer is 30 cm long.

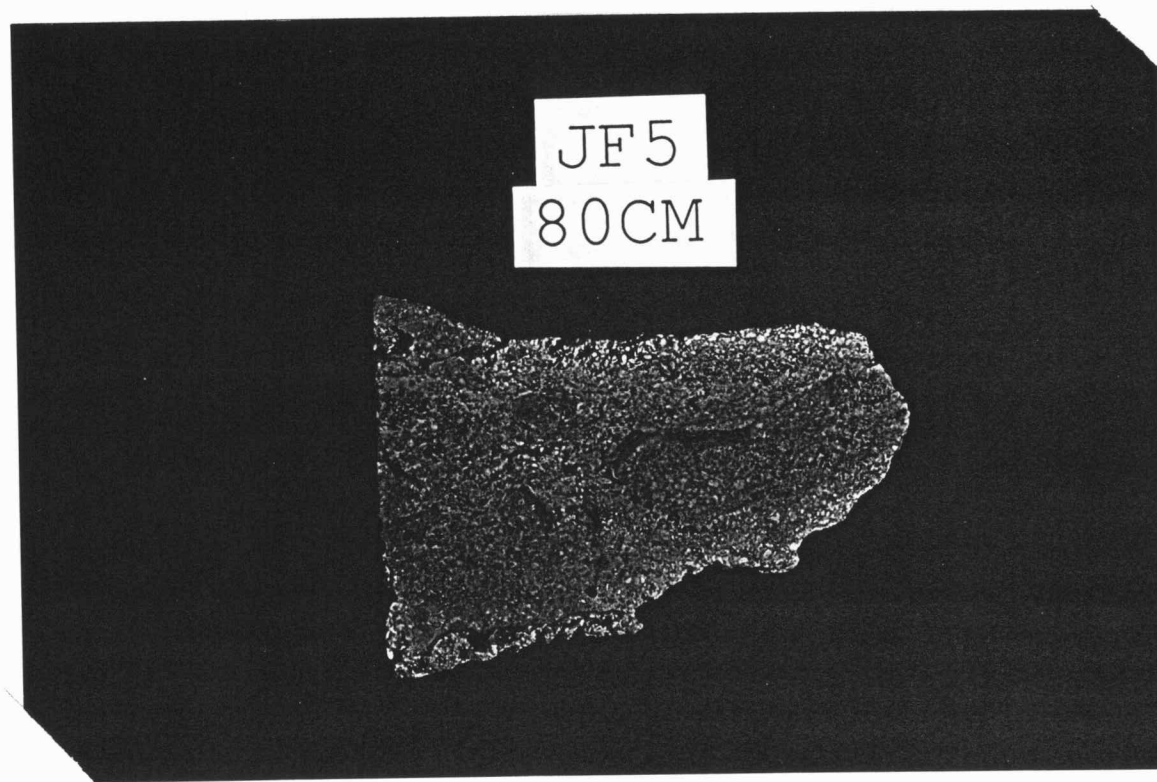


Photo 10. Clasts of a reworked micrite crust in the lower Ozawkie at JF5. Lettering is 1 cm high.

