KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 99-2

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

by

S.T. Franklin

Kansas Geological Survey
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047-3726

To the KGS
Thank you for some wonderful, productive years. Stephen T. Franklin

"Stratigraphy and Diagenesis of the Ozawkie Limestone (Pennsylvanian, Virgilian) in Northeastern Kansas"

by Stephen T. Franklin
B.S. University of Wisconsin-Oshkosh 1992

to be submitted in partial fulfillment
of the requirements for the degree
of Masters of Science

Advisory Committee

Paul Enos
(chair)

[illegible]

[illegible]

date issued ______________

date approved ______________

approval for department ______________

ABSTRACT

The Ozawkie Limestone Member, the lower limestone of the Deer Creek Formation (Pennsylvanian, Virgilian, Shawnee Group), consists of two limestone layers separated by shale in the central and southern Kansas outcrop belt, but contiguous further north. The lower layer of the Ozawkie in Osage County (southern area) is a fusulinid wackestone. The upper layer is a very fine packstone. In Shawnee, Douglas, and Jefferson Counties (central area), both layers are coated grainstones to packstones. In Atchison and Doniphan Counties (northern area), the Ozawkie is a packstone or, rarely, a grainstone with coated grains, micrite intraclasts, and fenestral porosity. In general, each layer of the Ozawkie represents a northward-shallowing sequence. The southern area represent deposits from a quiet, subtidal sea; the central area represents an agitated, shallow subtidal setting; and the northern area represents a shallow, restricted setting.

The Ozawkie was deposited during two episodes of transgression and regression. Laminated micrite crusts, rhizocasts and rhizoliths, prismatic columns, and microkarst cap each layer of the Ozawkie at most exposures. These features indicate subaerial exposure during each regression. Subaerial features capping the lower layer are less developed and less extensive areally suggesting that the first regression was not as extensive as the second. The shoreline was probably located in north Osage County, Kansas, during the first regression, and south of the study area during the second maximum regression. An earlier episode of exposure is near the top of the Tecumseh Shale, prior to the first Ozawkie transgression.

Three diagenetic facies are identified in the Ozawkie. Facies A marks the lower Ozawkie in the southern area where burial diagenesis dominated. Facies B, the bulk of the Ozawkie, was significantly impacted by early meteoric diagenesis. Facies C occurs in the uppermost centimeters of each layer and reflects subaerial exposure with freshwater vadose zone diagenesis. The Ozawkie incorporates diagenetic aspects of both middle and upper limestones and could be considered, diagenetically, a mini-cyclothem.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

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 cyclothems. The Ozawkie Limestone is generally described as a brown-weathering limestone with locally abundant ooids and fusulinids (Moore, 1936; Zeller, 1968) and crops out from southeastern Nebraska and southwestern Iowa to southern Kansas (Fig. 2) and possibly into Oklahoma. South of Coffey County, Kansas, correlations become difficult due to the apparent splitting of the Ozawkie Limestone and the thickening of an intervening shale (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 varied lithologies of the Ozawkie Limestone in northeastern Kansas to unravel the different depositional environments represented, to examine the diagenesis of the Ozawkie, and to elucidate the sea-level history during Ozawkie Limestone deposition. Particularly relevant to diagenetic and sea-level history are exposure surfaces reported by Robb (1990) and Robb and Michnick (1991) which were documented in more detail and placed in depositional context. This study has applications for other lower limestones and furthers our understanding of a dominant feature of Kansas Pennsylvanian geology, the cyclothem.

Cyclothems present some interesting geological problems. More than 100 cyclothems have been recognized in the Pennsylvanian and Lower Permian rocks of Kansas (Moore, 1964). Some individual members can be laterally traced hundreds of kilometers showing very little facies change (Moore, 1936; Zeller, 1968; and Troell, 1969). Geological process that could account for these observations remain enigmatic.

Moore (1964, p. 291) provides a practical framework for what constitutes a cyclothem: "Inherent in concepts of cyclic sedimentation is repetition of various

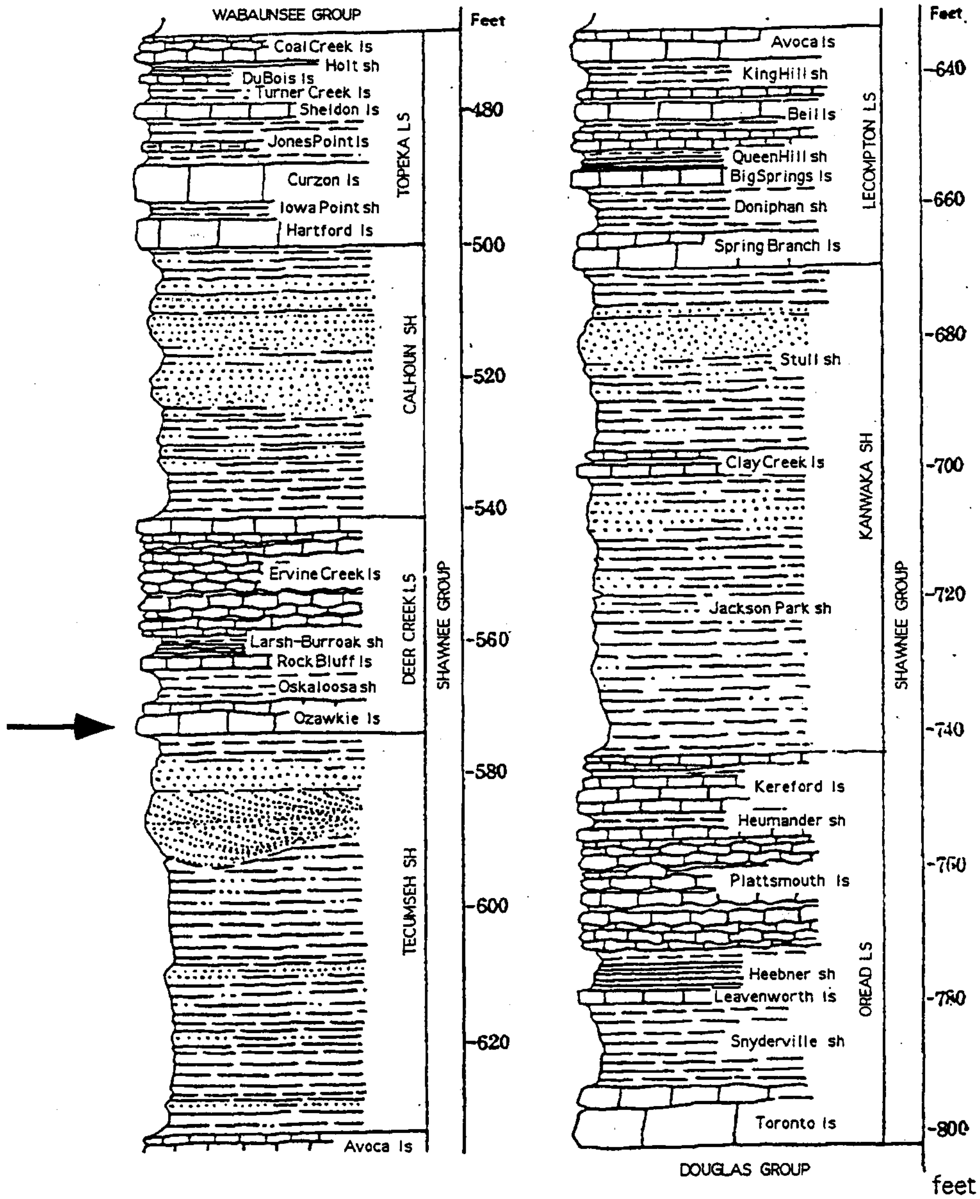


Figure 1. Generalized stratigraphic section of the Shawnee Group (Upper Pennsylvanian, Virgilian) of Kansas showing the Deer Creek Formation and the Ozawkie Limestone (arrow).
(modified from Moore et. al. 1949)

Figure 2.

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

Legend

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

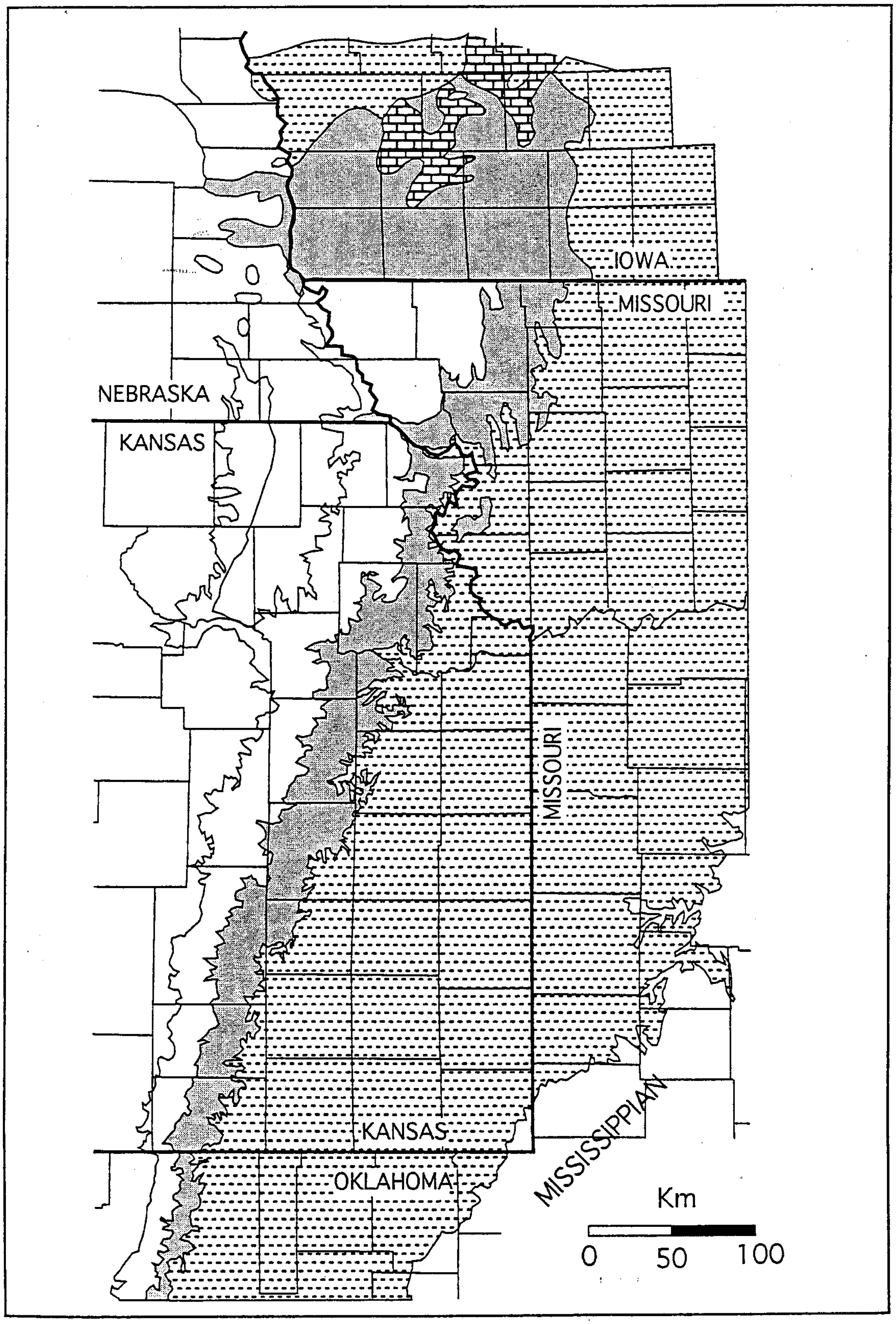
- Permian
- Post-Shawnee (Pennsylvanian)
- Shawnee Group (note: Deer Creek in middle)
- Pre-Shawnee

Iowa (from Preliminary Geologic Map of Iowa)

- Cretaceous
- Virgilian (includes Shawnee Group)
- Missourian

Nebraska

- Pennsylvanian (from Reed and Burchett, 1964)


IOWA
MISSOURI
NEBRASKA
KANSAS
MISSOURI
KANSAS
OKLAHOMA
MISSISSIPPIAN
Km
0
50
100

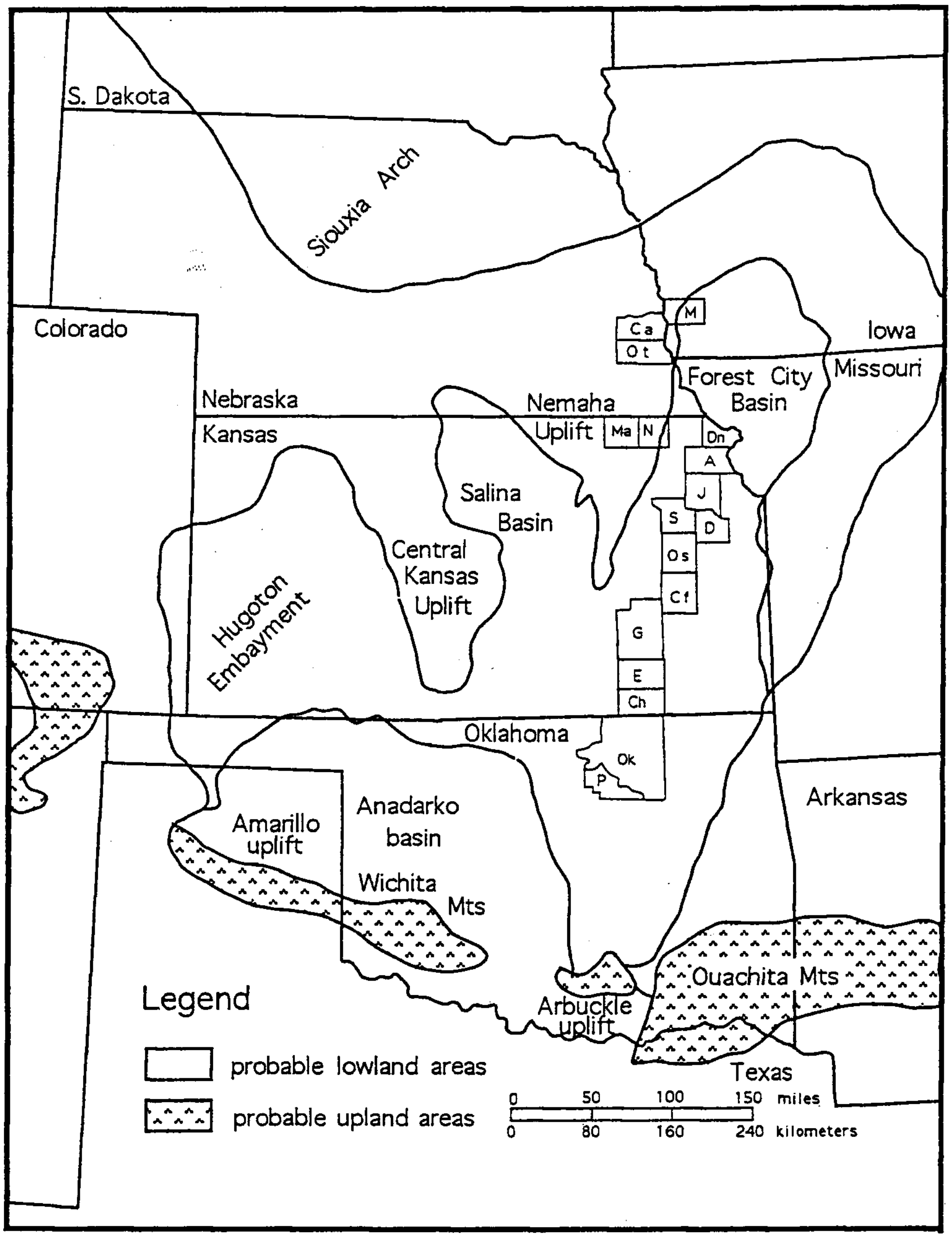


Figure 3. Major features of Kansas and surrounding areas during Virgilian time. (modified from Troell, 1969)

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

kinds of sedimentation in constant order as recorded at any locality. The changes in environments with lapse of time eventually introduced again and again a particular kind of biotope at places where they had existed before." An ideal Missourian cyclothem (Fig. 4) consists of an outside shale, a thin middle limestone, a core shale, and a thicker upper limestone (Heckel, 1980). This sequence is interpreted to represent deposition from a cycle of relative rise and fall of sea level (Heckel, 1980). Moore (1936) used the term megacyclothem for the more complicated Virgilian deposits. An idealized Virgilian megacyclothem consists of lower, middle, upper, and super limestone separated by shales. Virgilian cycles are attributed to some more complex cycles of rise and fall of sea level. Most authors (Moore, 1964; Troell, 1969; Heckel, 1979; Lamoreaux, 1983; Blaine, 1990) consider glacio-eustatic changes in sea level as the most important factor in cyclothem deposition, following Wanless and Shepard (1936). Other factors may exert influence, including amount and rate of terrigenous influx (Lamoreaux, 1983), tectonic movements and rate of basin subsidence (Klein and Kupperman, 1992), and compaction of sediments.

The lateral extent of cyclothems and of individual members or beds within a cyclothem is astonishing. "Many deposits only 10 to 20 inches in average thickness or less than 10 inches in maximum observed thickness have been identified in closely spaced outcrops extending from counties in southeastern Nebraska all the way to northern Oklahoma, and throughout this distance essential uniformity of physical and organic features is maintained." (Moore, 1964, p. 289) Extremely local and/or unique facies are, of course, present in typical cyclothems. The key is that: "Continuity and regularity are the rule, not the exception." (Moore, 1964, p. 289). Documenting facies change in a lower limestone illustrates important exceptions to such generalizations and may provide some clues to cyclothem formation.

Lower limestones are absent in Missourian cyclothems, leading Heckel (1980), who works almost exclusively in the Missourian, to refer to lower limestones as "fortuitous" In the Virgilian megacyclothem (Fig. 4), however, lower limestones

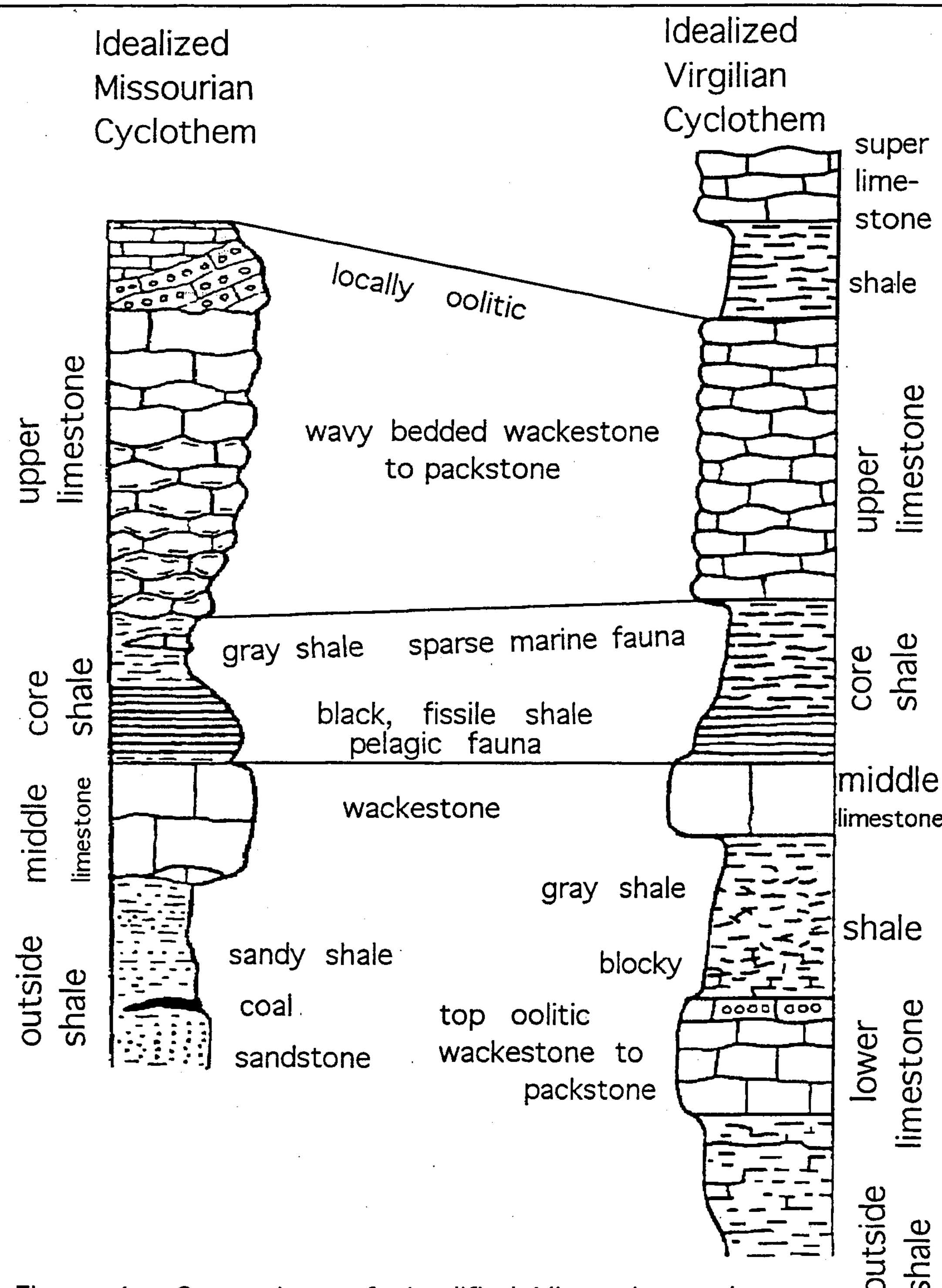


Figure 4. Comparison of simplified Missourian and Virgilian cyclothems. Note the additional, lower limestone in the Virgilian cyclothem.
(stratigraphic columns modified from Heckel et. al, 1978)

are a member of equal standing, present in each of the four megacyclothems. Understanding how lower limestones relate to cyclothem deposition is important in understanding a major variant of Midcontinent Pennsylvanian cyclothems.

Kansas is interpreted to have been an extremely flat platform episodically covered by a shallow, epicontinental (epeiric) sea during the Pennsylvanian (Lee, 1943; Heckel, 1980). Accordingly, even small changes in eustatic sea level could inundate vast areas. Northeastern Kansas was specifically part of the Forest City basin (Fig. 3), which included southeastern Nebraska, northwestern Missouri, and southwestern Iowa. The shoreline was typically in Nebraska or further north during relative sea-level high stands and migrated southward into Kansas during relative sea-level lows (Heckel, 1980). The Nemaha uplift in southeastern Nebraska was the western shoreline at certain times (Fagerstrom and Burchett, 1972), though cyclothems can be traced across this uplift into central Kansas (Moore, 1964). The platform edge was located in southeastern Kansas and northeastern Oklahoma and more open marine water lay to the south.

Troell (1969) was 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 southern Kansas and Oklahoma.

Troell (1969, p. 23) suggested that Toronto deposition was followed by a period of non-deposition, with local incised channels that eroded away the Toronto. Troell (1969, p. 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 overlying Snyderville Shale (Fig. 1), cyclic equivalent of the Oskaloosa Shale, and the upper Lawrence Formation below the Shawnee Group. The Lawrence paleosol is thickest and best developed in Nebraska and thins into Kansas. The thickness of the marine shale between the base of the Toronto and the Lawrence paleosol increases from 0 to 170 cm in Nebraska to 3 to 6 m in northeastern Kansas. This suggests that the Toronto transgression occurred south-to-north and involved an appreciable amount of time in contrast to the rapid transgression suggested by Troell (1969).

The bulk of the Snyderville Shale consists of two welded paleosols in southeastern Nebraska and a single paleosol in northeastern Kansas, but otherwise there was little differential development. A uniform, thin layer of marine shale was deposited upon the paleosol prior to deposition of the Leavenworth Limestone. Little differential development and the uniform thinness of overlying marine shale suggest that the transgression following formation of the Snyderville paleosol transgression was extensive and relatively rapid.

PREVIOUS WORK

Smith (1894, p.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." Moore (1936, p. 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, p. 317) section three miles from

Pawhuska shows 20 ft of limestone total, so the 10 ft must refer only to the quarried limestone bed. Mr. H. C. Hoover went on to become the President of the United States of America.

Bennett (1896, p. 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 ft of limestone [authors note: an unusually thin section], 4 ft of black shale, a 2-ft limestone bed, 10 ft of shale, and 6 ft of limestone.

In 1927, Condra recognized two distinct limestones separated by a black shale, and one thin limestone within the black shale, comprising 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, p. 183) stated, "The correspondence 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.

Moore (1964, p. 317) reported the presence of the Ozawkie Limestone as far south as Chautauqua County (sec. 2-T35S-R9E) in southernmost Kansas and correlated the Deer Creek Formation into northern Oklahoma. Moore identified a limestone at Turkey Run, Oklahoma, (from a section measured by N. D. Newell) as Ozawkie, though the Ozawkie interval was covered over two intervening sections, representing about 50 mi, between Turkey Run and Chautauqua County. Branson (1964, p. 60) showed 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 in (15 cm) thick, separated by about 5 ft (1.6m) of dark shale (Moore, 1936, p. 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, p. 341) defined an ecological 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 robust gastropods, abundant small and medium-sized colonies of Osagia, and a few large, very well-preserved bivalves. Osagia are oncoids, coated grains with crinkly laminations presumably formed by algae (or perhaps bacteria). It was originally named as a distinct fossil genus. Moore attributed this paleobiotope to have lived in marginal parts of a retreating sea. Moore (1964, p. 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." Thus Moore suggested that the lower Ozawkie represented a maximum flooding stage.

Moore (1964, p. 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.

B. A. Dickson (1965) constructed paleo-environmental maps of the Deer Creek members. Due to the stratigraphic thickness involved and the large geographical extent covered, interpretations were necessarily kept simple. The Ozawkie was interpreted simply as "normal marine lime" over most of its range. Interestingly enough, Dickson noted a very small area in northeastern Jefferson County and a second finger in southern Osage and northern Coffey County as "low positive area."

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 arch (equivalent to the Nemaha uplift in Kansas) in Cass County, Nebraska (Fig. 3), which they interpreted as shoreline.

Lamoreaux (1983) examined the Deer Creek Formation from Jefferson County, Kansas, to Chautauqua County, Kansas. He interpreted the entire 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 a fluvio-deltaic deposit (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 overlying Oskaloosa Shale was interpreted to represent sediment influx from the south in excess of the rate of sea-level rise. Thus, the transition from the Ozawkie to Oskaloosa would represent a shoaling, but not a withdrawal of the sea. 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 interpreted as deposits of local high-energy shoal environments and a lenticular lime mudstone to wackestone interpreted as deposits of an open-marine environment. In Jefferson County, they measured an average paleoflow direction of N470E in cross-bedded grainstones with a second mode 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 a"normal marine" deposit. 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 subaerial exposure of the topographically higher oolite shoals. Robb (1991) also reported paleosol development in the top of the underlying Tecumseh Shale in Douglas County and possibly Jefferson County.

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

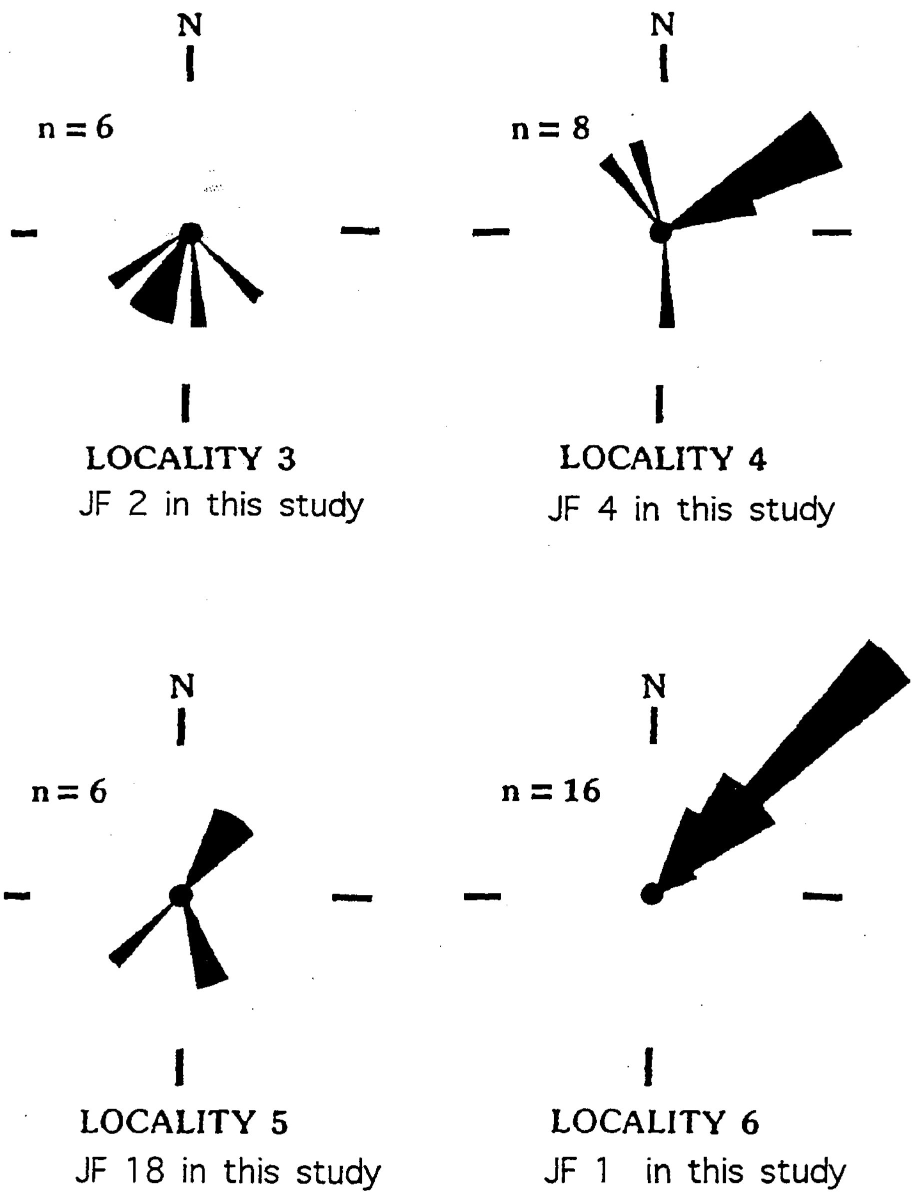


Figure 5. Frequency roses of paleocurrent measurements from the Ozawkie Limestone (Robb and Michnick, 1990).

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, HQ in Fig 6), and the Martin Marietta Aggregates quarry at Big Springs, Kansas (SW1/4, sec 26, T12S, R17E, Douglas County, MMQ in Fig 6). Five cores from the Kansas Geological Survey core facility from Marshall and Nemaha counties, Kansas, that contain the Deer Creek were also examined. All the data from Coffey and Greenwood Counties, Kansas, was collected during a day-long field trip with Chris Maples, then a Kansas Geological Survey researcher, who is 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 Ozawkie typically consists of two limestone units with significantly different lithologies, 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 central area from outcrops of the northern area, where exposures are typically poor, but in general the Ozawkie is two layers of peloidal or coated packstone lithology with a local shale parting.

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,

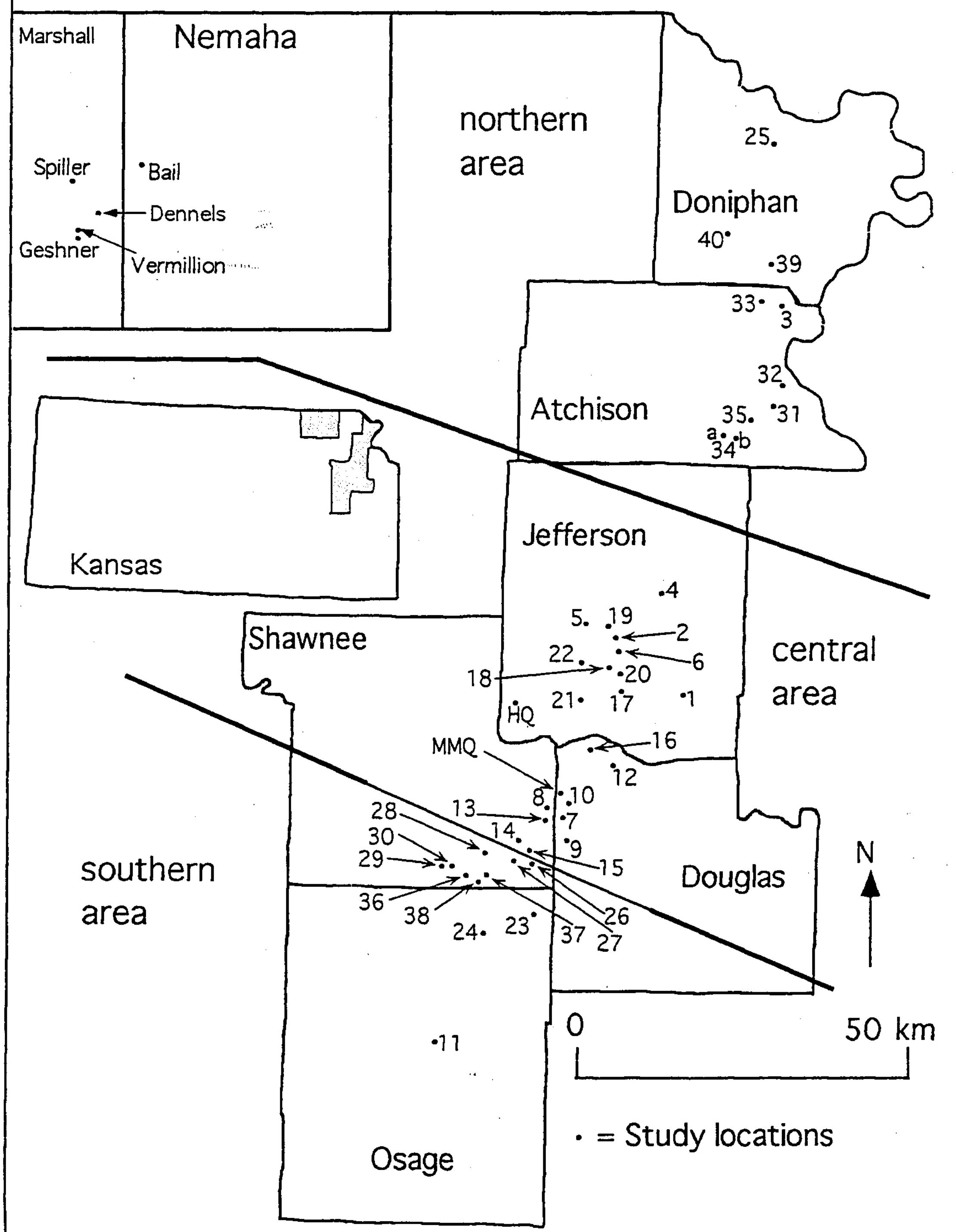


Figure 6. Map of northeastern Kansas showing locations of examined outcrops (numbers), cores (names), and quarries (letters).

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 contoured by hand because the narrow, linear distribution of data points and the outcrop edge precluded effective machine contouring.

FACIES

Avoca Limestone

The Avoca Limestone is the uppermost limestone member of the Lecompton Formation (Fig. 1) and is separated from the Ozawkie by the Tecumseh Shale. The Avoca is a persistent limestone that crops out from southern Nebraska to southern Kansas (Moore, 1936). The Avoca averages about 1 m in thickness and typically is a fusulinid packstone to grainstone. In the southern region, however, the Avoca is a fusulinid wackestone, hence the Avoca looks very similar to the lower fusulinid wackestone of the Ozawkie.

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 thin, rippled, 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; Zeller, 1968). Johnson and Adkison (1967) report crinoid columnals, foraminifers, and ostracodes in the base of the Tecumseh.

In the central area, the top of the Tecumseh is locally red or green, calcareous mudstone, up to a meter thick. Clay slickensides, irregular calcareous nodules (DG12), root casts up to 5 cm in diameter and centimeters in length (JF2), and vague prismatic columns (SH13) are also locally developed. This interval is from 0 to 2 m 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 developed within 3 to 4 m below the base of the Ozawkie. In the Bail core, sparse ostracodes and brachiopod shell fragments are found in the slickensided green shale.

Limestone is found locally within the upper 4m of the Tecumseh. In the southern area, the limestone is a sandy echinoid-clast packstone (OS11) or a lime mudstone with radially-oriented cracks filled with equant spar (SH30). Moore (1964, p. 322) recorded two *Osagia*-rich limestones, 30-cm-thick, separated by siltstone in the upper Tecumseh in Jefferson County. Tecumseh cores from Nemaha and Marshall Counties contain a persistent, argillaceous, fossiliferous wackestone about 30 cm thick capping the slickensided shale, from 3 to 4 m from the base of the Ozawkie. Fossils include crinoid stems, brachiopods, algae, and ostracodes.

The uppermost Tecumseh, above the limestone, is generally grey shale with marine biota. The Tecumseh above the lime mudstone at SH30 contains a rich fauna including crinoid stems (up to 5cm long preserved), brachiopods, ramose, fenestrate, and encrusting bryozoans, echinoids, ostracodes, gastropods, and fusulinids. Johnson and Adkison (1967) reported sparse crinoid columnals, bryozoans, brachiopods, and casts of pelecypods and gastropods in the top of the Tecumseh in Shawnee and adjacent Jefferson Counties. Inarticulate brachiopods, found sparsely throughout the Tecumseh within the Nemaha/Marshall County cores, increase in number above the thin wackestone layer. Sparse ostracodes are also present above the wackestone.

Oskaloosa Shale

The Oskaloosa Shale (Fig. 1), which overlies the Ozawkie, is a brown-grey, calcareous shale. The Oskaloosa is 1 to 4 m thick in northeastern Kansas and thickens to 8m in southern Kansas (Moore, 1936). Channel forms filled with siltstone or shale up to several meters wide and 2 m deep occur within the Oskaloosa (MMQ).

Calcareous shale or argillaceous limestone with well-developed prismatic columns (Buol et. al., 1973) occurs locally at the Ozawkie-Oskaloosa Shale contact in the northern and central areas. This interval is up to 30 cm thick (SH13, DG12, JF1, AT31). It was generally logged as Oskaloosa Shale because an interval of less altered calcareous shale separates it from limestone more characteristic of the Ozawkie.

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 preserved a full 1.5 m above what is coherent Ozawkie and 30 cm above the slickensided shale. Wispy laminae 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), and forms a bed from 30 cm to 1 m thick. The base of the Rock Bluff is irregular owing to large (cm-scale) horizontal burrows, and the top surface is planar. 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. Infauna is represented by pellet-packed burrows and burrow mottling.

Larsh-Burroak Shale

The Larsh-Burroak Shale (Fig. 1) is a typical core shale from 60 cm to 2m thick. At the base is 30 cm of black, fissile shale with conodonts, sparse fish scales, and imprints of fish fins on bedding planes that 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 typical upper limestone. It ranges from 3 to 7 m in thickness except where local erosion, either immediately post-depositional (JF19) or Pleistocene (HQ), has removed a portion of the limestone. The Ervine Creek is a fossiliferous, wavy-bedded wackestone to packstone, greyish orange (10YR 7/4) both weathered and fresh, and is nodular to wavy bedded. The base of the Ervine Creek is commonly flat to slightly wavy and typically contains oncoids up to 3 centimeters in diameter. In the Nemaha/Marshall County cores, the uppermost meter of the Ervine Creek contains thinly-bedded, 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. Chert is lacking in the Ervine Creek, in contrast to the facies-equivalent and otherwise similar Plattsmouth Limestone of the Oread Formation.

Ozawkie Limestone

The Ozawkie ranges up 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 limestone units, either in contact or separated by a southward-thickening shale. Fresh samples of the Ozawkie range from light olive grey (5Y 8/1) to light grey (N7). Weathered samples are approximately dark yellowish orange (10 YR 6/6)

Northern Area

Exposures of the Deer Creek in the northern area are sparse, due to cover by glacial till and loess deposits near the Missouri River, making it difficult to generalize about the Ozawkie Limestone. The Ozawkie is typically composed of two limestone layers. The lower layer is a coarse-grained, coated-grain packstone to peloidal wackestone. Micrite clasts up to 2 cm in diameter (average is 2 mm) are present at AT 3 (Fig. 7). 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 in peloidal wackestone. The top of the lower Ozawkie is very flaggy-bedded where weathered. A calcareous shale, 5 cm thick, locally separates the lower and upper Ozawkie.

The top layer is fine peloidal grainstone to packstone at the base grading upwards to lime mudstone. The base locally contains in-situ brachiopods, burrows, and fenestral pores occluded by spar. The lime mudstone at the top is flaggy-

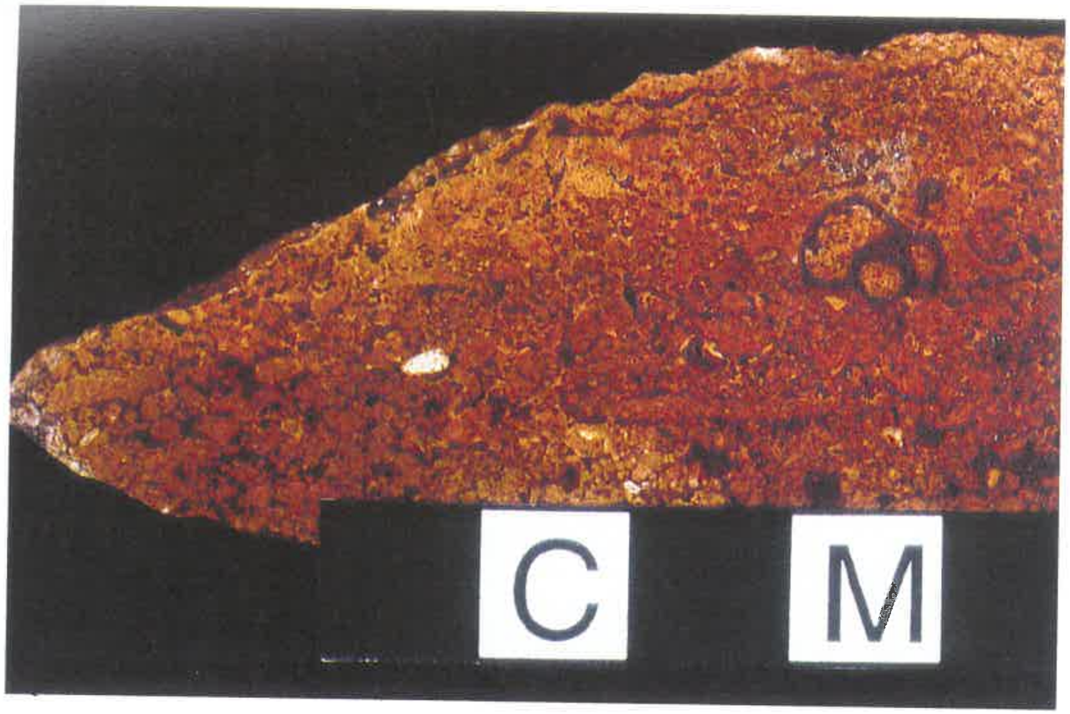


Figure 7. Fenestral fabric in peloidal packstone. Top of lower Ozawkie at Locality AT3.

bedded, displays abundant rhizocasts (Fig. 8), rhizoliths with laminated micrite aureoles, fenestrae, clotted micrite, circumgranular cracks, and vague prismatic columns.

The Ozawkie appears to be absent in southern Atchison County, over an area of about a township. Locales AT 34a, AT 34b, and AT 35 expose normal sections of Ervine Creek, Larsh-Burroak, and Rock Bluff. AT 34a has no hint of Ozawkie or a break in slope indicating a limestone. AT 34b has a visible break in slope where the Ozawkie should be, but no limestone is exposed. AT 35 has no Ozawkie exposed, but some float within the ditch has 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. In adjacent Jefferson County, thick glacial till covers the underlying bedrock.

Nemaha/Marshall County Cores

The Ozawkie is also composed of two limestone layers within cores about 100 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. The base is commonly burrowed and the burrows are filled by a coarse-grained, bedded, coated-skeletal wackestone or packstone. The top of the lower layer has undergone slight in-situ brecciation and contains some probable rhizocasts. Fine, wavy laminae are locally discernible within the mudstone. The wavy laminations are most likely stromatolitic layers that would be continuous across the core except for subsequent brecciation. Overall, a fairly diverse fossil assemblage is present including crinoids, fusulinids and other foraminifera, gastropods, and brachiopods.

Figure 8. Preserved rhizocasts on the upper Ozawkie at Locality AT30.
Bar is 1 cm long.

The lower and upper limestone layers are typically separated by a 5-cm-thick conglomerate of slickensided shale or flat shale pebbles (Fig. 9). 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. Asymmetrically-coated oncoids with intraclast nuclei up to 3 cm in diameter (Bail core) and intraclasts up to 1 cm in diameter with internal bedding have been observed at the base of the upper layer. Foraminifers are very common throughout the upper layer, and near the top typically constitute the dominant fossil. Crinoids and gastropods are also present. The top of the Ozawkie has undergone in-situ brecciation indicated by fractures, and angular, fitted clasts. Lithoclasts 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 the overlying Oskaloosa, are common in the upper Ozawkie (Figs. 10, 11). In the Dennels core, a karst pit several centimeters wide and filled with green shale penetrates to the base of the upper layer (Fig. 9). 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.

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

Figure 9. Laminated shale (arrow) in karst pit at the base of the upper Ozawkie. Bar is 1 cm long.

Figure 10. Probable rhizolith (arrow) in the upper Ozawkie in the Bail core. Bar is 1 cm long.

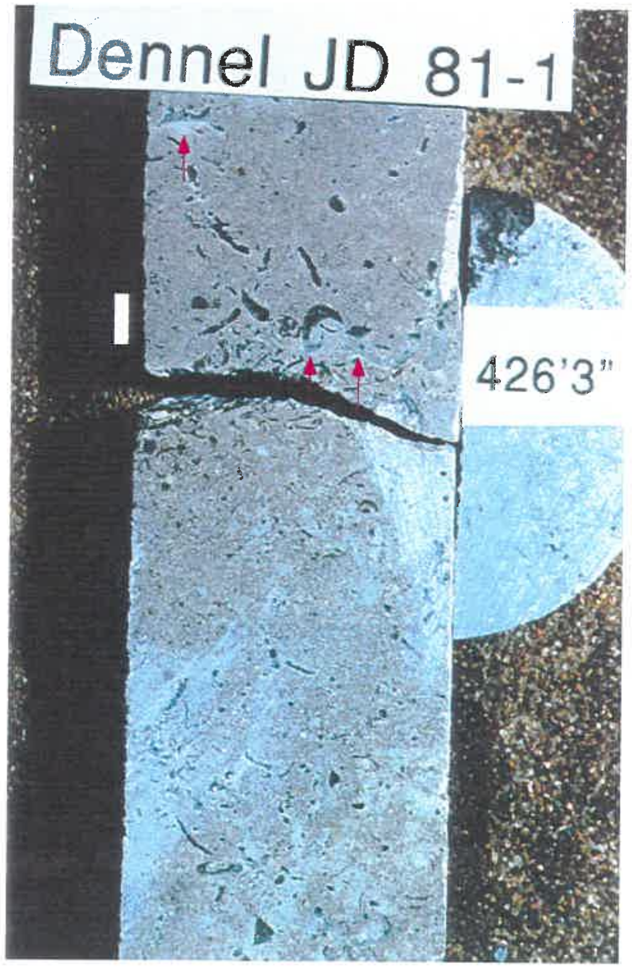


Figure 11. Green, internal sediment fill in moldic porosity (arrows) in the upper Ozawkie. Bar is 1 cm long.

columns (Buol et. al., 1973) up to 30 cm thick, locally overlies the Ozawkie (Fig. 12).

The lower coated grainstone to packstone (1) contains ooids and abundant coated grains, commonly up to 4 mm in size, typically with a whole fossil or bioclast as a nucleus. Coated caliche pebbles, up to 10 mm in diameter, presumably reworked from the top of the Tecumseh Shale, 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. Lime mudstone and ooid wackestone are interbedded at JF1.

Locally, clasts within the middle floatstone (2) can be fitted together suggesting auto-brecciation or at least minimal movement for larger clasts. Irregular lithoclasts with fragments of a thin, laminated, micrite crust are now randomly oriented at JF5 (Fig. 13). At JF18, a packstone lithoclast with a laminated micrite crust is well rounded suggesting significant transport.

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. Clast size ranges up to 20 cm in diameter, and at localities JF1 and JF20 the coarser clasts are concentrated near the top. The matrix of these floatstones tends to be muddy. The contact between the floatstone and the underlying coated grainstone appears erosional with locally up to 15 cm of relief.

Within both the middle and upper floatstones are laminated crusts, rhizocasts and rhizoliths, sheetcracks, circumgranular cracks, and solution pipes (Figs.14, 15). The crusts are up to several centimeters thick and consist of fine, wavy laminae.

Figure 12. Prismatic columns capping the upper Ozawkie at Locality DG12. Hammer is 30 cm long.

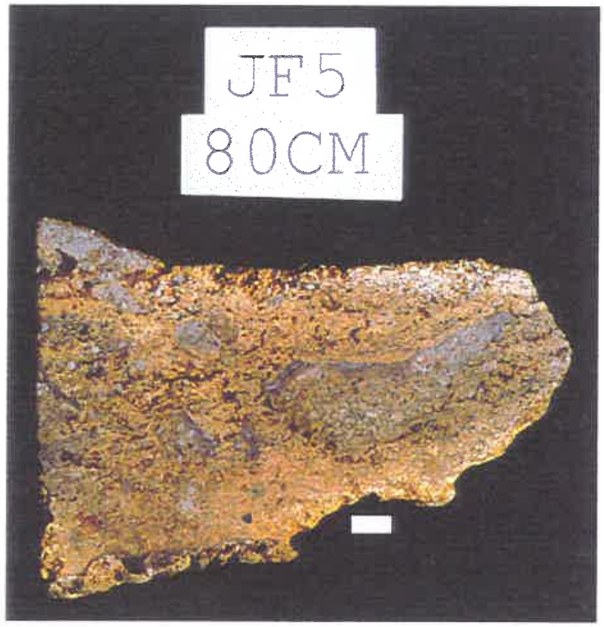


Figure 13. Reworked clasts with a laminated micrite crust at the top of the lower Ozawkie. Bar is 1 cm long.

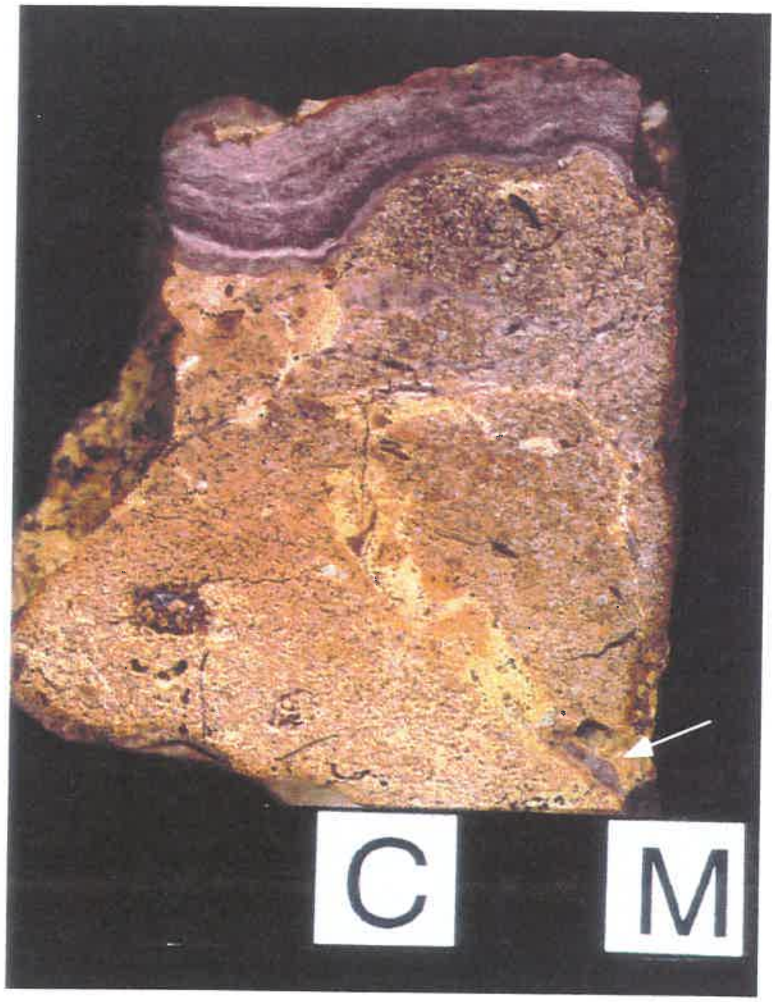


Figure 14. Laminated crust and root tubes (arrow) capping the upper Ozawkie at Locality DG7.

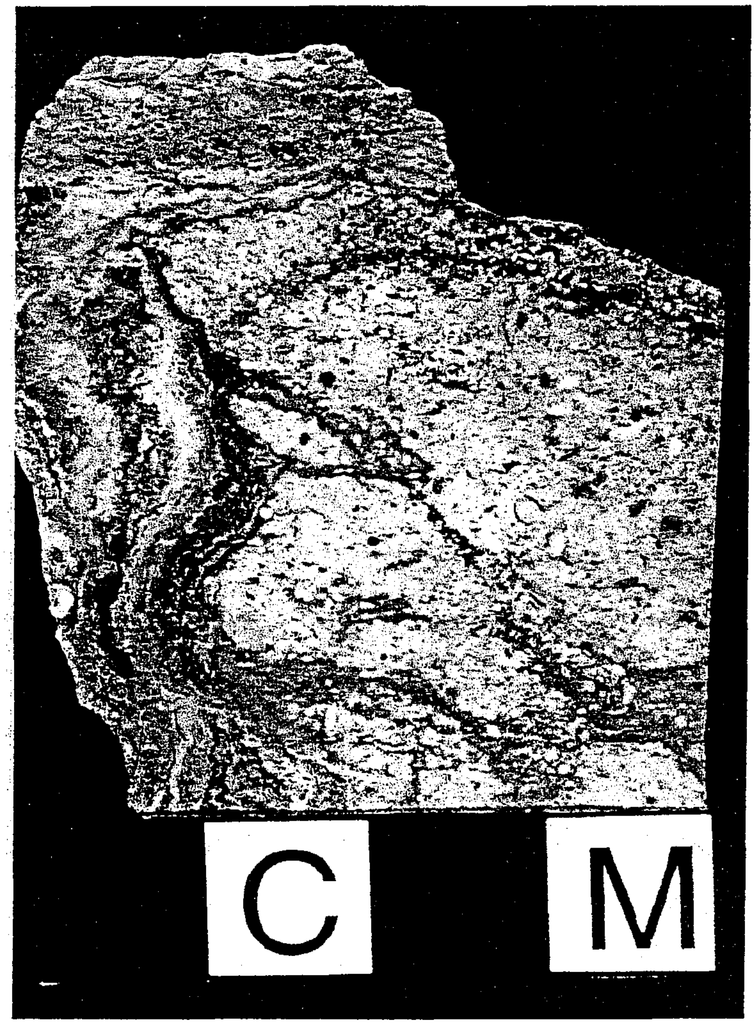


Figure 15. Laminated crust and root tubes in the upper Ozawkie at DG12.
note: the crust overhangs an edge.

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 [see photo in Esteban and Klappa, 1983, p. 44]. The crusts clearly truncate the underlying lithology, thicken into local lows attaining a thickness of 5 cm or more, and coat vertical to overhanging surfaces (Fig 15).

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 2m toward the south. Contrasting lithologies of the layers signal the subdivision even where the intervening shale is absent. At OS 23, a lenticular packstone bed of brachiopods in growth position, up to 30 cm thick, separates the two units. The upper unit is a fine-grained, skeletal packstone. Common identifiable fossil fragments include brachiopod spines and trilobites. The lower unit is a coarse-grained fusulinid wackestone or 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.

The generally calcareous, yellow, non-fissile shale that separates the lower and upper Ozawkie thickens from a featheredge at SH13 to 2 m at OS11. This shale was sampled at OS11 and SH30 for fossil content. At OS11, the base and top of the shale contains an assemblage of ostracodes, brachiopods, crinoids and echinoid spines, fenestrate bryozoans, and fusulinids. The middle of the shale contained only unidentified fragments of one species of a thin-shelled brachiopod and one species of ostracode (*Geisinia gregaria*). This middle part of the intervening shale is most likely the "Red Eagle-type" assemblage as described by Moore (1964, p. 305). At SH30, no fossils were found in the intra-Ozawkie shale.

South of the study area, in Coffey County, the Ozawkie is generally very poorly exposed and facies differ significantly from those to the north (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 about 30 cm thick with abundant thin-shelled brachiopods, both broken and whole. The lower two limestones are wackestones with fusulinids and oncolitically-coated grains. Presumably the lowest is the Avoca Limestone. The shales between the three limestones are each about 4 to 5 m thick. The limestones are very poorly exposed and accurate thicknesses cannot be measured, but the limestones have apparently thinned to around 30 cm each (Maples, oral communication, 1995).

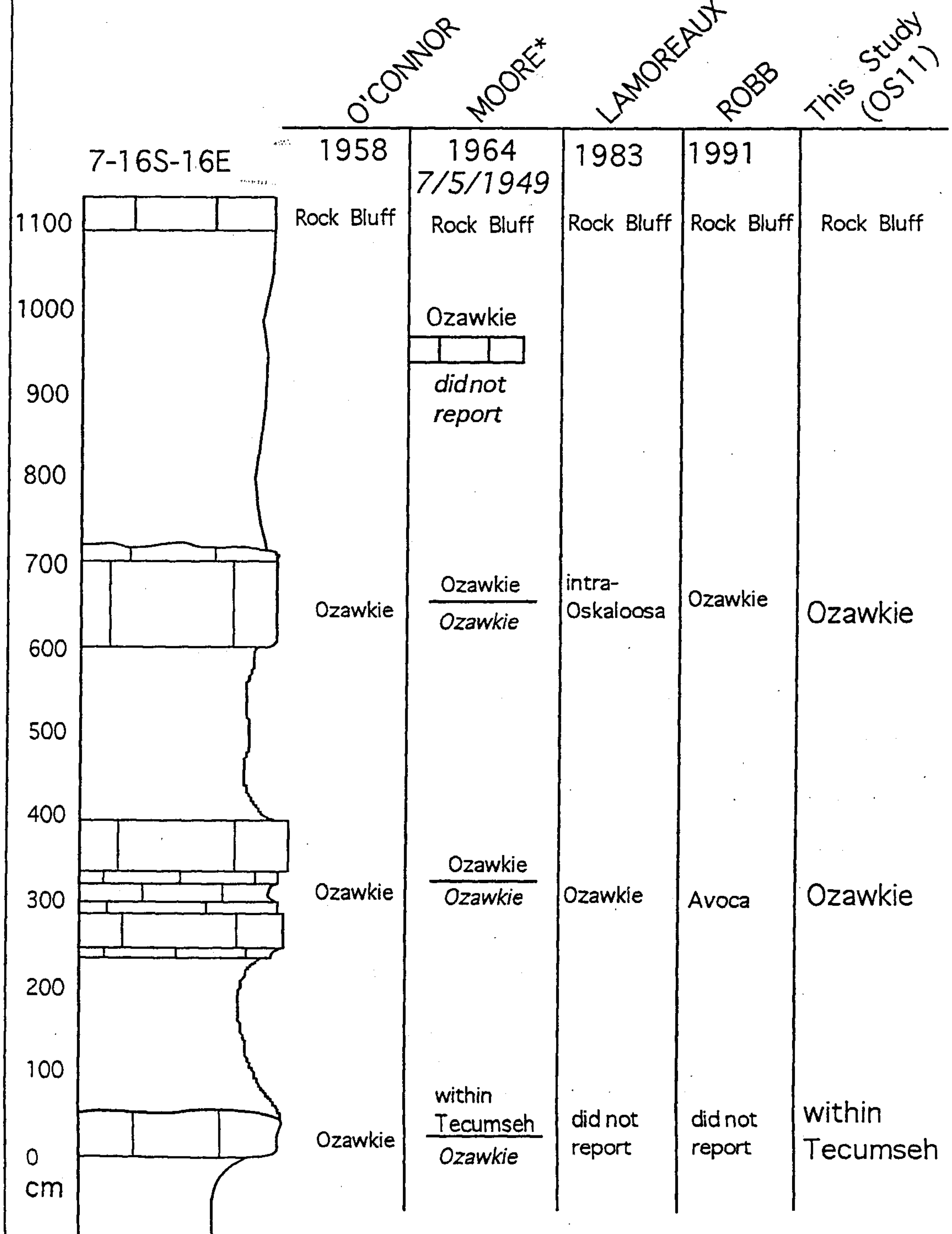
Further south, in central Greenwood County, the first limestone beneath the Rock Bluff Member, presumably the Ozawkie, is approximately 15 cm thick and comprises two thin layers. Both layers are skeletal grainstones to rudstones, pale yellowish brown (10YR 6/2), with abundant encrusting foraminifers, brachiopods, gastropods, trilobites, pelecypods, crinoids, echinoid spines, fusulinids and other foraminifera, ramose and fenestrate bryozoans, phylloid algal fragments, and coated grains.

STRATIGRAPHY OF THE OZAWKIE AND RELATED UNITS

The stratigraphy of the Ozawkie Limestone, especially in east-central Kansas, has long been problematic because three limstones, separated by shale, are locally present at the approximate stratigraphic position of the Ozawkie. Various workers attributed these limestones to different formations (Fig. 16).

O'Connor (1958), Lamoreaux (1983), and Robb (1991) all measured the section at sec. 7, T16S, R16E, Kansas (Locality OS11 in this study), and Moore (1964, p. 307) published a section at sec. 12, T16S, R15E, Kansas, less than a mile to the west (Fig 16). O'Connor (1958) suggested that all the limestones belonged to

Figure 16. Section at sec 7, T16S, R16E, Osage County, and various stratigraphic interpretations.



*Moore (1964, pg. 307) from 12-16S-15E
Moore (1949) from archived sections at KGS

the Ozawkie. Robb (1991) attributed the middle limestone to the Avoca, but did not report the lowest limestone.

The upper two limestones in the southern part of the study area apparently belong to the Ozawkie as the intervening shale pinches out northward and the upper fine-grained packstone and the lower coarse-grained wackestone persist into a two-layered Ozawkie. Into Coffey County, Kansas, both the units are fusulinid-rich limestones. The lowest (3rd) limestone, where present, falls within the Tecumseh Shale (Fig. 16, 17) based on limestone being in equivalent places within the Tecumseh in the central area and the Nemaha/Marshall County cores.

Understanding of the adjacent formations is essential in interpreting the Ozawkie. The Tecumseh Shale in Nebraska has been locally divided into three members: the Kenosha Shale, the Ost Limestone, and the Rakes Creek Shale in ascending order (Moore, 1936). The Ost Limestone is a thin, discontinuous limestone that is highly variable in lithology (Zeller, 1968; Moore, 1936). The Rakes Creek Shale lies between the Ost Limestone and the Rock Bluff Limestone, as the Ozawkie Limestone is absent at the Ost type locality (Condra, 1927; Moore, 1936; and Reed and Burchett, 1964). Moore (1936, p. 179-180) stated, "In the type region of the Ost, Kenosha, and Avoca beds, the association of these units as parts of a single cyclothem appears evident ....But when these beds are traced southward the Kenosha Shale appears to increase in thickness so greatly and to change character so considerably that the combination of Avoca, Kenosha and Ost can hardly be recognized as a natural stratigraphic unit, and certainly it cannot be regarded as a limestone unit." Moore tentatively interpreted the Avoca as the transgressive phase of a cyclothem, and the Kenosha-Ost as the regressive phase. Fagerstrom and Burchett (1972) interpreted the Ost Limestone as representing a transgression and the top of the Rakes Creek Shale as a second transgression leading to deposition of the Ozawkie.

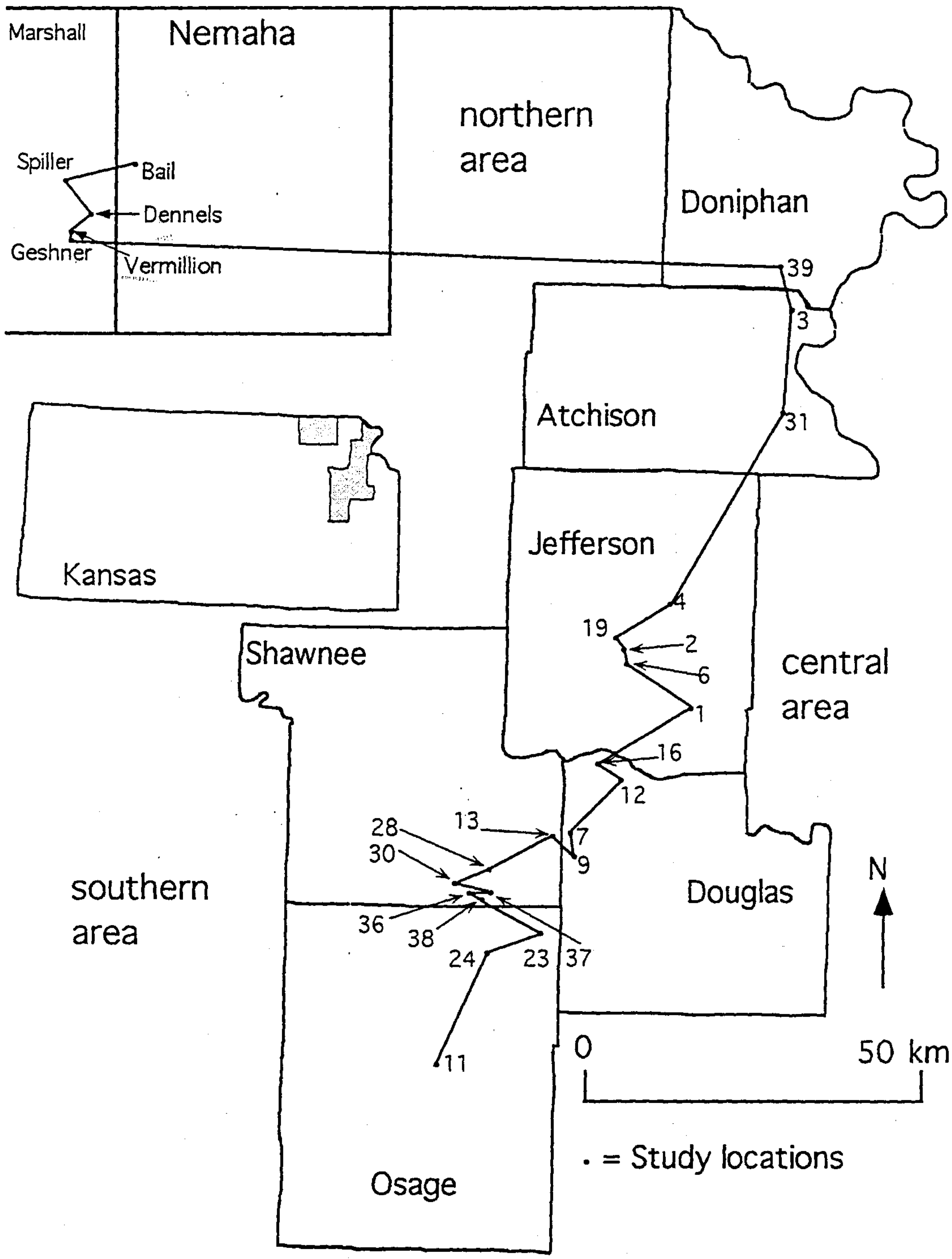


Figure 17A. Map of northeastern Kansas showing correlation line for cross-section of the Deer Creek and upper Tecumseh.

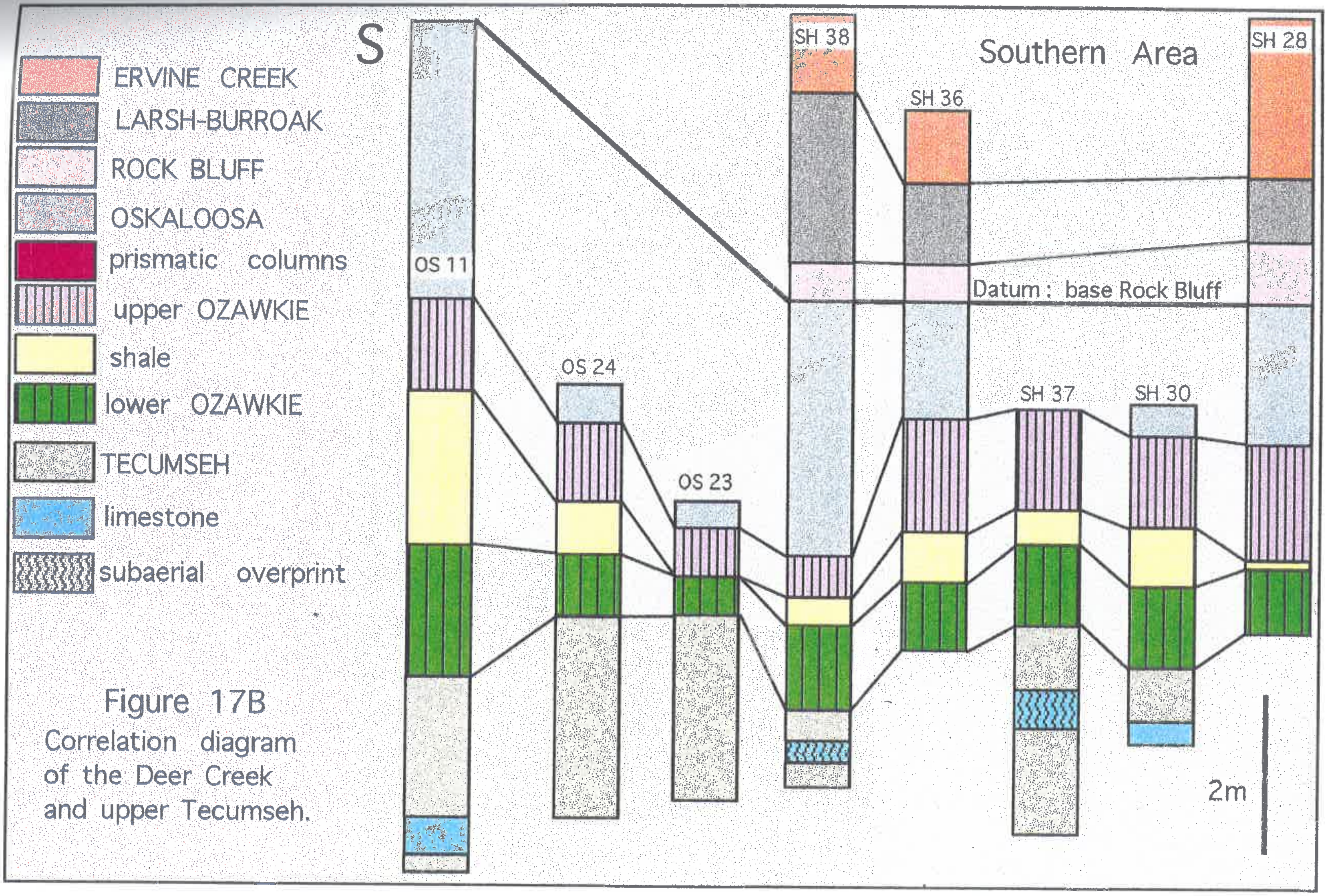


Figure 17B
Correlation diagram of the Deer Creek and upper Tecumseh.

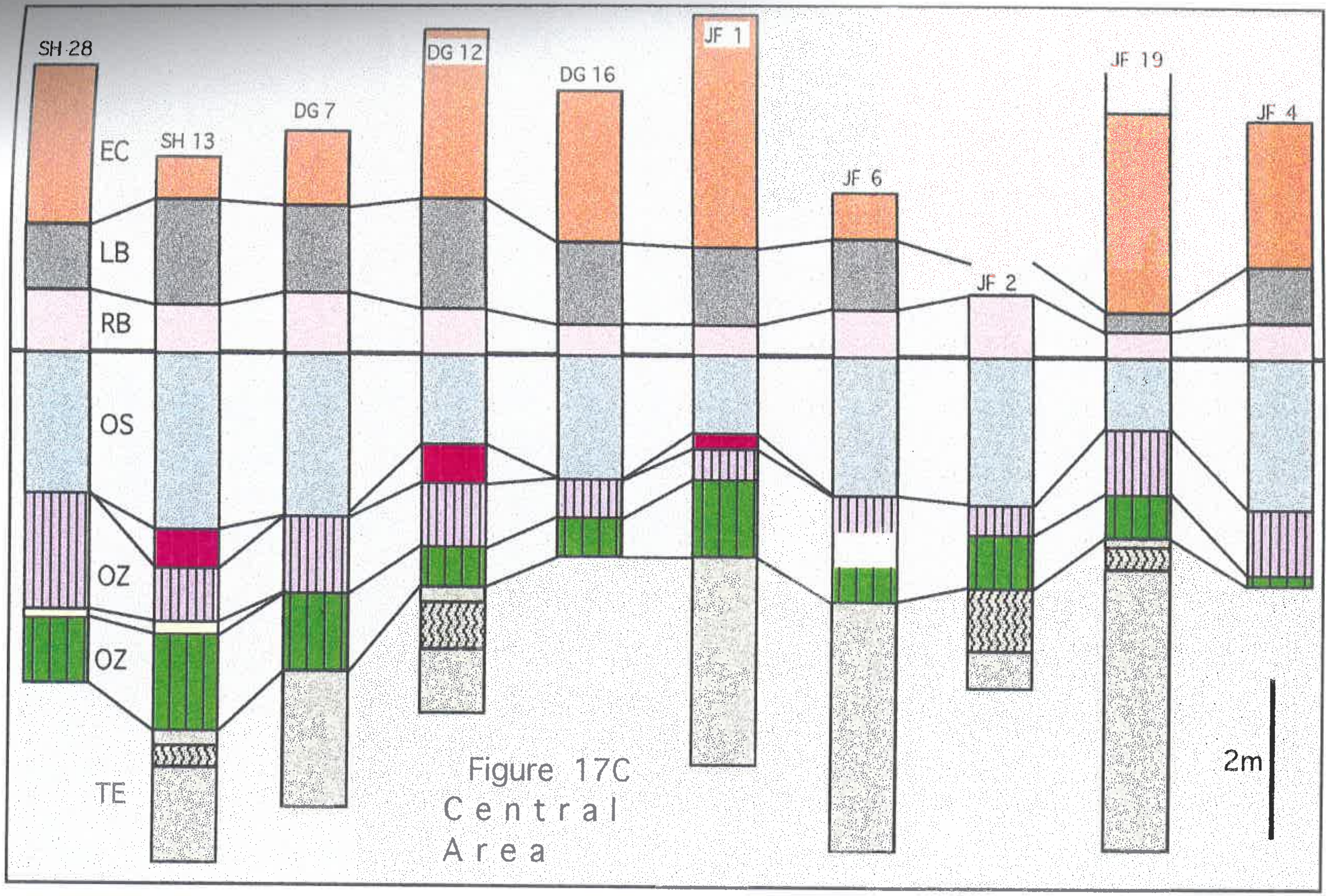


Figure 17C
Central
Area

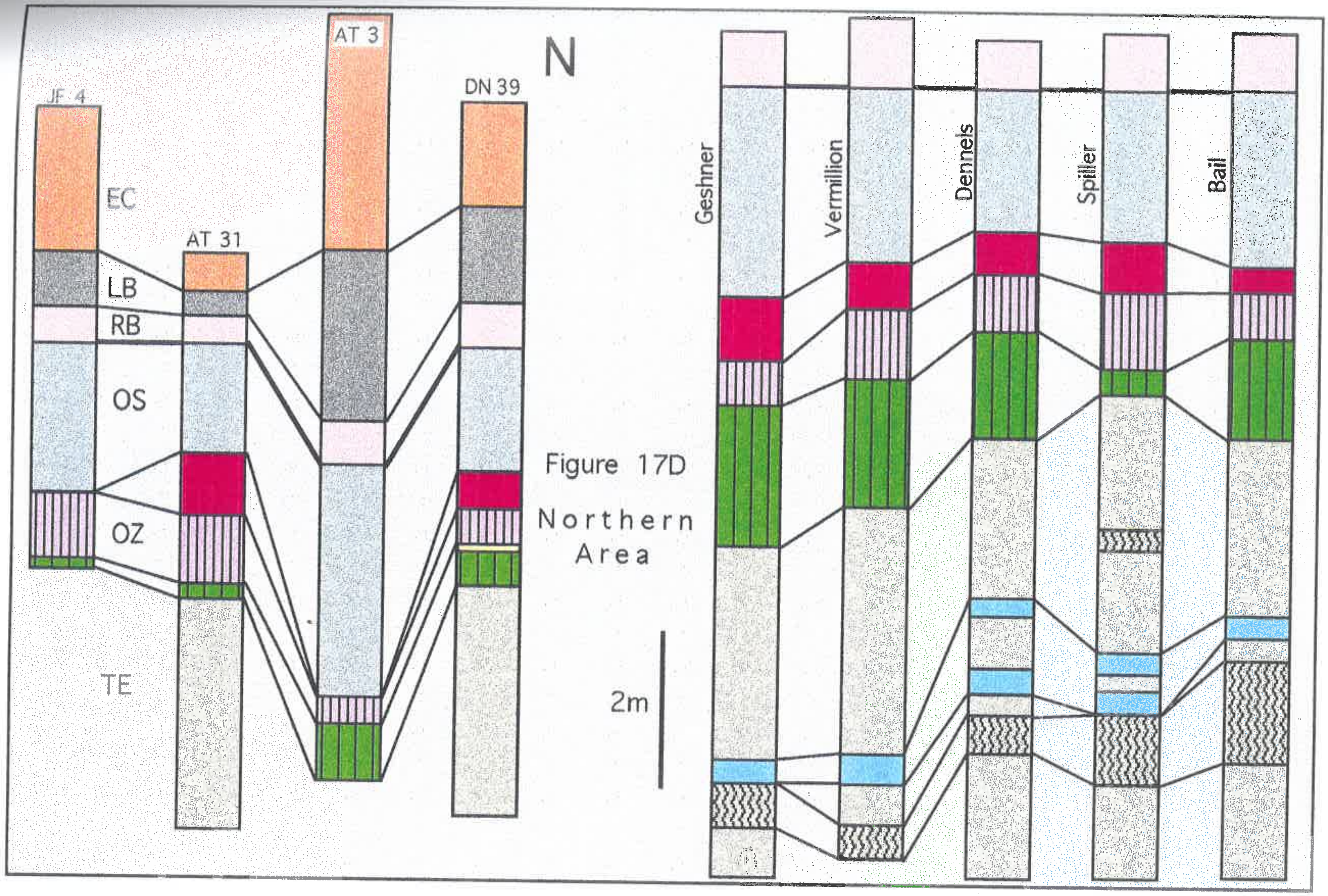


Figure 17D
Northern Area

The most obvious name to apply to the limestones within the Tecumseh would be the Ost Limestone. Moore et. al. (1951) decided, however, that the Ost was too patchy in occurrence to correlate and use to subdivide the Tecumseh in Kansas. Naming these limestones would also imply a time-equivalence or genetic relationship which cannot be justified.

Thickness data for the Deer Creek formation

Isopach maps for the Ozawkie Limestone (Fig. 18), Oskaloosa Shale (Fig. 19), and Larsh-Burroak Shale (Fig. 20) members were constructed to determine if paleotopography, which might be reflected by thickness variations in adjacent shales, played a significant role in deposition of the Deer Creek Limestone. The outcrop belt is relatively linear, and reliable subsurface data are too few to alleviate that problem, which makes it difficult to construct isopach maps. Thickness generalities along strike are probably valid, but a better aerial distribution of points is sorely needed. An isopach of the Tecumseh is critical to determining if paleotopography played a role in Ozawkie deposition, but too few reliable data were available.

Thickness of the Ozawkie increases greatly in the southern area because the intra-Ozawkie shale thickens. However, a relationship between the Ozawkie thickness and overlying shale's thickness is not recognizable, suggesting that paleotopography was not developed during deposition.

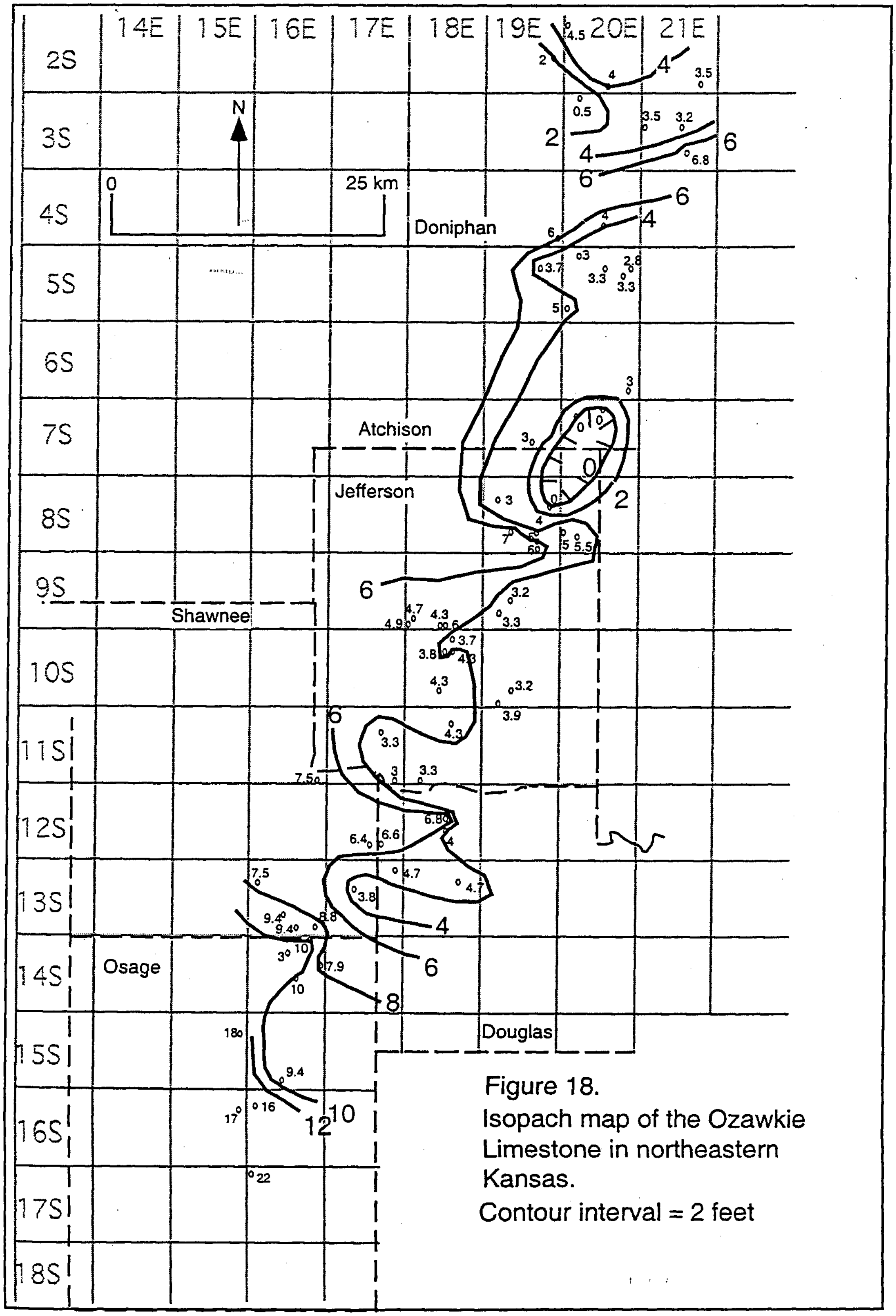


Figure 18.
Isopach map of the Ozawkie Limestone in northeastern Kansas.
Contour interval = 2 feet

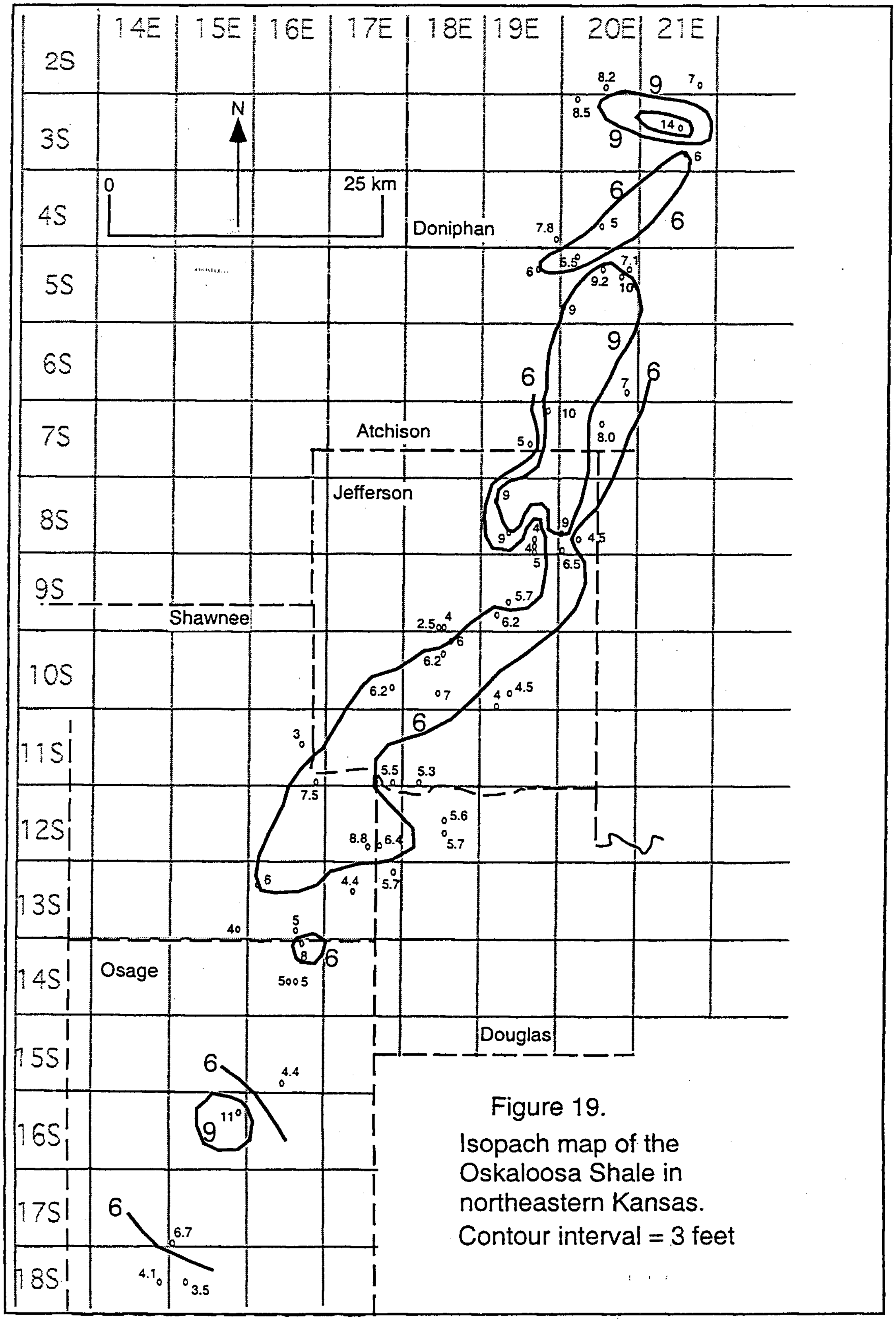


Figure 19.
Isopach map of the Oskaloosa Shale in northeastern Kansas.
Contour interval = 3 feet

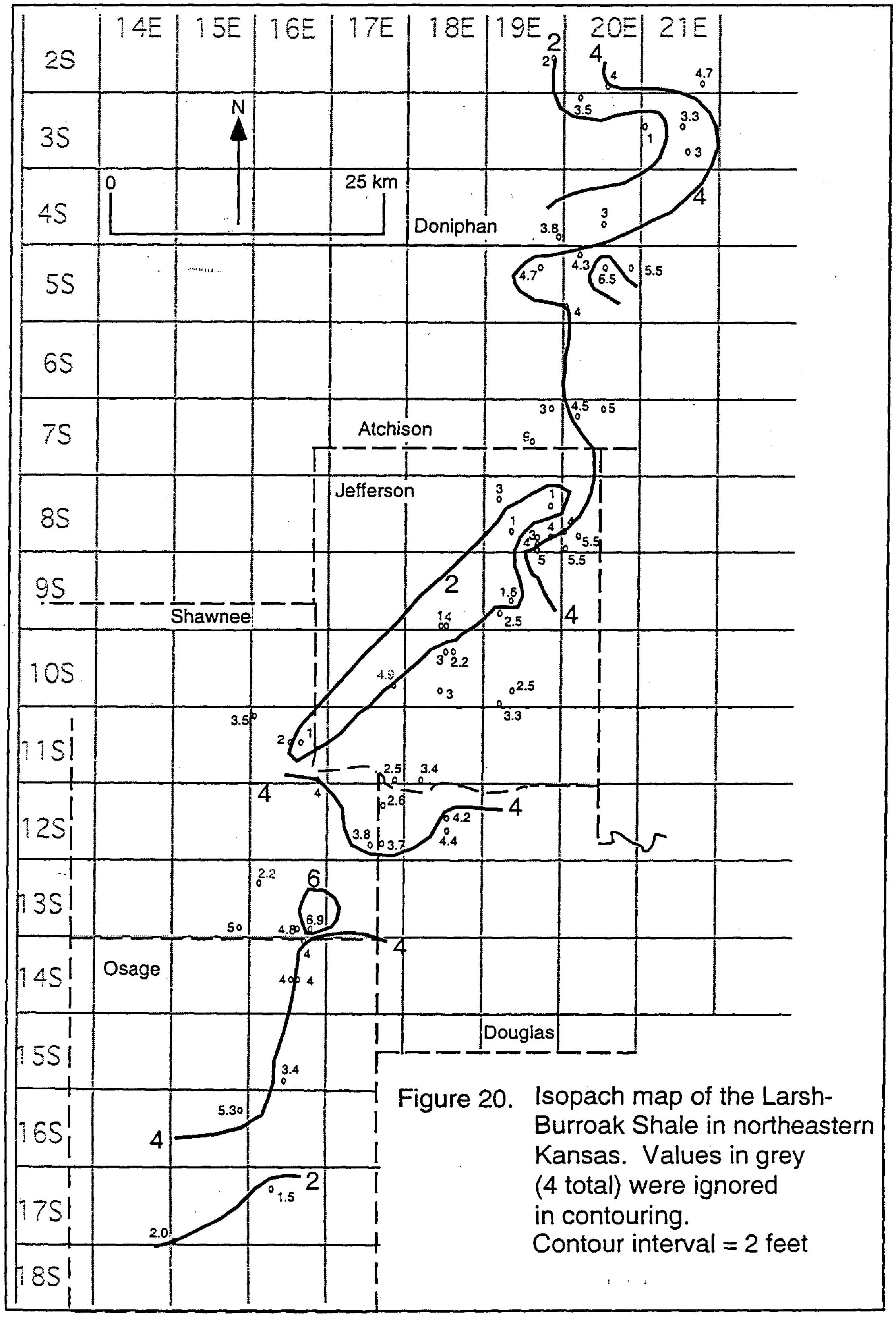


Figure 20. Isopach map of the Larsh-Burroak Shale in northeastern Kansas. Values in grey (4 total) were ignored in contouring.
Contour interval = 2 feet

DISTRIBUTION OF PALEOSOL FEATURES

Tecumseh

In the southern and central areas, prismatic columns (SH37, SH13), calcareous nodules (DG12), and rhizocasts (JF2, DG12), are locally present near the top of the Tecumseh. In general, these features are at the top of the Tecumseh in the central area and are progressively lower toward the south. The horizon that contains these features is found up to 2 meters below the Ozawkie in the southernmost exposure (SH37) and in contact with the Ozawkie in the central area (DG12). At JF1, the upper Tecumseh lacks such features, but micrite clasts, comparable to the calcareous nodules found elsewhere, were coated and incorporated into the basal Ozawkie. Slickensided shale is found 3 to 4 meters below the base of the Ozawkie in the Nemaha/Marshall County cores and is overlain by a thin marine limestone.