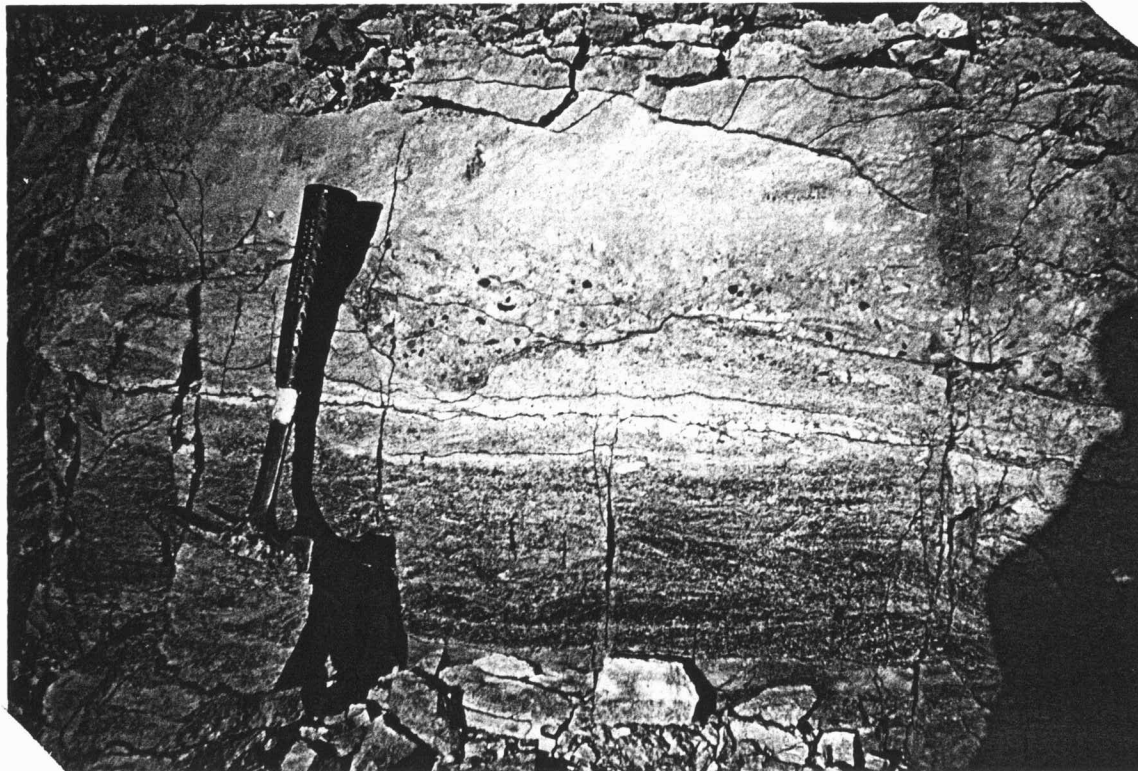


Photo 11. Photograph of the upper conglomerate (handle) at JF1 cutting down into the upper cross-bedded coated grainstone (head). Also visible are two mud lenses at the top of the grainstone where foraminifera abundance increases dramatically. Hammer is 30 cm long.

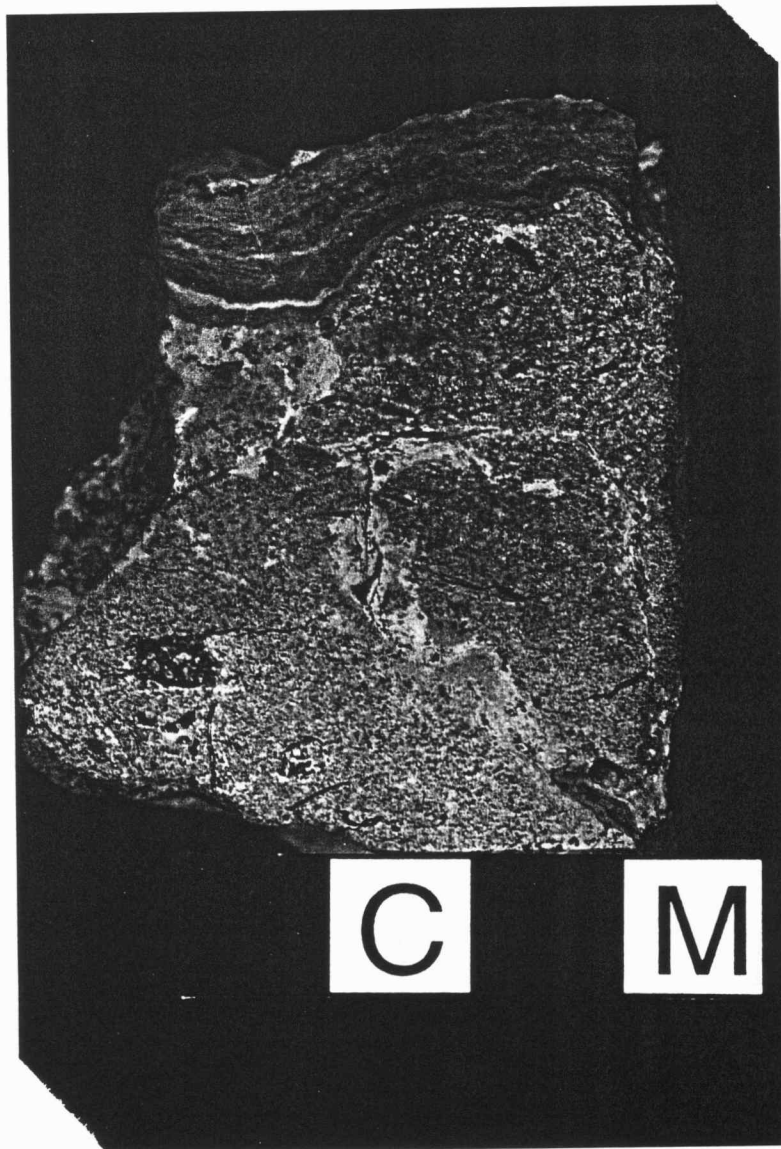


Photo 12. Photograph of laminated crust and root tubes capping the upper packstone at Locality DG7.