Lower Ozawkie

Rhizocasts, laminated micrite crusts, and circumgranular cracks are found at the top of the lower Ozawkie over much of the study area. These features are best developed in the central area and within the Nemaha/Marshall County cores. Development is progressively poorer southward. Within the southern area rhizocasts are found locally, but are sparse and poorly developed. No rhizocasts are found south of northern Osage County (OS23), Kansas. At JF5, irregularly-shaped lithoclasts with fragments of a laminated micrite crust have been reworked. At JF18, a rounded packstone lithoclast with a laminated micrite crust has been reworked.

Upper Ozawkie

A large variety of features, including rhizocasts and rhizoliths, laminated micrite crusts, clotted micrite, circumgranular cracks, karstic pits and pitted surfaces, slickensided shale, and prismatic columns cap the Ozawkie over the entire study area. Well-developed prismatic columns are locally found within the northern and central areas, 30 cm or more above the Ozawkie in the basal Oskaloosa Shale. Slickensided shale with weathered nodules of the upper Ozawkie is present above the Ozawkie in the Nemaha/Marshall County cores. All these features are best developed in the Nemaha/Marshall County cores and the central area and get progressively less developed southward. In the southernmost part of the study area, only vague rhizocasts are discernible at the top of the Ozawkie.

Esteban and Klappa (1983) identified a suite of features characteristic of subaerial exposure and soil development including rhizoliths and rhizocasts, laminated micrite crusts, clotted micrite, circumgranular cracking, caliche nodules, karst/solution holes, prismatic columns, and slickensides. This suite of features is present in three different stratigraphic positions within the study area (Fig 21, Fig 22): near the top of the Tecumseh, the top of the lower Ozawkie, and the top of the upper Ozawkie and possibly in the basal Oskaloosa. Collectively they clearly indicate subaerial exposure as a dominant diagenetic feature in the Ozawkie and adjacent units.

Subaerial features can be either syndepositional or post-date early diagenesis which implies differing sea-level history. Syndeposition can be recognized by features such as sheetcracks and rhizoliths following grain boundaries and bedding, implying that the sediments were not yet lithified. Subaerial features cross-cutting grains, cement and other diagenetic features is diagnostic of post-depositional exposure. In these cases, rhizocasts and micrite crusts may cut indiscriminately across grains, matrix, and any previous cements. Within the southern area of this

Figure 21.

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

FEATURE	CONFIDENCE LEVEL
Rl = rhizolith	! = definitely
Rc = rhizocast	+ = most likely
Ml = 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	

	TECUMSEH	lower OZAWKIE	upper OZAWKIE
Bail	S!	Rc!, F+	Rl!, S!
Spiller	S!	Rc-, F!	Rl!, 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	Ml-
DN 39	cover	Rc+	Rc!, P+, N+, Mc+
AT33	cover	poor	P-
AT3	cover	Rc+, F!	Rc!, Rl+, F!, Cc+
AT 32			Rc+, P-
AT 31			P!, Rc!, Rl+, F!, Cc+
AT 34a,b 35		noOZ	NoOz
JF 4	cover		Ml-
JF 19		Ml+, F-	K-
JF 5	cover	Rc+ Ml! F! Cc+	poor
JF 2	Rc!	poor	poor
JF 6		poor	poor
JF 22		poor	poor
JF 18	cover	Ml+, Cc+	Ml+
JF 20	cover	Ml+, N+	Rc!, Ml!, Cc+, Mc+
JF 1		Rc+, F+	P!, Ml!
JF 17	cover	poor	poor
JF 21		poor	poor
HQ		Ml! , F!, Rc-	Rc!, Ml!, Cc!, Mc!, F!
DG 16	cover		K-
DG 12	N+, Rc-	Rc+, F!, Ml+, N-	P!, Rl+, Rc+, Ml!, Cc+, Mc+
MMQ	cover	F!	Rl!, Rc+, Ml!, Mc!,Cc!, N+,K!,F!
DG 10	cover	poor	poor
SH 8	cover	poor	poor
DG 7	cover	Rc-	Ml!, Rl+, 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-

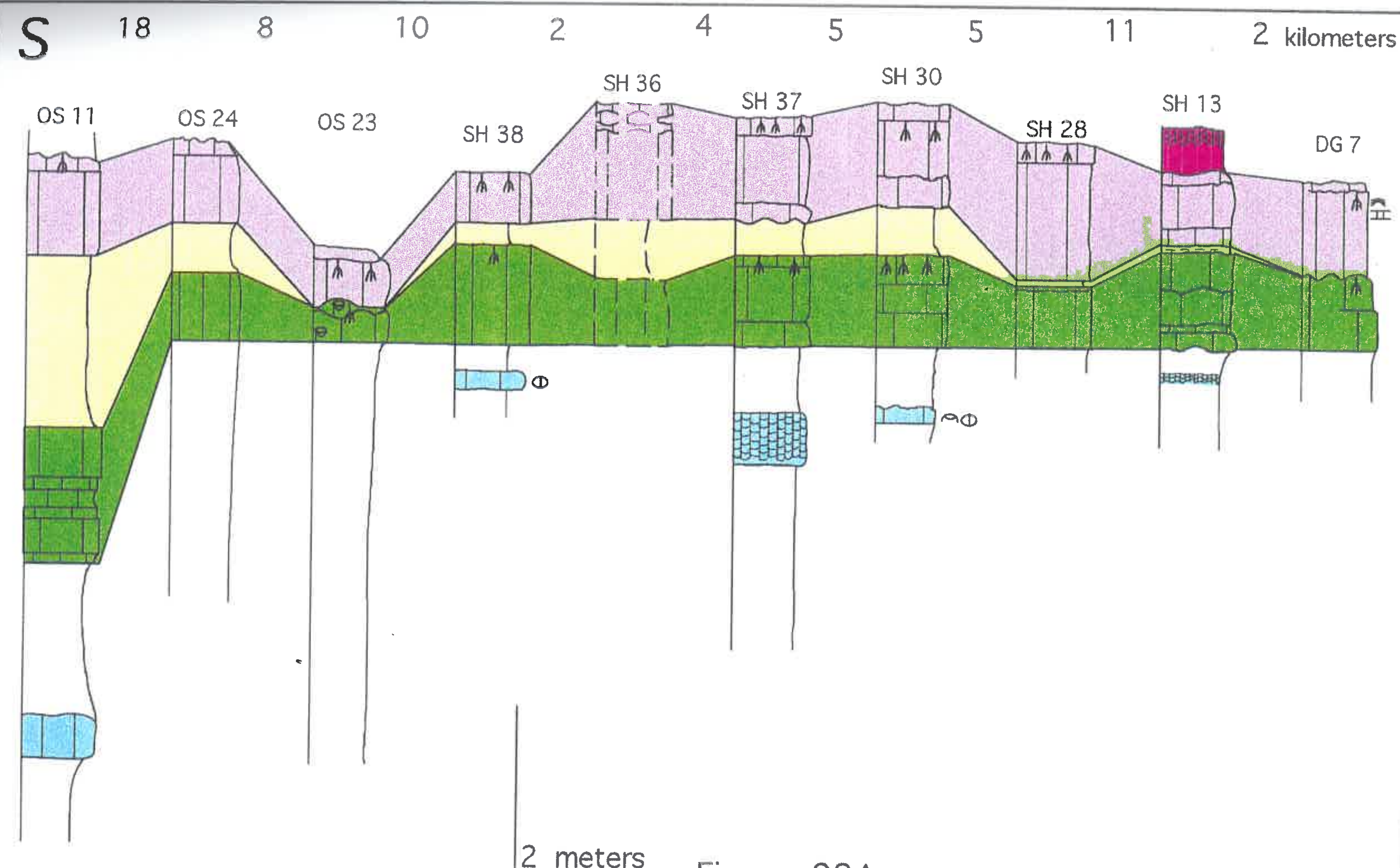


Figure 22A

SOUTHERN AREA

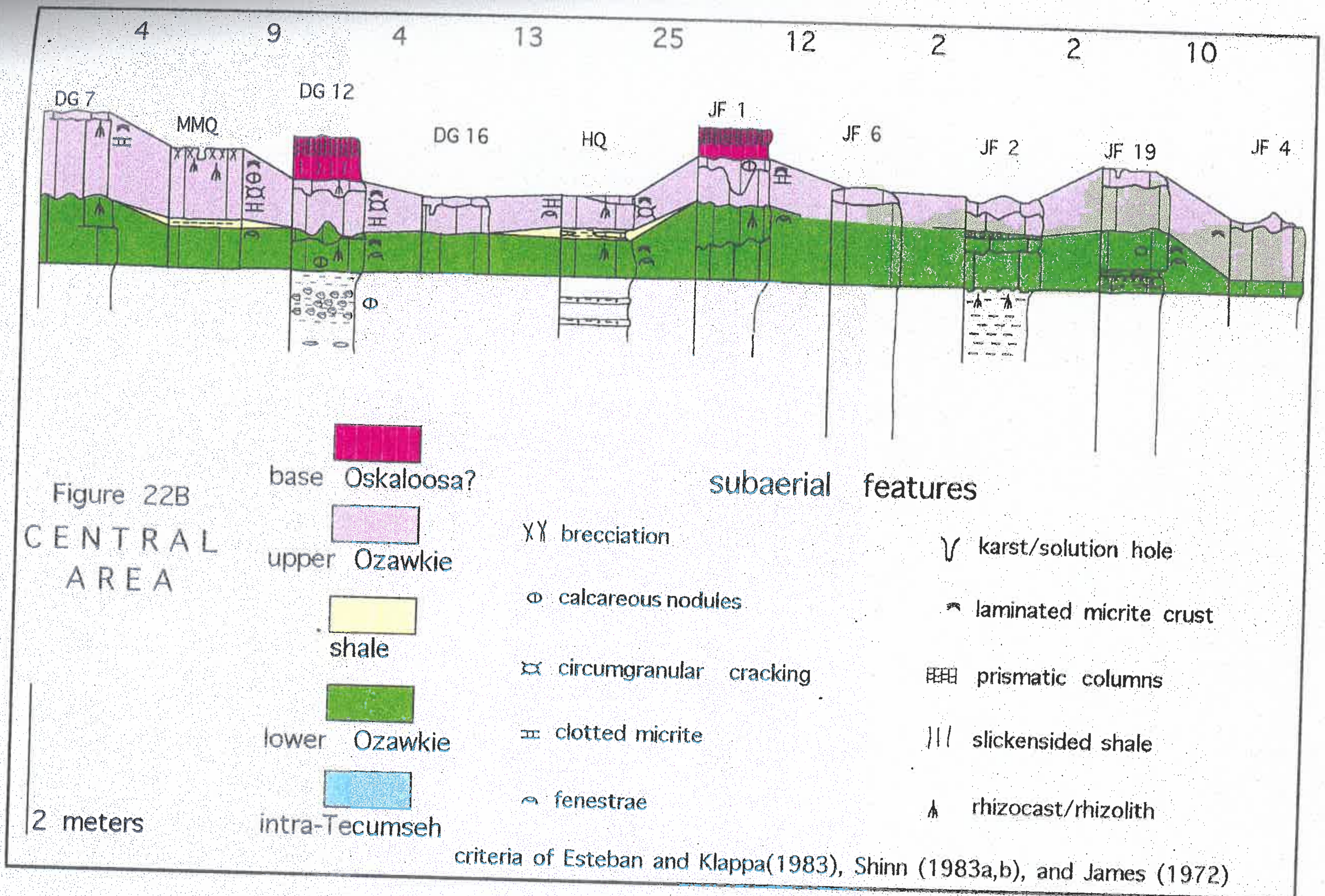


Figure 22B
CENTRAL AREA

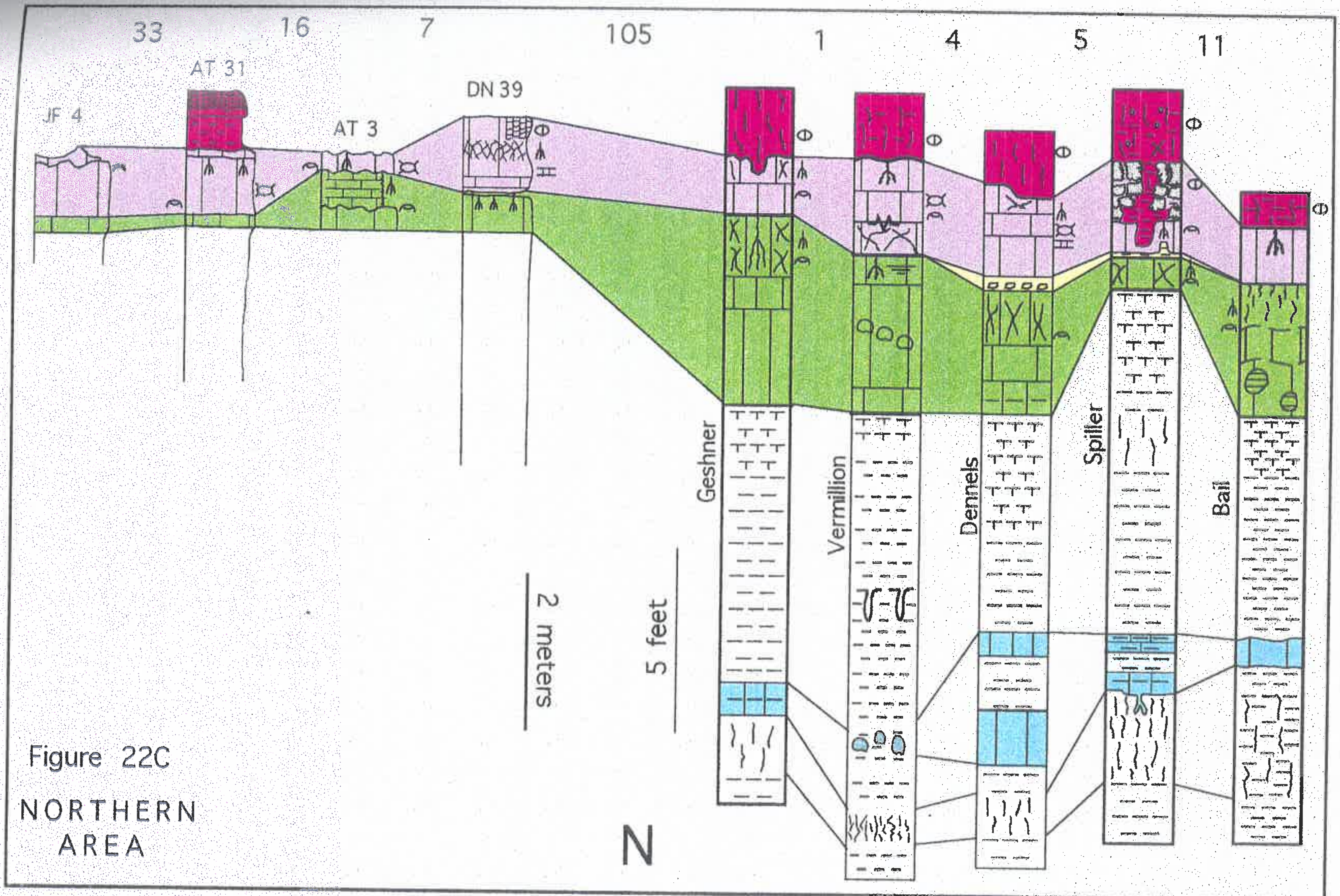


Figure 22C
NORTHERN AREA

study, subaerial exposure features post-date early diagenesis of the Ozawkie. Generally, subaerial features post-depositionally overprint the Ozawkie in the central area, but locally may be syndepositional. Within the northern area and Nemaha/Marshall County cores, subaerial features are found with both syndepositional and post-depositional relationships to the Ozawkie.

DEPOSITIONAL HISTORY OF THE TECUMSEH AND OZAWKIE

Tecumseh Shale

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

The middle of the Tecumseh is an unfossiliferous shale with local channel-fill siltstones to fine sandstones. Both Moore (1964) and Lamoreaux (1983) report thin coals in the upper Tecumseh, but do not give specific locations. Moore (1964, p. 294) showed a coal in his idealized diagram of the Deer Creek megacyclothem and drew a coal symbol in one section of the Deer Creek at location 6-17S-16E (Osage County, Kansas; Moore, 1964, p. 307). However, archived stratigraphic sections at the Kansas Geological Survey, including the Osage County sections, do not include any Tecumseh sections containing a coal. No coals were found in this study. Plant material is abundant along bedding planes, however, suggesting a nearby source.

Silty, calcareous mudstone with prismatic columns, carbonate nodules, and rhizocasts are locally present in the southern and central region up to 2 m below the top of the Tecumseh. Nemaha and Marshall County cores of the Tecumseh contain red or green slickensided shale between 3 and 4 m from the top. At JF1, no paleosol is evident in the Tecumseh, yet caliche clasts are coated and incorporated into the lower Ozawkie. These features likely represent widespread, but perhaps patchy, subaerial exposure and paleosol development (Fig. 22). Alternatively, the patchy distribution may reflect local erosion of the paleosol, as at JF1.

Johnson and Adkison (1967) postulated that the vast bulk of the Tecumseh represented terrestrial conditions based on the thick clastic section, the lack of any marine fossils, and the abundant plant material. This study further postulates widespread subaerial exposure near the top of the Tecumseh based on a suite of paleosol features.

In the Bail core, however, sparse fossils are present in the paleosol. The fossils, ostracodes and fragments of brachiopods, probably inarticulate, are not unequivocally marine, but brachiopods indicate at least brackish water. A local marine influence prior to subaerial exposure is indicated by this occurrence.

A thin limestone is present at OS11 (echinoid-clast packstone) and SH30 (lime mudstone with spar-filled cracks). Moore (1964, p. 322) reported two limestones (*Osagia*-rich) at one locality in Jefferson County, which were not present in an adjacent section about 2 km away. A thin, argillaceous, skeletal wackestone caps the paleosol in the Nemaha and Marshall cores. A rich marine fauna is present in the shale above the lime mudstone at SH30 and was reported widely in the central area by Johnson and Adkison (1967). A sparse fauna of inarticulate brachiopods and ostracodes are present elsewhere in the shale above the wackestone. Widespread yet patchy marine limestone capping the paleosol over the southern area and Nemaha/Marshall Counties, and shale with marine fossils at the top of the Tecumseh indicate that relative sea-level rise occurred following the Tecumseh paleosol. Micrite clasts incorporated into the basal Ozawkie further suggests that locally some pre-Ozawkie erosion occurred which stripped off marine deposits.

In summary, the lowermost Tecumseh was deposited in a marine environment. Johnson and Adkison (1967) interpreted the middle of the Tecumseh in Shawnee County, Kansas, to represent terrestrial deposits. A widespread paleosol is developed near the top of the Tecumseh, which indicates a period of subaerial exposure and soil development. Relative sea-level then rose and inundated the paleosol. Local pre-Ozawkie erosion stripped marine deposits and, very locally, the paleosol. The Tecumseh paleosol and subsequent transgression is analogous to the upper Lawrence Shale paleosol reported by Joeckel (1994).

More on Moore's Ost Limestone

Moore's (1936, p. 179-180) observation that the Avoca-Kenosha-Ost beds in Otoe County, Nebraska, seemed associated to constitute a cyclothem, yet lost that association to the south, deserves some revisiting. Moore (1936) noted that the Ost was within several feet of the Avoca Limestone, and a generalized stratigraphic section in Reed and Burchett (1964) showed 5 feet (1.5m) of shale between them.

In northeastern Kansas, an intra-Tecumseh limestone (ITL) that is local in occurrence and diachronous is better supported by evidence and theory. First, in northeastern Kansas the ITL seems to be in a different stratigraphic position than in Nebraska. In Nebraska the limestone is very near the Avoca in the lower Tecumseh; in Kansas it is very near the top of the Tecumseh. If the Ost limestone is hypothesized to be a continuous and/or time-equivalent unit, this observation causes some serious problems. Up to 30 feet (10 m) of shale must be differentially deposited and/or differentially eroded away over a two-state area, which is inconsistent with the low-relief geology of the Pennsylvanian Midcontinent. Second, the ITL has widely differing lithology from locale to locale. Third, stratigraphic relations suggest different times of formation. In the Nemaha/Marshall cores and OS11, the limestone is clearly marine and post-paleosol. At SH30, the limestone is likely marine. At SH37, SH38, SH13, DG12 and JF1, the calcareous unit is interpreted to be part of the paleosol. The decision of Moore, Frye, Jewett, and O'Connor (1951) to abandon the name Ost in Kansas was a good one.

Ozawkie Limestone

The Ozawkie Limestone consists of two clearly defined limestone units. A shale break or an exposure surface separates the two limestone layers in the northern and central areas, and the shale thickens in the southern area. The lithologies of the upper and lower layer are typically similar, but recognizably distinct. The lower Ozawkie is generally coarser-grained in both the southern and central areas. At some localities (JF2, Bail core, SH13) a fining-upward sequence is present at the base. The lithofacies distribution suggests that each unit generally shoals from south to north.

Lower Ozawkie

In the southern area, the lower Ozawkie grades northward from a fusulinid wackestone to a coated, skeletal packstone. The abundance of mud, good preservation of fossils along with pellets and burrows, and diverse fossil assemblage suggests that the lower Ozawkie was deposited from a relatively quiet, open-marine subtidal environment. Rhizocasts are locally superimposed onto the lower Ozawkie in the northern part of the southern area. At the southernmost outcrop (OS11), no subaerial features are present but the shale between 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.

In the central area, the lower Ozawkie is generally a coarse-grained, coated grain and oolitic, skeletal packstone to grainstone. A diverse fossil assemblage indicates that the water was open marine, and coated grains and ooids are typically found in areas with tidal or wave action. The lower Ozawkie in the central area most likely represents deposition from a shallow, agitated subtidal environment. A variety of subaerial features are superimposed onto the lower Ozawkie throughout the central area (Fig. 13). This is significant as subaerial features overprinted onto subtidal deposits suggests a relative drop of sea level as opposed to sediment accretion to sea level.

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 muddy. The lower Ozawkie in cores is very similar to that of the northern area. The base is gradational with the marine sediments of the upper Tecumseh, but the lower unit is generally a burrowed to wavy-laminated lime mudstone. The upper part of the lower layer is slightly brecciated and rhizocasts are present locally. The wavy laminations are most likely stromatolitic layers that would be continuous across the cores except for subsequent brecciation. The lower Ozawkie in the northern area and the Nemaha/Marshall area most likely represents quiet, semi-restricted shallow-marine deposits in the lee of shoal waters in the central area. Fenestrae, found in most of the cores and sparsely across the northern area, along with probable stromatolitic layers in the cores hints at some time spent in an intertidal environment (Shinn, 1983).

The lower Ozawkie shows a general trend towards shoaling northward with subtidal deposits in the southern area, shallow subtidal deposits in the central area, and shallow restricted-marine to perhaps intertidal in the northern area and the Nemaha/Marshall area.

Widespread distribution of subaerial features capping the lower Ozawkie in the central and northern areas suggests a basin-wide lowering of sea level as opposed to local build-up to sea level. Subaerial features overprinting subtidal deposits in the southern and central areas suggest that a relative drop of sea-level occurred. The position of the shoreline at maximum regression can be approximated. The southernmost probable rhizocasts are found at OS23. The intervening shale at OS11 contains a normal marine fauna at the base and passes upwards into a brackish fauna. This suggests that OS11 experienced a change in water quality by the maximum regression, but stayed submerged. Shoreline during maximum regression was located in northern Osage County, Kansas. Marine fauna present at the top of the intervening shale likely records a transgression prior to deposition of the upper Ozawkie.

Upper Ozawkie

In the southern area, the upper Ozawkie is a fine-grained packstone with abundant skeletal grains and likely represents agitated, subtidal deposits. In the central area most locales range from skeletal, coated-grain packstones to grainstones. Cross-bedding with a strong mode to the northeast and a weaker opposite mode to the southwest, along with locally dominant ooids probably reflects tidal influence. The central area likely represents deposits from a shallow, agitated, subtidal environment. Features such as rhizocasts, rhizoliths, laminated micrite crusts, clotted micrite, circumgranular cracks, brecciation, and shale-filled karstic pits are also overprint the top of the Ozawkie.

In the northern area and the Nemaha/Marshall cores, the Ozawkie is typically a skeletal or peloidal packstone. The upper Ozawkie has a low-diversity fauna dominated by foraminifers and high-spired gastropods. The Spiller and Bail cores contain large oncoids. Low faunal diversity, dominance of foraminifers and gastropods, and oncoids, is fairly typical of deposits from a restricted, shallow subtidal environment (Enos, 1983).

The upper unit of the Ozawkie also suggests a shallowing trend 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 in the central region, and restricted subtidal leeward of a shoal in the northern area and the Nemaha/Marshall area.

Subaerial features over the entire study area and the overprinting onto subtidal deposits to the south is strongly supportive of widespread exposure and a relative sea-level fall.

THE CASE FOR MULTIPLE EXPOSURE EPISODES

Subaerial exposure features are widespread at three stratigraphic intervals throughout the upper Tecumseh and Ozawkie Limestone. This study postulates that each position represents a unique period of subaerial exposure. It would be the simplest explanation for one post-Ozawkie subaerial event to be expressed at several different horizons. However, cross-cutting relationships show this is not the case.

Tecumseh paleosol

An interval near or at the top of the Tecumseh Shale represents the oldest subaerial exposure period. Micrite clasts, texturally identical to calcareous nodules from the Tecumseh interval, are coated and incorporated into the basal Ozawkie. The inclusion of coated Tecumseh caliche clasts within the Ozawkie indicates that the Tecumseh paleosol had to form before the Ozawkie was deposited. In the southern area and the Nemaha/Marshall County cores, it is also hard to imagine a scenario where up to several meters of shale between the Ozawkie paleosol and the Tecumseh paleosol were not affected at all if both formed from a single exposure episode.

Lower Ozawkie

The second period of subaerial exposure occurred following deposition of the lower Ozawkie. Cross-cutting relationships indicate a unique event. At JF5 (see Fig. 13) packstone lithoclasts with fragments of a laminated micrite crust have been extensively reworked and re-oriented. At JF2 and JF18, clasts of the lower Ozawkie have been rounded. It would be highly unlikely that enough movement could occur, in-situ, to round large clasts and rework what must have been an areally extensive and continuous laminated micrite crust at JF5.

The distribution and orientation of subaerial features also suggests a unique, lower Ozawkie exposure. The areal distribution of subaerial features is slightly different from the upper Ozawkie. Identifiable subaerial features are not found in the lower Ozawkie south of OS23 in the southern area, yet are found capping the upper Ozawkie throughout the entire study area. Secondly, no subaerial features are found in the shale intervening between the upper and lower Ozawkie or at the base of the upper limestone. If there had been only one post-Ozawkie exposure expressed at two horizons, it would be expected that some subaerial overprint would be found in the base of the upper Ozawkie and the intervening shale. The intervening shale would have acted as an aquitard and forced water to move laterally. It would not be expected that subaerial features developed equally between the top of the lower Ozawkie, the intervening shale, and the base of the upper Ozawkie. However, some development should have occurred in the shale and basal upper Ozawkie.

Based on the extensive reworking of subaerial features in the lower Ozawkie, the differing areal distribution of subaerial features in the lower and upper Ozawkie, and the total lack of subaerial exposure features in the intervening strata, it appears that a period of subaerial exposure followed deposition of the lower Ozawkie.

Upper Ozawkie

The evidence that a third extensive subaerial exposure event followed the upper Ozawkie is convincing. A suite of subaerial exposure features overprint the upper Ozawkie essentially throughout the study area as outlined above.

The well-developed prismatic columns above the Ozawkie (AT31, JF1, DG12, SH13) and the slickensided shale in the Nemaha/Marshall cores pose an interesting question. In the cores, the slickensided shale contains identifiable lithoclasts of the upper Ozawkie. The upper Ozawkie was deposited, then lithified, and finally reworked and incorporated. In the Geshner core, a carbonized rhizocast is preserved 0.5 meters above the slickensided shale. This suggests subaerial exposure after deposition of the lowermost Oskaloosa Shale. There are two possibilities: The prismatic columns in the basal Oskaloosa represent an accretionary soil that was a continuance of subaerial exposure following the upper Ozawkie, or a fourth subaerial exposure episode intervened. At this stage, there is no evidence to support either possibility over the other.

Summary of the Ozawkie Limestone Deposition

In summary, the Ozawkie Limestone was deposited during two cycles of transgression and regression (Fig. 23). During the first transgression, the southern area was a quiet subtidal environment, the central area was an agitated subtidal environment, and the northern region and Nemaha/Marshall area was a shallow restricted marine environment leeward of a shoal to perhaps locally an intertidal environment. Relative sea level then dropped. Based on the extent of subaerial exposure features, the most likely location for shoreline during maximum regression was the northern part of the southern area, somewhere in northern Osage County, Kansas. During the second transgression, very similar depositional environments were established. The southern area was generally agitated subtidal, the central area was agitated shallow subtidal, and the northern area was restricted shallow marine leeward of the shoal in the central area. Relative sea-level fell following deposition and the shoreline must have migrated south of Osage County, Kansas, 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, as well as more widespread.

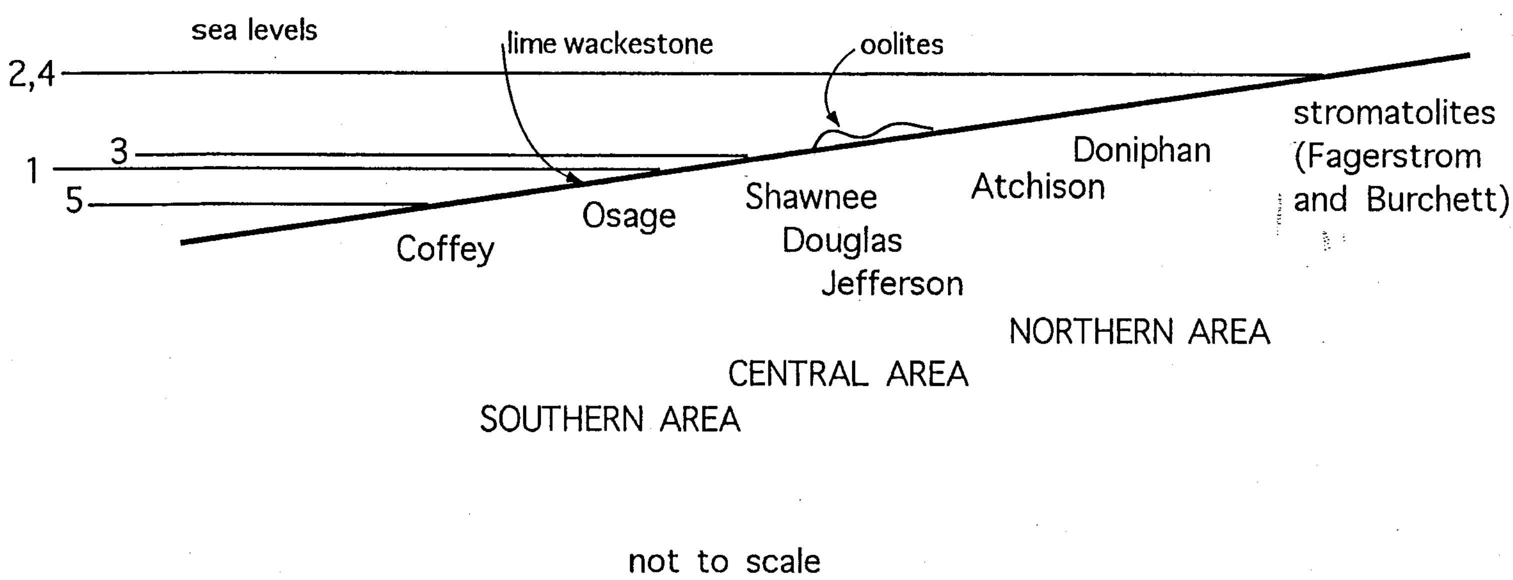


Figure 23. Sea level model for the Ozawkie Limestone and upper Tecumseh. Numbers indicate sequential sea-level maxima and minima.

1. Subaerial exposure of upper Tecumseh.
2. Deposition of lower Ozawkie layer.
3. Subaerial exposure of lower Ozawkie.
4. Deposition of upper Ozawkie layer.
5. Subaerial exposure of upper Ozawkie.

This second exposure event may have continued into the Oskaloosa Shale. Marine fossils at the top of the Oskaloosa, immediately underlying the Rock Bluff Limestone, indicate that relative sea-level rose during the end of Oskaloosa time.

Several observations suggest that a source of sediment was from the south. The top of the Tecumseh Shale above the paleosol, the intra-Ozawkie shale, and the Oskaloosa Shale, all thicken southward. Since the intra-Ozawkie shale pinches out to the north it appears that the only possible source of sediment was from the south.

CYCLOTHEMS AND THE MIDCONTINENT

Lee (1943) hypothesized that the greater area of northeastern Kansas, northwestern Missouri, southwestern Iowa, and southeastern Nebraska was a major basin, named the Forest City basin, during the Pennsylvanian (Fig. 3). While shoreline would have migrated with the sea, shoreline at maximum transgression would have been somewhere to the north in Nebraska.

Both units of the Ozawkie follow this predicted trend of shallowing from south to north, both in regard to lithofacies and extent of subaerial exposure. The less-extensive regression following the lower Ozawkie can be traced into northern Osage County, Kansas. The more-extensive regression following the upper Ozawkie is traced further south beyond the study area, likely into Coffey County, Kansas.

RELATIONSHIP OF LOWER LIMESTONES TO CYCLOTHEMS

The standard interpretation of the Missourian cyclothem is that the middle limestone represents a brief period of carbonate deposition during a relative sea-level rise. The black core shale represents maximum transgression, and the upper limestone represents deposition during a slowly regressing sea. Lower limestones are not present in Missourian cyclothems.

Lower limestones are found in Virgilian cyclothems and previously have been interpreted in two ways: 1. as a minor relative sea-level rise and fall that occurred before a major transgression (Moore, 1964; Troell, 1969; Heckel, 1980); and 2. as a carbonate unit deposited early during a major relative sea-level rise, with carbonate production ceasing due to sediment influx (Lamoreaux, 1983).

The Ozawkie Limestone is more consistent with the hypothesis that lower limestones represent minor sea-level rise and fall. In this particular case, each unit of the Ozawkie represents a minor sea-level rise and fall. Cessation of carbonate production due to sediment influx, as proposed by Lamoreaux (1983), can be eliminated as a possibility. Subaerial features are locally syndepositional. Had sediment influx halted carbonate production without eustatic sea-level change, no subaerial exposure would be recorded.

Troell (1969) identified several subfacies within the Toronto Limestone, the lower limestone of the Oread Formation. He concluded that those subfacies represented different local conditions of a standing sea and not migrating facies tracts of a transgressing sea. In essence, sea-level initially rose too quickly for carbonate deposition to keep pace and local environments were established.

The Ozawkie seems substantially different. Facies successions indicate shoaling northward in both units from quiet-subtidal to agitated-subtidal to restricted-marine. This suggests the Ozawkie transgressions were slow enough that carbonate production could generally keep pace and build up. Hence, the Ozawkie likely does represent migrating facies tracts of a transgressing and regressing sea.

It may be time to reexamine the other lower limestones in the four Virgilian megacyclothems: namely the Toronto Limestone in the Oread megacyclothem, the Spring Branch Limestone in the Lecompton megacyclothem, and the Hartford-Curzon Limestone in the Topeka megacyclothem.

Moore (1964, p. 312) noted an upper massive bed (3ft/1m) and a lower, thinly-bedded (5ft/1.5m) part in the Toronto in Douglas County. Elias (1964, p. 102) showed an idealized section of the Toronto from the Lawrence/Lecompton area with two distinct limestone beds separated by shale. Joeckel's (1994) main focus was documenting a paleosol in the Snyderville Shale, cycle equivalent to the Oskaloosa. However, his stratigraphic sections suggest a two-layered Toronto. Enos (1999, oral. comm) reported that probable rhizocasts are widespread in the top of the Toronto locally.

Johnson and Adkison (1967, p. 82) noted the Spring Branch Limestone to have a lower fusulinid part in Shawnee County, Kansas. Moore's (1964, p. 316) turnpike section in Douglas County, Kansas, showed a Spring Branch with a lower, massive limestone unit and an upper interlayering of limestones and shales.

The other lower limestones of the Virgilian (Toronto, Spring Branch, Hartford-Curzon) appear to share a superficial two-layer similarity to the Ozawkie. The Lawrence Shale and Snyderville Shale, cyclic equivalents of the Tecumseh Shale and the Oskaloosa Shale respectively, both contain paleosols. Cycle equivalents of the Tecumseh (Kanwaka Shale of Lecompton; Calhoun Shale of Topeka), and of the Oskaloosa (Doniphan Shale of Lecompton; Jones Point adn Turner Creek Shale of Topeka) warrant further examination for paleosols or evidence of subaerial exposure.

DIAGENETIC FEATURES OF THE OZAWKIE LIMESTONE

The Ozawkie Limestone can be divided into three diagenetic facies (Fig. 24). These facies are differentiated by the types of porosity-occluding cements present, and on differing preservation of originally unstable aragonite grains such as phylloid algae and gastropods. 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 centimeters of the lower and upper Ozawkie. Terminology is that of Folk (1965) and Choquette and Pray (1970).

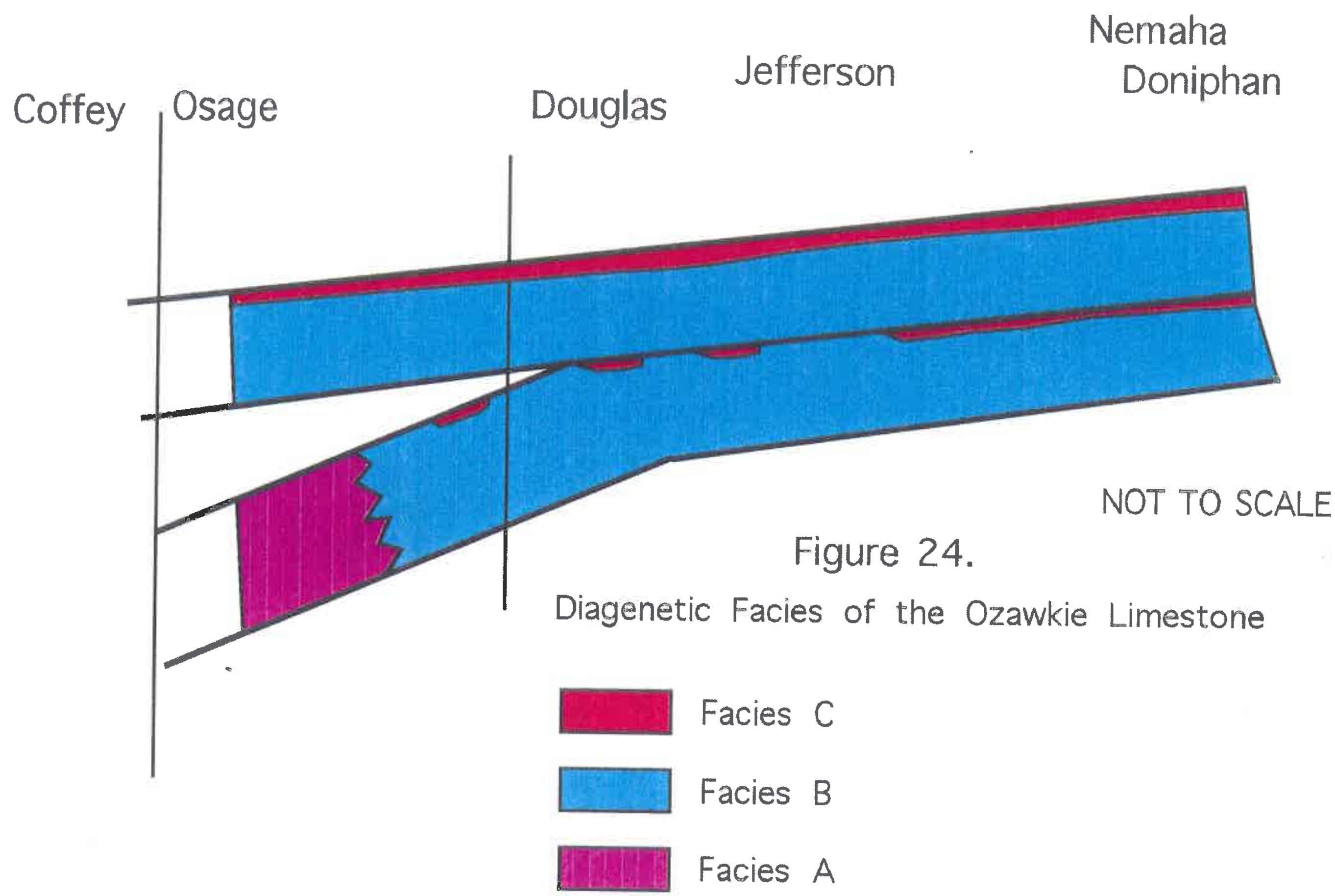


Figure 24.
Diagenetic Facies of the Ozawkie Limestone

Facies A

Facies A is found only in the lower Ozawkie in the southern part of the study area. The initial sediments were muddy, fusulinid wackestone, so pore space was largely confined to intraskeletal pores. A number of diagenetic features can be identified.

Micritization: The margins of many skeletal grains are heavily micritized.

Deformation: The muddy matrix typically has a draped fabric around skeletal grains. Pellets and pellet-packed burrows are slightly compacted (fitted and flattened). Skeletal grains are locally broken at fitted contacts. Skeletal grains are sutured or interpenetrating at mutual contacts.

Neomorphism: Originally aragonite skeletons such as (probably) phylloid algal grains and mollusk fragments have been converted to calcite. Some grains retain relict internal structure, which suggests neomorphism as opposed to leaching and cavity fill (Folk, 1965).

Pore-occluding cement: The most common primary pore space was intraparticle, mainly within fusulinids. Equant, ferroan calcite is most common. Equant dolomite is rare. Though rare, broken interior fusulinid chamber walls are surrounded by equant cement. The ferroan calcite and dolomite crystals are clear and have uniform extinction.

Facies B

Facies B encompasses the vast bulk of the upper and lower Ozawkie through the study area. Typical sediments included skeletal grainstones and packstones, so significant primary depositional pore space, interparticle and intraparticle, was present.

Meniscus cements: Micritic cement with prominent meniscate surfaces bridges grain contacts; equant calcite is locally present at grain contacts. Bladed cement crusts grew on micrite-bridge, meniscus cement. Micrite bridging was found at the base of the upper Ozawkie at DG12, and equant calcite was found in the middle of the upper Ozawkie.

Syntaxial rim cement: Locally, uncoated echinoid grains have syntaxial overgrowths. These Fe-poor calcite crystals typically show pointed terminations.

Bladed cement crusts (Fig. 25)

A. Fe-poor cement: Fe-poor equant cement patchily lines primary pores.

B. Ferroan calcite: Ferroan calcite crystals in optical continuity with any underlying Fe-poor cement continue into pore space. One spectacular sample showed a second alternation of Fe-poor/Fe-rich cement. Pyrite inclusions are locally common in this bladed calcite.

C. Dolomite with pyrite: At about one quarter of the thin sections, dolomite with pyrite inclusions is in optical continuity with calcite rims. In small pores, this dolomite may completely occlude the pore.

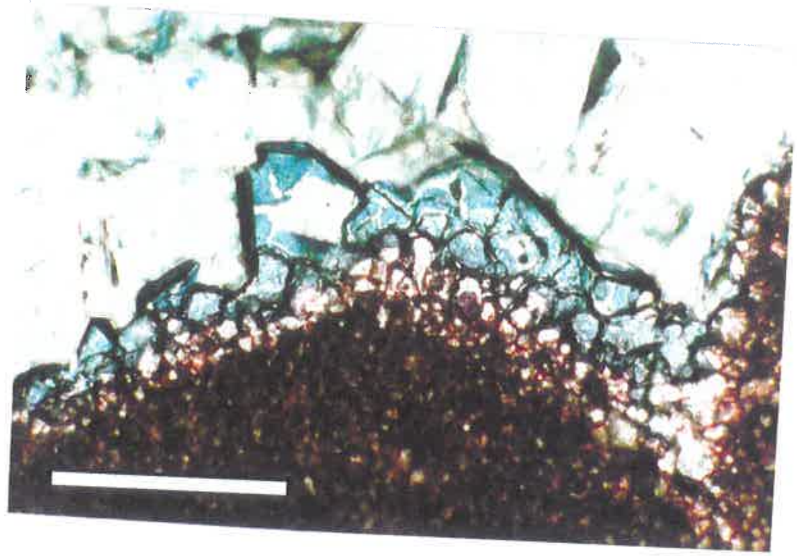


Figure 25. Cements in middle of Ozawkie at DG12.
Pink, Fe-poor calcite is patchy. Blue, ferroan calcite is mostly continuous. Pore-occluding cement is dolomite.
Bar is approximately 0.25 mm long.

Molds: Originally aragonite grains such as ooids, mollusk shells, and phylloid algal grains were leached creating moldic porosity (Fig. 13). Rarely, vugs (Fig. 9) are present. Molds are occluded by later ferroan calcite or dolomite, and cement rims are not within molds.

Sed fill: Internal sediment, identifiable as basal Oskaloosa Shale, filtered into moldic and vuggy porosity. This is present at MMQ and in the Dennels Core (Fig. 13).

Dolomite f.c. : Finely crystalline dolomite rhombs sparsely line sides of rhizocasts and burrows. These rhizocasts were later occluded by ferroan calcite (DG7 and OS23).

Pore-occluding cement:

Baroque dolomite: Coarsely crystalline baroque or saddle dolomite with undulatory extinction is best seen occluding pore space at DG12 (Fig. 25) and JF1. At MMQ, moldic porosity reduced by internal sediment was occluded by this dolomite. Dolomite occurs in the same samples as ferroan calcite, but rarely in the same pores. At key localites, euhedral terminations of dolomite are overlain by equant ferroan calcite, and equant ferroan calcite abutts a curved crystal boundary of dolomite.

Ferroan calcite: Equant ferroan calcite generally occluded all remaining pore space. This ferroan calcite is commonly poikilotopic, single crystals can be several millimeters in size.

Facies C

Facies C consists of subaerial features such as laminated micrite crusts, clotted micrite, rhizocasts and rhizoliths, karst holes and pitted surfaces, and circumgranular cracks. Facies C is typically confined to the uppermost centimeters of the lower and upper Ozawkie.

The crusts range from millimeters to centimeters thick, are comprised of wavy laminations of micrite, and generally thicken into depressions and thin over highs. Crusts commonly truncate grains in the host lithology. Crusts locally overhang edges of karst/solution pits, and several generations of crust may be superposed. Clotted micrite is common in the crusts. Circumgranular cracks around grains, now spar-occluded, are commonly found in the upper few centimeters underlying a micrite crust.

Rhizolith preservation includes carbonized traces defining a tube and pyrite-filled tubes with micrite aureoles. Rhizocasts are generally 1 mm in thickness and several centimeters long. Micrite aureoles surround what was a hollow tube, now occluded by calcite cement. Where associated with crusts, rhizocasts begin in the crust and penetrate into the underlying lithology.

Most subaerial features do not include open pore space making direct correlation to pore cement stratigraphy difficult. However, rhizocasts generally do not have any isopachous rims associated within them, but are occluded by ferroan calcite or dolomite. One rhizocast at JF5 had isopachous ferroan calcite rims.

PARAGENESIS OF THE OZAWKIE LIMESTONE

Facies A

Facies A (Fig. 26) is found in muddy lithologies which limited water flow and room for any obvious cements. Interpretation of Facies A is difficult, but some generalities can be made.

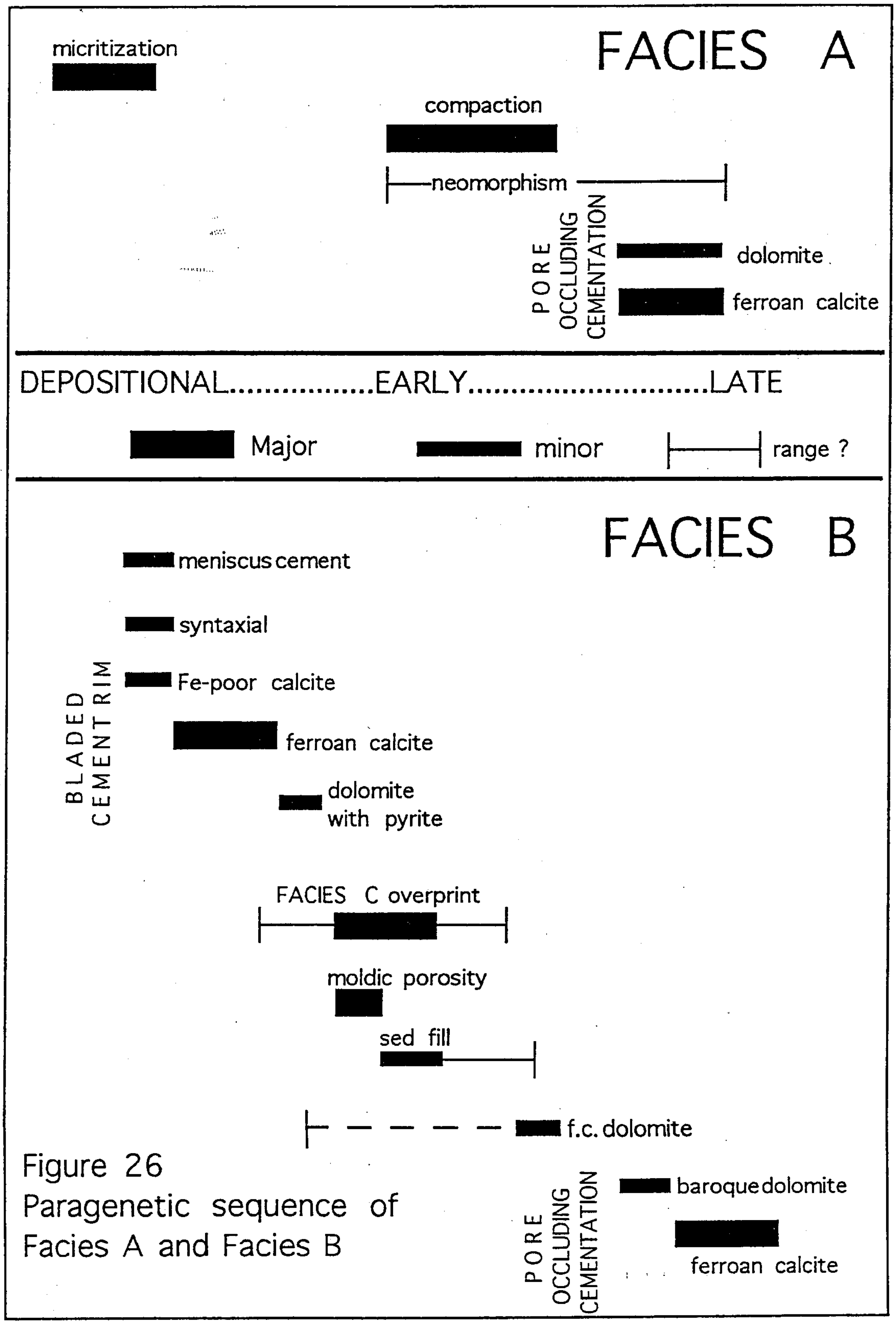


Figure 26
Paragenetic sequence of
Facies A and Facies B

Fitted pellets within burrows suggests that some burial preceded lithification. Had early lithification occurred, burrow walls would have prevented pellets within from being compressed. Early compaction created the draped fabric of the muddy matrix.

Broken interior chamber walls of fusulinids surrounded by equant spar cement, and clear crystals free of undulatory extinction suggests that pore-occluding cements postdate all compaction.

Facies B and Facies C

The paragensis of Facies B and Facies C (Fig 26.) is easier to establish than Facies A, as significant depositional pore space was present. Syntaxial rims of Fe-poor calcite on uncoated echinoid grains and Fe-poor calcite patchily lining pore space are the earliest widespread event. They are the same event expressed differently because of substrate control. At DG12, meniscus cements in the form of micrite bridges or equant cement came first. No cross-cutting relationship between the meniscus cements and the Fe-poor calcite was observed, so exact age realtion between the two is unknown. Bladed ferroan calcite, and rarely dolomite with pyrite inclusions, grew on top of the initial Fe-poor calcite.

Most rhizocasts are occluded by equant ferroan calcite or dolomite and do not have bladed cements rims. This suggests that Facies C came after the bladed cement rims and before later pore-occluding cements. One exposure had rhizocasts with bladed ferroan calcite rims, so there must have been some overlap in time, at least locally. The moldic porosity and subsequent internal sediment fill probably developed synchronously with Facies C. MMQ and the Dennels core have molds or vugs reduced with green shale from the overlying basal Oskaloosa, and none are reduced by bladed cement. Molds formed after the bladed cement rims and before sediment infiltration during Oskaloosa deposition.

At isolated locales, finely crystalline, rhombohedral dolomite reduces rhizocasts. Those rhizocasts are later occluded by equant ferroan calcite. No other cross-cutting relationships were observed, so this most likely places the finely crystalline dolomite after the bladed calcite rims, yet before pore-occluding cements.

The last event is occlusion by locally significant amounts of baroque dolomite with undulatory extinction, and finally by ferroan calcite. Euhedral terminations and curved crystal boundaries of baroque dolomite are overgrown by ferroan calcite in Facies B. This suggests that the baroque dolomite came before the ferroan calcite, late in the diagenetic history.

INTERPRETATIONS OF DIAGENESIS

Interpretation of Facies A

Facies A records no early diagenesis from either the early marine or meteoric environments because of lack of early cementation. Compaction is the first event and predates any discernible cementation. Ferroan calcite and rare dolomite are at least consistent, but not diagnostic, of late-stage diagenesis. This is consistent with their timing in Facies B and elsewhere in Kansas cyclothems. It is likely that the overlying calcareous shale acted as an aquitard and removed the lower Ozawkie from marine environment influence and prevented later meteoric water from penetrating.

Interpretation of Facies B

Micritic, bridging, meniscus cement and the assemblage of subaerial features of Facies C, is diagnostic of the meteoric-vadose zone (Dunham, 1971; Halley and Harris, 1979; James and Choquette, 1984).

The earliest widespread event recorded in Facies B is compositionally-zoned, bladed calcite cements. Meyers (1974) noted that there is not enough Fe(II) in sea water to make a ferroan calcite directly from sea water. This indicates that early ferroan calcite is not marine. Meyers (1974) noted that knowledge of partition coefficients of Fe(II) is incomplete, but suggested that early ferroan bladed calcite cement was likely indicative of the meteoric phreatic environment. Longman (1980) proposed that the meteoric phreatic environment is characterized by leaching of originally aragonite grains and precipitation of isopachous bladed cement. Isopachous, bladed, ferroan calcite cement, along with extensive leaching of aragonite, suggests that the meteoric diagenetic environment dominated early diagenesis.

Baroque dolomite (Radke and Mathis, 1980) that occludes remaining pore spaces has been noted by other local carbonate workers (Anderson, 1989; and Wojcik, 1992) and interpreted as late-stage diagenesis with a temperature range of formation of 45 to 135^{0}C. Radke and Mathis (1980) suggested that baroque dolomite formation is related to sulfate reduction. Anderson (1989), who worked in the Missourian-aged Lansing and Kansas City Group, postulated that later Permian brines, which precipitated anhydrite at the surface, seeped downward and precipitated dolomite and calcite. Anderson measured dolomite formation temperatures from 45 to 70^{0}C, which is consistent with the proposed geothermal gradient. Wojcik (1992), who also worked in the Lansing-Kansas City, measured dolomite formation temperatures of 85 to 135^{0}C, inconsistent with proposed geothermal gradient, and proposed invasion of hot basinal fluids. At this point, it appears probable that baroque dolomite and ferroan calcite occluding pore space in the Ozawkie Limestone is late-stage burial diagenesis.

DIAGENESIS OF MISSOURIAN CYCLOTHEMS

For idealized Missourian cyclothems, Heckel (1983) showed that general patterns of diagenesis can be predicted from the interpreted sea-level history of cyclothems. Limestones deposited as different stages of a 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 mollusks), and cementation by 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 meteoric diagenesis of the upper limestones. This style of diagenesis is analogous to Facies A in the Ozawkie.

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. These features are found in Facies B of the Ozawkie. This indicated movement into meteoric waters. During the following transgression, deeper connate water from below would slowly move into the upper limestone.

Railsback (1984) recognized five diagenetic zones in his study of a Missourian cyclothem (Dennis Formation). Diagenetic facies were generally based on varying degrees of preservation of originally unstable aragonite grains such as phylloid algae, ooids, and mollusks. The amount of preservation of aragonite grains was related to the extent of influence of freshwater on the sediments. Railsback noticed that the extent of preservation of aragonite grains decreased from south to north, and from bottom to top, in the upper limestone. As the regression proceeded, the northern or shallowest end of the limestone was subjected to freshwater the longest, hence the least amount of preservation of original aragonite grains. The middle limestone did not show a trend in preservation from north to south.

A comprehensive diagenetic study has not been done on a Virgilian cyclothem in Kansas. It is to be expected that the diagenesis of the upper and middle limestones are similar to their Missourian counterparts (Fig. 4). Lower limestones have no Missourian equivalent, so are not included in this scheme.

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. The Ozawkie limestone seems to incorporate diagenetic features from both middle (transgressive) limestones and upper (regressive) limestones of cyclothem models. That would suggest that different locations of the same limestone were experiencing different environments of diagenesis.

The general depositional trend of both the upper and lower Ozawkie shallowing from south to north suggests that topographically higher parts were to the north. A relative sea-level fall should expose northern areas first and for a longer duration. The general diagenetic trend of the Ozawkie is consistent with the model. However, other factors can influence the diagenetic history. A change in climate, specifically amount of rainfall, could change the local hydrology and create a similar effect to a sea-level fall. The shale between the upper and lower Ozawkie, presumably a barrier to water flow, could also enhance or retard hydrologic changes.

Railsback's study showed that both sea-level history and paleotopography play a role in diagenesis of upper limestones. Middle limestones were affected mostly by sea-level history. This is logical because the sea level is at the relative highest stand following limestone deposition, hence all the middle limestone is under marine waters.

In the Ozawkie, part of the lower Ozawkie in the southern area, Facies A, appears to have never been subjected to freshwater, and diagenetically resembles a middle limestone. The remainder of the Ozawkie, Facies B, diagenetically resembles an upper limestone.

CONCLUSIONS

1) The Ozawkie Limestone is comprised of two limestone layers with an intervening shale to the south. The limestone layers are distinct even where in contact.

2) 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; agitated, shallow subtidal environments in the central area; and restricted, shallow subtidal environments leeward of central-area-shoals in the northern area.

3) The Ozawkie was deposited during 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.

4) 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 pits. Subaerial features capping the lower layer of the Ozawkie are less developed and less extensive aerially than features capping the upper layer, indicating that the first regression was less extensive and of shorter duration than the second regression.

5) Subaerial exposure also occurred near the top of the Tecumseh Shale. Up to 3 m of marine shale lies between the Tecumseh paleosol and the Ozawkie limestone. In the central area, the shale and Tecumseh paleosol appear to have been eroded away.

6) Three diagenetic facies are identified in the Ozawkie. Facies A, found in the lower layer in the southern part of the study, likely represents sediments which were not influenced by early diagenetic environments. Facies B, the remaining bulk of the lower and upper Ozawkie, represents sediments where the meteoric diagenesis exerted the greatest early influence before the rocks moved to a late-stage burial environment. Facies C, the uppermost centimeters of each Ozawkie layer, represents sediments which were altered extensively by subaerial exposure, including the freshwater vadose zone. The Ozawkie incorporates diagenetic features of both middle and upper limestones in Heckel's (1983) and Railsback's (1984) diagenetic schemes for cyclothems.

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. Roger Kaesler helped with the identification of ostracodes in the shale at OS11. 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.

REFERENCES CITED

Anderson, J. 1989, Diagenesis of the Lansing and Kansas City Group (Upper Pennsylvanian) Northwestern Kansas and Southeastern Nebraska: M.S. thesis, University of Kansas, Lawrence, Kansas 259 p.

Bayne, C. K., 1973, Geohydrology of Doniphan County, northeastern Kansas: United States Geological Survey Atlas HA-462.

Bennett, J., 1896, A geologic section along the Kansas River from Kansas City to McFarland: State Geological Survey of Kansas Bulletin, vol. 1, p. 107-128.

Blaine, C.B., 1990, Paleoclimatic controls on stratigraphic repetition of chemical and siliciclastic rocks : Geology, vol. 18, no. 6, p. 533-536.

Branson, C.C., 1964, Cyclicity in Oklahoma Paleozoic Rocks: *in* Merriam, D.F., ed., Symposium on Cyclic Sedimentation: State Geological Survey of Kansas Bulletin 169, vol. 1, p. 57-62.

Buol, S.W., Hole, F.D., and McCracken, R.J., 1973. Soil Genesis and Classification: The Iowa State University Press, Ames, Iowa. 360 p.

Choquette, P. W., and Pray, L. C., 1970, Geological nomenclature and classification of porosity in sedimentary carbonates: American Association of Petroleum Geologists Bulletin, vol. 54, no. 2., p. 207-250.

Condra, G. E., 1927, The stratigraphy of the Pennsylvanian System in Nebraska: Nebraska Geological Survey Bulletin, no. 1, 291 p.

Conkin, B.M., 1954, Microfossils of the Deer Creek Limestone of Kansas and northern Oklahoma : Ph.D. dissertation. University of Kansas, Lawrence, Kansas. 90 p.

Dickson, B.A., 1965, Environmental mapping of the Topeka and Deer Creek Megacycles of the Shawnee Group (Upper Pennsylvanian) of the Midcontinent: M.S. thesis. University of Illinois, Urbana, Illinois 48 p.

Dickson, J. A. D., 1965, A modified staining technique for carbonates in thin section: Nature, no. 4971, p. 587.

Dunham, R. J., 1971, Meniscus cement, *in* Bricker, O.P., ed., Carbonate Cements: Johns Hopkins Press, Baltimore, MD 21218, pp. 297-300.

Elias, M. K., 1964, Depth of Late Paleozoic sea in Kansas and its megacyclic sedimentation, *in* Merriam, D. F., eds., Symposium on Cyclic Sedimentation: State Geological Survey of Kansas Bulletin 169, pp. 87-106.

Enos, P., 1983, Shelf, *in* Scholle, P. E., Bebout, D. G., Moore, C.H., eds., Carbonate Depositional Environments: American Association of Petroleum Geologists Memoir 33, p. 267-296.

Esteban, M., and Klappa, C.F., 1983, Subaerial Exposure, *in* Scholle, P.E., Bebout, D.G., Moore, C.H., eds., Carbonate Depositional Environments: American Association of Petroleum Geologists Memoir 33, p. 1-54.

Fagerstrom, R.A., and Burchett, R.R., 1972, Upper Pennsylvanian shoreline deposits from Iowa and Nebraska: Their recognition, variation, and significance : Geological Society of America Bulletin, vol 83, p. 367-388.

Fischer, A. G., 1964, The Lofer Cyclothems of the Alpine Triassic, *in* Merriam, D. F., eds., Symposium on Cyclic Sedimentation: State Geological Survey of Kansas Bulletin 169, p. 107-149.

Folk, R. L., 1965, Some aspects of recrystallization in ancient limestones: *in* Pray, L. C., and Murray, R. C., eds., Dolomitization and limestone diagenesis: SEPM Special Publication 13, pp. 14-48.

Halley, R. B., and Harris, P. M., 1979, Fresh-water cementation of a 1000-year-old oolite: Journal of Sedimentary Petrology, vol. 49, no. 3, pp. 969-988.

Heckel, P.W., 1980, Paleogeography of eustatic model for deposition of Midcontinent Upper Pennsylvanian Cyclothems, *in* T.D. Fouch and E.R. Magathan, eds., Paleozoic Paleogeography of the West-Central United States: Society for Economic Paleontologists and Mineralogists, Rocky Mountains, Paleogeography Symposium 1, p. 197-216.

Heckel, P.W., 1983, Diagenetic model for carbonate rocks in Midcontinent Pennsylvanian eustatic cyclothems : Journal of Sedimentary Petrology, vol. 53, no. 3. p. 733-759.

Heckel, P.W., Mitchell, J.C., Nelson, D.L., and Ravn, R.L., 1978, Field guide to Upper Pennsylvanian cyclothemic limestone facies in eastern Kansas : State Geological Survey of Kansas Guidebook Series 2, 79 p.

Heckel, P.H., Brady L.L., Ebanks, W.J., and Pabian, R.K., 1979, Pennsylvanian cyclic platform deposits of Kansas and Nebraska : State Geological Survey of Kansas Guidebook Series 4, 79 p.

Iowa Geological Survey, 1962, Preliminary Geologic Map of Iowa.

Imbrie, J., Laporte, L. F., and Merriam, D.F., 1964, Beattie Limestone facies (lower Permian) of the Northern Midcontinent, *in* Merriam, D. F., eds., Symposium on Cyclic Sedimentation: State Geological Survey of Kansas Bulletin 169, p. 219-238.

James, N. P., 1972, Holocene and Pleistocene calcareous crust (caliche) profiles : Criteria for subaerial exposure : Journal of Sedimentary Petrology, vol. 42, pp. 817-836.

James, N. P., and Choquette, P. W., 1984, Limestones-The meteoric diagenetic environment: Geoscience Canada, vol. 11, no. 4, pp. 161-194.

Joeckel, R. M., 1994, Virgilian (Upper Pennsylvanian) paleosols in the upper Lawrence Formation (Douglas Group) and in the Snyderville Shale Member (Oread Formation, Shawnee Group) of the northern midcontinent, USA: Pedological contrasts in a cyclothem sequence: Journal of Sedimentary Research vol. 64, no. 4, pp. 853-866.

Johnson, W.D., and Adkison, W.L., 1967, Geology of Eastern Shawnee County, Kansas and Vicinity: United States Geological Survey Bulletin 1215-A, 254 p.

Klein, G. D., and Kupperman, J. B., 1992, Pennsylvanian cyclothems: Methods of distinguishing tectonically induced changes in sea level from climatically induced changes: Geological Society of America Bulletin, vol. 104, pp. 166-175.

Lamoreaux, S.B., 1983, Field study of the Deer Creek Limestone (Shawnee Group, Upper Pennsylvanian), eastern Kansas : The Compass of Sigma Gamma Epsilon, vol. 61, no.1, p. 8-17.

Lee, W., 1943, The stratigraphy and structural development of the Forest City Basin in Kansas: State Geological Survey of Kansas Bulletin 51, 142 p.

Longman, M. W., 1980, Carbonate diagenetic textures from nearsurface diagenetic environments : The American Association of Petroleum Geologists Bulletin, vol. 64, no. 4, pp. 461-487.

Meyers, W. J., 1974, Carbonate cement stratigraphy of the Lake Valley Formation (Mississippian) Sacramento Mountains, New Mexico: Journal of Sedimentary Petrology, vol. 44, no. 3, pp. 837-861.

Moore, R.C., 1936, Stratigraphic classification of the Pennsylvanian rocks of Kansas : State Geological Survey of Kansas Bulletin vol. 22, 256 p.

Moore, R.C., 1949, Divisions of the Pennsylvanian System in Kansas : State Geological Survey of Kansas Bulletin 83, 203 p.

Moore, R.C., Frye, J.C., Jewett, J.M., Lee, W., and O'Connor, H.G., 1951, The Kansas rock column : State Geological Survey of Kansas Bulletin 89, 132 p.

Moore, R.C., 1964, Paleoecological aspects of Kansas Pennsylvanian and Permian cyclothems, *in* Merriam, D. F., eds., Symposium on Cyclic Sedimentation: State Geological Survey of Kansas Bulletin 169, p. 287-380.

O'Connor, H.G., 1955, Geology, Mineral Resources, and Ground-Water Resources of Osage County, Kansas: State Geological Survey of Kansas, University of Kansas Publication, vol. 13, 50 p.

O'Connor, H.G., 1958, Field stratigraphy of the Lecompton, Deer Creek and Howard Limestones, eastern Kansas : State Geological Survey of Kansas Open File Report 58-5, 10 p.

O'Connor, H. G., 1960, Geology and groundwater resources of Douglas County, Kansas : State Geological Survey of Kansas, Bulletin 148, 199 p.

O'Connor, H. G., 1992 (revised), Geologic Map, Douglas County, Kansas : Kansas Geological Survey, Map M-26.

Radke, B. M., and Mathis, R. L., 1980, On the formation and occurrence of saddle dolomite: Journal of Sedimentary Petrology, vol. 50, no.4, pp. 1149-1168.

Railsback, B. L., 1984, Carbonate diagenetic facies in the Upper Pennsylvanian Dennis Formation in Iowa, Missouri, and Kansas : Journal of Sedimentary Petrology, vol. 54., no. 3, p. 986-999.

Reed, E. C., and Burchett, R. R., 1964, Stratigraphic sequences in the Pennsylvanian and their relationships to cyclic sedimentation, *in* Merriam, D. F., eds., Symposium on Cyclic Sedimentation: State Geological Survey of Kansas Bulletin 169, p. 441-448.

Robb, A.J., 1991, Subaerial exposure surfaces associated with shoaling facies, Ozawkie Limestone Member of the Deer Creek Limestone (Virgilian), northeastern Kansas : State Geological Survey of Kansas Open File Report 91-26, 43 p.

Robb, A.J. and Michnick, S.M., 1990, Preliminary report on paleocurrents and depositional environments of the Ozawkie Limestone Member of the Deer Creek Limestone (Virgilian) within Jefferson County, Kansas : The Compass of Sigma Gamma Epsilon, vol 67, no. 3, p. 166-174.

Shinn, E. A., 1983a, Birdseye's, fenestrae, shrinkage pores, and loferites: a reevaluation: Journal of Sedimentary Petrology, v. 53, no. 2, p. 619-628.

Shinn, E. A., 1983b, Tidal Flats, in Scholle, P.E., Bebout, D.G., Moore, C.H., eds., Carbonate Depositional Environments: American Association of Petroleum Geologists Memoir 33, pp. 171-210.

Smith, J. P., 1894, The Arkansas Coal Measures in their relation to the Pacific Carboniferous Province: Journal of Geology, vol. 2, p. 187-204.

Troell, A.R., 1969, Depositional facies of Toronto Limestone Member (Oread Limestone, Pennsylvanian), subsurface marker unit in Kansas: State Geological Survey of Kansas Bulletin 197, 29 p.

Wanless, H. R., and Shepard, F. P., 1936, Sea level changes and climatic changes related to late Paleozoic cycles: Geological Society of America Bulletin vol. 47, pp. 1177-1206.

Ward, J. R., 1973, Geohydrology of Atchison County, northeastern Kansas : United States Geological Survey Atlas HA-467.

Winslow, J.D., 1972, Geohydrology of Jefferson County, northeastern Kansas : State Geological Survey of Kansas Bulletin 202, part 4, 20 p.

Wojcik, K. 1992, Diagenesis of Pennsylvanian sandstones and limestones, Cherokee Basin, Southeastern Kansas: Importance of regional fluid flow: Ph. D dissertation, University of Kansas, Lawrence, Kansas 349 p.

Zeller, D.E., 1968, The stratigraphic succession of Kansas: State Geological Survey of Kansas Bulletin 189, 81 p.

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.

5-155 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.

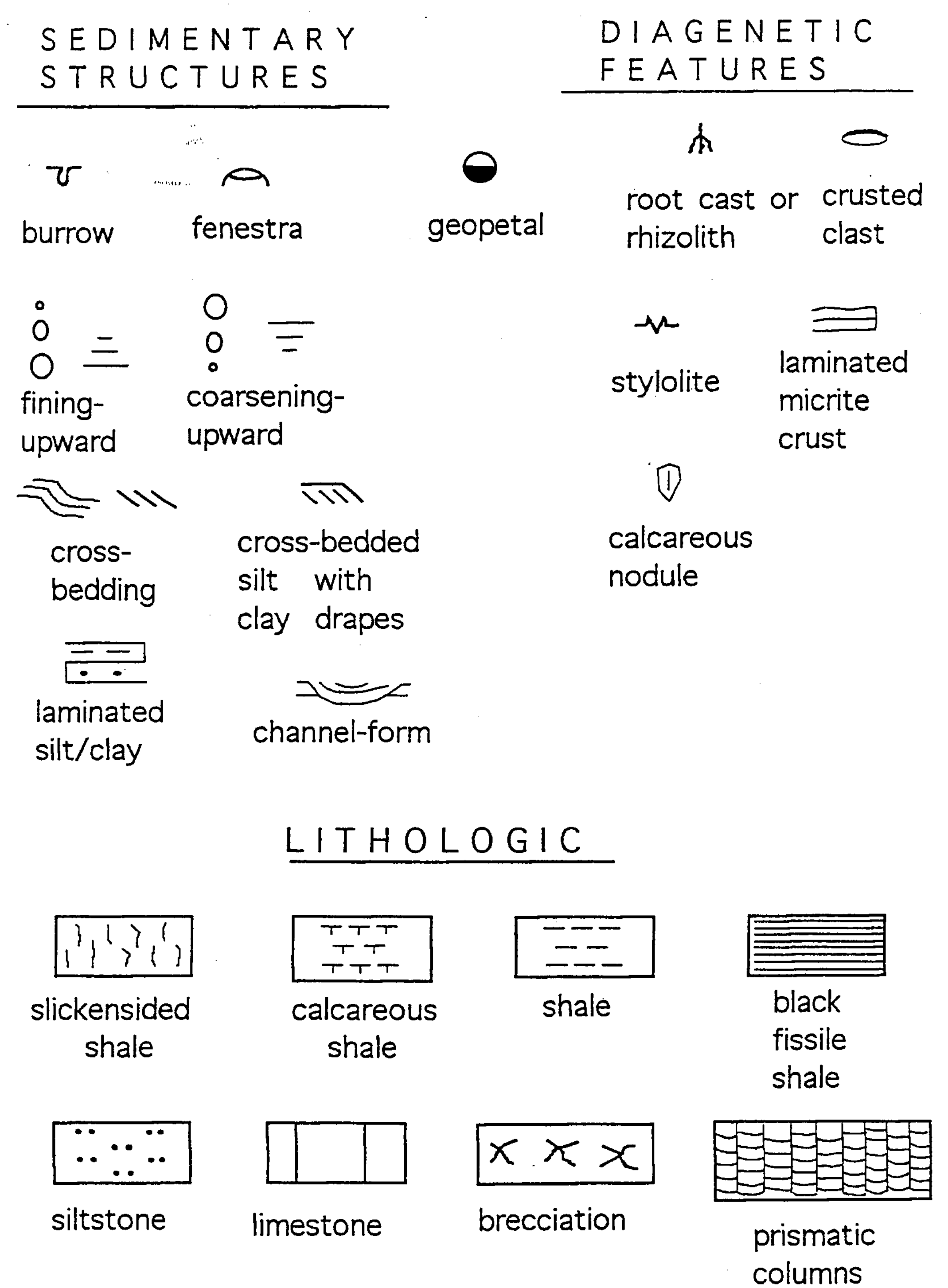
Locality HQ: Hamm Quarry NW 1/4, sec 15, T11S, R17E.

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.

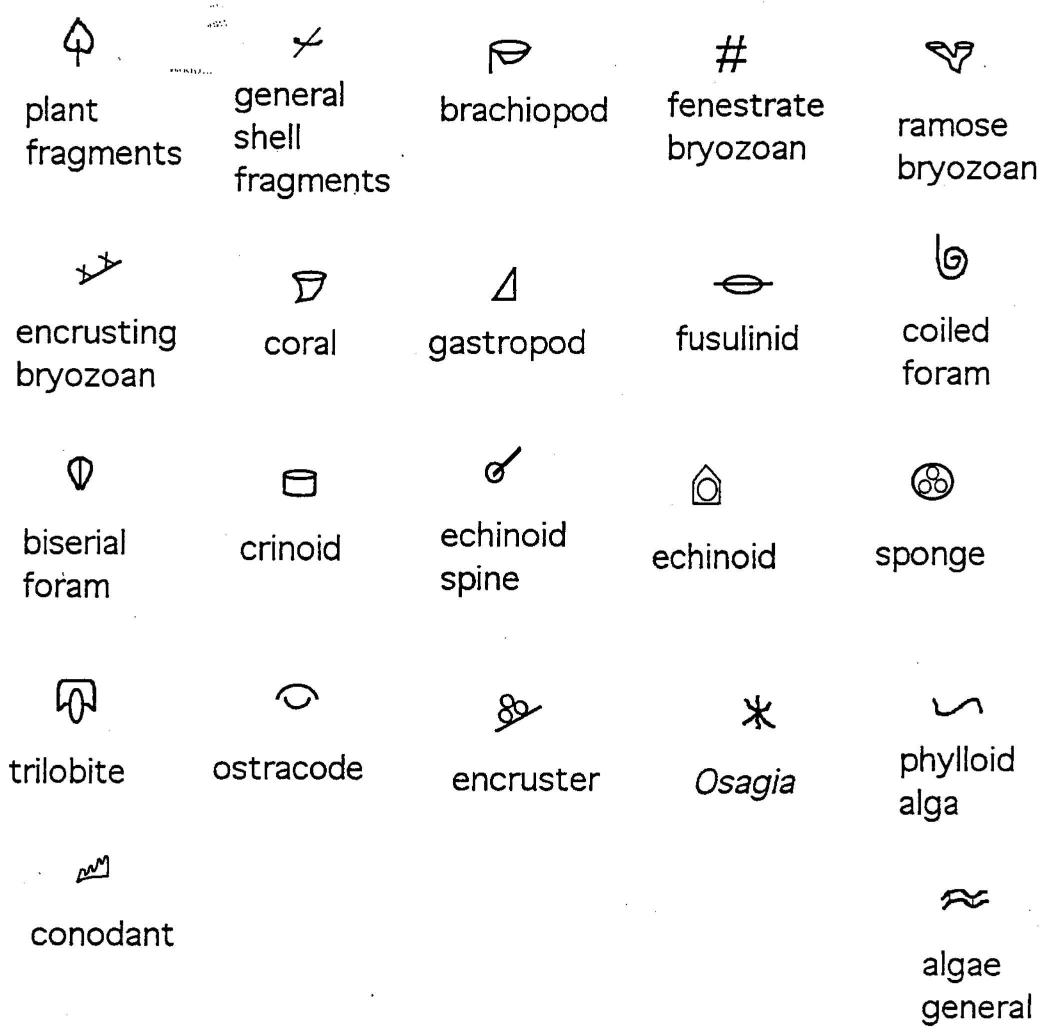
Examined in north section of western pit. Entire Deer Creek should be available in either west pit or east pit at most times.