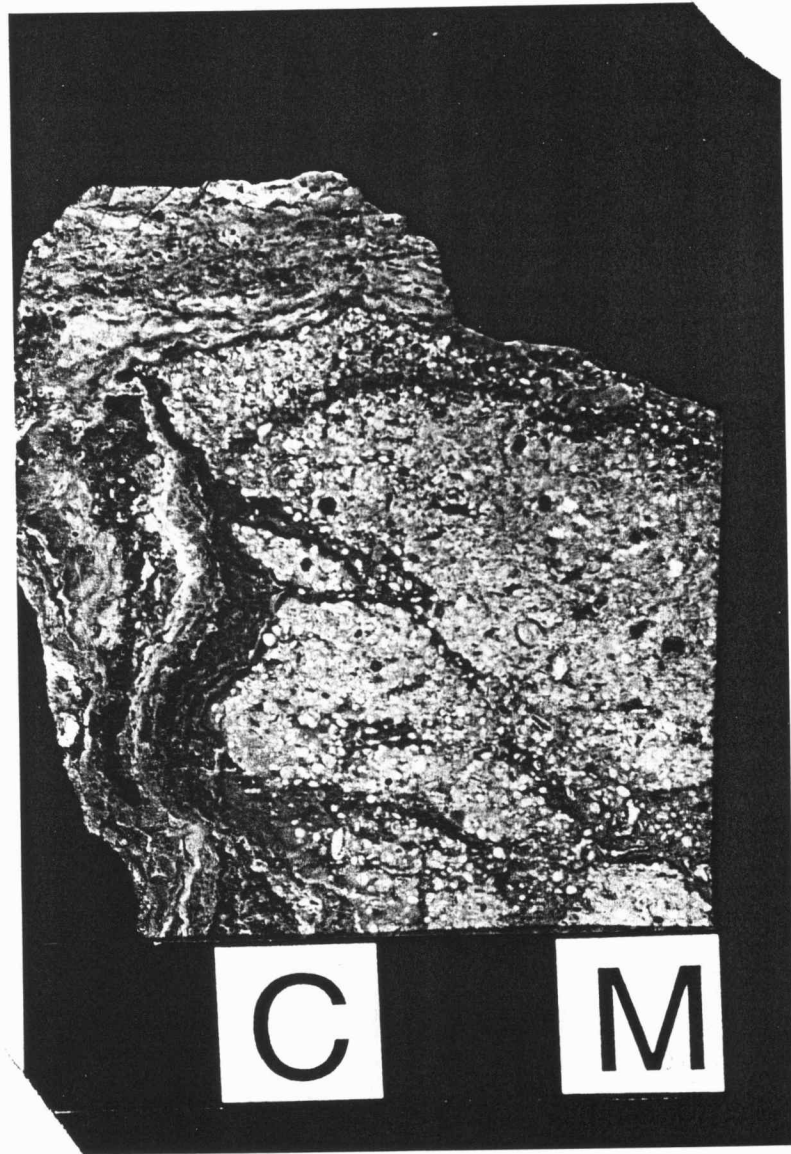


Photo 13. Photograph of two laminated crusts and root tubes in the upper floatstone at Locality DG12. Note that the upper crust is horizontal, the second crust is overhanging an edge and vertical like the crust formed in a pit.