SYMBOLS FOR SECTIONS

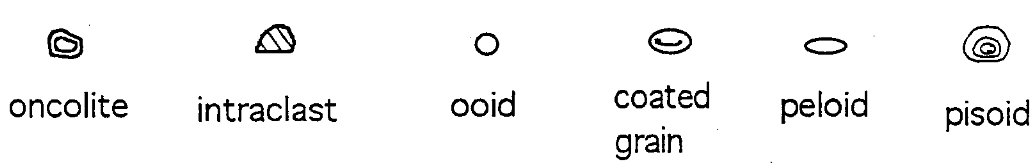


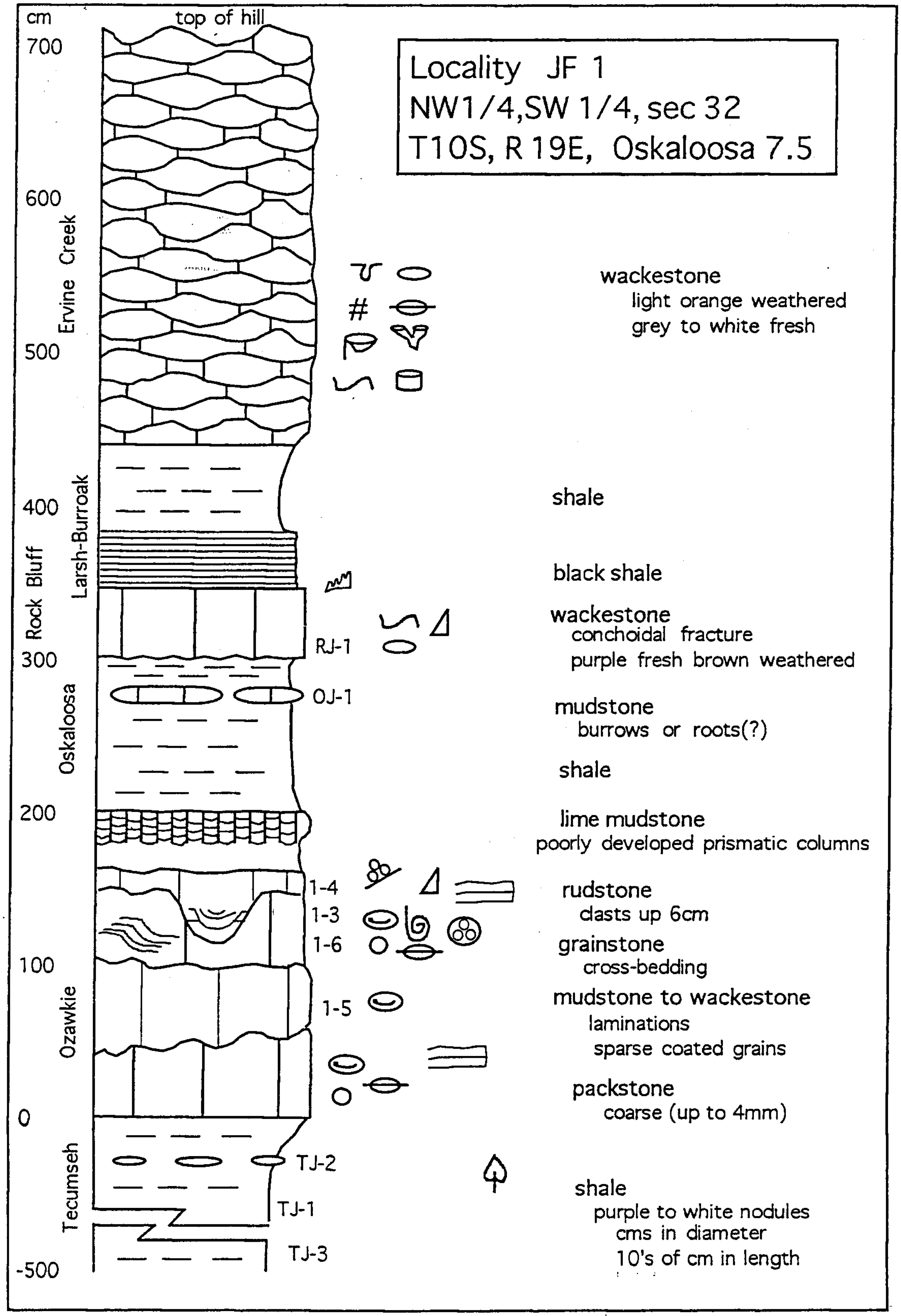
SYMBOLS USED

FOSSILS

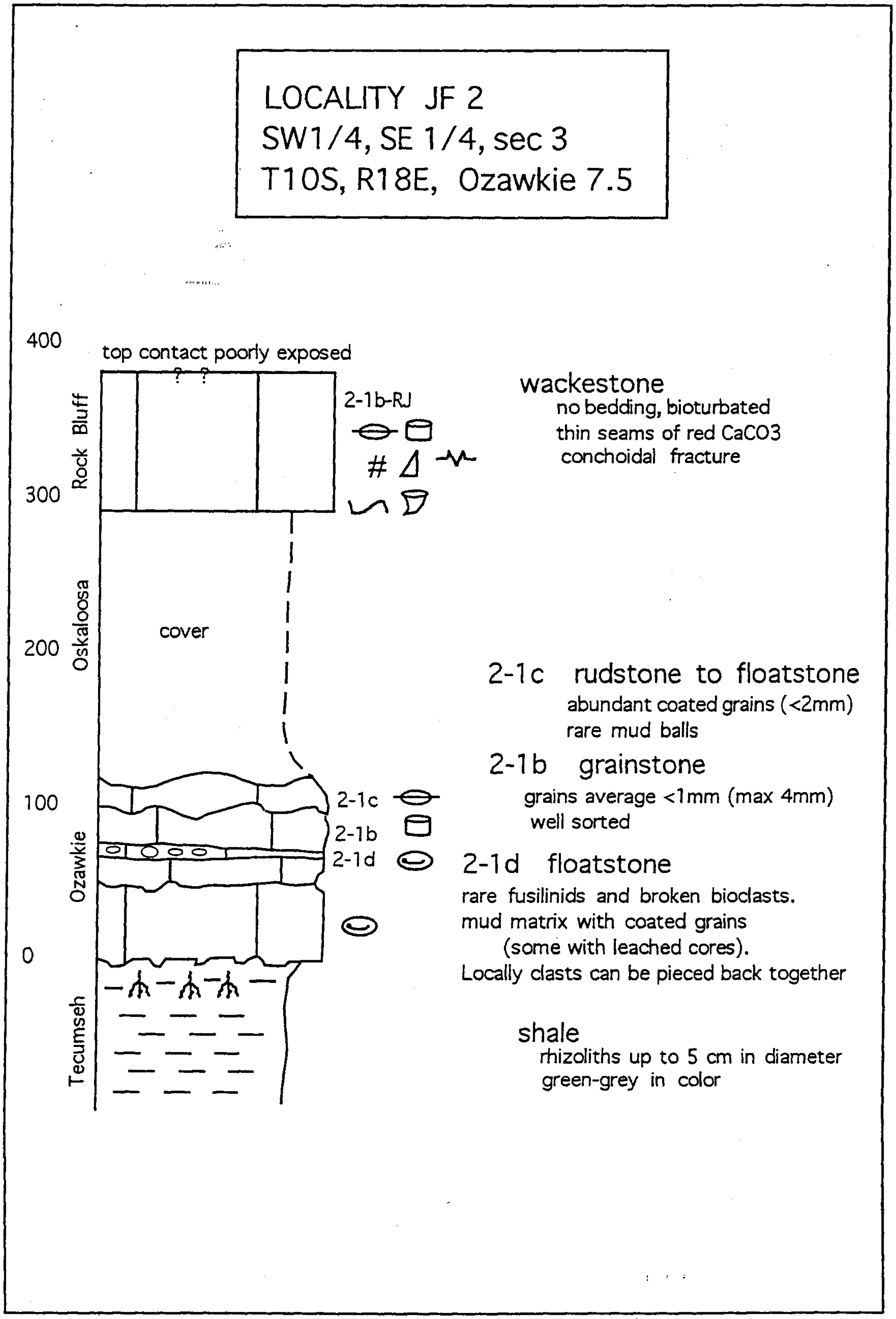


PARTICLES

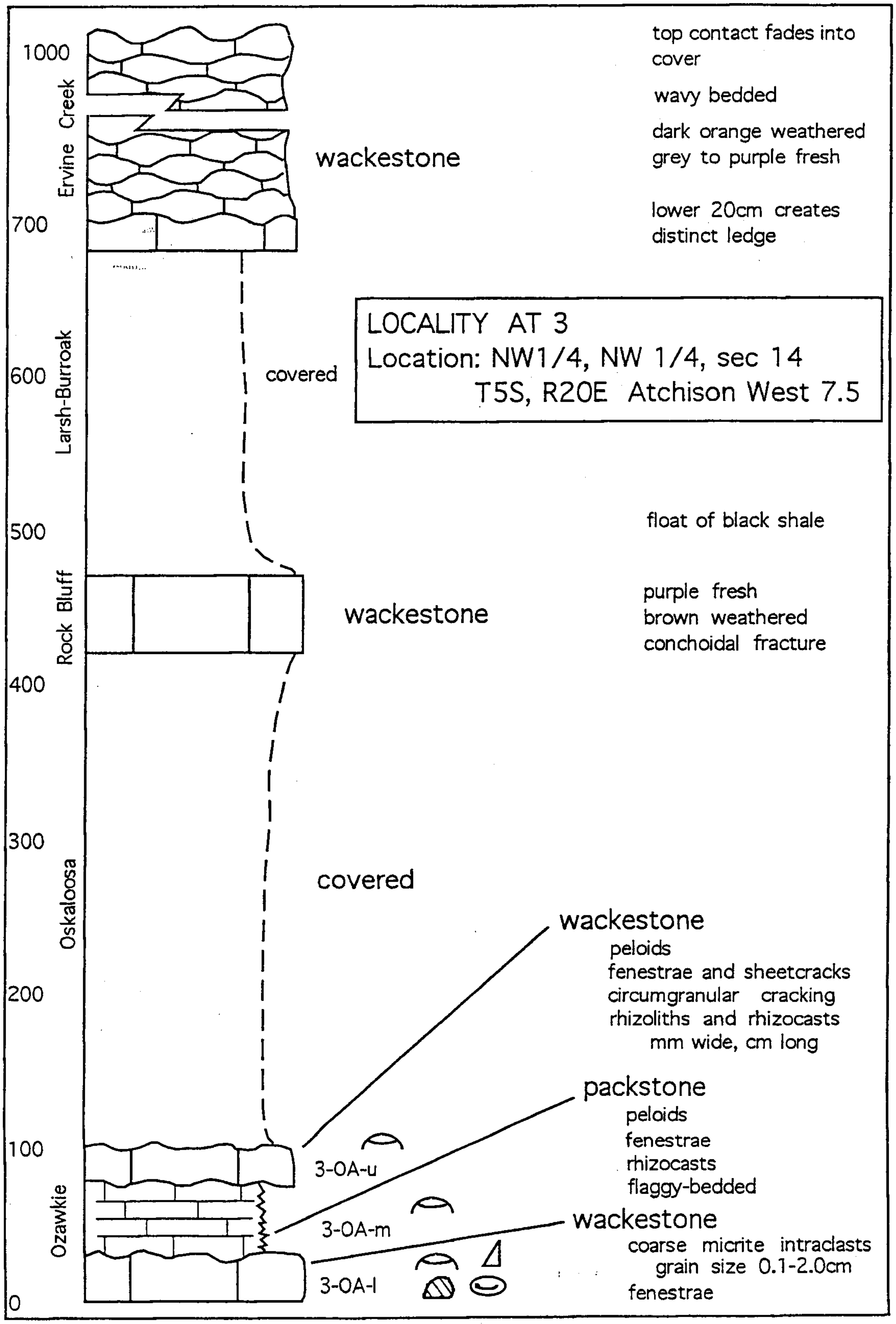




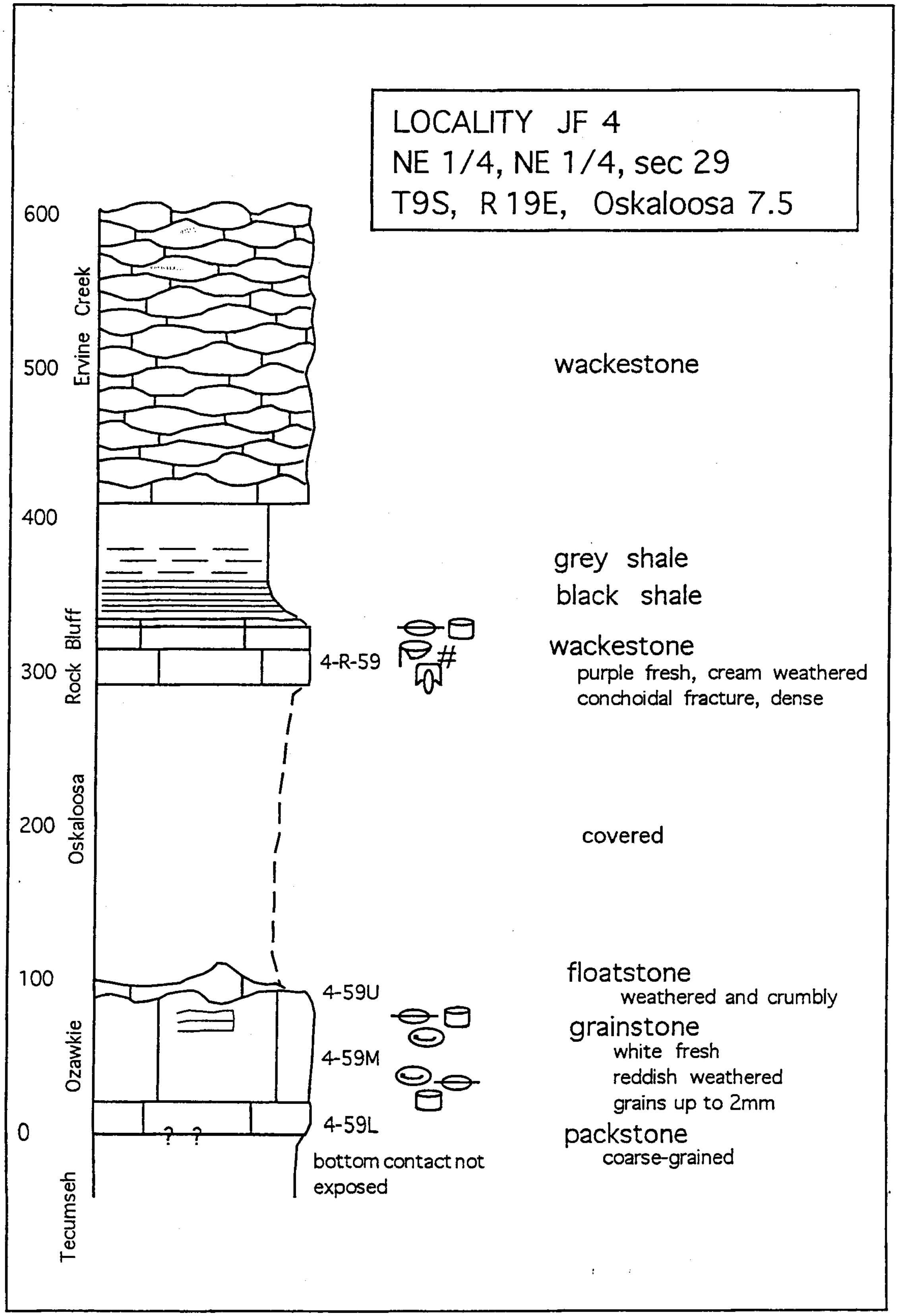
cm
top of hill
700
600
500
400
300
200
100
0
-500
Locality JF 1
NW1/4,SW 1/4, sec 32
T10S, R 19E, Oskaloosa 7.5
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
wackestone
light orange weathered
grey to white fresh
shale
black shale
wackestone
conchoidal fracture
purple fresh brown weathered
RJ-1
OJ-1
mudstone
burrows or roots(?)
shale
lime mudstone
poorly developed prismatic columns
1-4
1-3
1-6
rudstone
clasts up 6cm
grainstone
cross-bedding
1-5
mudstone to wackestone
laminations
sparse coated grains
packstone
coarse (up to 4mm)
TJ-2
TJ-1
TJ-3
shale
purple to white nodules
cms in diameter
10's of cm in length



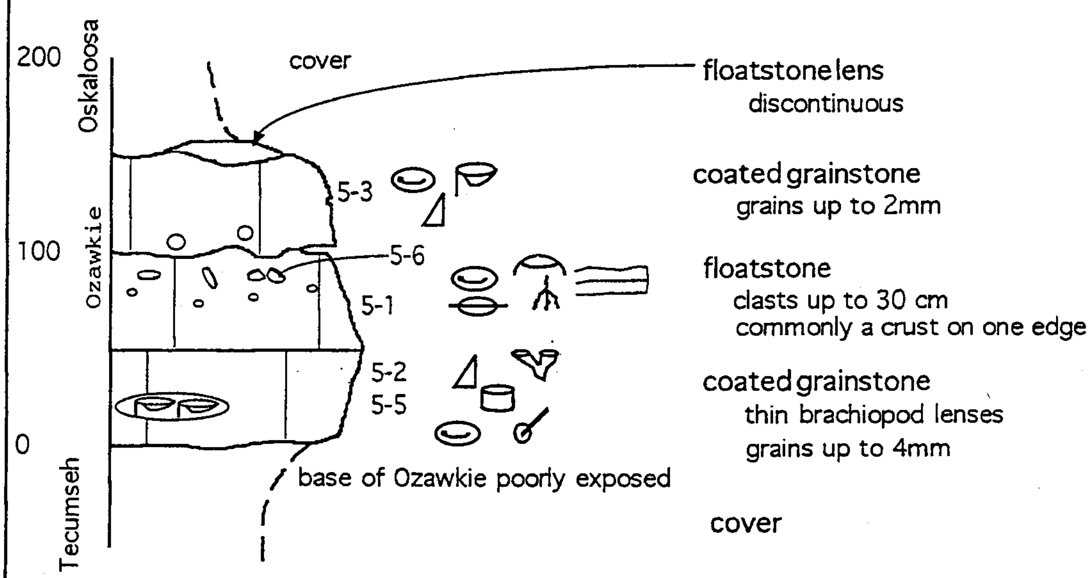
LOCALITY JF 2
SW1/4, SE 1/4, sec 3
T10S, R18E, Ozawkie 7.5
400
300
200
100
0
top contact poorly exposed
? ?
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
cover
2-1b-RJ
#
2-1c
2-1b
2-1d
wackestone
no bedding, bioturbated
thin seams of red CaCO3
conchoidal fracture
2-1c rudstone to floatstone
abundant coated grains (<2mm)
rare mud balls
2-1b grainstone
grains average <1mm (max 4mm)
well sorted
2-1d floatstone
rare fusilinids and broken bioclasts.
mud matrix with coated grains
(some with leached cores).
Locally clasts can be pieced back together
shale
rhizoliths up to 5 cm in diameter
green-grey in color

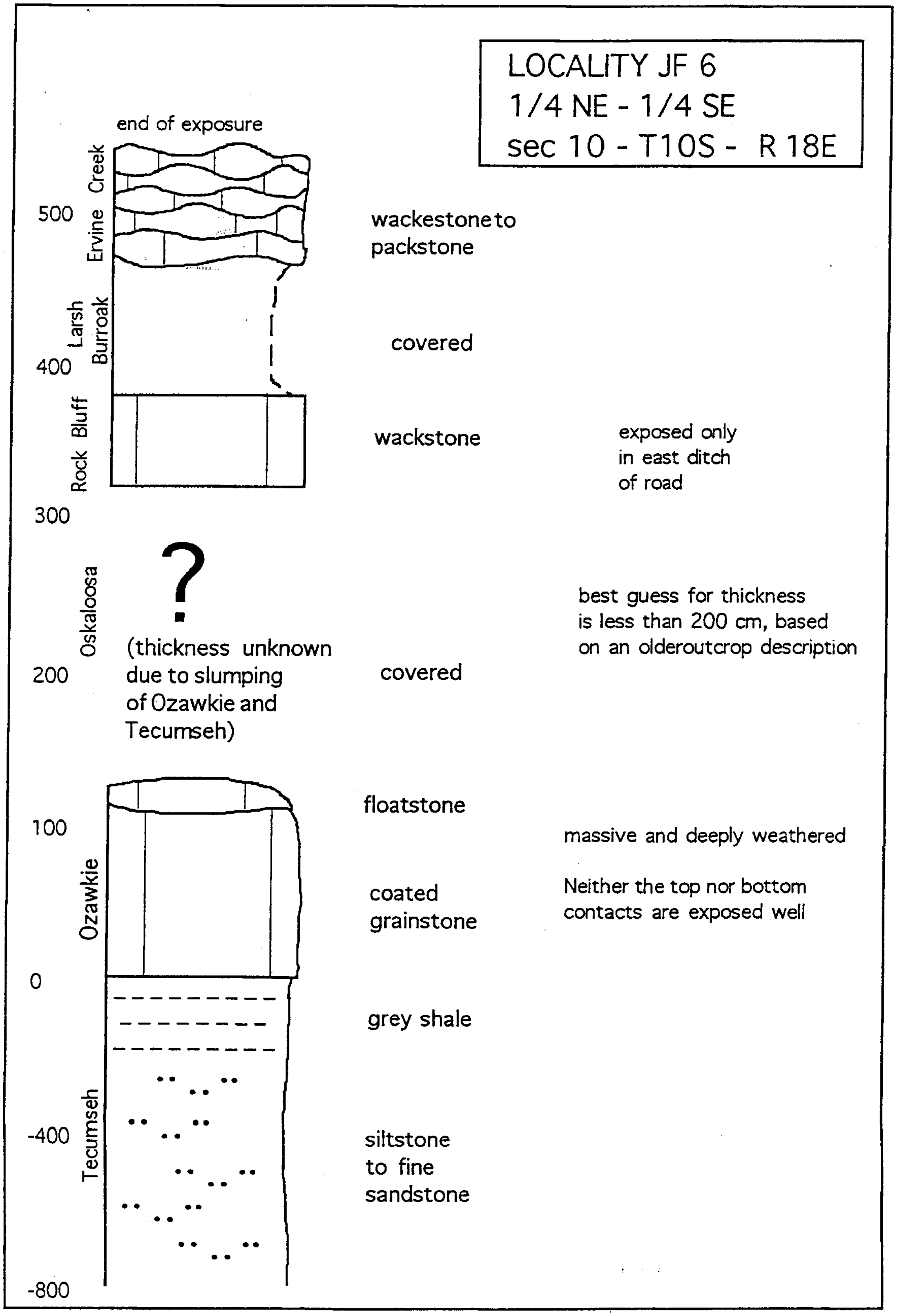


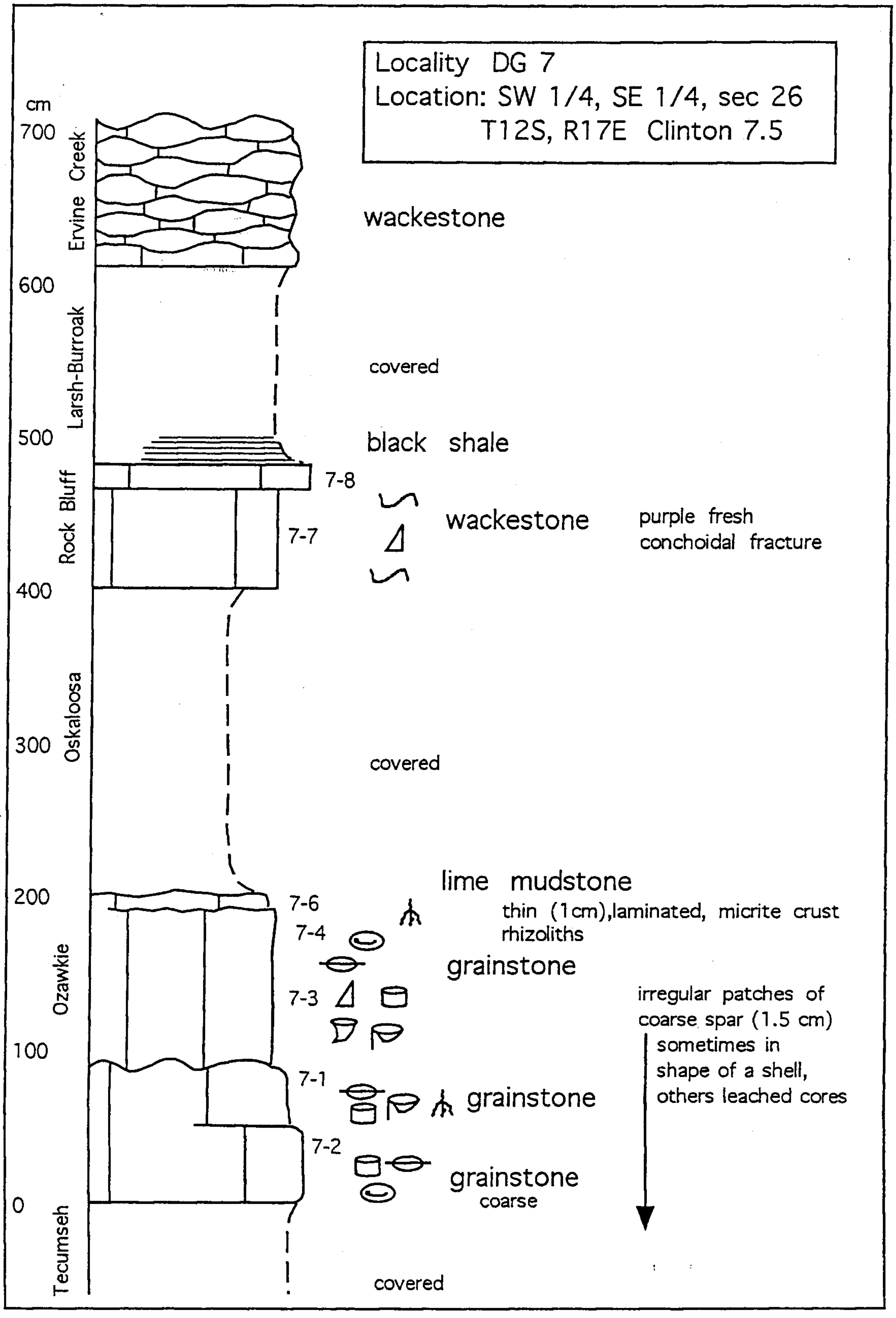
1000
700
600
500
400
300
200
100
0
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
top contact fades into cover
wavy bedded
dark orange weathered
grey to purple fresh
lower 20cm creates distinct ledge
wackestone
covered
LOCALITY AT 3
Location: NW1/4, NW 1/4, sec 14
T5S, R20E Atchison West 7.5
float of black shale
wackestone
purple fresh
brown weathered
conchoidal fracture
covered
wackestone
peloids
fenestrae and sheetcracks
circumgranular cracking
rhizoliths and rhizocasts
mm wide, cm long
packstone
peloids
fenestrae
rhizocasts
flaggy-bedded
wackestone
coarse micrite intraclasts
grain size 0.1-2.0cm
fenestrae
3-OA-u
3-OA-m
3-OA-l

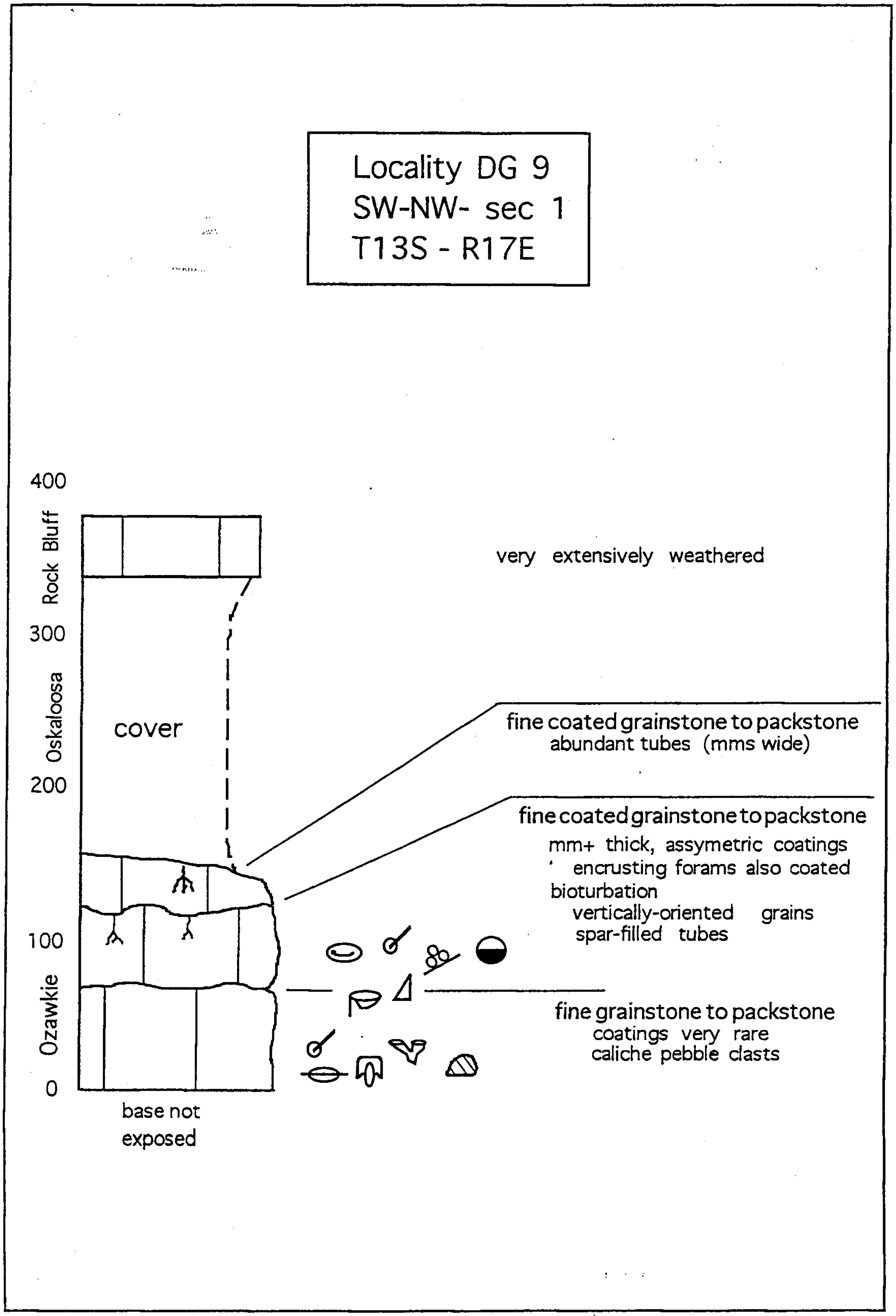

LOCALITY JF 4
NE 1/4, NE 1/4, sec 29
T9S, R 19E, Oskaloosa 7.5
600
500
400
300
200
100
0
Ervine Creek
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
wackestone
grey shale
black shale
wackestone
purple fresh, cream weathered
conchoidal fracture, dense
4-R-59
covered
floatstone
weathered and crumbly
grainstone
white fresh
reddish weathered
grains up to 2mm
packstone
coarse-grained
4-59U
4-59M
4-59L
? ?
bottom contact not
exposed

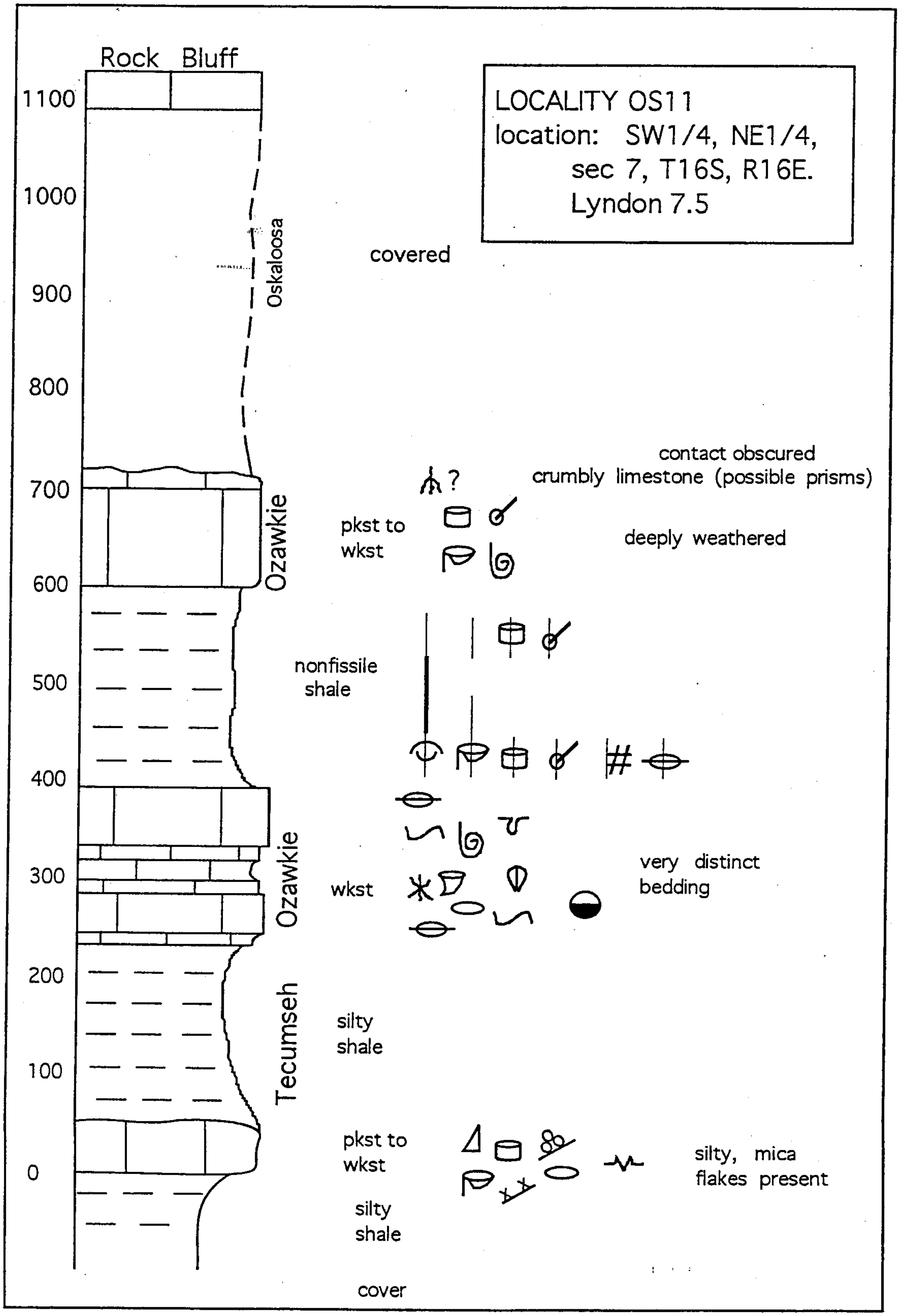
LOCALITY JF 5
NE 1/16 - sec 31
T9S - R 18E

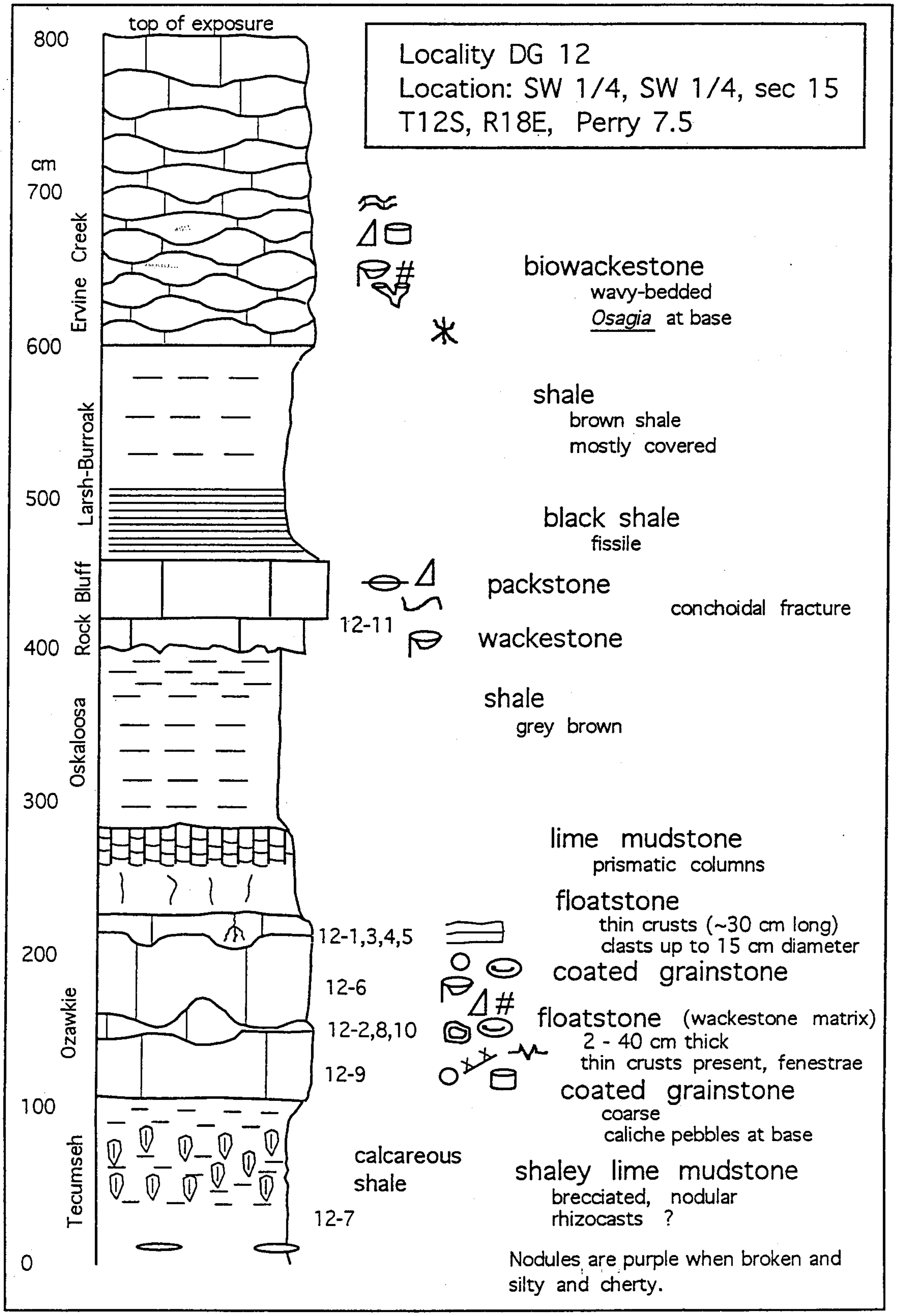



LOCALITY JF 6
1/4 NE - 1/4 SE
sec 10 - T10S - R 18E
end of exposure
Ervine Creek
500
wackestone to packstone
Larsh Burroak
covered
400
Rock Bluff
wackstone
exposed only in east ditch of road
300
Oskaloosa
?
(thickness unknown due to slumping of Ozawkie and Tecumseh)
200
covered
best guess for thickness is less than 200 cm, based on an olderoutcrop description
floatstone
100
massive and deeply weathered
Ozawkie
coated grainstone
Neither the top nor bottom contacts are exposed well
0
grey shale
Tecumseh
-400
siltstone to fine sandstone
-800

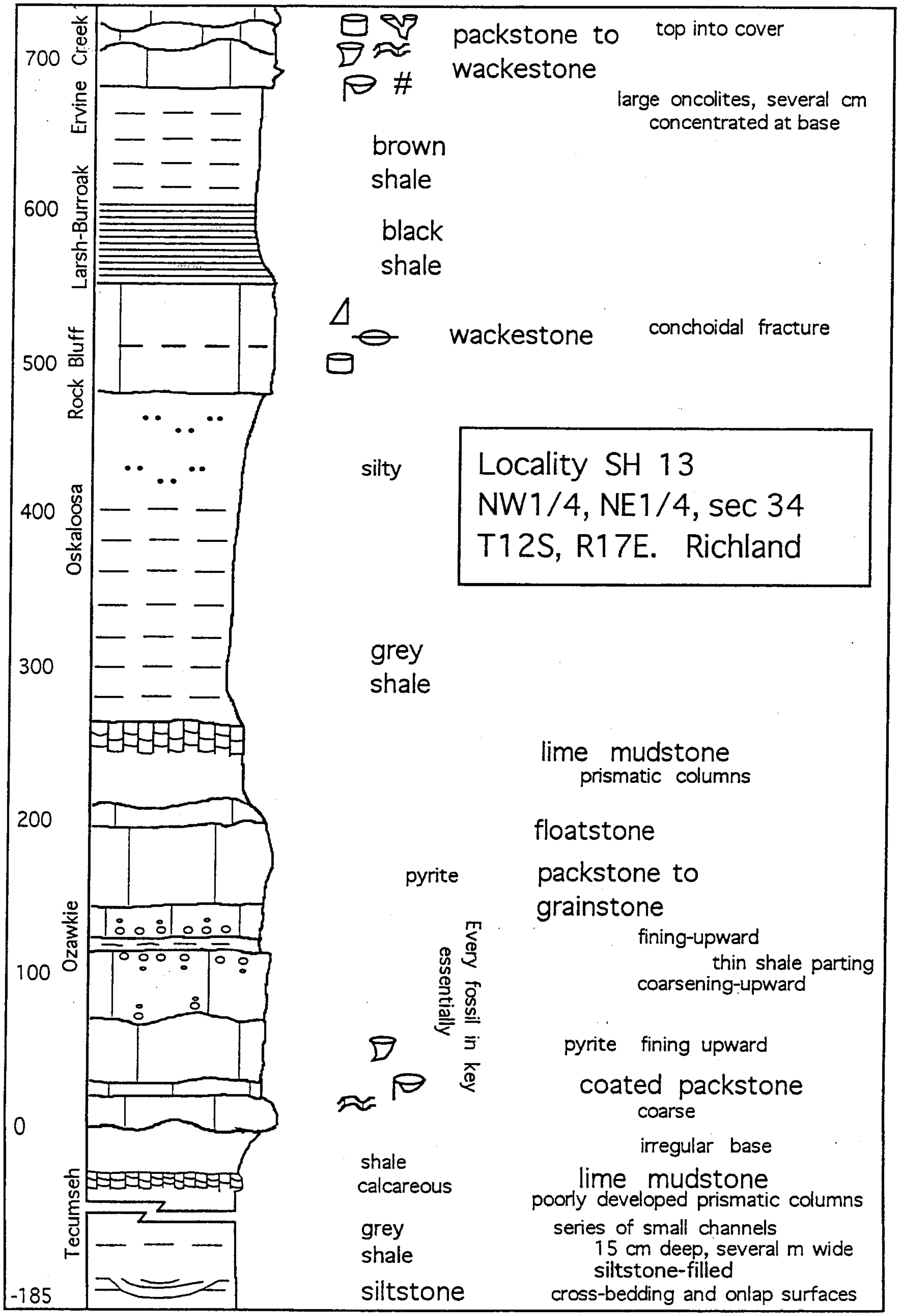

Locality DG 7
Location: SW 1/4, SE 1/4, sec 26
T12S, R17E Clinton 7.5
cm
700
600
500
400
300
200
100
0
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
wackestone
covered
black shale
7-8
7-7
wackestone
purple fresh
conchoidal fracture
covered
lime mudstone
7-6
thin (1cm),laminated, micrite crust
rhizoliths
7-4
grainstone
7-3
irregular patches of
coarse spar (1.5 cm)
sometimes in
shape of a shell,
others leached cores
7-1
grainstone
7-2
grainstone
coarse
covered


Locality DG 9
SW-NW- sec 1
T13S - R17E
400
300
200
100
0
Rock Bluff
Oskaloosa
Ozawkie
cover
very extensively weathered
fine coated grainstone to packstone
abundant tubes (mms wide)
fine coated grainstone to packstone
mm+ thick, assymetric coatings
encrusting forams also coated
bioturbation
vertically-oriented grains
spar-filled tubes
fine grainstone to packstone
coatings very rare
caliche pebble clasts
base not
exposed

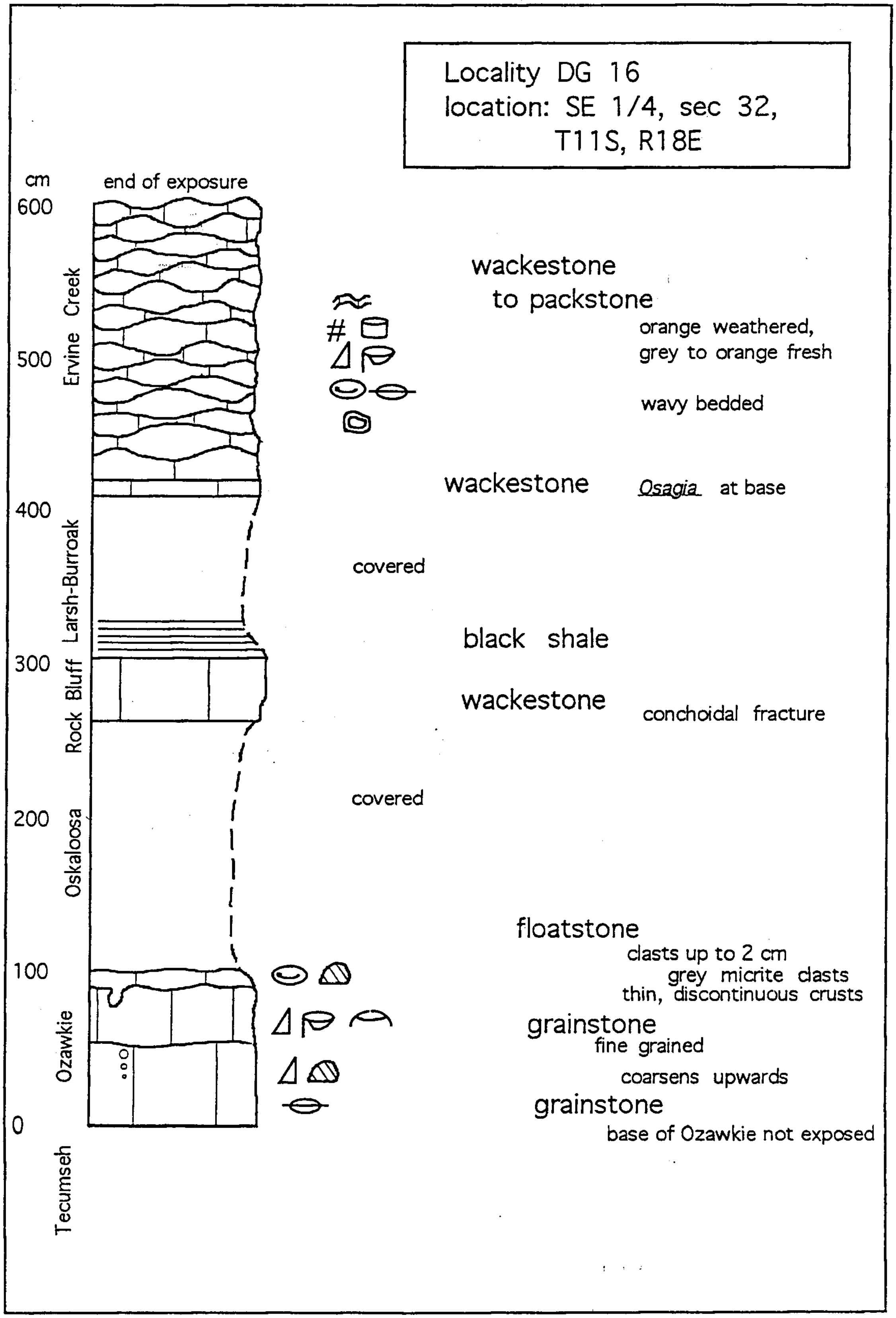

Rock Bluff
1100
1000
900
800
700
600
500
400
300
200
100
0
LOCALITY OS11
location: SW1/4, NE1/4,
sec 7, T16S, R16E.
Lyndon 7.5
Oskaloosa
covered
contact obscured
crumbly limestone (possible prisms)
Ozawkie
pkst to
wkst
deeply weathered
nonfissile
shale
Ozawkie
wkst
very distinct
bedding
Tecumseh
silty
shale
pkst to
wkst
silty, mica
flakes present
silty
shale
cover



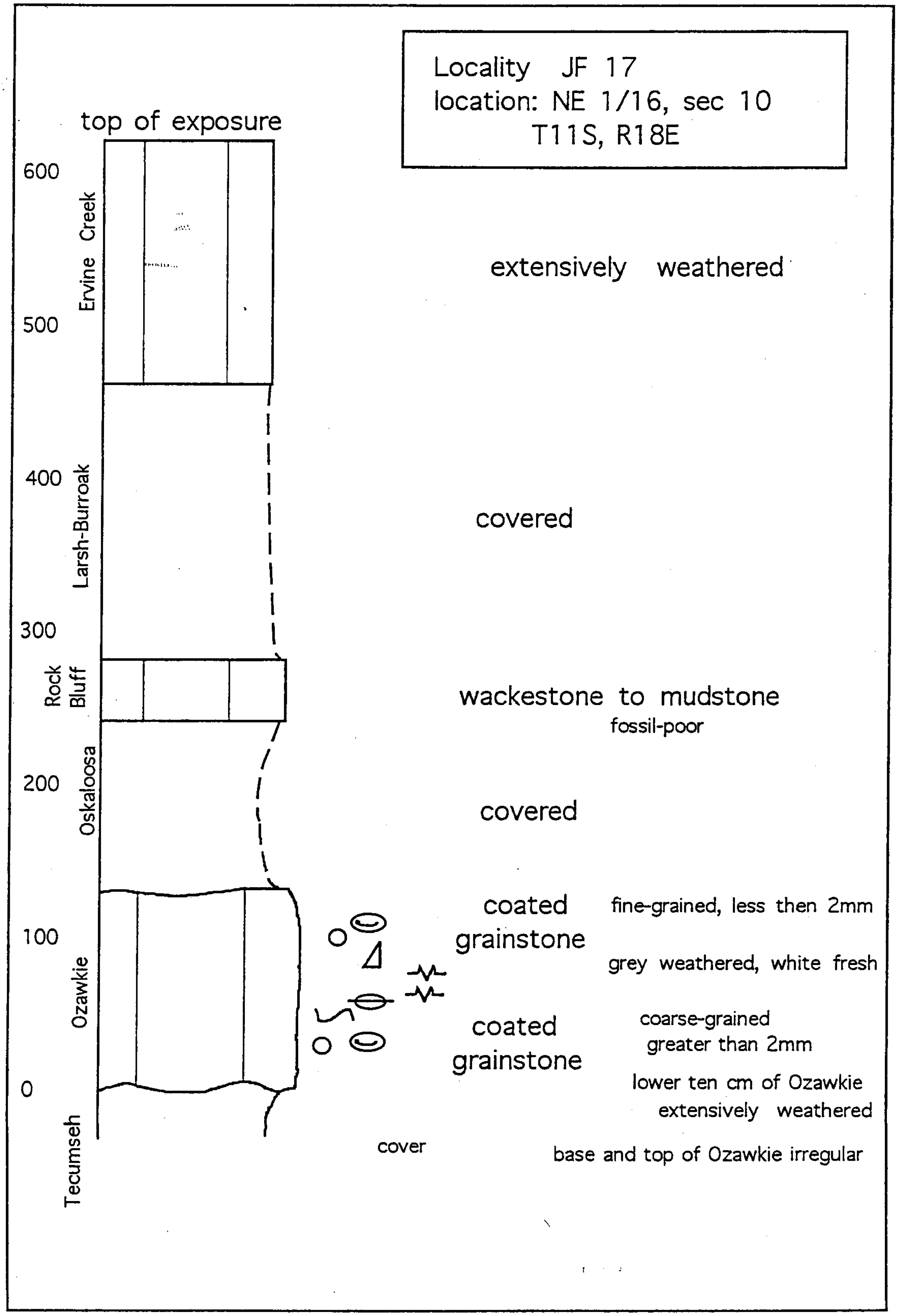
top of exposure
Locality DG 12
Location: SW 1/4, SW 1/4, sec 15
T12S, R18E, Perry 7.5
800
cm
700
600
500
400
300
200
100
0
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
biowackestone
wavy-bedded
Osagia at base
shale
brown shale
mostly covered
black shale
fissile
packstone
conchoidal fracture
12-11
wackestone
shale
grey brown
lime mudstone
prismatic columns
floatstone
thin crusts (~30 cm long)
clasts up to 15 cm diameter
12-1,3,4,5
12-6
coated grainstone
12-2,8,10
floatstone (wackestone matrix)
2 - 40 cm thick
thin crusts present, fenestrae
12-9
coated grainstone
coarse
caliche pebbles at base
calcareous
shale
shaley lime mudstone
brecciated, nodular
rhizocasts ?
12-7
Nodules are purple when broken and
silty and cherty.

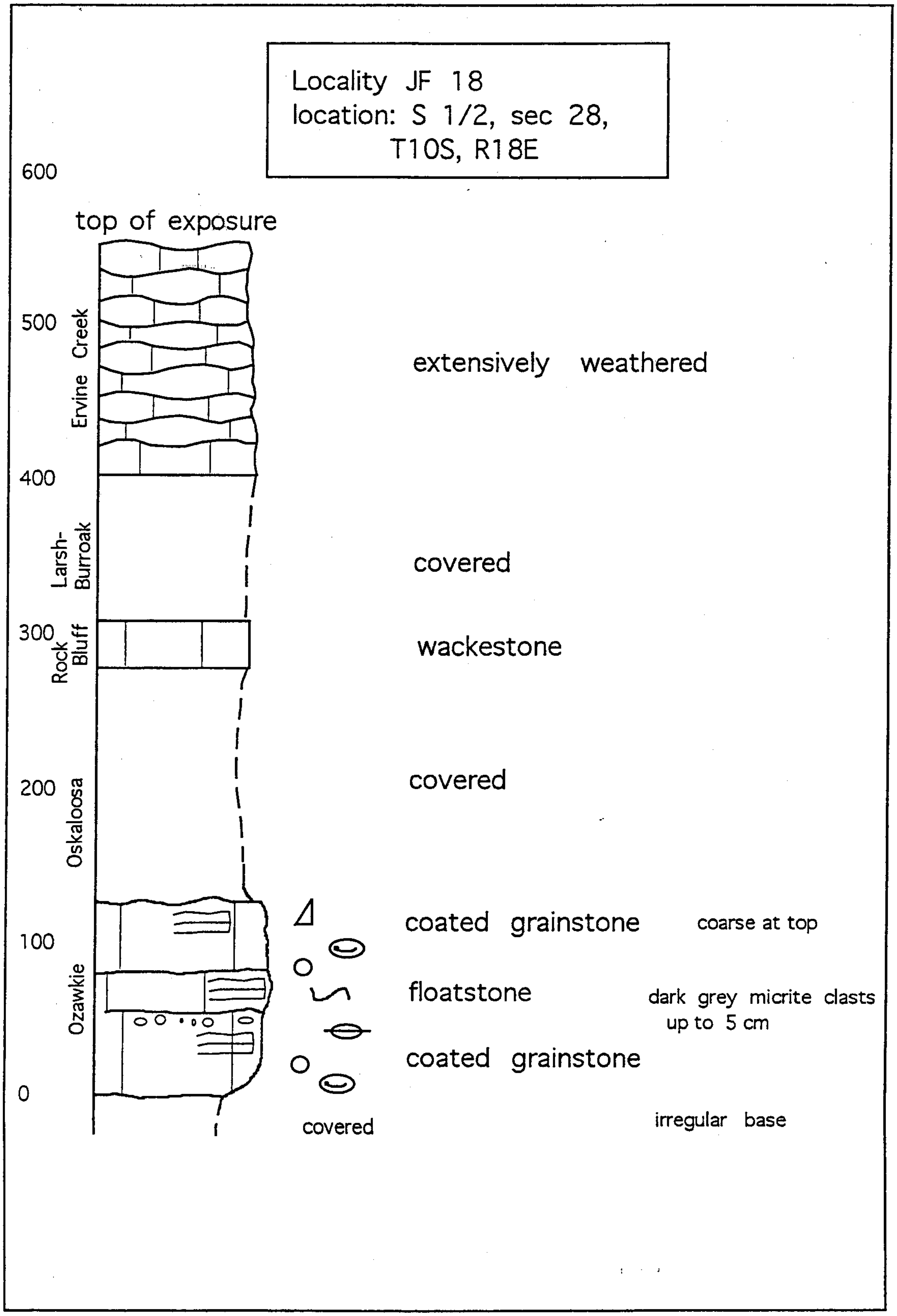


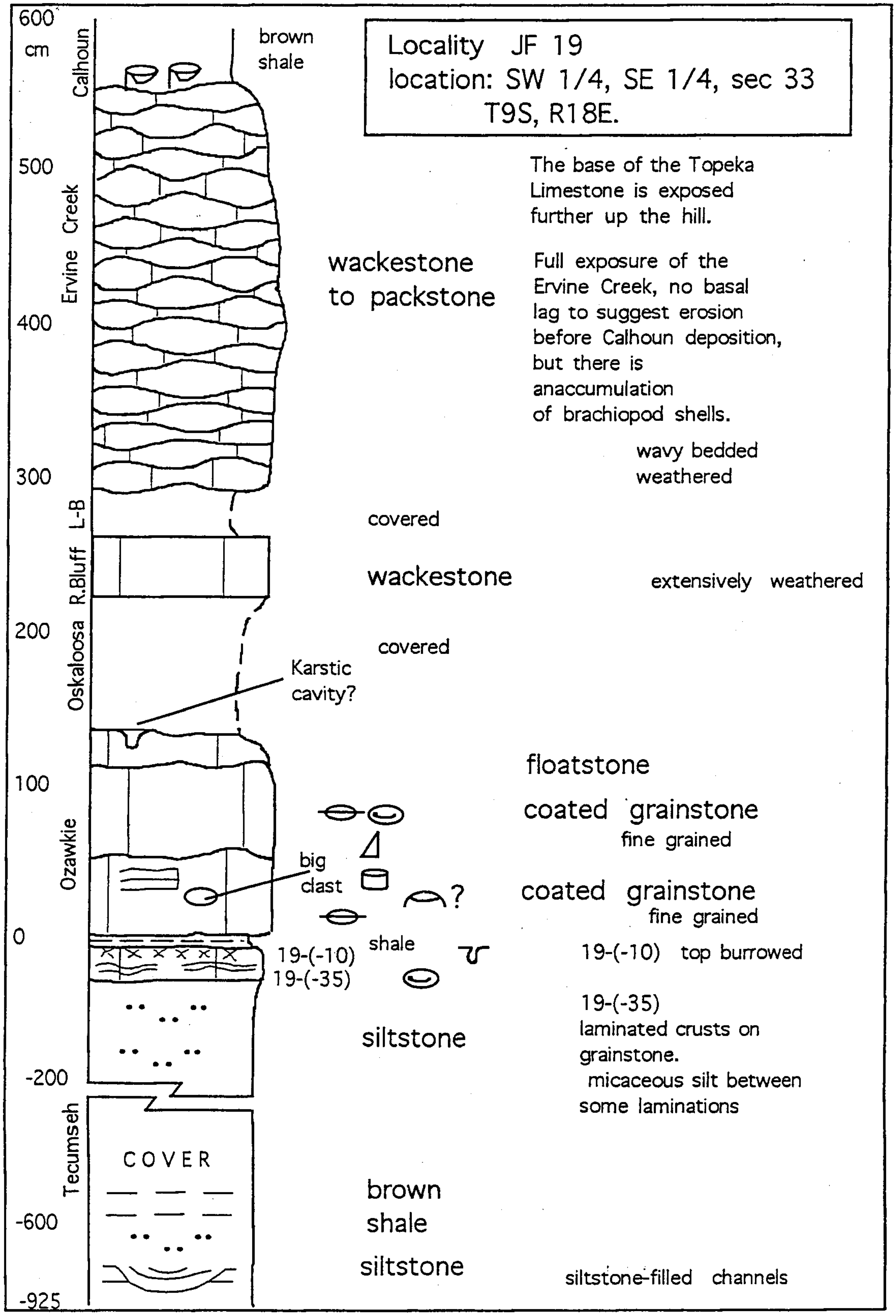
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
700
600
500
400
300
200
100
0
-185
#
packstone to wackestone
top into cover
large oncolites, several cm concentrated at base
brown shale
black shale
wackestone
conchoidal fracture
silty
Locality SH 13
NW1/4, NE1/4, sec 34
T12S, R17E. Richland
grey shale
lime mudstone
prismatic columns
floatstone
pyrite
packstone to grainstone
fining-upward
thin shale parting
coarsening-upward
Every fossil in key essentially
pyrite
fining upward
coated packstone
coarse
irregular base
shale calcareous
lime mudstone
poorly developed prismatic columns
grey shale
series of small channels
15 cm deep, several m wide
siltstone-filled
siltstone
cross-bedding and onlap surfaces

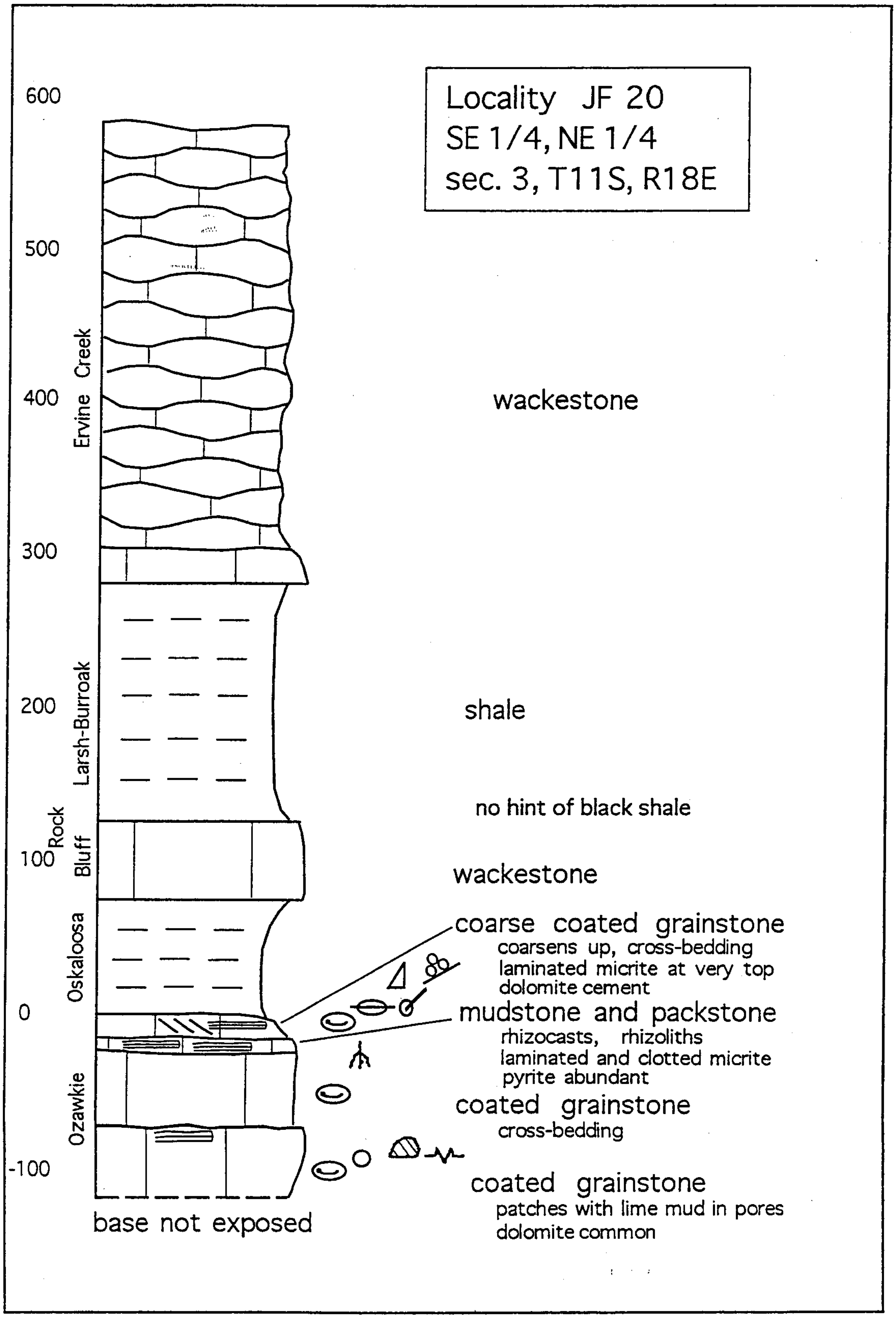


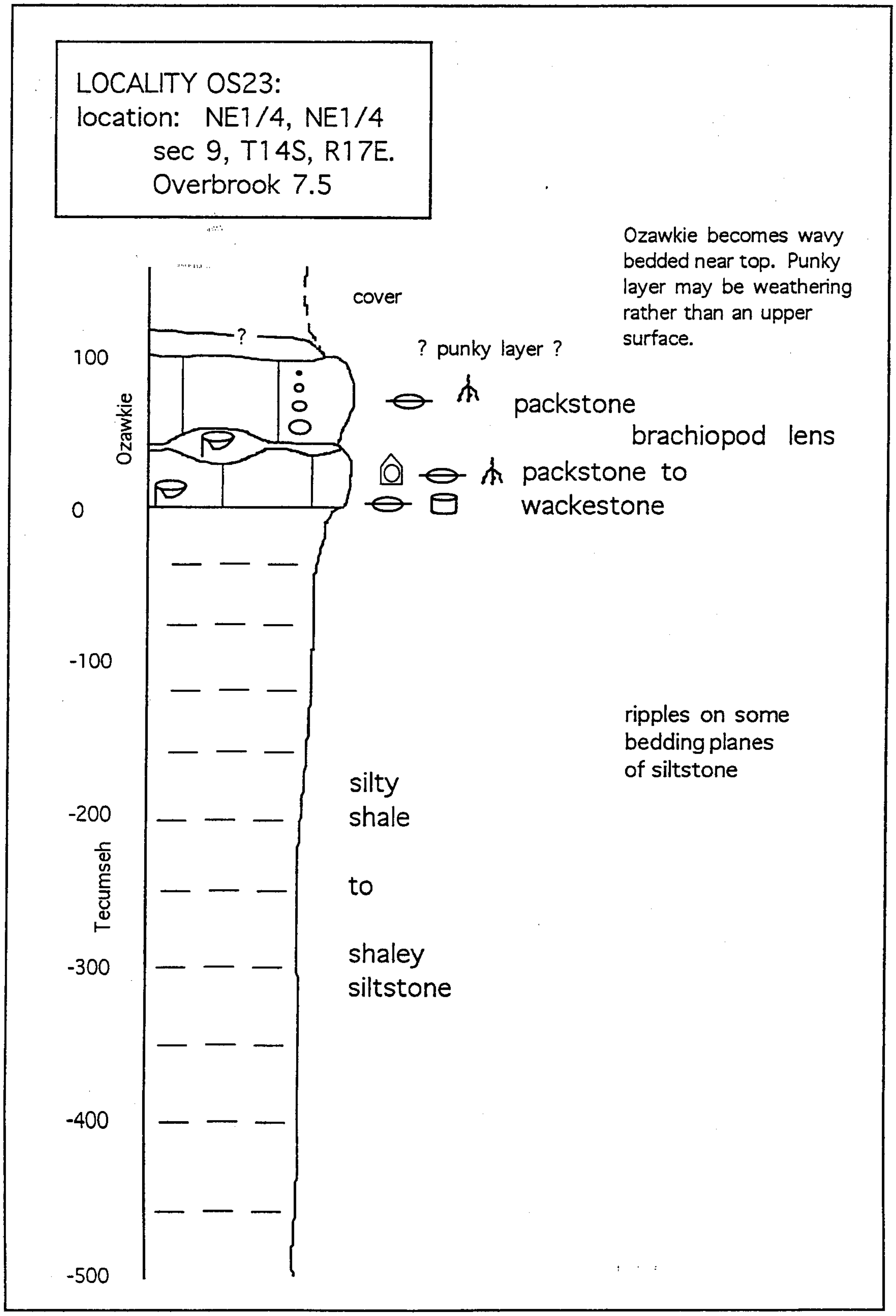
Locality DG 16
location: SE 1/4, sec 32,
T11S, R18E
cm
end of exposure
600
500
400
300
200
100
0
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
wackestone
to packstone
orange weathered,
grey to orange fresh
wavy bedded
wackestone
Osagia at base
covered
black shale
wackestone
conchoidal fracture
covered
floatstone
clasts up to 2 cm
grey micrite clasts
thin, discontinuous crusts
grainstone
fine grained
coarsens upwards
grainstone
base of Ozawkie not exposed


Locality JF 17
location: NE 1/16, sec 10
T11S, R18E
top of exposure
600
500
400
300
200
100
0
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
extensively weathered
covered
wackestone to mudstone
fossil-poor
covered
coated grainstone
fine-grained, less then 2mm
grey weathered, white fresh
coated grainstone
coarse-grained
greater than 2mm
lower ten cm of Ozawkie
extensively weathered
cover
base and top of Ozawkie irregular

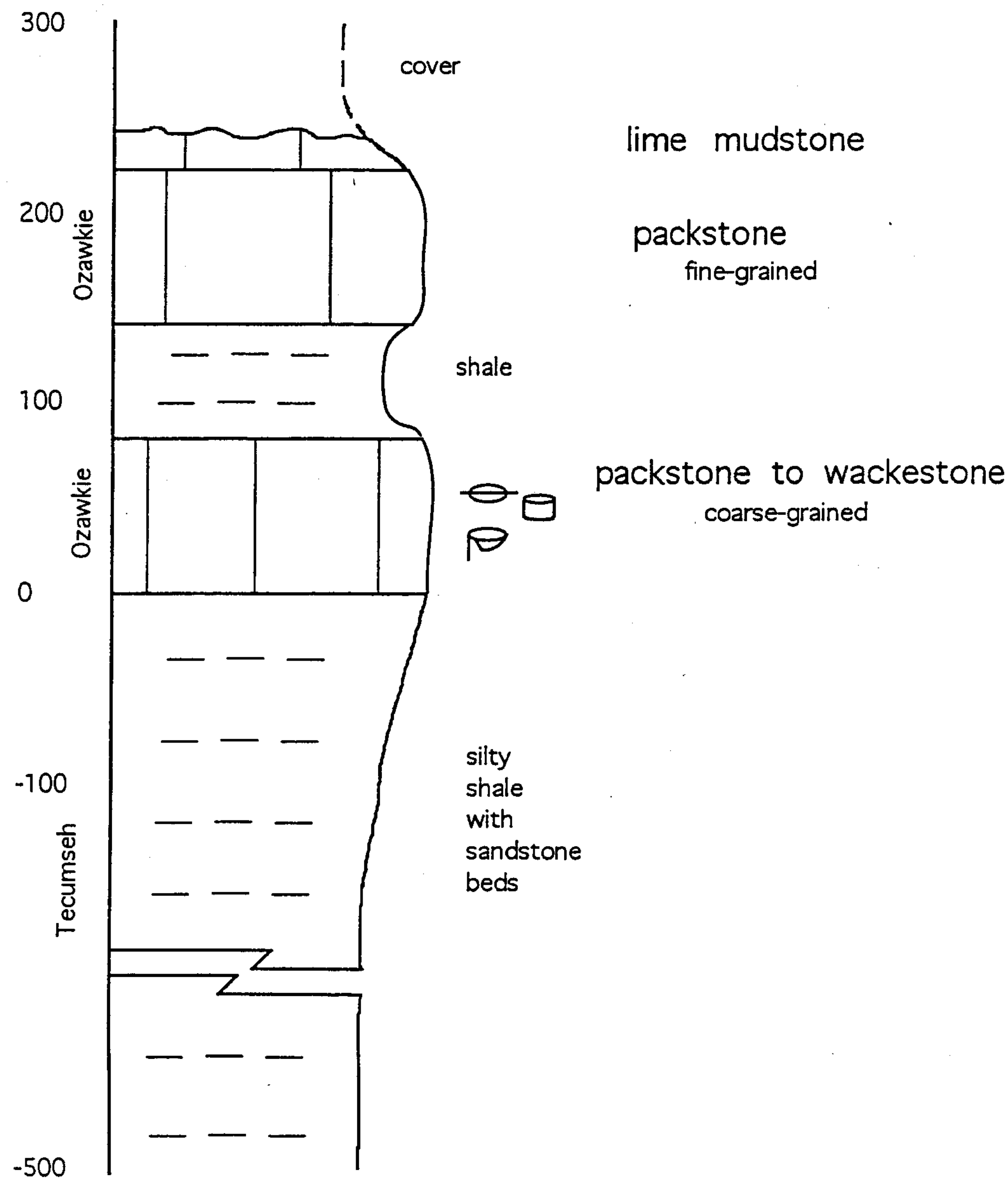

Locality JF 18
location: S 1/2, sec 28,
T10S, R18E
600
top of exposure
500
Ervine Creek
extensively weathered
400
Larsh-Burroak
covered
300
Rock Bluff
wackestone
200
Oskaloosa
covered
100
Ozawkie
coated grainstone
coarse at top
floatstone
dark grey micrite clasts up to 5 cm
coated grainstone
0
covered
irregular base

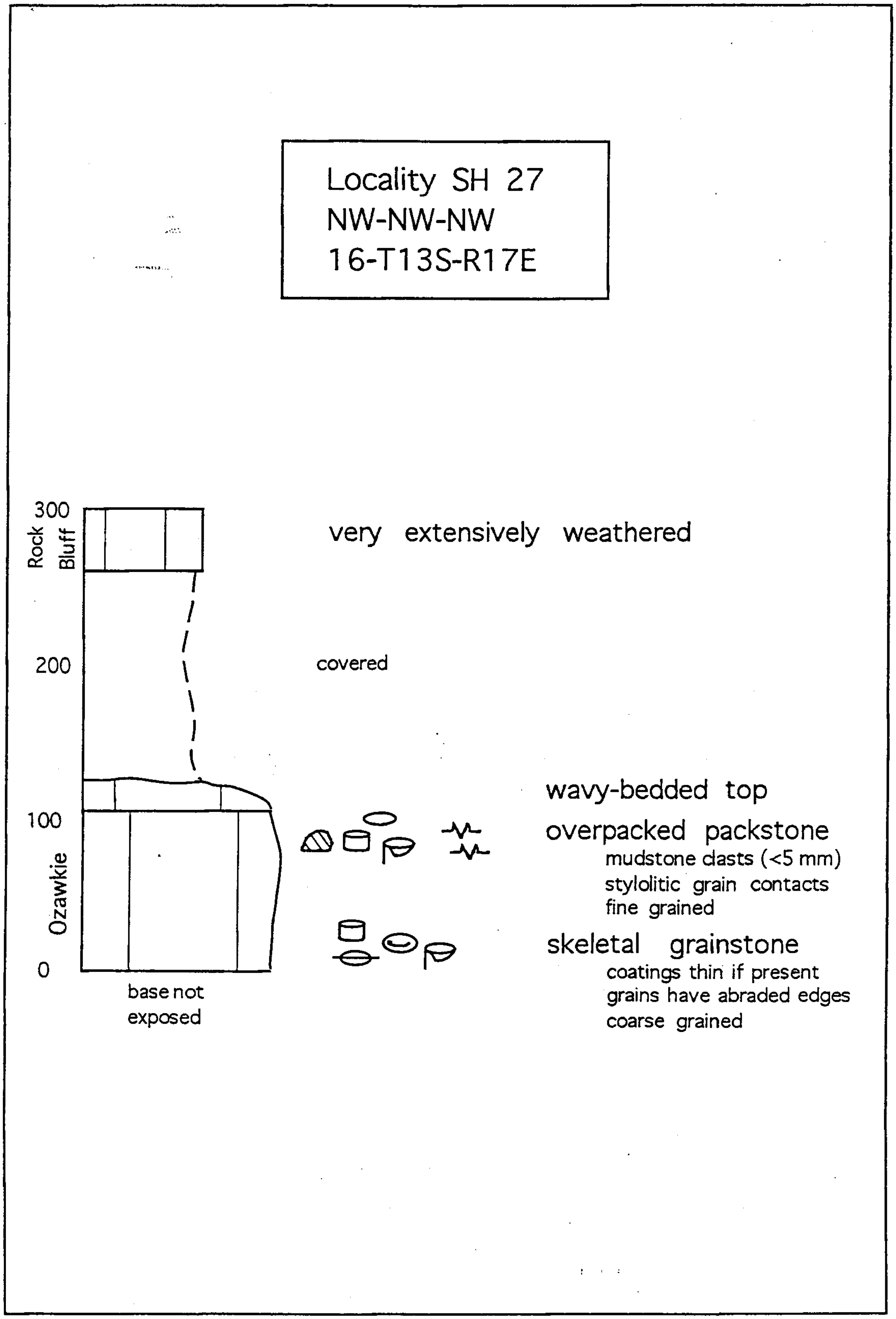

600 cm
500
400
300
200
100
0
-200
-600
-925
Calhoun
Ervine Creek
L-B
R.Bluff
Oskaloosa
Ozawkie
Tecumseh
brown shale
Locality JF 19
location: SW 1/4, SE 1/4, sec 33
T9S, R18E.
The base of the Topeka Limestone is exposed further up the hill.
wackestone to packstone
Full exposure of the Ervine Creek, no basal lag to suggest erosion before Calhoun deposition, but there is anaccumulation of brachiopod shells.
wavy bedded weathered
covered
wackestone
extensively weathered
covered
Karstic cavity?
floatstone
coated grainstone
fine grained
big clast
coated grainstone
fine grained
shale
19-(-10)
19-(-35)
19-(-10) top burrowed
19-(-35)
laminated crusts on grainstone.
micaceous silt between some laminations
siltstone
COVER
brown shale
siltstone
siltstone-filled channels

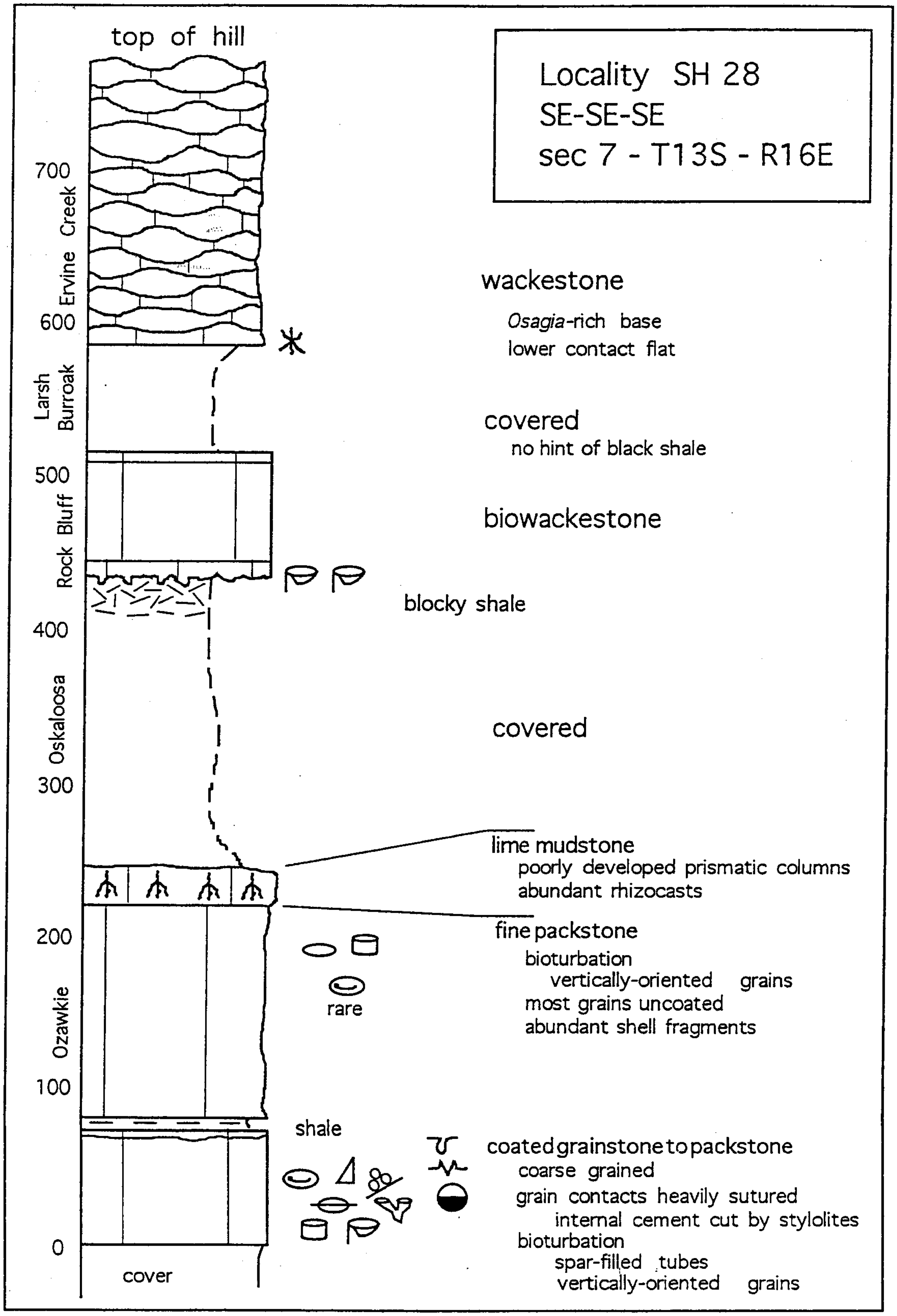

Locality JF 20
SE 1/4, NE 1/4
sec. 3, T11S, R18E
600
500
400
300
200
100
0
-100
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
wackestone
shale
no hint of black shale
wackestone
coarse coated grainstone
coarsens up, cross-bedding
laminated micrite at very top
dolomite cement
mudstone and packstone
rhizocasts, rhizoliths
laminated and clotted micrite
pyrite abundant
coated grainstone
cross-bedding
coated grainstone
patches with lime mud in pores
dolomite common
base not exposed


LOCALITY OS23:
location: NE1/4, NE1/4
sec 9, T14S, R17E.
Overbrook 7.5
Ozawkie becomes wavy bedded near top. Punky layer may be weathering rather than an upper surface.
cover
?
? punky layer ?
100
Ozawkie
packstone
brachiopod lens
packstone to wackestone
0
-100
ripples on some bedding planes of siltstone
silty shale
to
shaley siltstone
-200
Tecumseh
-300
-400
-500

LOCALITY OS24
location: center, sec 13,
T14S, R16E.
Overbrook 7.5

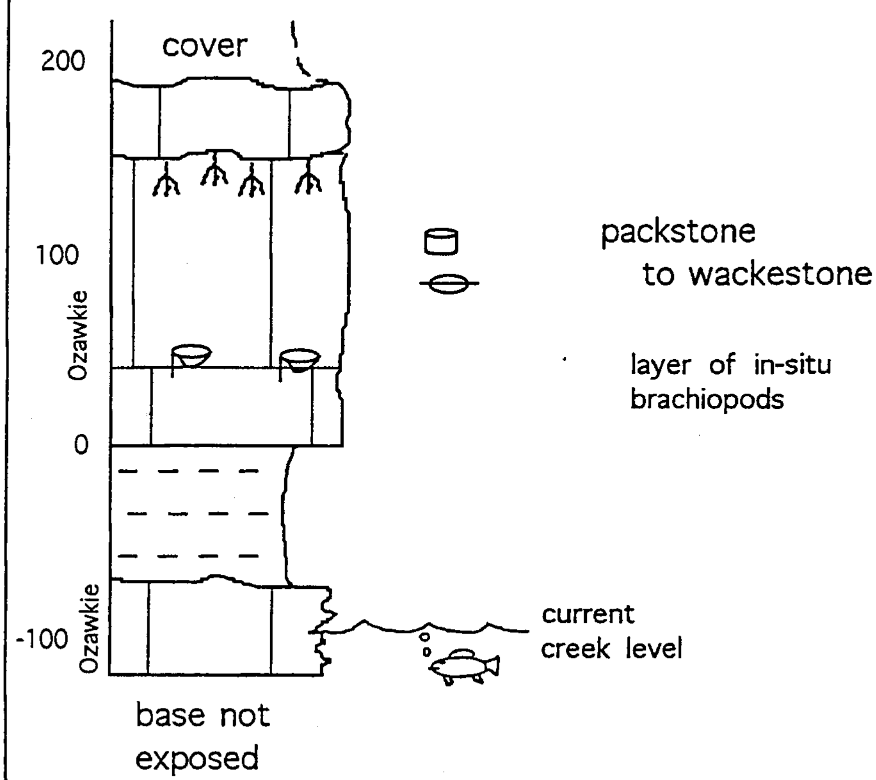


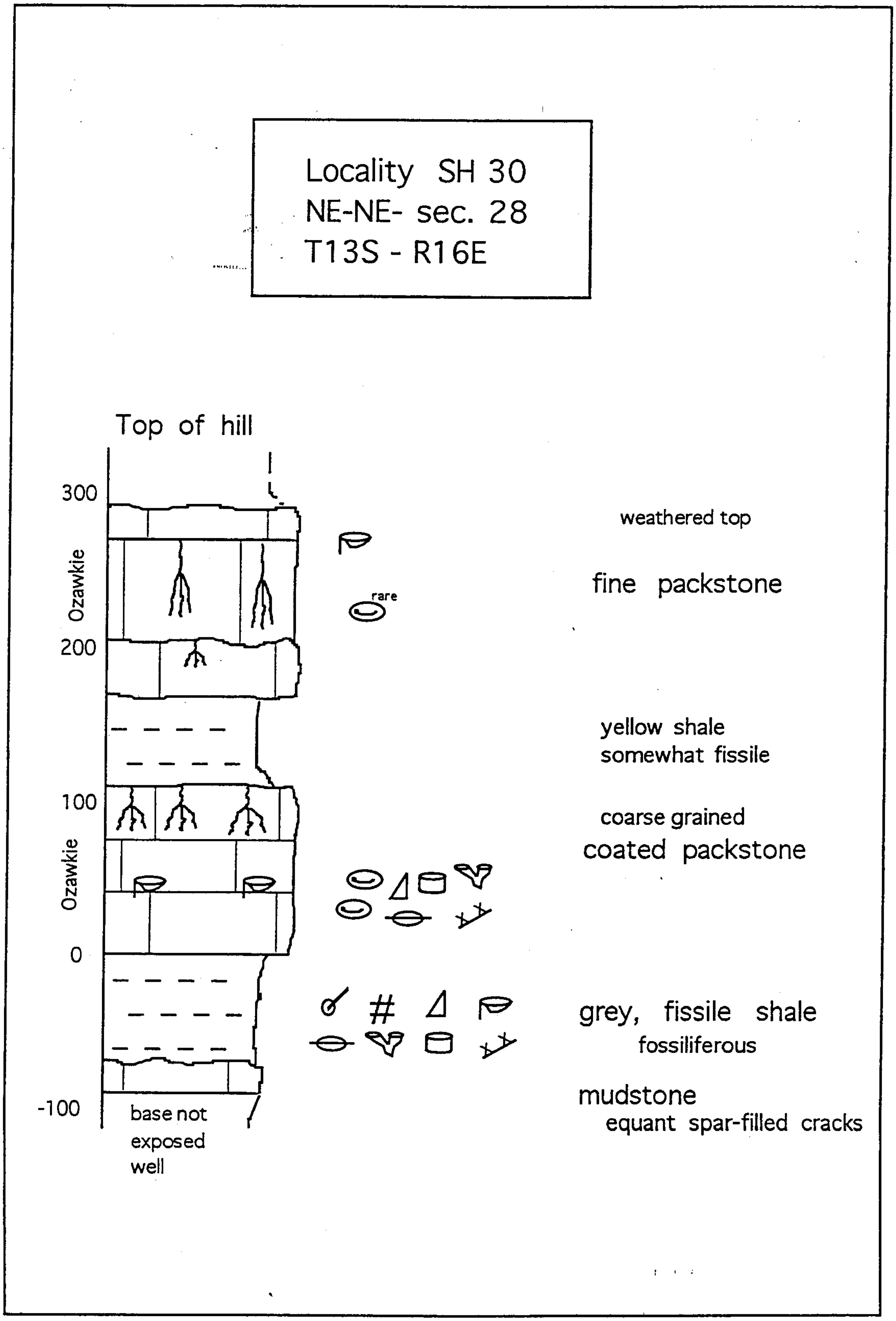

Locality SH 27
NW-NW-NW
16-T13S-R17E
300
200
100
0
Rock Bluff
Ozawkie
base not exposed
very extensively weathered
covered
wavy-bedded top
overpacked packstone
mudstone clasts (<5 mm)
stylolitic grain contacts
fine grained
skeletal grainstone
coatings thin if present
grains have abraded edges
coarse grained