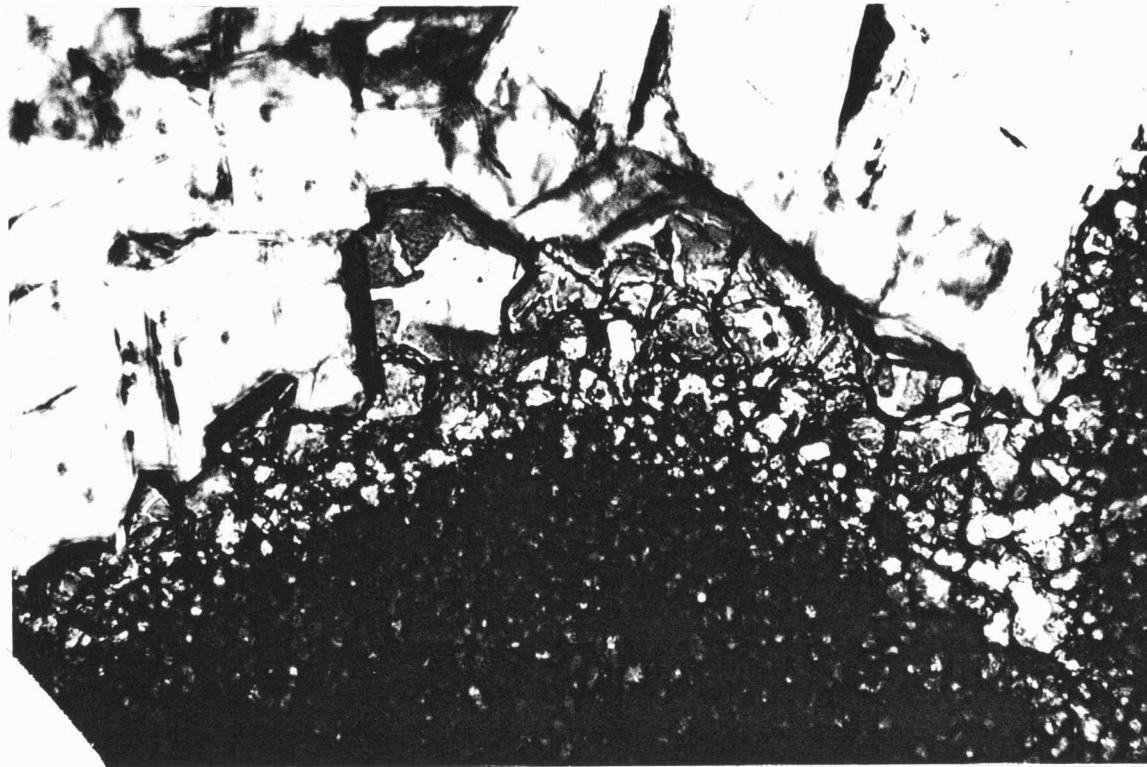


Photo 14. Photograph of cements in middle floatstone at Locality DG12. Distribution of pink, Fe-poor is patchy. Blue Fe-rich cement is mostly continuous around pore. Pore-occluding cement is dolomite. Width of photo is approximately 0.75mm.

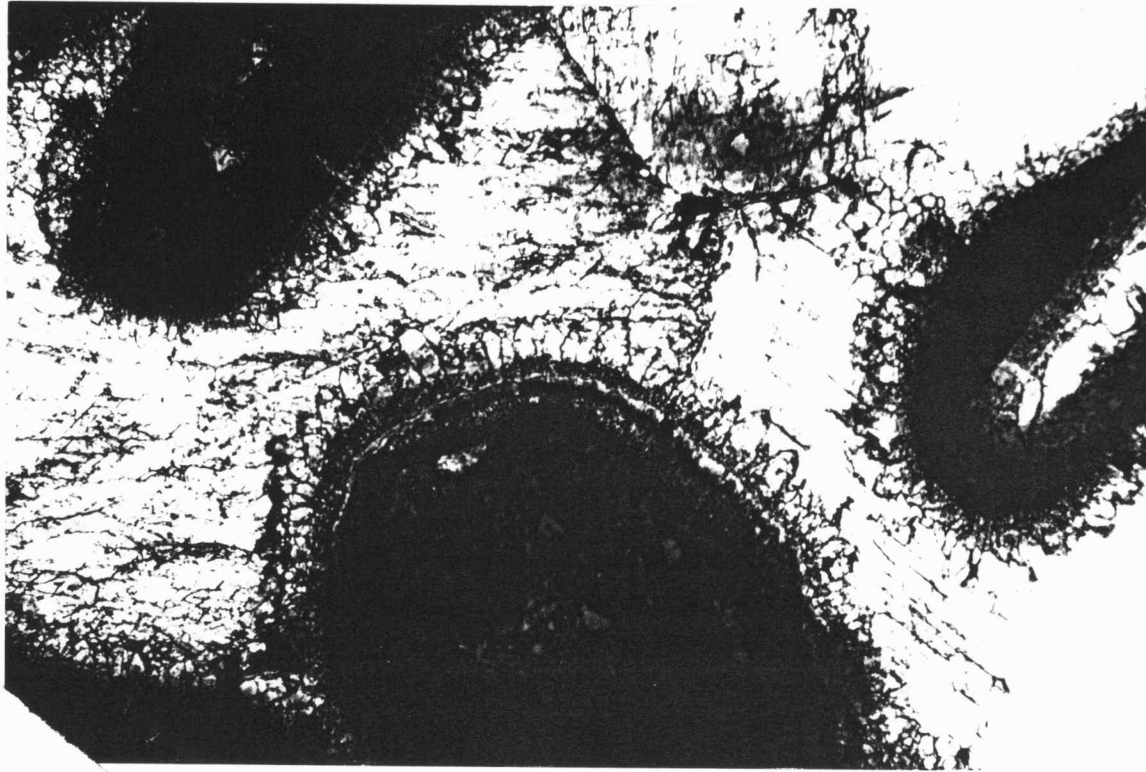


Photo 15. Photograph of five cement zones in the cement of the lower grainstone of the Ozawkie at Locality DG12. Width of photo is approximately 1 mm. Blotchy appearance of grain interiors created during the staining process.