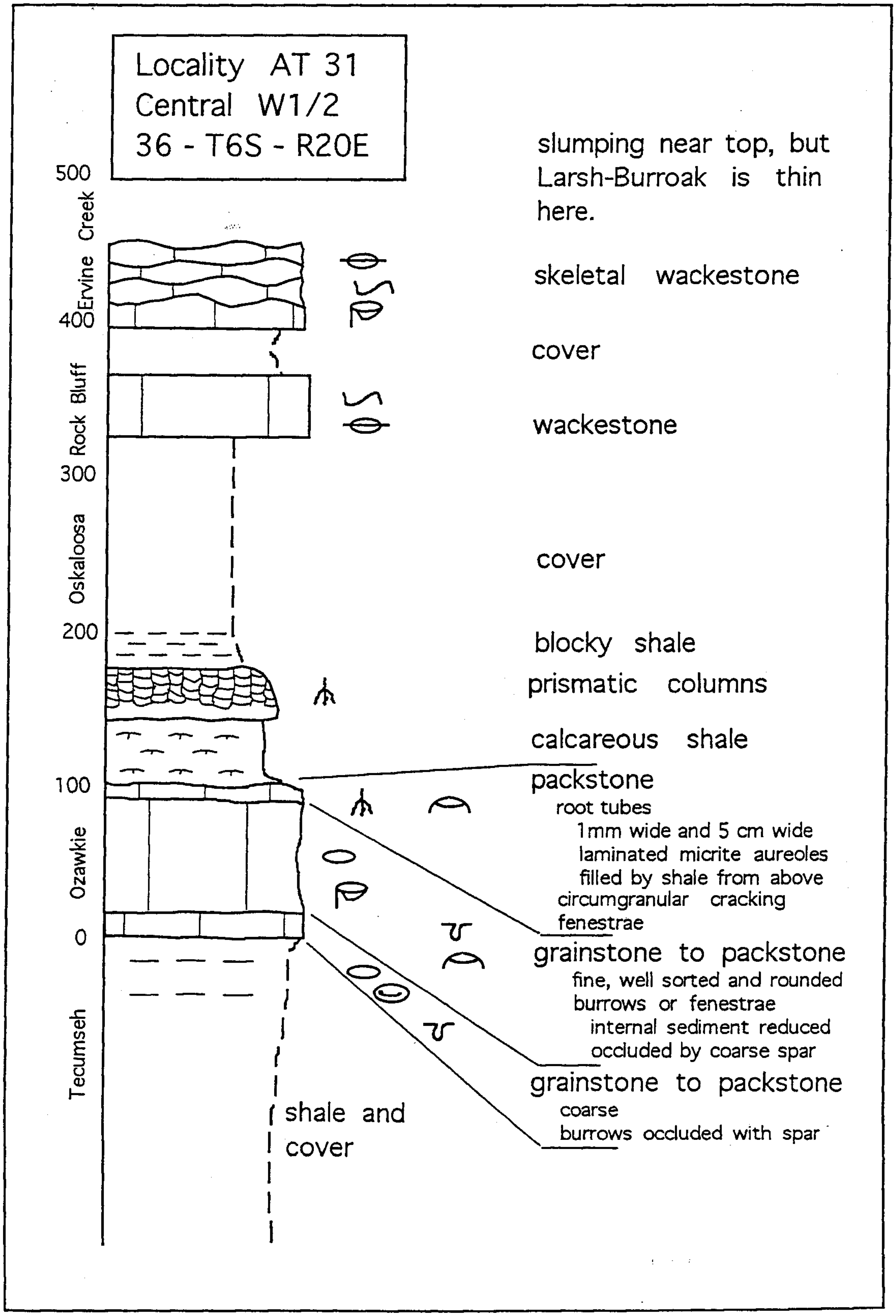


top of hill
Locality SH 28
SE-SE-SE
sec 7 - T13S - R16E
700
Ervine Creek
600
wackestone
Osagia-rich base
lower contact flat
Larsh Burroak
covered
no hint of black shale
500
Rock Bluff
biowackestone
blocky shale
400
Oskaloosa
covered
300
lime mudstone
poorly developed prismatic columns
abundant rhizocasts
200
fine packstone
bioturbation
vertically-oriented grains
most grains uncoated
abundant shell fragments
rare
Ozawkie
100
shale
coated grainstone to packstone
coarse grained
grain contacts heavily sutured
internal cement cut by stylolites
bioturbation
spar-filled tubes
vertically-oriented grains
0
cover

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

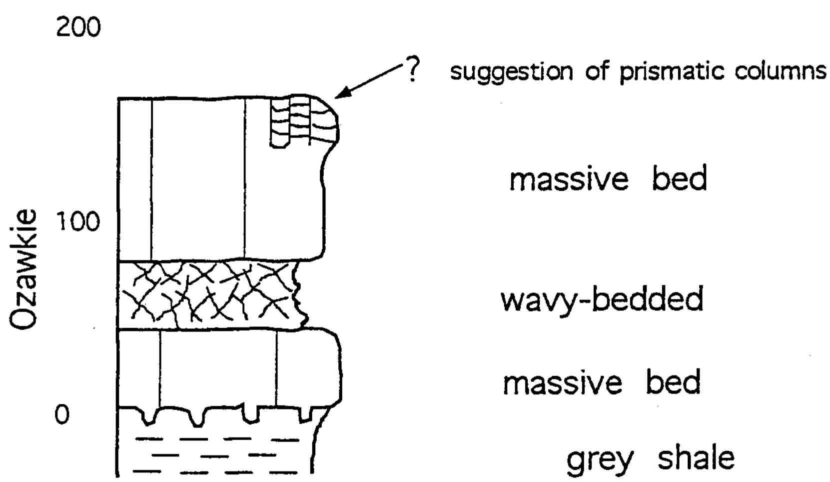



Locality SH 30
NE-NE- sec. 28
T13S - R16E
Top of hill
300
200
100
0
-100
Ozawkie
Ozawkie
rare
weathered top
fine packstone
yellow shale
somewhat fissile
coarse grained
coated packstone
grey, fissile shale
fossiliferous
mudstone
equant spar-filled cracks
base not
exposed
well

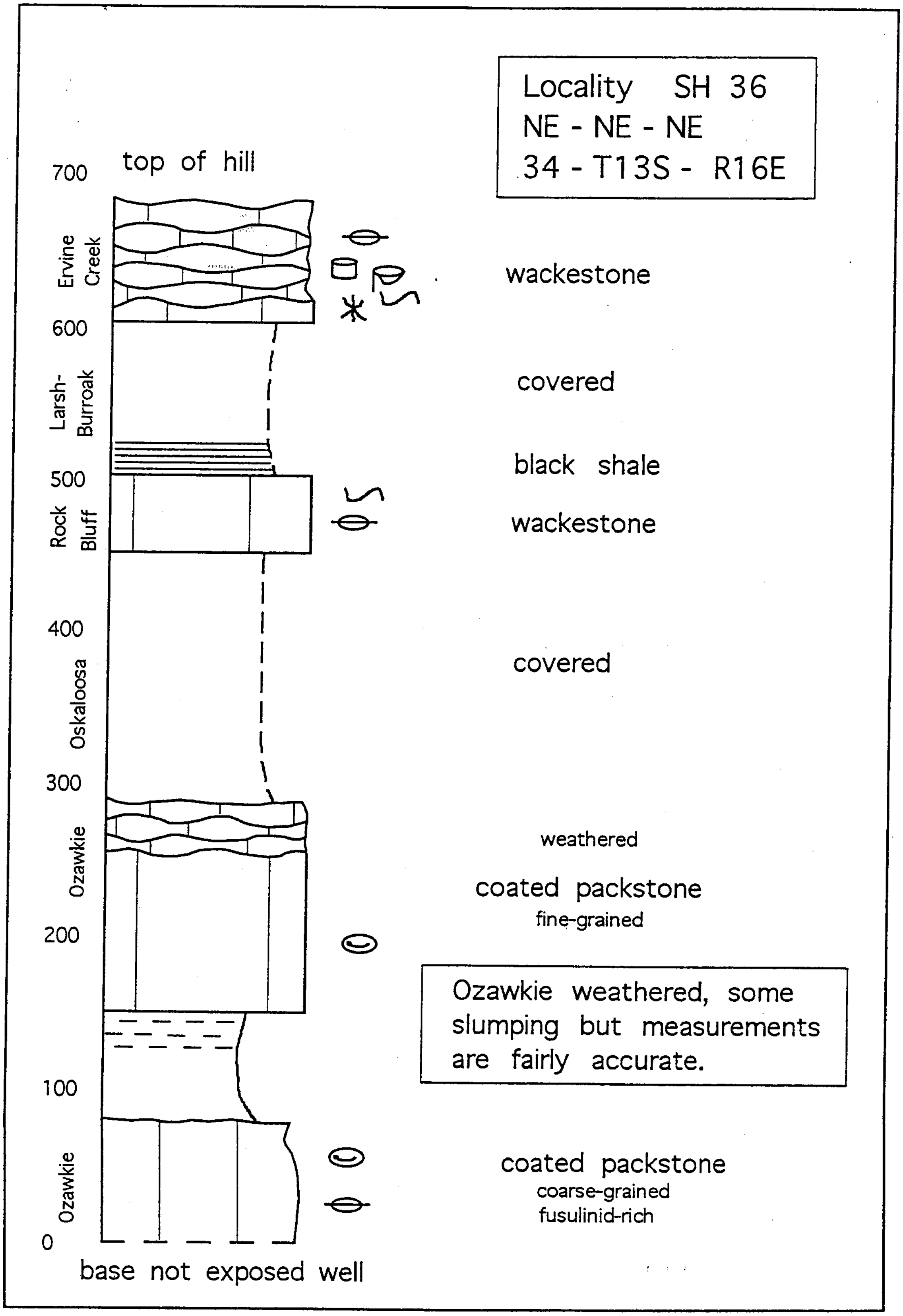

Locality AT 31
Central W1/2
36 - T6S - R20E
500
400
300
200
100
0
Ervine Creek
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
slumping near top, but Larsh-Burroak is thin here.
skeletal wackestone
cover
wackestone
cover
blocky shale
prismatic columns
calcareous shale
packstone
root tubes
1mm wide and 5 cm wide
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

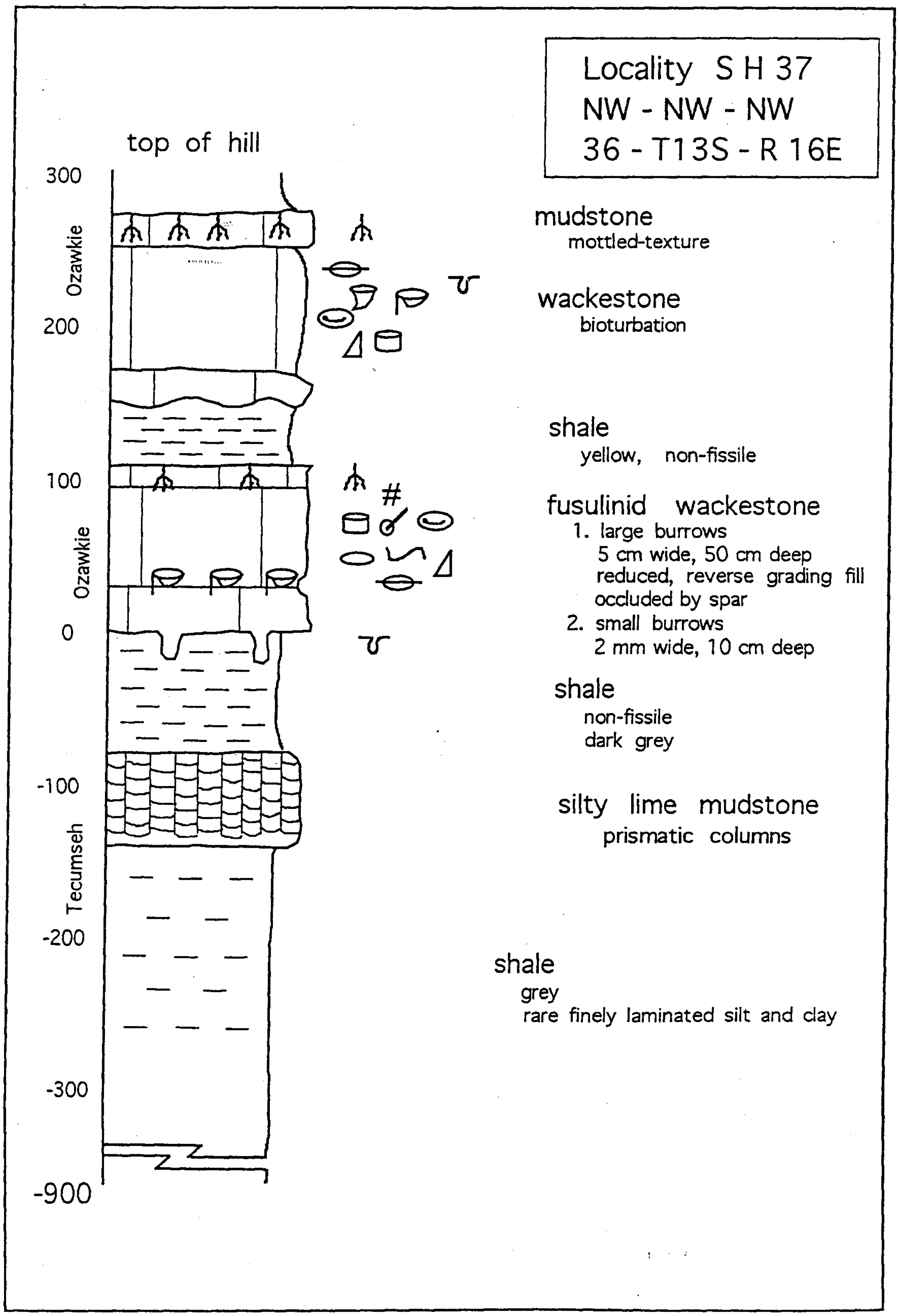
Locality AT 33
SW - SW
11 - T5S - R 20E

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

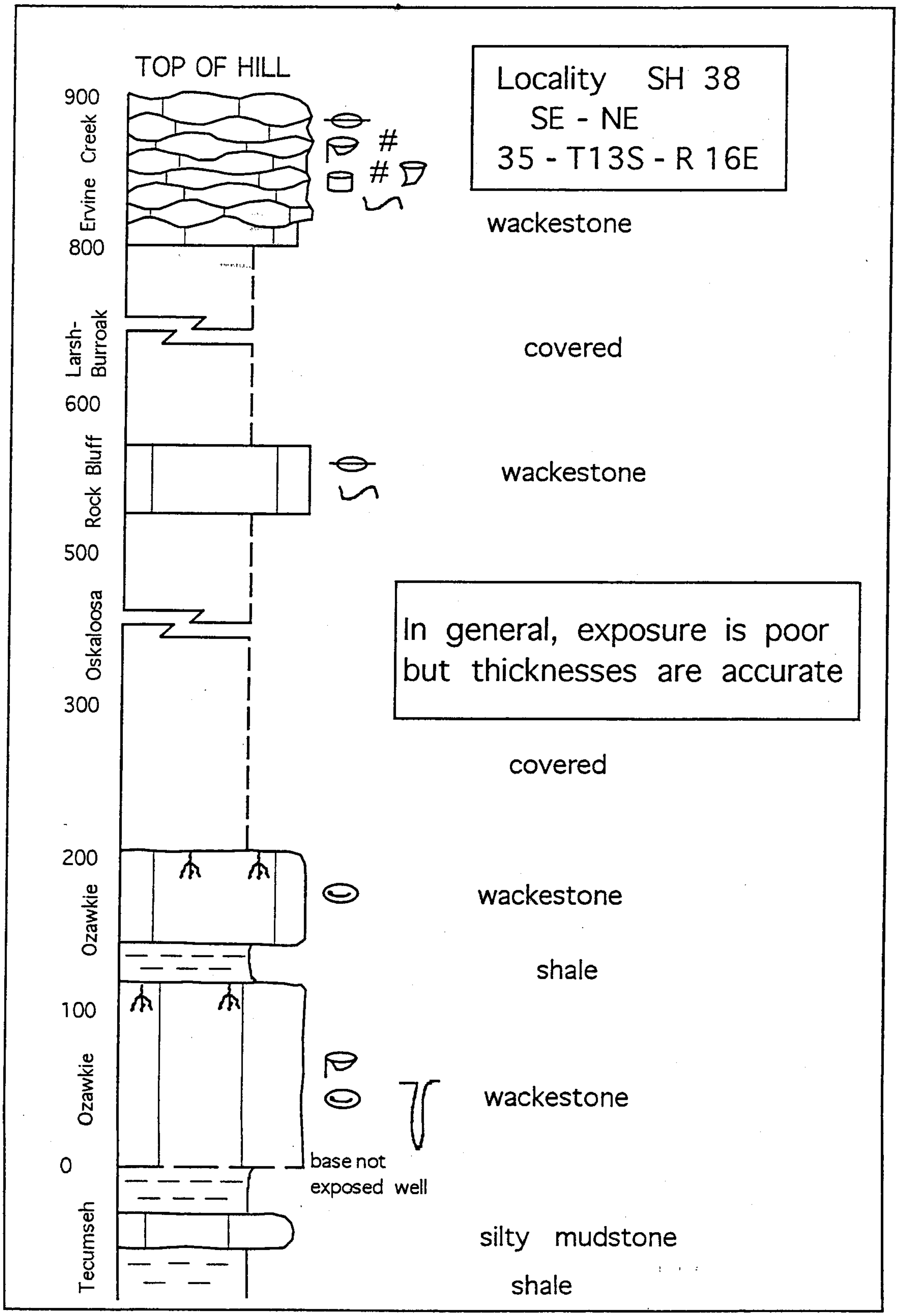


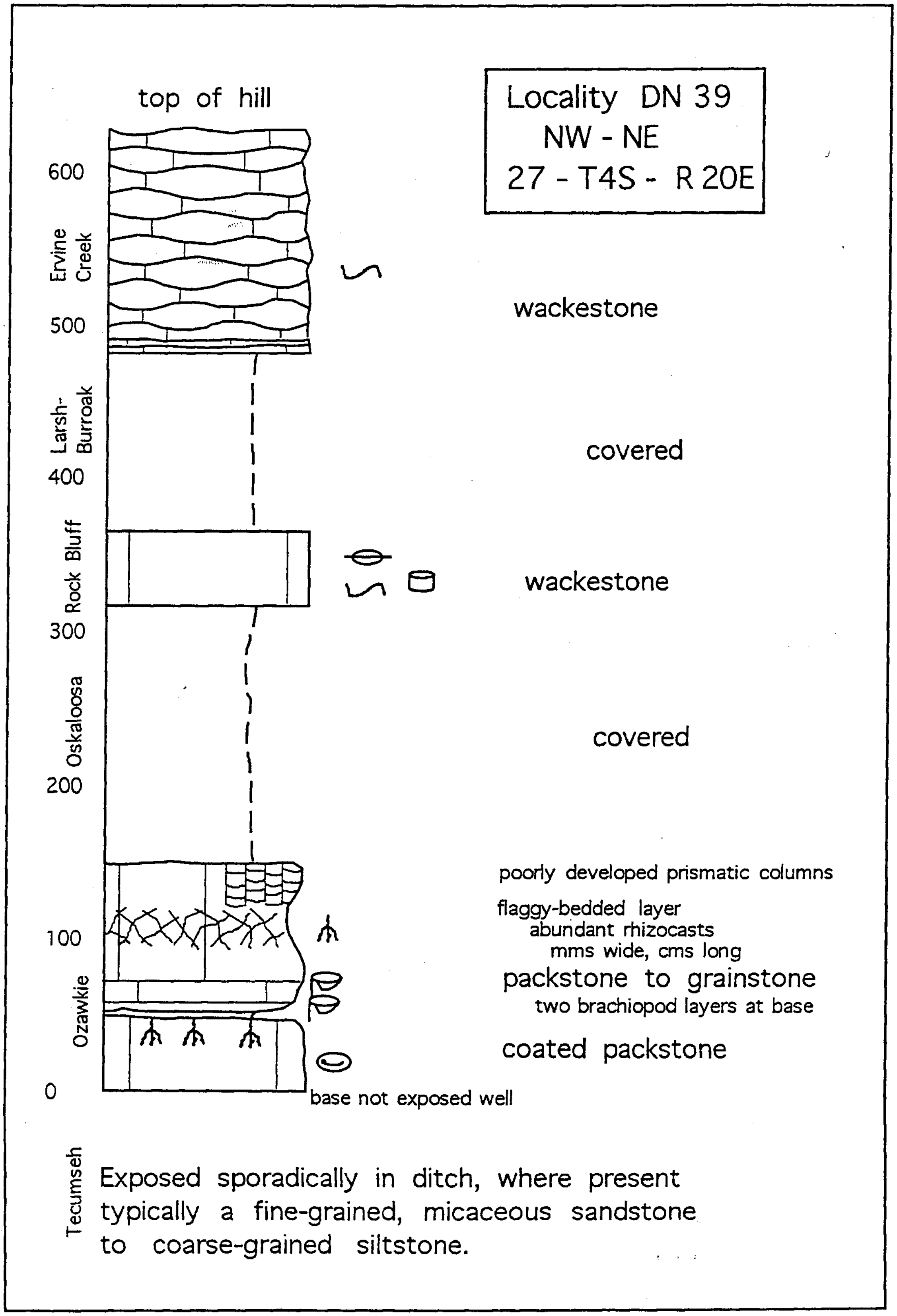
Ozawkie is deeply weathered. The Ozawkie was most likely a packstone, but grains are too weathered to determine origin.


Locality SH 36
NE - NE - NE
34 - T13S - R16E
700
top of hill
Ervine Creek
wackestone
600
Larsh-Burroak
covered
black shale
500
Rock Bluff
wackestone
400
Oskaloosa
covered
300
Ozawkie
weathered
coated packstone
fine-grained
200
Ozawkie weathered, some slumping but measurements are fairly accurate.
100
Ozawkie
coated packstone
coarse-grained
fusulinid-rich
0
base not exposed well

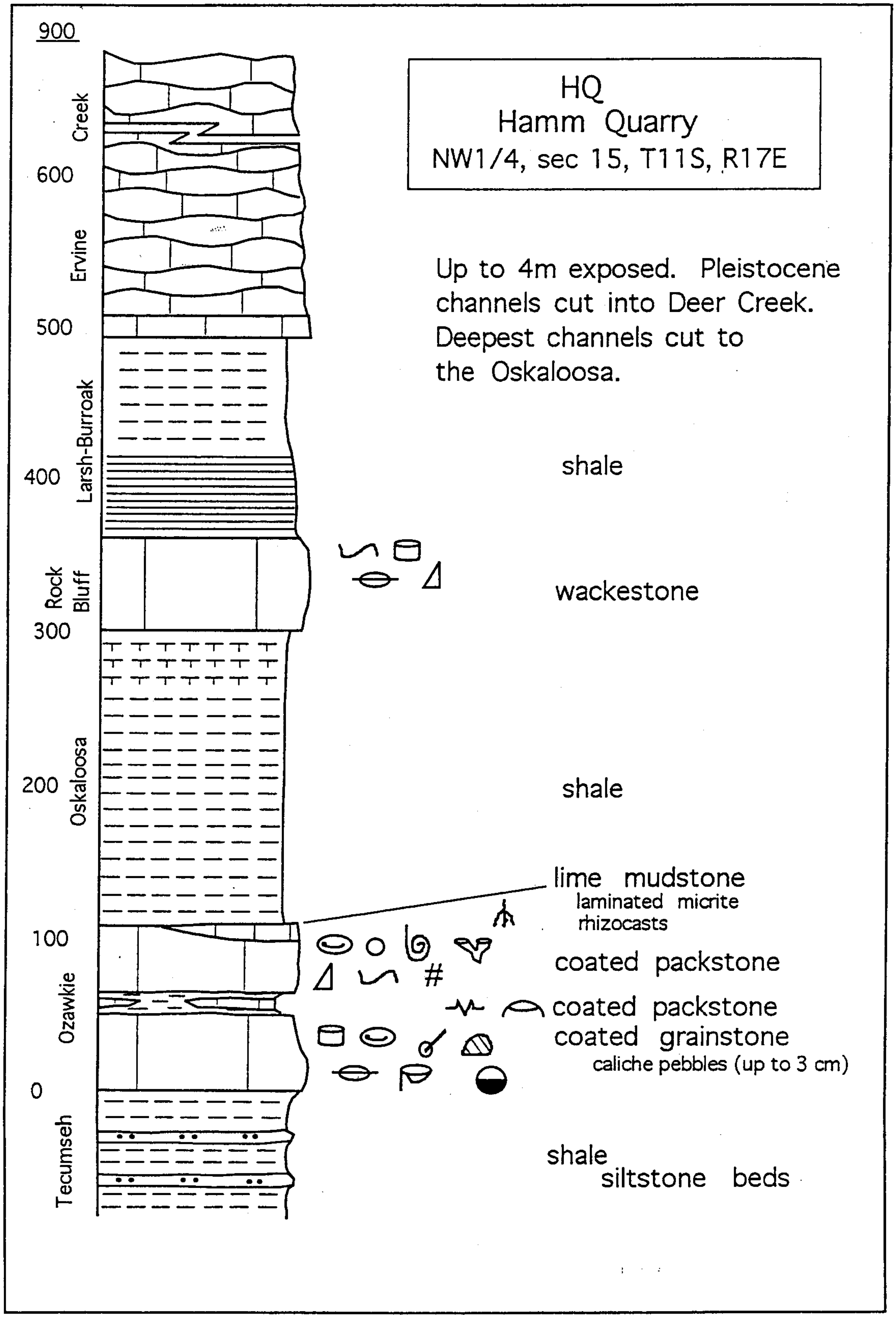


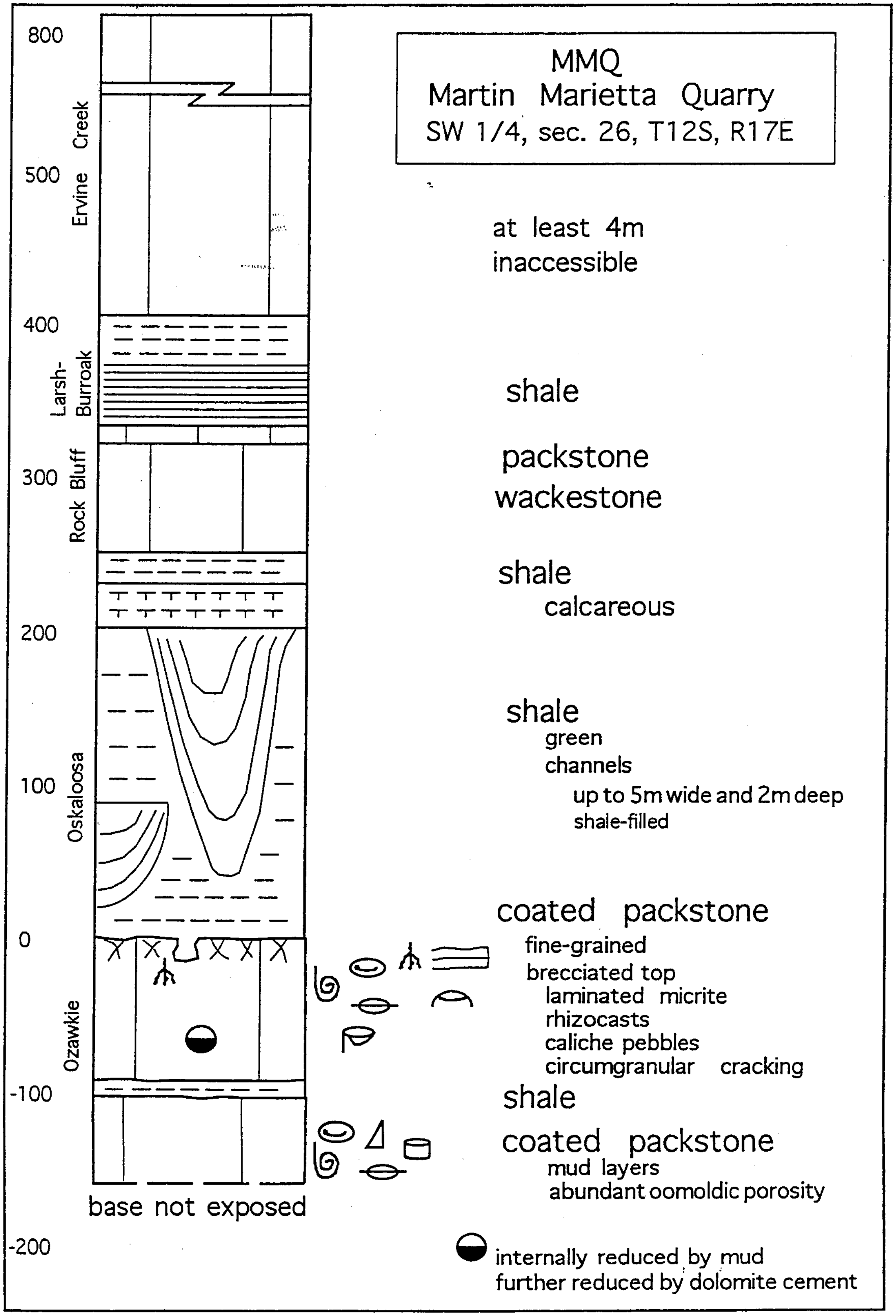
Locality S H 37
NW - NW - NW
36 - T13S - R 16E
top of hill
300
200
100
0
-100
-200
-300
-900
Ozawkie
Ozawkie
Tecumseh
mudstone
mottled-texture
wackestone
bioturbation
shale
yellow, non-fissile
fusulinid wackestone
1. large burrows
5 cm wide, 50 cm deep
reduced, reverse grading fill
occluded by spar
2. small burrows
2 mm wide, 10 cm deep
shale
non-fissile
dark grey
silty lime mudstone
prismatic columns
shale
grey
rare finely laminated silt and clay


TOP OF HILL
Locality SH 38
SE - NE
35 - T13S - R 16E
900
Ervine Creek
800
wackestone
Larsh-Burroak
covered
600
Rock Bluff
wackestone
500
Oskaloosa
In general, exposure is poor but thicknesses are accurate
300
covered
200
Ozawkie
wackestone
shale
100
Ozawkie
wackestone
0
base not exposed well
Tecumseh
silty mudstone
shale



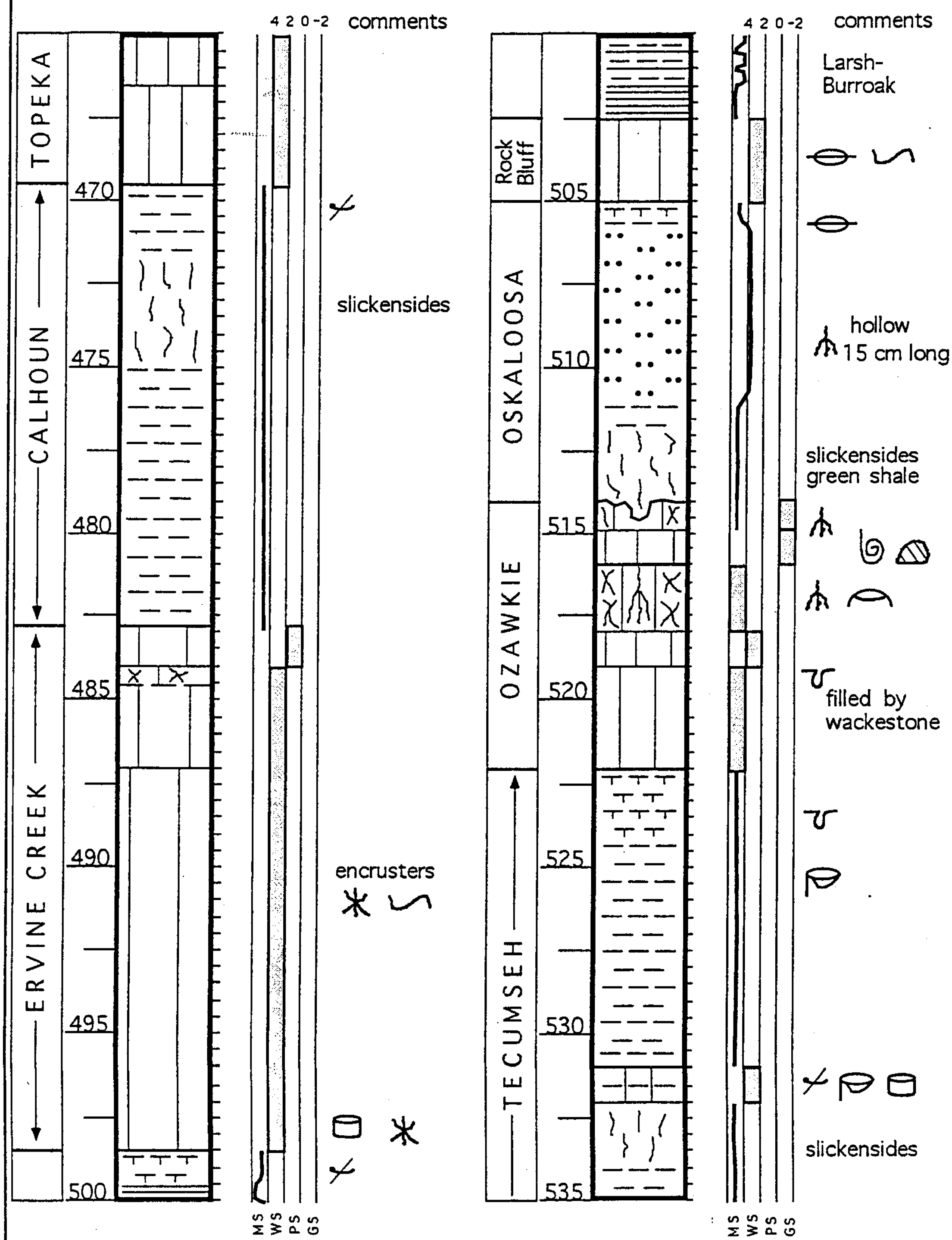
Locality DN 39
NW - NE
27 - T4S - R 20E
top of hill
600
500
400
300
200
100
0
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
wackestone
covered
wackestone
covered
poorly developed prismatic columns
flaggy-bedded layer
abundant rhizocasts
mms wide, cms long
packstone to grainstone
two brachiopod layers at base
coated packstone
base not exposed well
Exposed sporadically in ditch, where present typically a fine-grained, micaceous sandstone to coarse-grained siltstone.


HQ
Hamm Quarry
NW1/4, sec 15, T11S, R17E
Up to 4m exposed. Pleistocene channels cut into Deer Creek. Deepest channels cut to the Oskaloosa.
900
600
500
400
300
200
100
0
Creek
Ervine
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
Tecumseh
shale
wackestone
shale
lime mudstone
laminated micrite
rhizocasts
coated packstone
coated packstone
coated grainstone
caliche pebbles (up to 3 cm)
shale
siltstone beds


MMQ
Martin Marietta Quarry
SW 1/4, sec. 26, T12S, R17E
800
500
400
300
200
100
0
-100
-200
Ervine Creek
Larsh-Burroak
Rock Bluff
Oskaloosa
Ozawkie
at least 4m
inaccessible
shale
packstone
wackestone
shale
calcareous
shale
green
channels
up to 5m wide and 2m deep
shale-filled
coated packstone
fine-grained
brecciated top
laminated micrite
rhizocasts
caliche pebbles
circumgranular cracking
shale
coated packstone
mud layers
abundant oomoldic porosity
base not exposed
internally reduced by mud
further reduced by dolomite cement

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

feet depths 465' to 535'
page



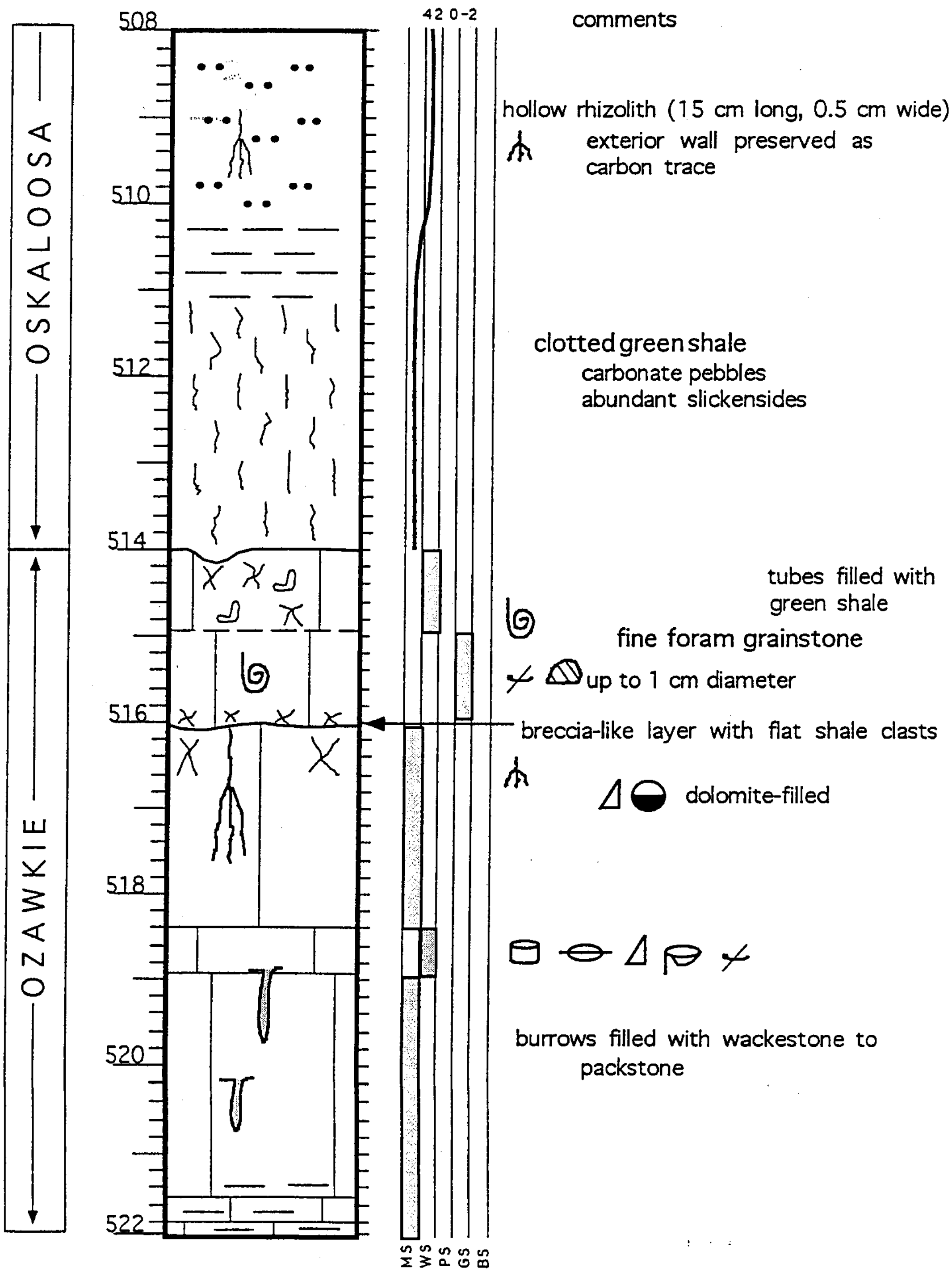
Operator Texas Gulf

Lease Geshner VC 81-1

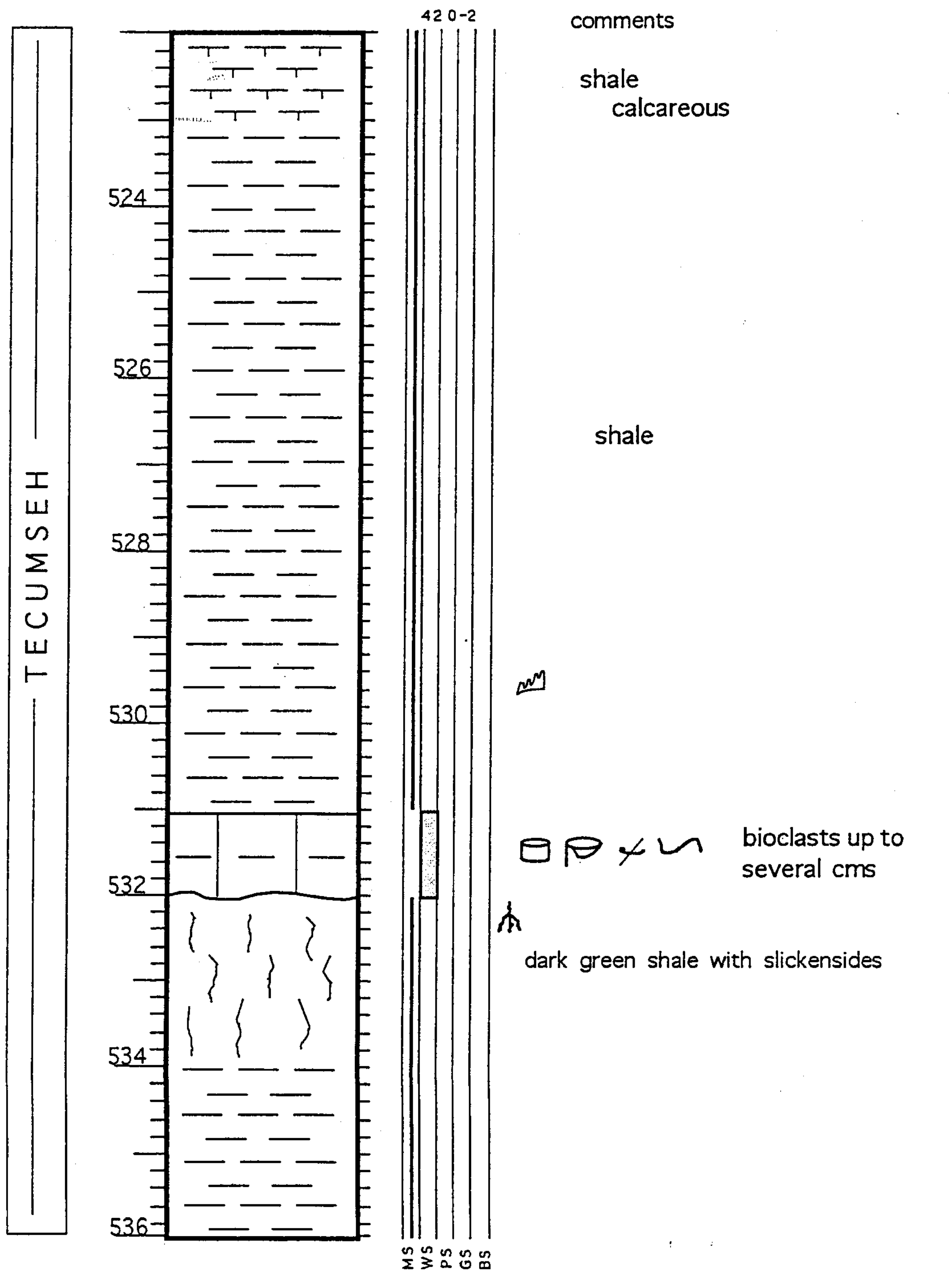
Location 12 - 4S - 9E

page

depths 508' to 522' feet



Operator	Texas Gulf	page	
Lease	Geshner VC 81-1	depths feet	522' to 536'
Location	12 - 4S - 9E		



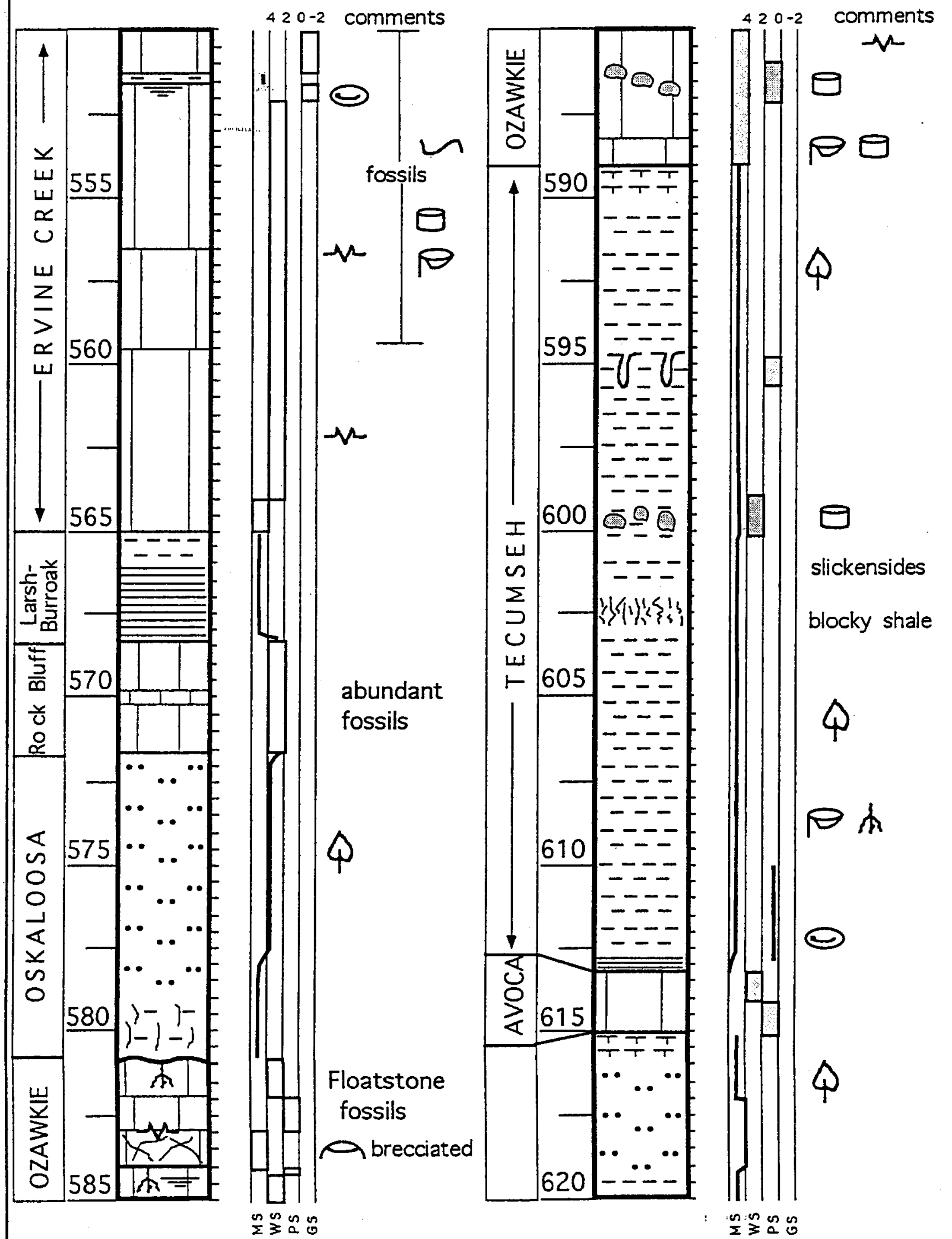
Operator Houston Oil and Mineral

Lease #1 Vermillion

Location 1 - 4S - 9E

feet depths 550' to 620'

page



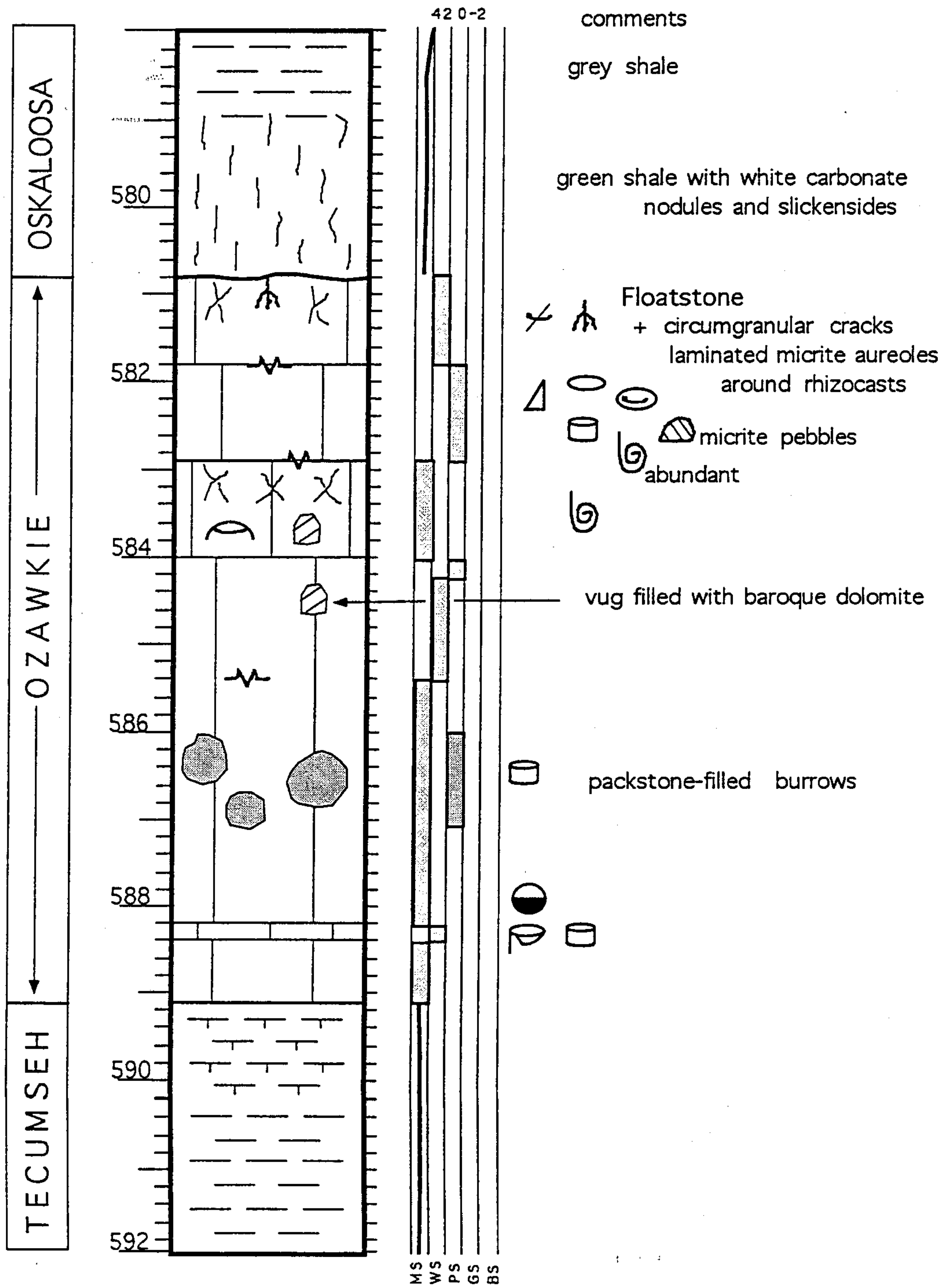
Operator Houston Oil and Mineral

Lease #1 Vermillion

Location 1 - 4S - 9E

page

depths 578' to 592'
feet



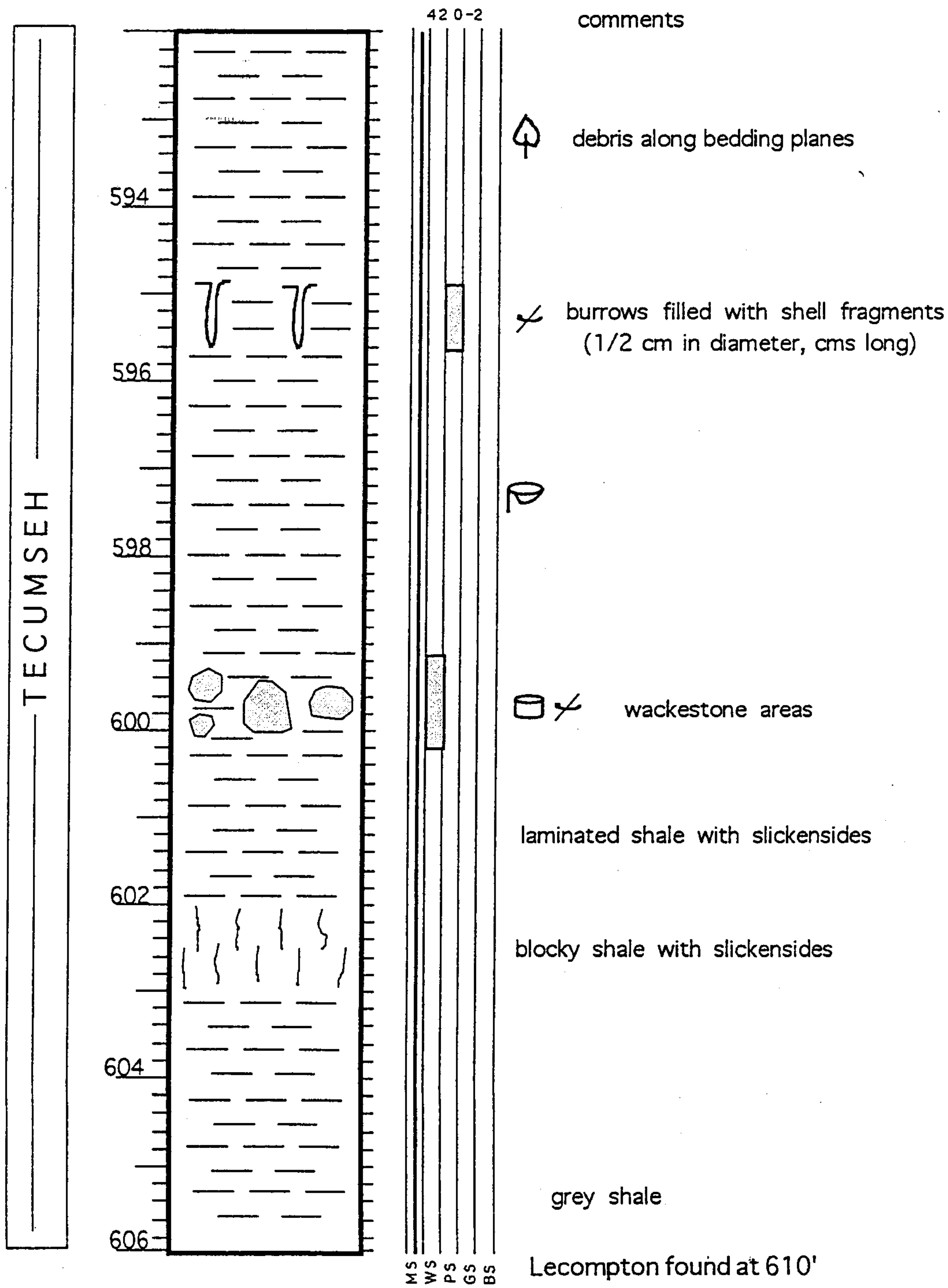
Operator Houston Oil and Mineral

Lease #1 Vermillion

Location 1 - 4S - 9E

page

depths 592' to 606'
feet



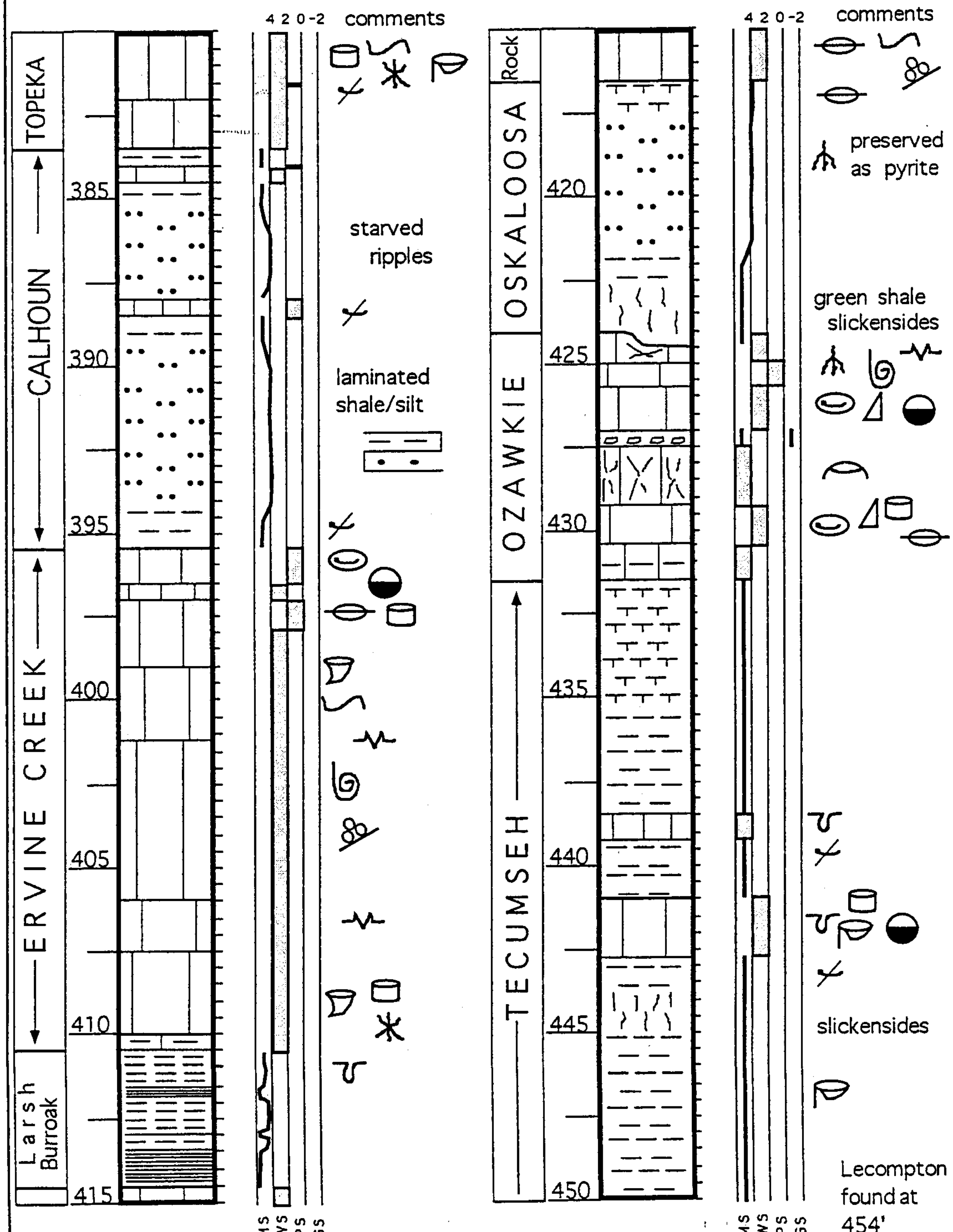
Operator Texas Gulf

Lease Dennels JD 81-1

Location 27 - 3S - 10E

depths 380' to 450'

page



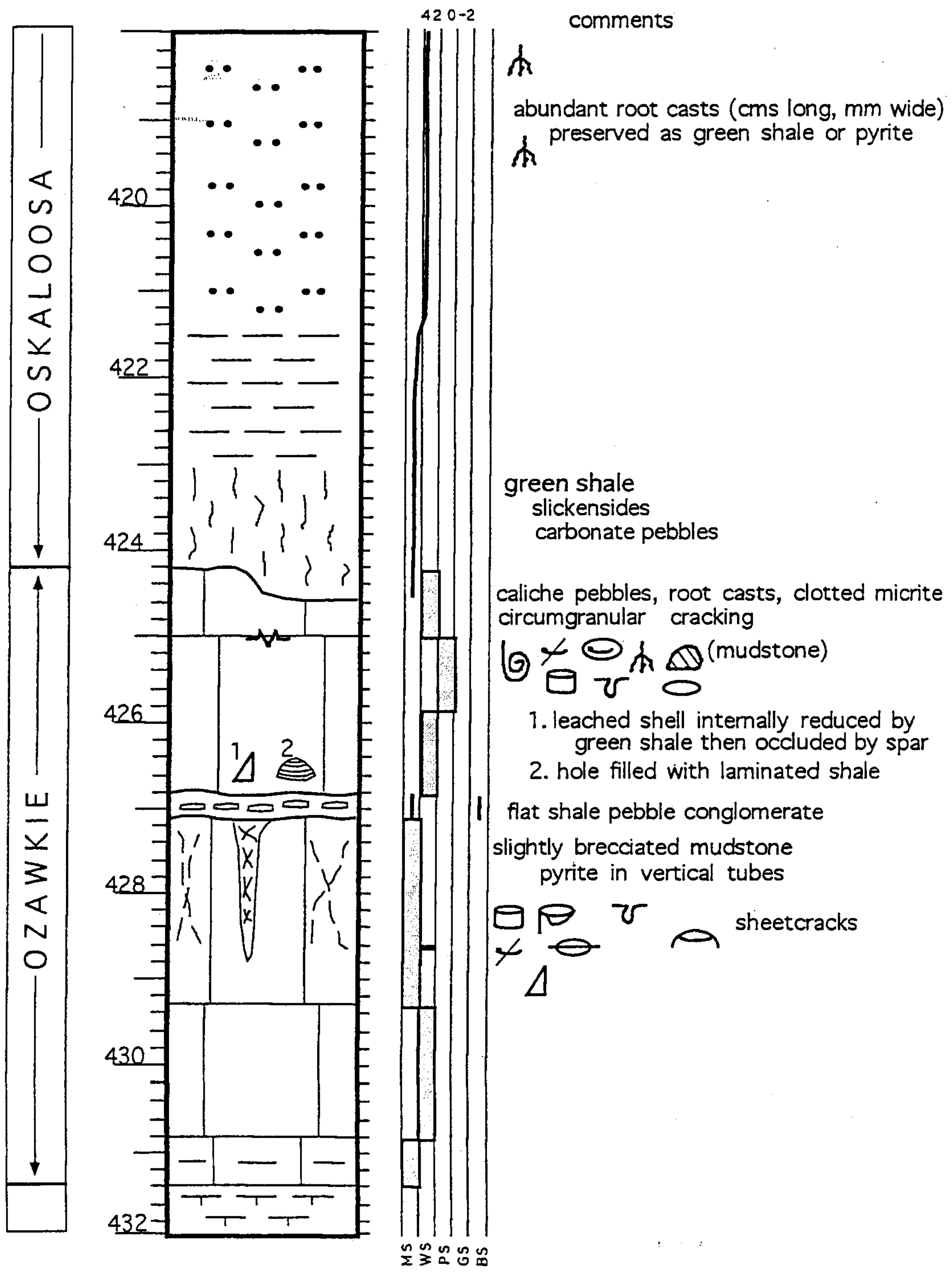
Operator Texas Gulf

Lease Dennels JD 81-1

Location 27 - 3S - 10E

page ________

depths 418' to 432'



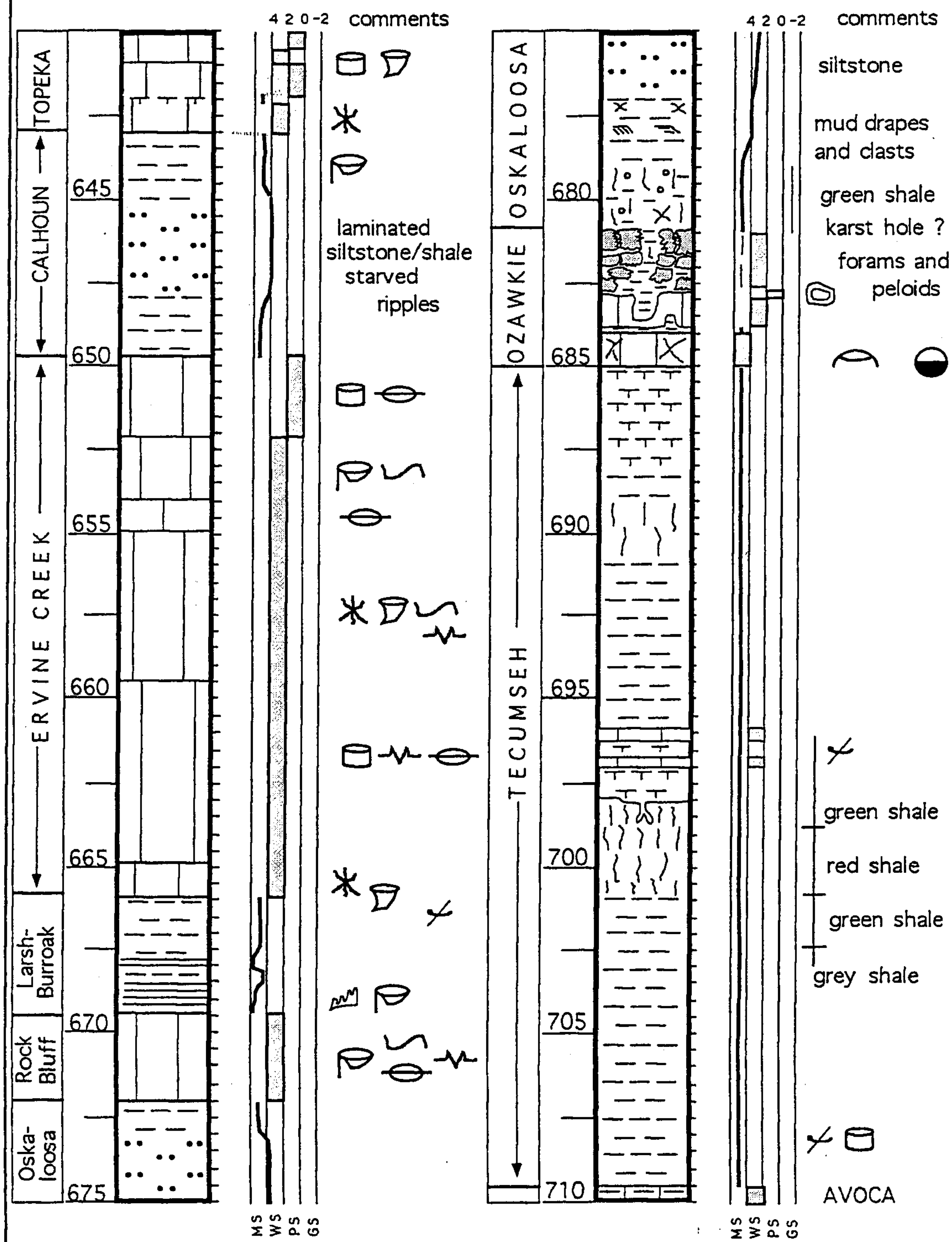
Operator Texas Gulf

Lease Joe Spiller 81-1B

Location 11 - 3S - 9E

feet depths 640' to 710'

page



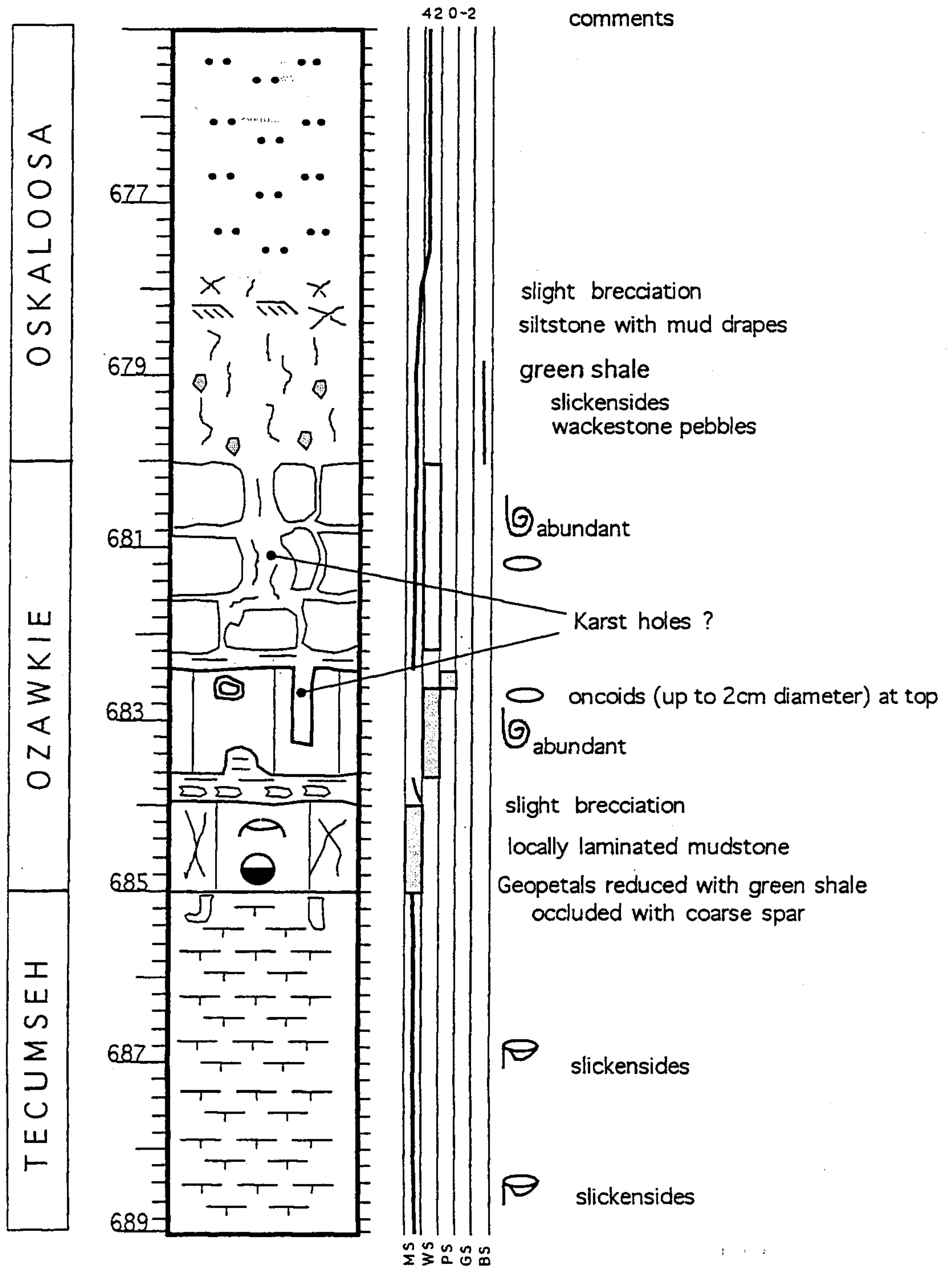
Operator Texas Gulf

Lease Joe Spiller 81-1B

Location 11 - 3S - 9E

page ______

depths 675' to 689'
feet



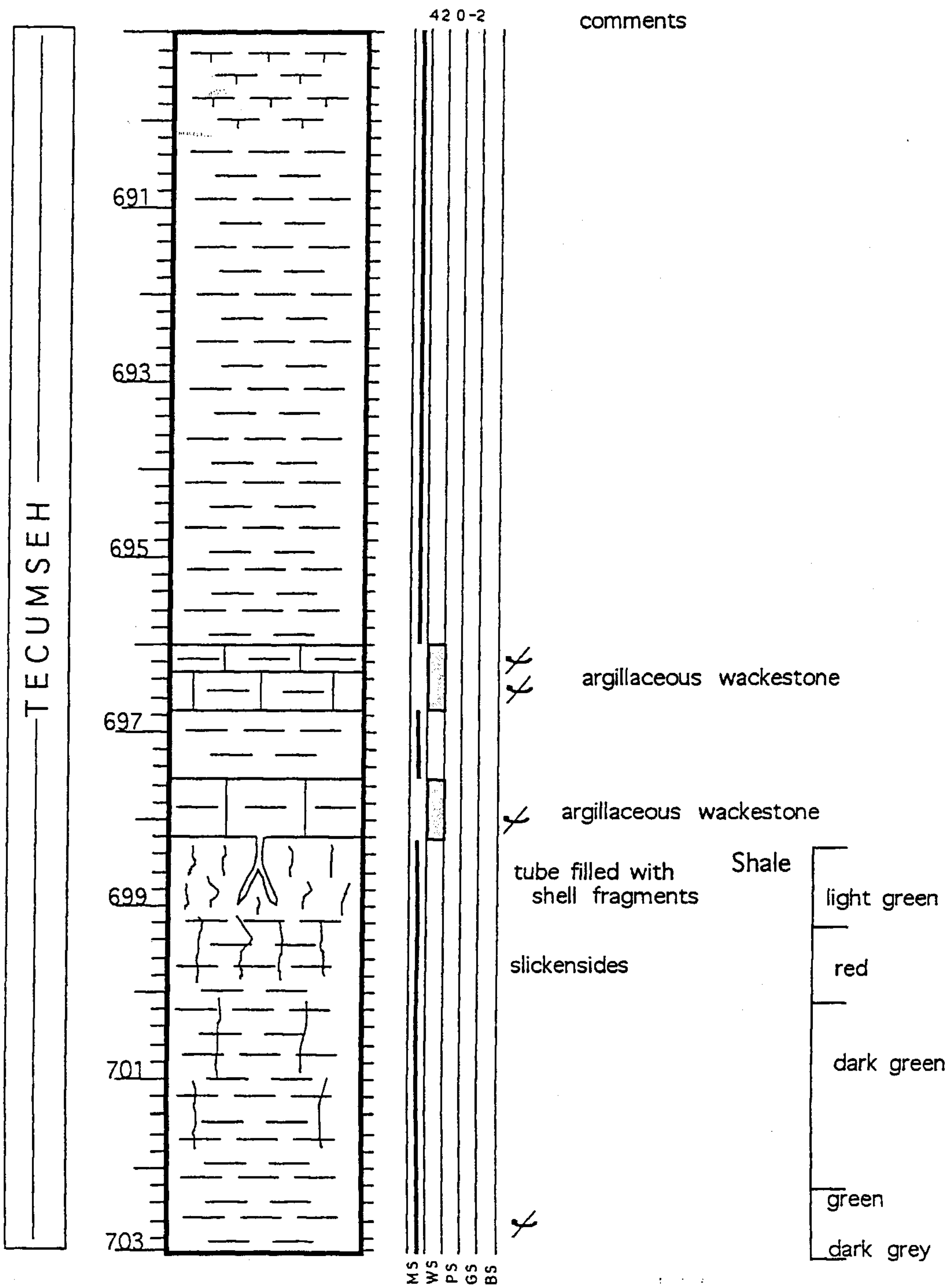
Operator Texas Gulf

Lease Joe Spiller 81-1B

Location 11 - 3S - 9E

page

depths 689' to 703'
feet



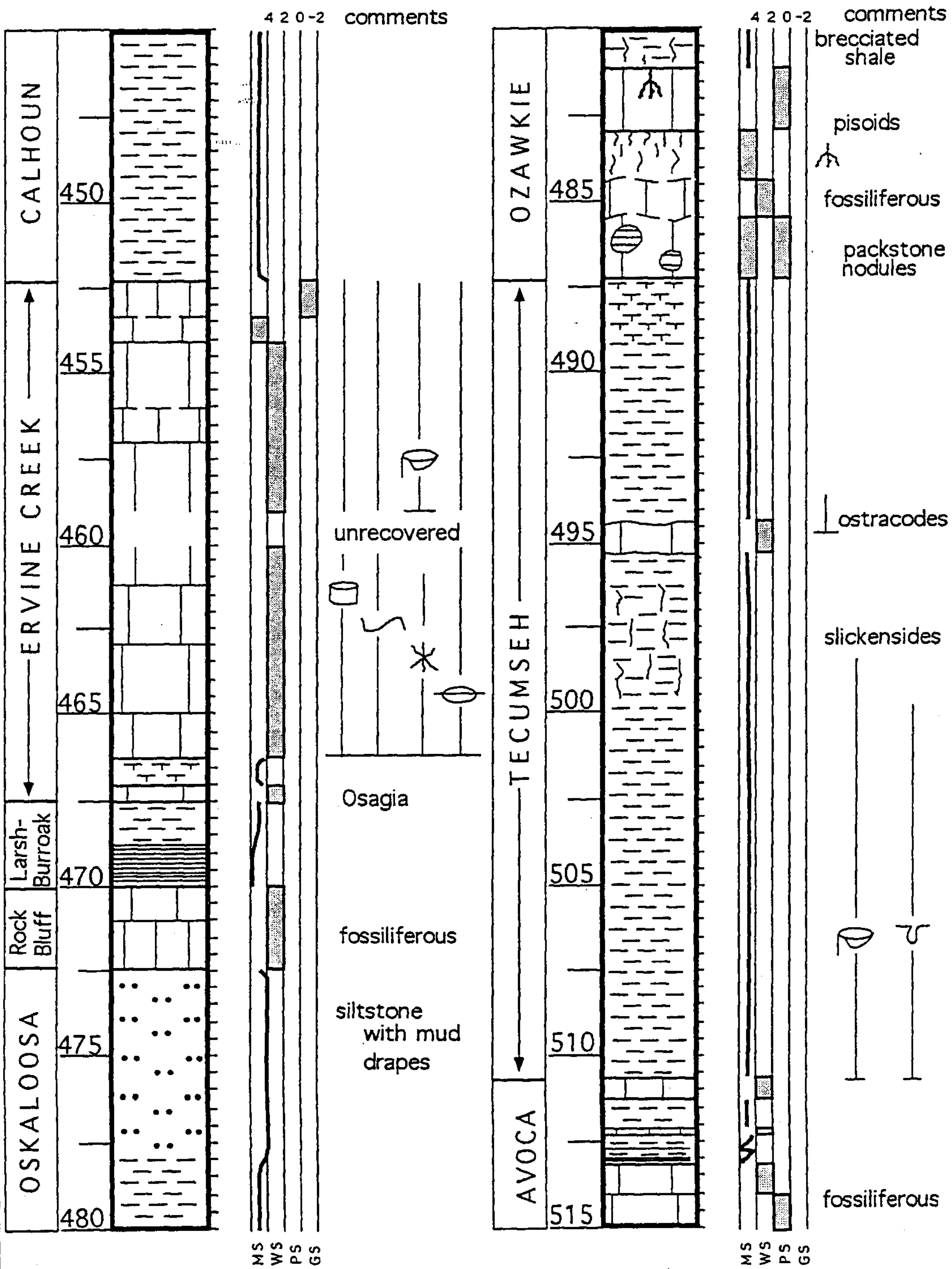
Operator Houston Oil and Mineral

Lease #1 Bail

Location 33 - 2S - 11E

feet depths 445' to 515'

page



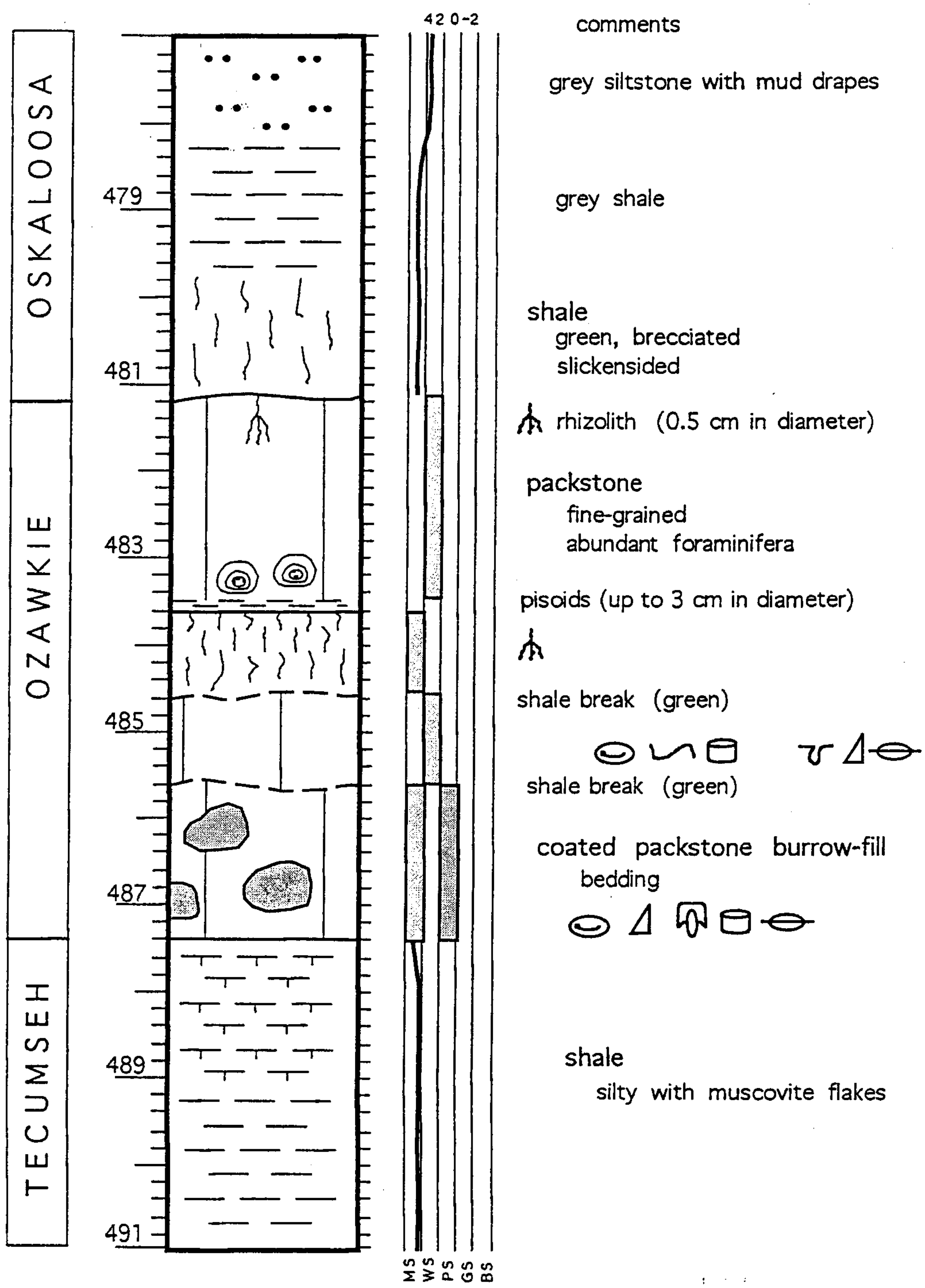
Operator Houston Oil and Mineral

Lease #1 Bail

Location 33 - 2S - 11E

page

depths 477' to 491'
feet



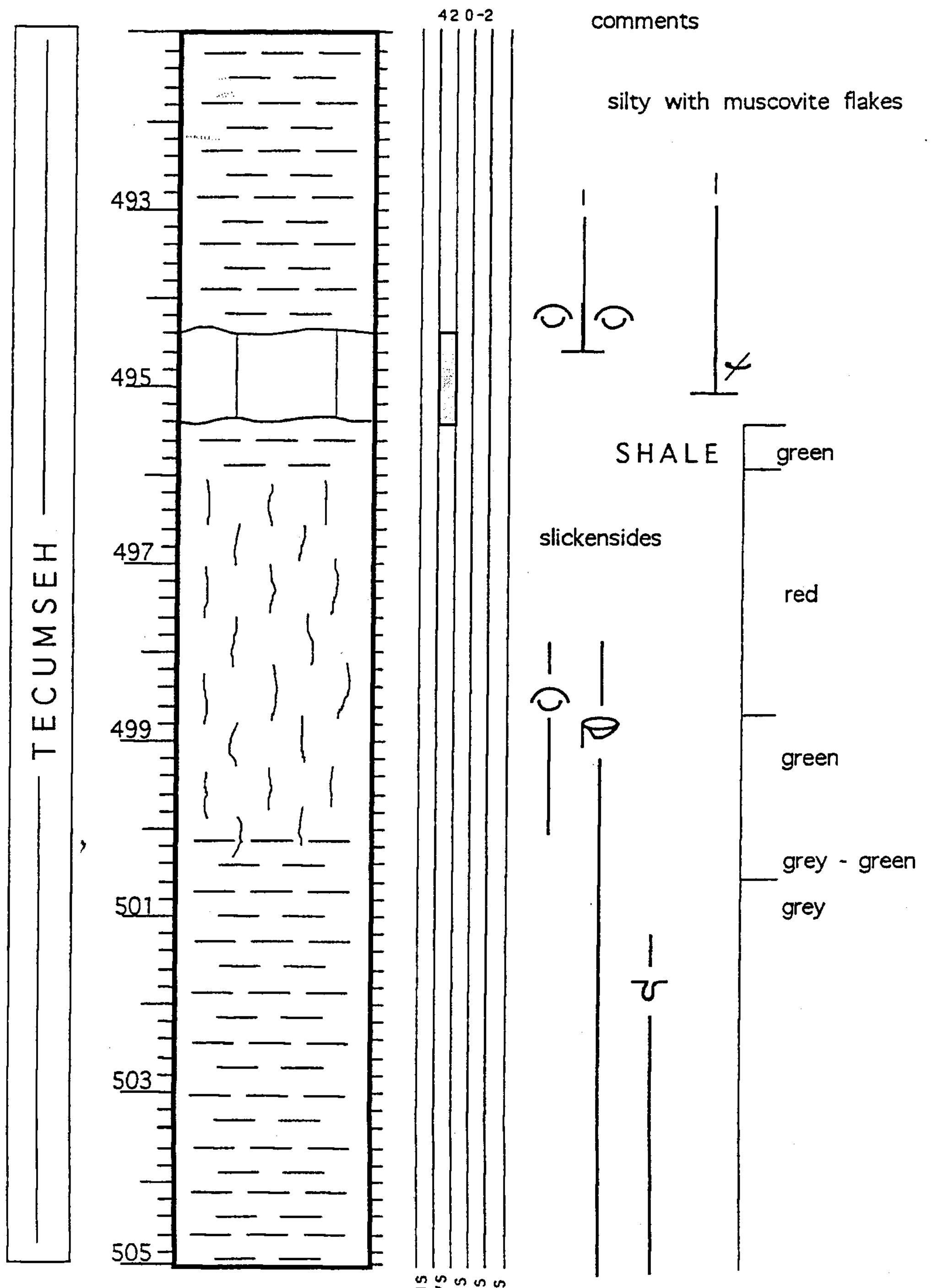
Operator Houston Oil and Mineral

Lease #1 Bail

Location 33 - 2S - 11E

page

depths 491' to 505'
feet



Lecompton found at depth 510' 6"